IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT

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PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA

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PETROLEUM INDUSTRY TRAINING SERVICE

IMPROVED IMMERSION FIRE-TUBE HEATER EFFICIENCY PROJECT

Joint Project By:

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Petroleum Industry Training Service (PITS) – Nisku, AB

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Typical 2 MM BTU/hr line heater

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PREFACE

This report presents the results of an in-depth study of various technical and non-technical aspects of the efficiency of immersion fire-tube heaters used in the petroleum industry. A background in the basics of heat transfer, chemistry and combustion technology is helpful in proper understanding of the material. Although some familiarity with the thermodynamics and fluid mechanics will aid in the understanding of the underlying principles, it is not the intent of this material to provide the user with mathematical models and formulas used in the computations of the heaters efficiency. At the same time, this report assumes user's familiarity with the subject matter and its nomenclature, and does not go into details of explaining the terminology and the basic technical definitions. Readers are encouraged to look for these definitions in the reference materials cited in this report.

This study was focused on addressing the "real" measurable and quantifiable problems leading to low efficiencies and to provide "real" practical solutions to these problems, in a way, that would address the largest number of new and existing installations at the lowest cost. This intent is described in detail in Chapter 2 entitled: "Project Background". This chapter also discusses various possible reasons for low efficiencies.

The material presented recognizes the fact that the efficiency of a fire-tube heater is closely related to the theory of combustion and by its physical nature is complicated. Combustion being an exothermic chemical reaction in flows combined with heat and mass transfer, it involves thermodynamics, chemical kinetics, fluid mechanics, electromagnetic radiation, aerodynamics and transport processes with multiphase flow and turbulence. Because of the interdisciplinary nature and complexity of combustion and how it relates to heat transfer it is quite often misunderstood.

The key to understanding the combustion processes is in realizing that unlike many other chemical processes, combustion is a very fast occurring (fractions of a second), dynamic and violent process, which has been described in the past as a "controlled series of mini-explosions". Yet, the results of it are slow to occur in terms of changes in liquid temperature, measurable fuel efficiency, or even longer in the form of corrosion effects on heat transfer surfaces. A relatively small change in adjustment of combustion processes can have a large impact on the long-term economics of the process or perhaps even on its short-term safety. There is no doubt that the combustion process carries a stigma of "to be reckoned with" or perhaps even one of "not to be touched". There are also some old "well proven" methods of making combustion "work better" which are technically incorrect. Education helps to deal with these perceptions.

Chapter 3 entitled "Literature Study" looks for the existing sources of the information related to the topic of combustion and efficiency of fire-tube heaters. Available literature on this subject tends to be either very complex and "academic" or oversimplified and lacking scientific validity. Some claims published today by equipment suppliers are simply technically incorrect. A total of forty-four publications are discussed, and more detailed information is included in the Appendix A.

This study identifies many of the technically questionable claims and "myths" related to fire-tube heater efficiencies and addresses them through application of basic laws of thermodynamics. Chapter 4 entitled: "Heater Efficiency Principles" explains in depths various concepts related to these laws, and offers suggestions on how to apply these laws to the fire-tube efficiency evaluations. Numerous graphs are included in this chapter to help quantifying these concepts. Basics of combustion and mass/energy balances are explained, as well as, the concepts of convective, conductive and radiative heat transfer and their simultaneous nature are discussed in the context of the fire-tube application.

Much of the progress in the field of industrial combustion has been historically achieved through "trial-and-error" methods and plagued by difficulties with technical verification. Only in the recent years has verification been made possible with computer and sensor technologies. Using computer modeling, mass/energy balances, combined with stack analyzer readings and flow, and temperature trending, it is possible to better monitor and understand combustion processes In the past, these techniques were limited to only large industrial boilers or similar installations due to their high cost. With the advances in low cost PLC and sensor products make them justifiable in smaller installations.

For the purpose of this study a "user-friendly" fire tube rating software was developed. The software is described in Chapter 5 and also provided on a CD include with this report. The program is intended to resemble a heat exchanger rating software with the exception that it also takes under consideration combustion reaction and simultaneous radiative heat transfer in the fire tube. This approach allows not only the prediction of an average (overall) heat flux rate for the entire tube (conventional method) but also a more precise prediction of the temperature, pressure and heat flux rate profile along the tube and into the stack. This yields much more accurate results than traditional simplified methods, but also allows the use of variable fire-tube and stack geometry, between 1 and 4 passes and with decreasing tube diameters.

Chapter 6 describes the results of field surveys, which included 43 existing installations. The survey included design and performance parameters of each heater, as well as, its main efficiency related problem and main opportunity for improvement.

Chapter 7 provides a record from the phase of the project in which a test heater was designed and built at the PITS training facilities in Nisku. All test heaters' features, as well as, the details of instrumentation are presented in a photo gallery with comments.

Chapter 8 contains a summary of bench testing of 25 burners from 10 manufacturers. The results include flame shaping capability, sound pressure levels, primary air induction and gas and mixture pressures. In addition, mechanical details of each burner are described in detail with comments regarding their possible impact on the performance. Side-by-side comparisons of all these burner characteristics are provided. Appendix C contains the manufacturers literature related to these burners.

Chapter 9 includes summaries of performance data from firing tests of the above burners in the test unit. These results include fire-tube temperature profiles, burner turndown and excess air characteristics, as well as, NOx, CO, sound pressure levels and efficiency measurements. Similar to the previous chapter, side-by-side comparisons of performance with various burners are provided.

Chapter 10 presents the results of the heat transfer tests in the test unit 2-, 3-, and 4-pass fire tube configuration with water, ethylene glycol, and light oil on the liquid bath side. Tube temperature profiles from these tests are demonstrated and compared. In addition, the results of tests with turbulators inside the fire-tube are shown. The results of these tests conclude with the calculation of the surface heat flux rates along the tube length, used to calibrate the fire-tube rating program described in chapter 5.

Chapter 11 provides the reader with simple to follow fire-tube rating charts designed for "rough estimation of fire-tube performance, and to allow analysis of what varying the tube length or diameter will do to the thermal efficiency of the heater. Charts are designed for tube diameters between 4" and 26" and U-tube length between 5' and 30'. Comparisons of fire tube performance for 2-pass natural draft, 4-pass natural draft, and 4-pass forced draft designs are possible. The charts are organized by either process duty, burner heat input, or heat flux rates

Chapter 12 contains the analysis of surface and crossectional heat flux rates with emphasis of their impact on heaters efficiency. The results of this analysis are compared to heat flux rates currently used in the industry. In addition, the design rules related to fire-tube L/D ratio (length/diameter) and to the constant-fire-tube length principle are challenged.

Chapter 13 provides simple to follow guidelines for fire-tube heater efficiency and reliability, as well as, heater's combustion system tune-up guidelines.

Chapter 14 presents a concept of an industry-wide training program for installation, operation and maintenance of fire-tube heaters.

Finally, chapter 15 contains the summary of the different areas for efficiency improvements and their possible solutions. This chapter recognizes that many of the areas are not purely of technical nature, but are also related to organizational aspects of the fire-tube heater operation. An organizational paradigm is proposed to address the efficiency challenges of the fire-tube heater installation though their entire life cycle, starting with the process assessment and initial specifications, through design, fabrication, installation, commissioning, operation, and maintenance. Education and training aspect is seen as the most essential ingredient recurring through every step of this process. This chapter concludes with the final conclusions and recommendations.

In terms of petroleum industries substantial use of fire-tube immersion heaters, the emphasis of the study is a focus of stewarding to the large inventory already in use. By applying the above recommendations based on good fundamentals into current designs and operation, we can establish sound economic improvements to them and we can work to sustain these benefits through education and operational tools. With the increasing cost of fuel, diminishing reserves and the ever increasing concern of the environmental impact of combustion processes it is now time to have a closer look at this technology in terms of reasonable fuel efficiencies and cleaner exhaust.

In the end, there are no “silver bullet” solutions in the operation of these heaters to obtain 30% to 50% fuel reductions on the entire fleet of installations already out there. However, there are many good learnings and fundamentals to be applied to obtain 10% to 15% fuel reductions in general and much more on poorly sized and operated units.

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DISCLAIMER

Although exceptional care has been demonstrated by all project performers and participants, in the research, design, data collection and analysis, and preparation of this report, the results presented in this report may contain in them certain assumptions and objective errors which influence the final outcome. During the project, the participants became quickly aware that the scope of research is much broader than originally assumed and that there is a lack of reliable published scientific data on this subject. We found that sometimes various sources of data, formulas and charts and conclusions contradict each other.

The variability of the operational requirements and process parameters made it difficult to come up with generalized practical recommendations. Every effort has been made to measure various scenarios, but in some cases we had to base our conclusions simply on past experience, recommendations from other sources, or simply assumptions and sound engineering judgment.

The field and lab measurements of heater performance were conducted only on selected configurations and sizes of fire-tubes and then mathematically interpolated to other tube sizes. These calculations are based on an assumption that the equipment is operating with reasonable firing range, and that it is in good condition. Factors such as tube fouling (inside or outside), partial tube flows, or simply equipment disrepair were identified as possible problems but not quantified in the heat transfer calculations. It is assumed that the heater equipment is properly sized, operated, and maintained.

It is also assumed that there are appropriate controls and sensors in place (permanent or portable) to allow sufficient heater performance assessment. It is our observation, that there are many existing heaters, which are either lacking rudimentary instrumentation or even a suitable connection to install such instrumentation. In many instances the existing instrumentation is not working. It is our conclusion that without having reliable tools to measure temperatures, pressures, flows, and stack gas composition, the heater performance cannot be properly assessed.

During the testing phase of this project we used a number of burners and other equipment contributed by various vendors. The performance results presented in this study show specific burner size operating in a specific tube configuration under specific conditions, and should not be misconstrued as representative to all other equipment sizes and configurations. In the report, we purposely tried to avoid showing preferences towards any specific equipment manufacturer, and only to assess the possible variability of the results. Any statements or data presentations, which may be viewed by the reader as preferential recommendations towards any specific equipment manufacturer or model are unintentional. Specific equipment selections must be based on process requirements and properly assessed on a project-by-project basis.

Will this report answer all the questions and give exact prescriptions on the design and operation of petroleum immersion fire-tube heaters? Probably it will not. It is our hope however that the presented results will address the most common challenges, and that they will encourage further research and operational assessment of this type of equipment by both manufacturers and users.

When using the results of this study and generalized recommendations to specific operational scenarios, sound engineering assessment and practices must be applied and further verified by field measurements.

The report is a compilation of engineering practice, theory, and recommendations, all of which are subject to local, provincial, state or federal codes, insurance requirements and good common sense.

No patent liability is assumed with respect to the use of information contained in this report. While every precaution has been taken in preparation of this report, neither author, other project performers, not project sponsors or administrators assume any responsibility for errors or omissions; nor is any liability assumed for damages resulting from use of this information.

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EXECUTIVE SUMMARY

The principal objective of this project was to define practical methods for increasing energy efficiency and reducing emissions of gas fired immersion fire-tube heaters used in the petroleum industry. In addition, these methods were designed, to provide the improvement to the largest number of both the existing heaters, and new installations, at the lowest cost and with a minimum of modifications.

A detailed study of the existing technology, background information, literature, and the existing standards, led to the conclusion, that many relevant references are outdated, incomplete, unclear, or may in some cases, be partially to blame for the lower efficiencies. To address this “information-gap” a detailed guideline of the fire-tube heater efficiency principles was prepared. Numerous graphs are included to help in estimating the impact of these parameters on the heaters efficiency.

This project has identified an achievable theoretical target gross efficiency for fire-tube heaters at between 72% and 82% depending on the bath liquid temperature. To confirm the reality of these efficiency targets, a detailed survey of 43 field installations in various applications was conducted, and eight installations with efficiencies as low as 30% were found. Simple readjustment of all eight of these units during the survey returned them to higher efficiencies between 64% and 82%, with an average efficiency of 72.3%. This part of the project also produced guidelines and data collection methods for evaluating fire-tube heater efficiencies in the field.

In addition to the theoretical guidelines of the fire-tube efficiency principles, and the field data collection methods, a software program was also developed as part of this project, to aid in the evaluation of the fire-tube performance. This fire-tube rating program predicts a temperature, pressure, and heat flux profile along the fire-tube in addition to average heat flux value, and allows modeling of both natural draft and forced draft fire-tube designs of varying geometry.

To calibrate the above software program and also to test the impact of various burner designs on the heater efficiency, a fire-tube test unit was designed, constructed, and operated at the PITS facilities in Nisku. This test unit was extensively tested with varying fuel input, using water, 50/50 ethylene glycol, and oil on the “bath side” of the fire-tube. The liquid type was found not to make a significant difference on the heat transfer in the fire-tube.

Twenty-five burner configurations from various manufacturers were tested to establish their flame shape, primary airflow, air/gas mixture pressure and sound pressure levels, as well as, thermal performance in a 2-pass fire-tube configuration of the test unit. Once properly selected, and adjusted, most of these burners could be fired reliably with at least a 4:1 turndown and did not impact significantly the efficiency of the heater.

The above tests confirmed that the heat transfer in the fire-tube is controlled by the gas side with very little impact of the bath liquid type on the heater performance. The heater was also tested with two different types of turbulators inside the fire-tube, leading to the conclusion that the turbulators in the gas path offer little improvement in the overall efficiency.

The calibrated fire-tube rating software program was then used to produce fire-tube rating charts for tube diameters, between 4” and 36”, U-tube lengths between 5’ and 30’, and for 2-pass natural draft, 4-pass natural draft, and 4-pass forced draft fire-tube configurations.

The impact of the surface and cross-sectional heat flux rates on the heater efficiency was investigated in order to address the applicability of the commonly used design values of 10,000 BTU/hr/ft2 and 15,000 BTU/hr/in2. This analysis showed that with a 2-pass design in line heater application both of these values are almost guaranteed to produce heater efficiencies lower than the 72% low efficiency target. Instead of using these traditional design values a more accurate assessment can now be performed using the fire tube rating charts and the fire-tube rating software.

A very important aspect of both existing and new installations is that many of them are already, or very likely will become, oversized for the actual process energy requirement, due to decline in production volumes. If these heaters were fired at duties less than design, the extra surface of the fire-tube would improve the heat transfer, as well as, reduce the typical ON/OFF cycling to a more consistent operation. This approach offers an excellent opportunity for energy savings with minimal modification to the existing heater.

Although a standard engineering solution to this problem would be to use a conventional method of burner fuel modulation, this study shows that this method is ineffective without addressing the secondary air control. This can be achieved without any mechanical means, simply by utilizing natural characteristics of the Venturi style burner.

The general concept of maximizing the efficiency of the fire-tube heater is by the proper matching of the fire-tube configuration, burner size and design, and modulating controls, without shutting the heater down and while maintaining its low excess air operation (between 2% and 3% oxygen in the stack). Additional energy efficiency measures, include turning the pilot OFF; eliminating the instrument gas powered pneumatic controls, and using solar power to operate heater controls.

The research described in this study also led to a conclusion that energy efficiency issues related to the fire-tube heaters often go beyond the technical aspects of fire-tube sizing, burner selection or controls design. The operational and maintenance aspects, and concerns about heater reliability, availability, and safety also influence them. These concerns often overrule the requirements for higher efficiencies and lower emissions. It is the conclusion of this study that all of these aspects Reliability-Safety-Efficiency can, and should go hand-in-hand, when all engineering and organizational aspects are properly addressed.

This study contains information, design tools, evaluation and maintenance guidelines, as well as, both engineering and organizational concepts and recommendations, which could be used to solve the fire-tube heater energy efficiency and emissions challenge on an industry wide scale.

One of the recurring topics of this research is the need for education related to the energy efficiency of the fire-tube heaters. This study proposes the development under the auspices of PITS of an industry and government sanctioned sub-trade, which would provide a suitable knowledge base in the industry, to properly install, operate, and maintain thousands of high efficiency fire-tube heaters.

A common barrier in achieving the above goals is seen in the current lack of a broad based industry stewardship and support for these topics.

1 INTRODUCTION

1.1 Request For Proposal (RFP) Background

The Upstream Oil and Gas Industry is an energy intensive industry. The industry is required to consume significant amounts of energy to process raw gas and liquids to either a finished or semi-finished product of sales gas, LPG's, sulphur and oil or condensate. This energy requirement is commonly referred to as the Production Energy Intensity (PEI). One specific area that is of common concern to many upstream operating companies is the energy consumption associated with fire tube immersion heaters. The energy frequently used to fire these heaters is high-quality refined sales gas. In 1979, a study estimated that in Alberta line-heaters and treaters consumed 70 Bcf/A in fuel gas, which is equivalent to 8 billion BTU/hr, at a cost in excess of $320 million/A.

A common problem with the immersion heaters is that individual heaters generally have low fuel efficiencies between 30% and 60%. Compared to common boiler technology, these heaters should be able to run at between 70 to 80% efficiency. Even when taking into consideration the cyclic nature of operation associated with many of the applications, these heaters currently waste in excess of 2 to 3 billion BTU/hr of fuel (1360 to 2040 e3m3/d gas) that could be conserved to generate added sales. At an average cost of $5/GJ this represents $100 to $150 million of lost revenues due to inefficient use of fuel gas. This also represents an associated 1.5 million additional tonnes of carbon dioxide being discharged into the atmosphere per year.

Often lower heater efficiencies are associated with high levels of oxygen or combustibles and high stack temperatures. These can result from poor burner performance and poor control of combustion air or improper configuration or the size of the fire-tube. Unlike steam or hot water boiler practices of efficiency calculations and/or guarantees, the efficiencies of immersion heaters are rarely considered during the typical specification, design, manufacturing, or operation cycle of the equipment.

1.2 Requirement

Taking under consideration the rising fuel costs and more stringent environmental regulations, there is a requirement recognized by the industry for improvements in the evaluation, design, operation, and maintenance practices leading to higher efficiencies of immersion fire-tube heaters.

1.3 Project Sponsors

Developing new design standards and operating parameters, while sharing the development costs and operational support, is essential to improved efficiency projects. BP Canada Energy, EnCana, Husky Energy, Nexen, Petro-Canada, Shell Canada, and CETAC – West have all contributed toward this project.

1.4 Resulting Request For Proposal (RFP)

The Request for Proposals (RFP) for Improving Immersion Fire-Tube Heater Efficiency (RFP EETR 0401) was issued in May as a direct result of the Technology for Emission Reduction and Eco-Efficiency (TEREE) Steering Committee meeting held in April 2004.

The RFP included the following scope of work specification:

a) review of historical design data, current industry practices and the study of burner and fire-tube designs and their associated efficiencies;

b) develop theoretical heat transfer, combustion calculations and computer modeling to optimize the designs;

c) perform actual firing tests to confirm the new results;

d) develop a general industry design and performance standard for these heaters as a requirement for bids on all future equipment;

e) develop an education component to improve the level of understanding within the industry, as it applies to the design of new equipment, the improvement to existing equipment, and, to provide tools for operating companies to achieve and sustain the improved performance.

The work required the support of operating company members and the assistance of an independent third party with outside expertise for additional technical support.

Project performers were to work under the technical direction of the TEREE Immersion Heater Efficiency working group.

A number of proposals were received from leading experts in the field of combustion and heat transfer including consulting engineering firms, universities, research labs, and, equipment manufacturers.

A panel of petroleum industry experts reviewed the submitted proposals in July and chose ENEFEN Energy Efficiency Engineering Ltd. to provide a more efficient and cost-effective way to address the problem of inefficient immersion tube heaters. This report summarizes the work performed and the findings of this project.

1.5 General Concept of this Project

To address the RFQ requirements, ENEFEN's solution brought together three expert groups to perform this contract:

a) ENEFEN Energy Efficiency Engineering Ltd. – provided project management, basic research, combustion systems and controls design, field testing, and report writing expertise;

b) COEN Company – with world class expertise in combustion modeling, burner design and radiative and convective heat transfer solutions – developed immersion tube rating software and consulting support for the heat transfer and burner design evaluation; and,

c) PITS Petroleum Industry Training Service – provided fully instrumented testing facilities in Nisku, AB, for burner and tube testing and software calibration testing, as well as, an expertise in developing an industry-training concept for this project.

This project included the following tasks:

a) literature survey;

b) applicable technology identification;

c) fire-tube rating software development (COEN);

d) field performance data collection;

e) lab (PITS) heater performance data collection;

f) comparative burner tests;

g) selected burner testing in the heater (PITS);

h) rating software calibration;

i) control system design;

j) fire-tube design guideline development;

k) test and research results documentation; and,

l) training program concept development.

1.6 Future Benefits

The main benefits of this project will include:

a) rating software for immersion tube evaluation and design testing and calibration on real heater applications;

b) industry guidelines for evaluation, design, operation and maintenance of immersion heaters aimed at maximizing their efficiency;

c) practical and economical solutions to existing heater improvements; and,

d) a training program concept to improve the level of understanding within the industry, as it applies to the design of new equipment, the improvement to existing equipment, and, recommended tools for the operating companies to achieve and sustain improved performance.

1.7 Access to Project Results

Project sponsors have access to the project results for up to one year prior to public release.

The results once released, will be made available in the public domain. This eliminates alignment to any vendor or manufacturer specifications.

2 PROJECT BACKGROUND

The following is a general discussion of immersion fire-tube heater applications, their basic design and operational concepts, which our project team used at the onset of this project. They were the starting point of this project.

It is our sincere hope that the data and recommendations presented further in this report will answer some of these questions and will help in the better understanding of how design, operation and maintenance issues impact immersion fire-tube heater efficiencies.

2.1 Project Assumptions and General Intent

This project and report is structured with the assumption that the reader possesses a basic knowledge of thermodynamics, combustion, and heat transfer. We have included in this report an extensive list of references, which contain formulae, tables, charts, and examples of calculations similar to the ones, which we used for the evaluation of fire-tube heaters in this report. It was not our intent to quote these formulae, or show the user the exact numerical methods but rather to concentrate on their practical application and verification through field and laboratory measurements, as well as, the interpretation of the results of this research.

2.2 Complexity of the Subject Matter

Although readers are encouraged to refer to the textbooks referenced in this report, for the definitions and principles discussed, it should be done with caution. As demonstrated in this report, the subject of efficiency of fire-tube heaters is relatively complex, as it depends on a numerous factors, such as: process and environmental conditions, equipment design, operation and maintenance, as well as, measurement and evaluation methods. Consequently, any simple "rule of thumb" principles used commonly in the industry simply cannot address all of these conditions and in many cases lead to erroneous conclusions. It is our professional opinion that the complexity of the subject matter is currently underestimated by the industry.

2.3 Shell and Tube Heat Exchanger Analogy

To use an analogy to a shell and tube heat exchanger design, it is simply impossible to come up with a "most efficient" heat exchanger design in terms of the number and size of the tubes, tube diameter to length ratio or optimum number of passes. There is not a single "best" U-value (overall heat transfer coefficient), or a single LMTD-value (log-mean-temperature-differential), which all heat exchangers could be designed to. All these parameters depend on what each heat exchanger is used for. No one would also expect to find such generalized "one-fits-all rule of thumb" for shell and tube heat exchanger sizing.

2.4 "Most Efficient" Fire-Tube Heater Design

There is no such thing as a "most efficient" fire-tube heater design. Every design has to be treated in a similar manner as shell and tube heat exchanger, except it is more complex due to the presence of combustion, simultaneous radiative and convective heat transfer, impact of ambient conditions, cyclic nature of operation, and, the potential for both internal and external tube fouling. We believe, however, that there are sound engineering principles and guidelines, which can be applied to fire-tube heater design, to customize this design to a variety of applications. These techniques are presented in this report.

2.5 Reliability, Availability and Safety are Paramount

The reoccurring theme in this discussion is that production volume and product value are more important than potential efficiency gains and fuel savings.

Heater design must assure the reliability and availability to keep the process operating. Simple, robust and proven designs are preferred to more refined approaches to heat transfer. More advanced heat transfer techniques such as finned or dimpled tubes used in other industries and not well suited to this environment nor are they essential to achieving improvements.

The difference in the heater efficiency and associated fuel savings may not be significant when considering how essential these heaters are in oil and gas production.

Potential for process upsets or perhaps even unsafe condition in the case of a heater failure are the driving factors for heater design. In addition, the large number of heaters installed in remote locations need to be maintained and operated with minimum resources and by personnel with limited skills.

2.6 Various Myths and "Rules-Of-Thumb" Related to Heater Reliability – Safety - Efficiency

There are numerous myths in the industry related to fire-tube heater reliability, safety and efficiency.

To quote a few:

a) "The more "gadgets" the heater has the less reliable it is"

b) "The more heat you put into the heater the better it will work"

c) "The further you can "throw" the flame (heat) down the tube the more efficient it will be"

d) "Long and lazy flames increase heat transfer and prevent liquid overheating"

e) "Flame in a good heater reaches to the end of the first pass."

f) "Oversized fire-tube increases efficiency."

g) "The more orange the flame the better the heater works."

h) "The more air you let into the heater the better the heat transfer."

i) "You should never use a damper in the stack."

j) "You should never use a secondary air control in the tube."

k) "There is nothing wrong with heater smoking from the stack, at least you can see that it works."

l) "Roaring (noisy) burner makes good heat."

m) "Fire-tube heaters never back-fire or blow up."

n) "This burner will not overheat (degrade) the liquid being heated."

o) "This design will save you 60% of your fuel cost."

p) "You should always size the fire-tube for XXX BTU/hr/ft2 heat flux rate."

q) "Tube length to diameter ratio should always be equal to YYY."

r) "You should always fire ZZZ BTU/in2 of tube cross-section."

s) "Bath liquid makes big difference on fire-tube performance"

t) "Burner modulation will save you lots of money."

u) "Flame arrestor will always stop the burner flame from spreading to outside in case of a major external fuel leak".

v) etc.

There is probably a "grain of truth" in many of the above myths. There are probably past examples, which could, or probably were interpreted as supporting these statements. It is likely, that some of the above "rules of thumb" work for a specific fire-tube application under a specific set of conditions.

In general, these myths do not seem to be based on sound scientific and engineering principles and do not offer a valid basis for optimized combustion and efficient heat transfer solutions.

2.7 Compromise to Heater Reliability and Availability due to Additional Controls and Efficiency Improvements

There is a perception in the industry that increased complexity of the design, additional controls and other "attachments", which may be required for efficiency reasons, will actually lead to the degradation in heater reliability and availability. There is some truth to this perception since any additional devices may indeed create an opportunity for failure or nuisance trips, which could compromise the heater operation, particularly if these devices are of poor quality or not suitable for the harsh operating environment.

On the other hand, it could be argued, that the lack of controls or rudimentary safety devices combined with their unmanned operation in remote locations does not necessarily make the heaters or the process more reliable or available, and definitely it does not make them more efficient. The increasing acceptance of RTU technology to immersion fire-tube heaters shows the benefits of such additional controls. Although it is typically used more to monitor the well performance, production rates, etc, it could also be extended to monitor the heater performance in terms of fuel consumption, efficiency, stack temperature, duty cycle or the need for maintenance.

There is definitely room for sensible, benefit-based approach to heater and their controls designs, which could address availability, reliability, and efficiency of these installations.

2.8 Reliability-Safety-Efficiency of Immersion Fire-Tube Heaters Should Go Hand-in-Hand

It is our opinion that if properly applied and understood, all three of these aspects: Reliability-Safety-Efficiency can, and should go hand-in-hand. It is therefore important to differentiate the non-scientific "rules-of-thumb" and "myths" from technically valid and verifiable considerations and methods when specifying new equipment or undertaking upgrades or maintenance projects on existing heaters.

There is a strong possibility that applying these considerations to both new designs, essential maintenance and reliability issues of existing installations will result in fuel gas savings and reductions in greenhouse gas (GHG) emissions. It is also likely that improved control of the combustion process will result in elimination of fire-tube overheating and corrosion and overall improvement of system safety and reliability.

2.9 Competitive Nature Of Fire-Tube Heater Market

The immersion fire-tube heater market in the oil and gas industry is mature and very competitive and any additions or changes to old, well established methods are considered by some manufacturers as risky and therefore making their product less competitive. It is also not unusual for some manufacturers to apply deep cost cutting measures to controls or burner components translated to relatively low dollar values, regardless of long term effects of such small savings on equipment performance or on fuel consumption. Equipment seems to be often sold on a price per pound basis with little understanding and focus on the performance of its fire tube and burner and its life cycle efficiency.

2.10 Fire Tube Heater Efficiency a Non-Issue in the Past

The heater efficiency has not been an issue in the oil and gas industry in the past. Neither the heater purchaser specified the required heater efficiency, nor did the heater manufacturers provide any guarantees of this efficiency.

Our survey of a selected group of manufacturers shows, that few of them knew what the efficiency of their designs actually was, nor did they have any idea how to get such information. The common statement from the manufacturers was: *"We do not install or run these units and have no way in our shop of testing them, we just manufacture them… It is up to the users to measure these efficiencies if they wish to…."*

This statement clearly describes the "old" approach to immersion fire-tube efficiency. With the increasing cost of fuel and environmental concerns, this approach is now changing.

2.11 Immersion Fire-Tube Heaters Applications in the Petroleum Industry

Immersion fire-tube heaters are very common in the petroleum industry operations. The following are some of the examples of their applications:

a) line heaters for gas transmission lines;

b) reboilers in the gas dehydration or desulphurization process (TEG or amine);

c) regen gas heaters;

d) heat-medium heaters for both glycol or diesel oil;

e) oil treaters;

f) tank heaters for oil storage; and

g) butane, propane or LNG evaporators.

2.12 Fire-Tube is Common to all Heaters

A common characteristic of all fire-tube heaters is a long and relatively small diameter (4" to 36") horizontal fire-tube immersed in liquid "bath", with a burner firing into the tube on one end, and an open-to-atmosphere stack at the other end. The fire-tube is formed into a U-tube configuration, with a U-bend in either the horizontal or the vertical plane, which is mounted inside a horizontal vessel so that it is removable from one end of the heater's vessel.

Figure 2.1 illustrates a forced draft 4-pass fire-tube configuration with a process coil located above the fire-tube.

Although longer tubes are often supported vertically in order to compensate for both the tube weight and buoyancy they are allowed to freely "float" in the horizontal direction, thus compensating for their thermal expansion when heated with the products of combustion. Most heaters currently used in the petroleum industry are of natural draft 2-pass fire-tube design, however some manufacturers offer forced draft designs with a larger number of passes. For larger process duties multiple tubes are used in a single vessel.

Figure 2.2 illustrates twin 12MM BTU/hr amine reboiler installation. Each reboiler is equipped with three (3) 30" diameter tubes each rated for 4 MM BTU/hr HHV heat input.

Fire-tubes, in petroleum applications, are typically of constant diameter inside the vessel and continue into the stack of the same diameter. Some older designs combine multiple smaller tubes into one larger stack. Figure 2.3 shows a natural draft line heater with dual tubes connected to one common stack design.

The disadvantage of these single stack designs is that the natural draft may be affected by the number of tubes firing at a given moment. An independent draft control for each tube is more suitable for higher efficiency solutions.

There are also designs, which use one single "windbox" at the entrance to multiple fire tubes. Figures 2.4 and 2.5 show an amine reboiler with this tube configuration. This design offers a convenience of easier maintenance due to the easy access to the fire tubes through a large windbox. However, special considerations must be given to the safety of multiple ignition sources within the confined space of a single windbox.

Most fire-tubes used in petroleum heaters are made out of standard steel pipe or rolled plate and **do not** use any heat transfer augmentation methods such as ribs, fins, etc. However, some heat transfer improvements are being claimed through the use of turbulators. Step-down tube diameter designs split-tube or ribbed tube designs, which are used in other industries are not common in the petroleum industry. Figure 2.6 shows a ribbed Morrison fire tube inside a hot water heater. Figure 2.7 shows the burner firing into a ribbed tube used in a salt bath regen gas heater application.

Although there are various heat augmentation techniques used for fire heater applications in other industries, they are rarely used in the petroleum industry primarily due to their higher capital and maintenance costs and often because the industry is not aware of their availability. It is only a few heater manufacturers who will try new solutions on individual projects, on a trial basis.

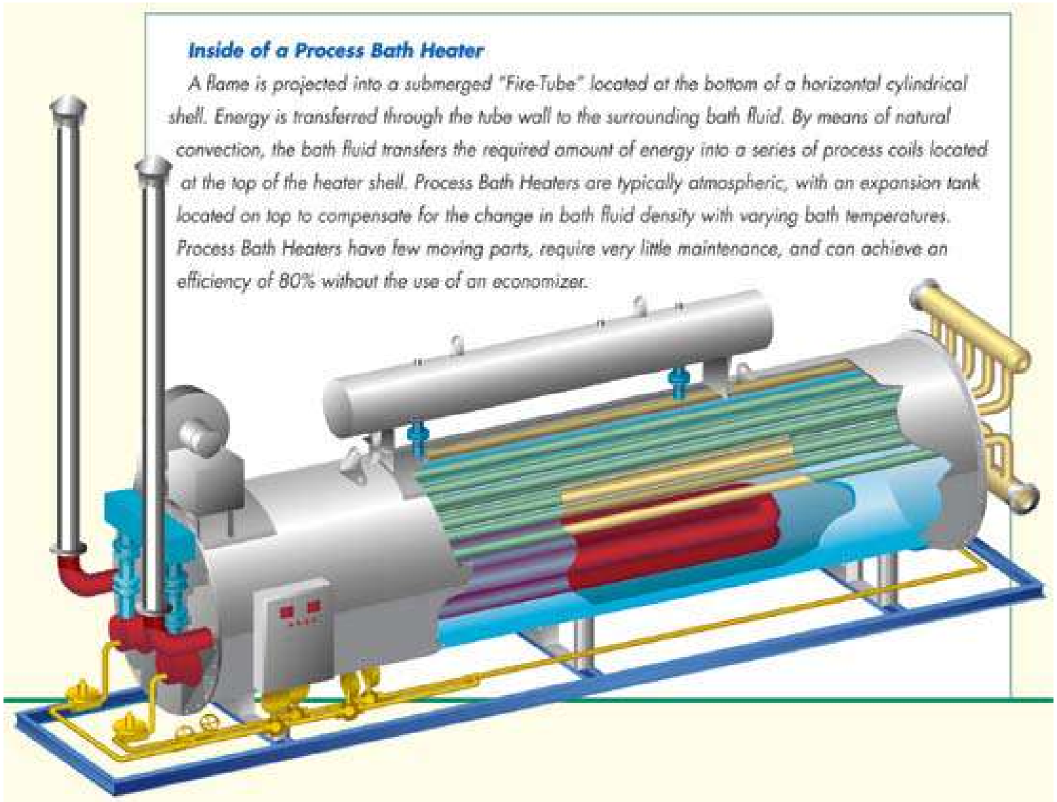

FIGURE 2.1 Cross-section of a heater with forced draft 4-pass fire-tube configuration with a process coil located above the fire-tube.

(from GTS Energy Process Bath Heater sales brochure)

FIGURE 2.2 Twin 12MM BTU/hr each amine reboiler installation.

Each reboiler is equipped with three (3) 30” diameter tubes each rated at 4 MM BTU/hr HHV heat input.

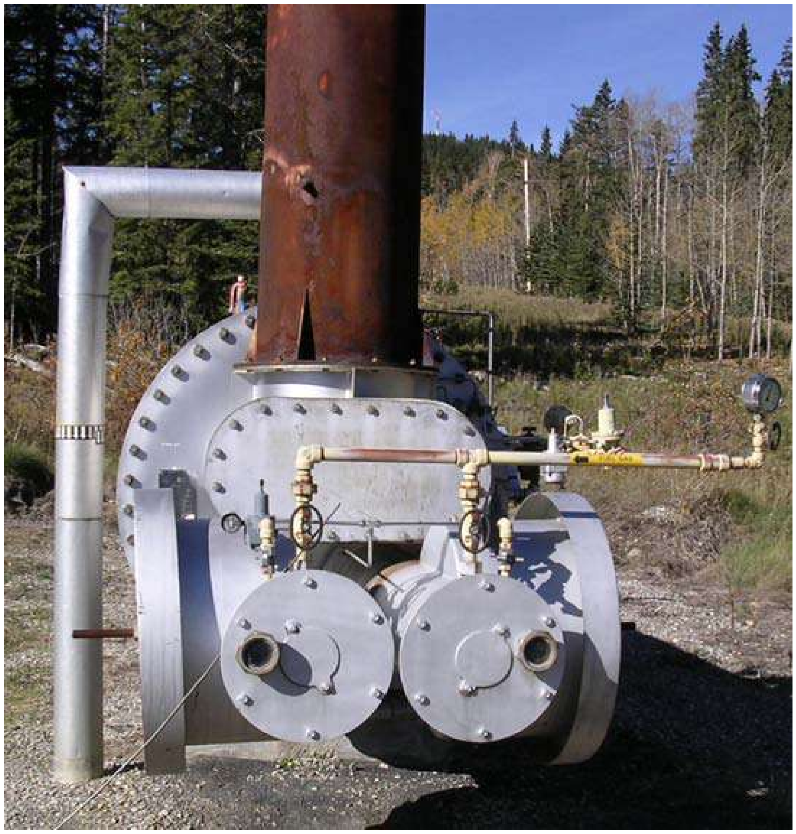

FIGURE 2.3 Natural draft line heater with dual tubes connected to one common stack design.

FIGURE 2.4 Natural draft amine reboilers with dual tubes connected to a single "windbox" and single stack

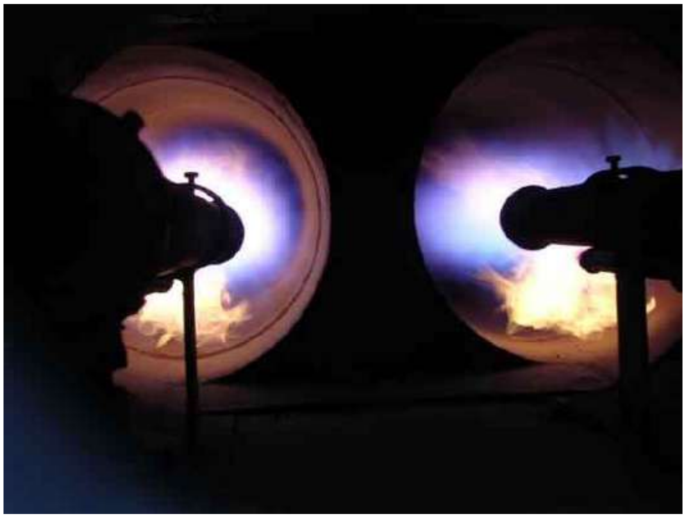

FIGURE 2.5 Burners firing into two tubes connected to a common windbox.

FIGURE 2.6 Ribbed Morrison tube in a hot water heater

FIGURE 2.7 Burner firing into a ribbed tube in a salt bath regen gas heater application

Taking under consideration how the petroleum industry has standardized and is familiar with conventional tube design, we decided, early in the project to focus on efficiency solutions that provide the "biggest bang for the buck". Our goal is to achieve highest relative energy savings with the least physical change to the existing heater fleet.

In terms of fire tube configurations for existing installations this means that the proposed solution would have to be designed to fit in place of the existing tube without requiring and major changes to the heater vessel. For new installations, which provide more flexibility in heater vessel design (for example in its length to diameter ratio), optimized fire tube configurations could be also incorporated.

Therefore our emphasis in the research was to find out how a conventional fire tube design affects the heater efficiency and what could be done with the fire tube to improve that efficiency.

2.13 Direct and Indirect Heat Transfer Configurations

Immersion fire-tube heaters utilize either indirect or direct heat transfer methods.

In a direct heat transfer design, the energy from combustion of fuel is transferred in a one-step process through the fire-tube wall directly to the process liquid, which is in this case the "bath" liquid. Oil storage tanks, oil treaters, glycol and amine reboilers are examples of such single-step heaters. Similarly, glycol heat medium and diesel oil heaters work on a one-step principal, although these two liquids are pumped through the heater, reheated, and used in a process heat exchanger as a source of heat, then returned back to the heater.

In an indirect heat transfer design, a two-step process is used. In the first step the heat is transferred from the inside of the fire-tube through its wall to the surrounding "bath" liquid. In the second step the heat is transferred from the "bath" liquid through process coil wall into the process fluid. Typically, the secondary process coil is inserted from the opposite end of the vessel and located above the fire tube. Sometimes multiple, secondary process coils are incorporated into a single vessel design. Examples of indirect heat transfer designs include line heater, propane, butane or LNG, evaporator, salt bath regen gas heater. Depending on the temperature requirements of this process, the "bath" liquid is typically glycol for lower temperature ranges and molten salt for higher ranges.

2.14 Other Common Immersion Fire-Tube Heater Characteristics

In addition to the fundamental fire-tube design principle, fire-tube heaters share a number of other common characteristics, which must be taken under consideration when discussing potential improvements aimed at increased heater efficiency, such as:

a) simple construction with few or no moving parts for high reliability;

b) limited electric power at various sites (solar panel, thermo-electric generator (TEG), or 12VDC power off a pump jack engine);

c) remote, unmanned sites which in good weather conditions may be over an hour drive from the central plant;

d) some sites are not accessible by road;

e) larger heaters are sometimes equipped with radio transmitters (RTU/SCADA) which relay their status to the central plant;

f) the majority of small heaters, especially oil tank heaters, have no data communications with a central plant and are only irregularly checked during rounds by operators or oil tanker drivers;

g) numerous heaters have no flame supervision or electronic ignition and therefore must be lit by hand;

h) numerous heaters have no safeties compliant with current standards such as low liquid level protection, high temperature protection or high gas pressure protection;

i) most of the heaters operate in an ON/OFF mode and have no fuel modulation, fuel measurement or stack temperature measuring equipment; and,

j) the large numbers of heaters combined with the remote access to their locations make routine maintenance a very labour intensive job.

2.15 Fire-Tube Heater Capacity Ratings

Fire-tube heater capacities typically range from 150,000 BTU/hr to 6 MM BTU/hr per fire-tube. Smaller heaters typically use single fire tubes and larger heaters incorporate multiple tubes. Manufacturers seem to limit the single tube input rating to 5 to 6 MM BTU/hr, as the physical size becomes difficult to handle.

In many cases manufacturers use a standard heat flux rate of 10,000 BTU/hr/ft2, irrespective of tube diameter. This may lead to tube designs which are either “short-and-fat” or “long-and-skinny”, both resulting in significantly different heat transfer performance. The relevance of this will be more apparent as we discuss fire tube rating curves.

2.16 Number Of Fire-Tube Heater Installations

Although the exact numbers of installations are not published by owner companies, estimates indicate that there are between and 20,000 to 40,000 existing fire-tube heaters in Alberta, with approximately 1,000 new/replacement installations and at least 2,000 upgrade/repair projects every year. This means that on average there are 10 heater projects completed in Alberta every day. A large majority of these heaters are small oil storage tank heaters, however there are also significant numbers (approx. 5,000) heaters rated at between 1 and 2 MM BTU/hr. Although tackling the efficiency problems of all these installations seems like an insurmountable task, it would likely be best to look at the largest and least efficient units first, as this would provide the fastest payback for efficiency upgrade projects. Once the upgrade techniques and solutions are fully developed and tested, smaller heater projects could then be addressed.

2.17 Overall Impact of Fire-Tube Heaters on Economics and Environment

The total estimated heat input capacity of these heaters could be as high at 10 billion BTU/hr. Since most of the heaters use ON/OFF controls and cycle, the actual hourly fuel consumption is lower than the total capacity. At this point the only estimates found of how much fuel is actually consumed annually by fire-tube heaters indicate that they use approximately 25% of all natural gas consumed as a fuel source in the upstream processes. Further research in this area will be required.

2.18 Average Thermal Efficiency of Fire-Tube Heaters

Some sources claim that the thermal efficiency of individual heaters could be as low as 30%. In practical terms, these claims mean that 70% of energy released from the fuel is lost to the atmosphere.

This can be surprising to readers familiar with conventional boiler or fired heater technology, which typically operate with stack temperatures between 350 to 1000 deg F and with excess combustion air levels between 10% and 40% (2% to 11% oxygen in the stack). Using a standard natural gas efficiency chart (Figure 2.8) the corresponding combustion efficiency should be in the range of 61% to 82% of the fuel higher heating value (HHV).

The 61% efficiency point might represent either a poorly designed or a misadjusted heater or a heater operating with high temperature fluid such as steam, thermal oil heater of salt bath heater. The 82% efficiency point would represent an average efficiency heater operating with lower temperature fluids such as water or glycol and without heat recovery. The 85% HHV efficiency point is considered to be the maximum practical efficiency limit due to the flue gas dew point (water condensation) problems inside the fire-tube and stack.

Using this reasoning, which is based on standard industrial boiler and heater technology, we can assume that these higher efficiencies are attainable both from the point of view of the combustion equipment, as well as, from an economically viable heat transfer area. Consequently, there does not seem to be any technical limitation why the petroleum immersion fire-tube heaters could not operate in these efficiency ranges if properly designed and maintained to operate with similar stack temperatures and excess air levels.

Conversely, there is no explanation why some reports quote heater efficiencies in the 30% range, other than through significant overfiring, heat transfer surface under-sizing, misadjustment of combustion equipment or lack of appropriate maintenance.

2.19 Thermal Efficiency Target for Fire-Tube Heaters

For the purpose of this study, we established the theoretically obtainable combustion efficiency range for these heaters between 72% and 82% as marked in the Figure 2.8 within the red area.

Any operation outside of this area and shown in the black area, can be explained by either poor thermal and combustion design or inadequate maintenance. The operation in the blue area down to 30% efficiency range can be explained as misapplication of a given heater size to a much larger process requirement. We will discuss these efficiencies in more detail in the next chapter.

The research conducted in this project concentrated on the methods of achieving efficiency goals between 72% and 82% HHV.

2.20 Possible Reasons for Low Efficiency of Fire-Tube Heaters

There are a number of possible explanations from the point of view of heat transfer and combustion principals for possible low heater efficiency. Depending on the heater configuration its condition and tuning, any of these explanations or their combinations may apply:

a) mismatch between tube size and process requirements;

b) tube diameter is too large for radiative heat transfer;

c) tube diameter is too large for convective heat transfer;

d) partial tube flow of products of combustion;

e) tube diameter is too small for flame size;

f) incomplete combustion due to high excess air;

g) lower flame temperature due to high excess air;

h) substoichiometric combustion;

i) poor fuel and air mixing;

j) ON/OFF heater control with low duty cycle; and,

k) poor burner design or setup resulting in increased tube fouling.

The rationale for low efficiency is described in the following paragraphs, and will be further investigated in this study.

2.20.1 Mismatch Between Tube Size and Process Requirements

This can be confirmed by comparing the fuel consumption multiplied by a nominal 65% efficiency used by most manufacturers to the physical surface area of the fire-tube. Heaters are typically designed for a nominal surface heat flux rate of 10,000 BTU/hr/sqft., so a 1 MM BTU/hr heat transfer would require 100 sqft. and would consume 1/0.65 = 1.54 MM BTU/hr of fuel HHV.

2.20.2 Tube Diameter Too Large for Radiative Heat Transfer

The radiant heat transfer component diminishes with the increasing distance between hot gases and the tube surface. Even if gases were hot enough (in excess of 1100 deg F), the distance between the gas flow and the wall of an oversized tube may significantly reduce this radiant heat transfer.

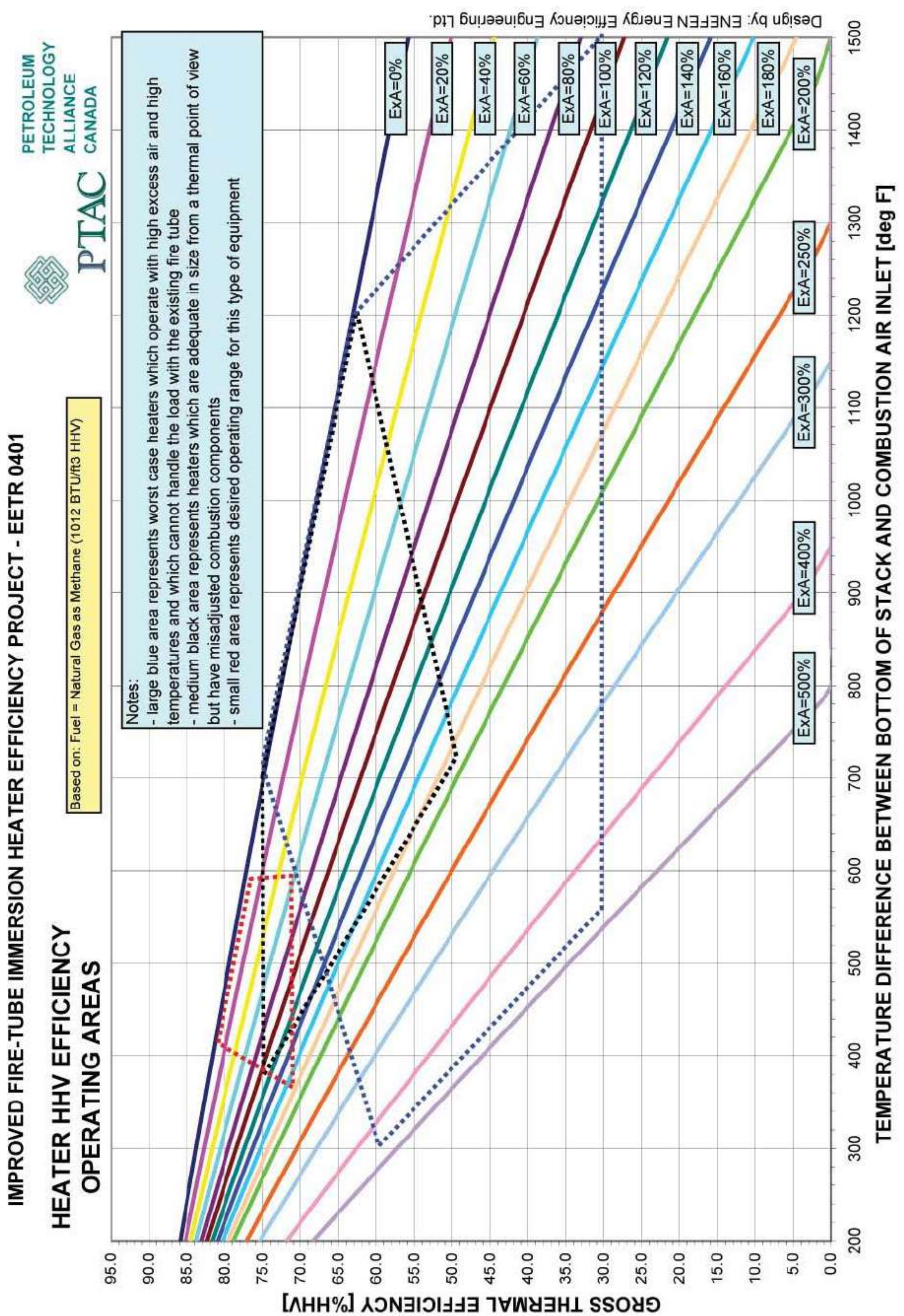

FIGURE 2.8 Chart of gross thermal efficiencies for various excess air levels

2.20.3 Tube Diameter too Large for Convective Heat Transfer

- The convective heat transfer is proportional to the tube-side heat transfer coefficient, which in turn changes with the gas velocity and turbulence expressed as a Reynolds Number. For oversized tubes flow is laminar and velocities and heat transfer coefficient are low.

2.20.4 Partial Tube Flow of Products of Combustion in the Tube

- In extreme cases with really low flow velocities, high excess air and strong natural draft condition, the stratification of products of combustion flow may be present such that the hot gas only flows in the upper portion of the tube while cold air is being pulled along the bottom of the tube.
- In this case only a portion (upper sector) of the tube cross-section takes part in the heat transfer. In other words, the tube may have a large surface area but a significant portion of its lower circumference always stays cold and is therefore ineffective. Figure 2.9 shows an output of the FLUENT finite element modeling software illustrating this phenomenon.

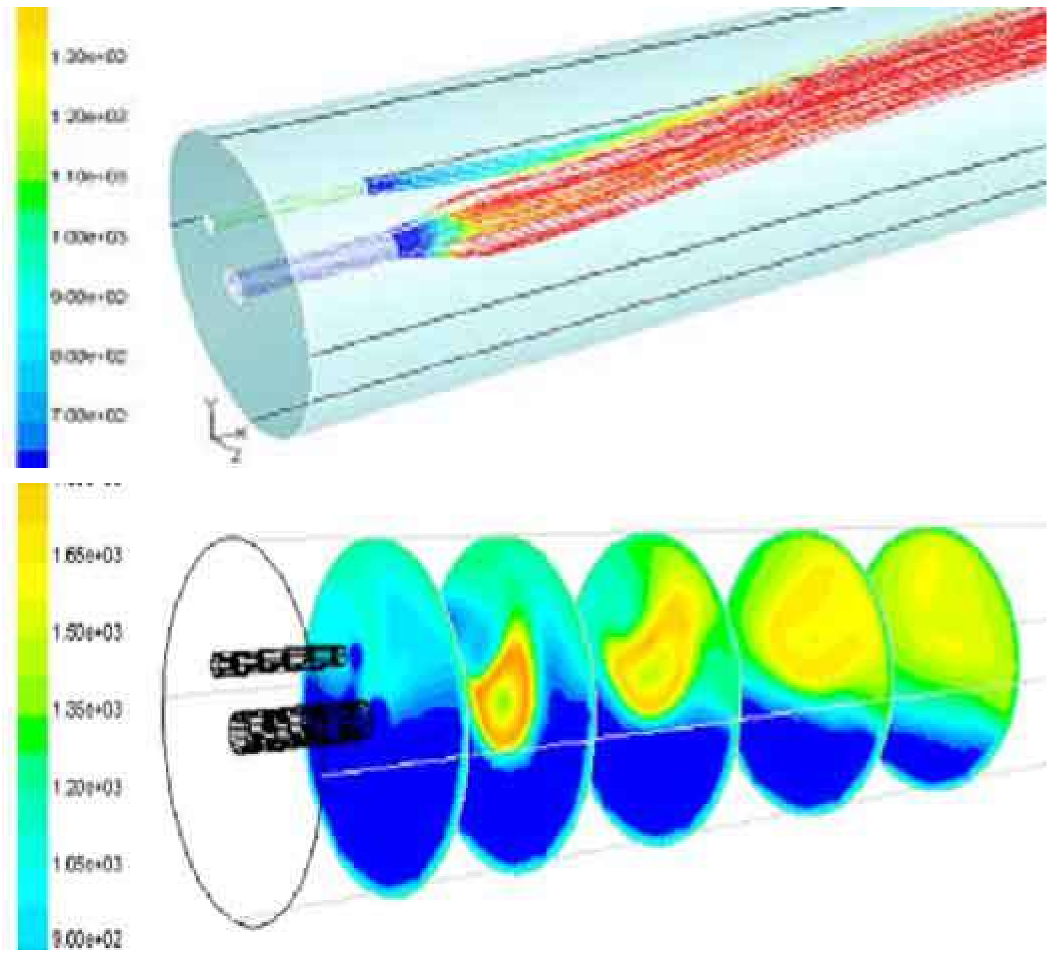

FIGURE 2.9 Output of the FLUENT finite element modeling software illustrating temperature profiles when firing main and pilot burners into and oversized tube.

(Courtesy of Coen Co.)

2.20.5 Tube Diameter Too Small for Flame Size

- Flame impingement is present leading to flame quenching and incomplete combustion. Soot deposits are formed on the inside of the tube and oil cokes on the outside of the tube acting as an insulator.

Unburned CO, aldehydes, and hydrocarbons, left over from interrupted combustion are exhausted through the stack. There are signs of overheating on the tube surface, such as discoloration warping, increased oxidation and reduced metal thickness or thermal stress cracking. Thermal degradation of glycol or coking of hydrocarbons may occur on the bath side.

2.20.6 Incomplete Combustion due To High Excess Air

In a situation where there is either too much (typically more than13% Oxygen) combustion air entering the system, high levels of carbon monoxide may be formed and the flame is quenched resulting in incomplete combustion and fuel loss.

2.20.7 Lower Flame Temperature due to High Excess Air

Too much combustion air may be entrained into the system due to a high natural draft and misadjusted (or lack of) air inlet control mechanism. The result is lower adiabatic flame temperature and decreased LMTD (log mean temperature difference). With the fixed surface area of the tube, the heat transfer is limited. For example 15% oxygen in the stack, which is equivalent to 224% excess air and 1000 deg F, products of combustion temperature would result in 32% thermal efficiency and a 60% reduction in LMTD value. In addition, a significant amount of CO could be formed due to flame quenching, lowering this efficiency even further. These are examples of extremely poorly operated heaters with easy opportunity for improvement.

2.20.8 Substoichiometric Combustion

There is not enough combustion air entrained into the system due to insufficient natural draft action and the burner is running substoichiometrically with a high CO and unburned fuel present in the stack. This is a common situation during system startup with a cold stack and cold tube.

2.20.9 Poor Fuel and Air Mixing

Poor mixing of fuel and air by the burner is a common concern for some Venturi style burners, which require high gas pressure (about 25 psig) to provide 100% stoichiometric air aeration through the primary air ports. At lower gas pressure, the aeration could be as low as 30% to 50% and the fuel/air mixture is rich. Without a significant draft action, secondary air is not present to make up the air deficiency or does not have sufficient kinetic energy or spin to effectively mix into the flame bushel.

2.20.10 ON/OFF Heater Control with Low Cycle Duty

Most heaters have ON/OFF temperature control. In some cases the heater burner may be significantly oversized due to initial design contingencies or process load decline. Such systems turn the burner ON for a very short time then turn it OFF (low duty cycle). The tube and stack do not have sufficient time to develop a natural draft action to provide secondary source of combustion air. Consequently, the heater is often firing rich, backfires, soots-up the tube and wastes significant amounts of unburned fuel. This topic will be discussed in detail later in this report.

2.20.11 Poor Burner Design or Set-Up Resulting in Tube Fouling

Poor combustion equipment design and setup may lead to flame impingement on the fire-tube resulting in fouling of heat transfer surfaces through soot (carbon) deposits on the inside of the tube and coking of the bath liquid on the outside, This fouling reduces the heat transfer.

3 LITERATURE STUDY

Following the review and analysis of the project background information, we proceeded with an extensive literature study through various database searches, including some via the courtesy of PTAC, and some through the University of British Columbia Mechanical Engineering Department. Also included in the search were recommendations of Coen CO, and other project participants.

From a long list of possible "hits" we ended up with 44 references, which formed the basis for this study. The synopsis for each of these references is included in Appendix A of this report.

While reviewing and analyzing these references we noticed that they can be grouped into the following three distinct categories:

a) textbooks, which provide a variety of basic or general information but do not specifically address the subject of this research. These include the following references: A1, A5, A6, A11, A17, A23, A24, A25, A26, A27, A34, A35, A37, A38, and A41;

b) scientific papers, which concentrate on a limited detail related to the subject, which may be applicable in some situations. These include the following references: A12, A13, A14, A18, A28, A36, A40, and A42; and,

c) practical "how-to papers" and guidelines, which talk about practical issues of heaters and draw general conclusions and recommendations related to the design, operation and maintenance of fire-tube heaters. In this group we include the following references: A2, A3, A4, A7, A8, A9, A10, A15, A16, A19, A20, A21, A22, A29, A30, A31, A32, A33, A39, A43, and A44.

Out of the 44 references, 10 referred directly to the aspects of the immersion fire-tube design, operation or maintenance including: A1, A3, A4, A23, A29, A30, A31, A32, A42, and A43. The remaining provided background information, formulas, data, and concepts.

In the process of compiling the lists of recommendations, we found a number of inconsistencies and conflicts with the various references, including technically incorrect and erroneous information. We also found a number of common conclusions, observations, and recommendations, which we compiled into one consistent and non-conflicting guideline. The results of this analysis can be found throughout this study.

It was our conclusion that there were no good current reports available on this subject, which would bring together proper engineering, scientific approach and practical applications. It is our hope that this study can to a certain extent bridge this information gap.

In bringing this information together, we compiled the following three spreadsheets:

a) TOOLS PROVIDED spreadsheet (Figure 3.1) – indicates which references provide information which can be usefully applied to designs and the evaluation of immersion-fire-tube heaters;

b) PARAMETERS ADDRESSED spreadsheet (Figure 3.2) – shows which topic a given reference concentrates on; and,

c) EFFICIENCY MEASURES PROPOSED spreadsheet (Figure 3.3) – shows the recommendations, and conclusions related to the immersion fire-tube heaters, which are discussed in each reference.

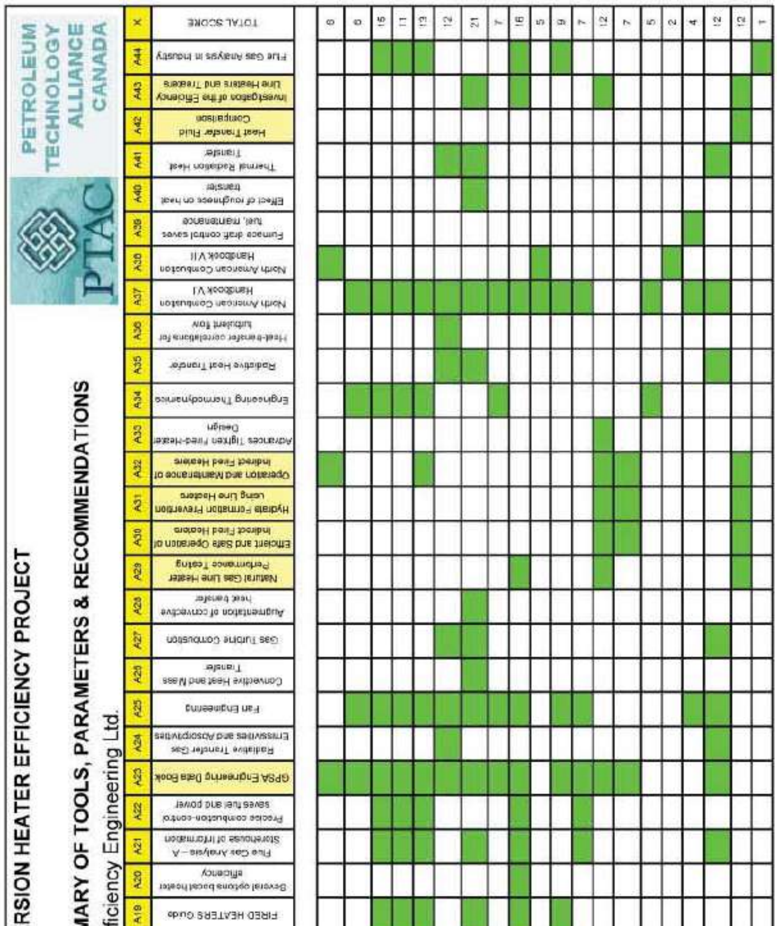

FIGURE 3.1 Literature Study – Summary Of Tools Provided

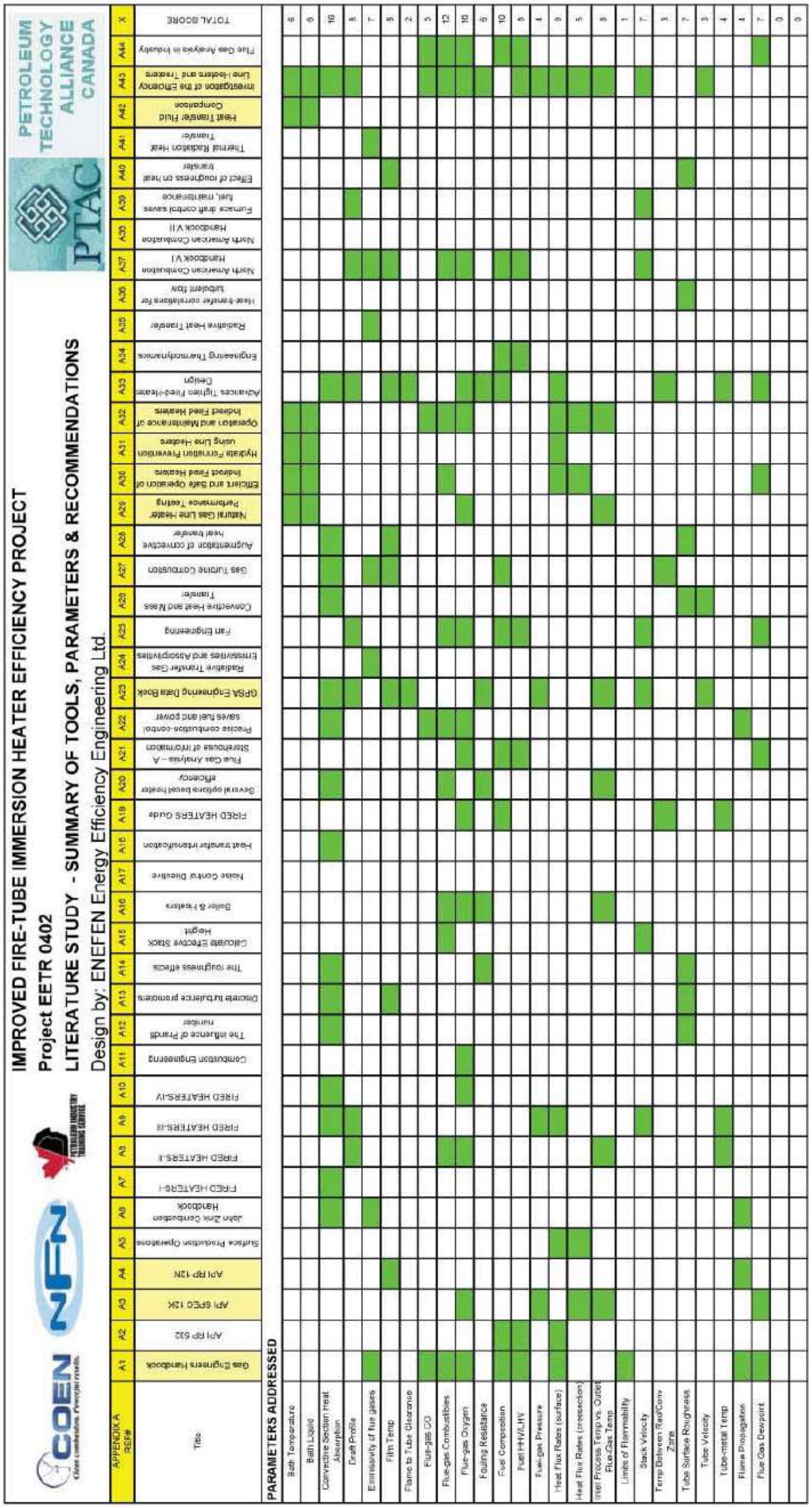

FIGURE 3.2 Literature Study – Summary Of Parameters Addressed

IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT

Project EETR 0402

LITERATURE STUDY - SUMMARY OF TOOLS, PARAMETERS & RECOMMENDATIONS

Design by: ENEFEN Energy Efficiency Engineering Ltd.

COEN Clean combustion. Powerful results. | NFN | PETROLEUM INDUSTRY TRAINING SERVICE | PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA

APPENDIX A REF#	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22
Title	Gas Engineers Handbook	API RP 532	API SPEC 12K	API RP 12N	Surface Production Operations	John Zink Combustion Handbook	FIRED HEATERS-I	FIRED HEATERS-II	FIRED HEATERS-III	FIRED HEATERS-IV	Combustion Engineering	The influence of Prandtl number	Discrete turbulence promoters	The roughness effects	Calculate Effective Stack Height	Boiler & Heaters	Noise Control Directive	Heat transfer intensification	FIRED HEATERS Guide	Several options boost heater efficiency	Flue Gas Analysis – A Storehouse of Information	Precise combustion-control saves fuel and power
EFFICIENCY MEASURES PROPOSED																						
Basic Maintenance			■					■								■				■		
Burner Design			■								■											
Combustion Volume																						
Convective Zone Configuration							■		■	■												
Draft Control								■		■						■				■		
Education																■						
Enhanced heat transfer							■		■	■		■	■	■				■				
Excess Air Control	■		■					■		■	■					■						■
Extended surface Area								■		■		■	■	■						■		
Flue Gas Dew Point Control	■		■																			
Flue-gas Distribution																						
Instrumentation																						■
Preheat Comb Air	■	■								■						■				■		
Process requirements																■			■	■		
Pulsed Combustion											■											
Radiant vs. Convective Zones	■								■													
Radiant Zone Configuration	■						■		■													
Reduce Film Resistance	■											■		■				■				
Reduce Losses (insulation)	■							■								■				■		
Stack Design								■	■													
Tube Diameter					■				■										■			
Tube Fouling							■	■						■		■				■		
Tube-metal Resistance																						
Turbulence Device												■	■	■		■		■				

APPENDIX A REF#	A23	A24	A25	A26	A27	A28	A29	A30	A31	A32	A33	A34	A35	A36	A37	A38	A39	A40	A41	A42	A43	A44	X
Title	GPSA Engineering Data Book	Radiative Transfer Gas Emissivities and Absorptivities	Fan Engineering	Convective Heat and Mass Transfer	Gas Turbine Combustion	Augmentation of convective heat transfer	Natural Gas Line Heater Performance Testing	Efficient and Safe Operation of Indirect Fired Heaters	Hydrate Formation Prevention using Line Heaters	Operation and Maintenance of Indirect Fired Heaters	Advances Tighten Fired-Heater Design	Engineering Thermodynamics	Radiative Heat Transfer	Heat-transfer correlations for turbulent flow	North American Combustion Handbook V.I	North American Combustion Handbook V.II	Furnace draft control saves fuel, maintenance	Effect of roughness on heat transfer	Thermal Radiation Heat Transfer	Heat Transfer Fluid Comparison	Investigation of the Efficiency of Line Heaters and Treaters	Flue Gas Analysis in Industry	TOTAL SCORE
EFFICIENCY MEASURES PROPOSED																							
Basic Maintenance	■							■	■	■	■										■	■	11
Burner Design								■	■	■	■												6
Combustion Volume											■										■		2
Convective Zone Configuration	■						■				■										■		7
Draft Control	■							■			■						■				■		9
Education								■	■	■													4
Enhanced heat transfer	■					■					■			■				■			■		13
Excess Air Control	■		■					■	■	■	■										■		14
Extended surface Area	■					■					■			■							■		11
Flue Gas Dew Point Control			■							■	■												5
Flue-gas Distribution											■										■		2
Instrumentation							■	■		■												■	5
Preheat Comb Air	■		■								■										■		9
Process requirements							■	■	■	■													7
Pulsed Combustion																					■		2
Radiant vs. Convective Zones	■				■						■												5
Radiant Zone Configuration	■										■												5
Reduce Film Resistance	■			■		■					■							■					9
Reduce Losses (insulation)	■										■										■		7
Stack Design	■								■	■	■						■				■		8
Tube Diameter	■							■	■	■	■										■		9
Tube Fouling	■										■										■		8
Tube-metal Resistance											■												1
Turbulence Device	■					■															■		8
																							0

FIGURE 3.3 Literature Study – Summary Of Efficiency Measures Proposed

To get a better understanding of the trends in the literature related to individual topics, we created a TOTAL SCORE column for each spreadsheet. Although somewhat subjective by the topic selection and perhaps literature selection, the TOTAL SCORE shows which topics are "popular / common" and which are "rare" and perhaps unexplored. Below are the individual results sorted from highest score to lowest:

3.1 Analysis of Tools Provided in Literature

TOOLS PROVIDED	
Convective Heat Transfer Calculations	21
Efficiency Data	16
Combustion Calculations	15
Combustion Principles	13
Conductive Heat Transfer Calculations	12
Heater Design	12
Radiant Heat Transfer Calculations	12
Testing Methods	12
Combustion Data	11
Fuel Properties	9
Conversion Tables	7
Heat Loss Calculations	7
Immersion Tube Calculations	7
Burner Design And Operating Principles	6
Combustion Air Properties	6
Flame Characteristics	5
Laws of Thermodynamics	5
Stack calculations	4
Noise Guidelines	2

Clearly, the most popular topic addressed in the literature is the convective heat transfer with a score of 21 out of 44 references. It is consistent with the most common approach to immersion-fire-tube heat transfer using the standard LMTD approach common for heat exchanger calculations. This is followed by standard combustion calculations, efficiency data and an explanation of combustion principles. Although, we specifically looked for heater design and radiant heat transfer calculations, there were only 12 out of 44 publications found that were applicable. This was closely followed, by testing methods, combustion data and fuel properties.

Since most of the literature is based on combustion of natural gas there was very little attention given to "unusual" fuels such as casing gas, or sour gas, or fuel containing heavier hydrocarbons. Topics such as heat-loss calculations, tube calculations, burner design, flame characteristics, stack calculations, or noise guidelines are considered "specialty" topics and were rarely discussed.

One topic, which we specifically looked for, and which showed up in only 5 of 44 publications, is the laws of thermodynamics. Although it cannot be expected that the basic laws of thermodynamics would be explained in every application, it should be expected that technical papers of this nature would be based on sound engineering principles and foremost on the laws of physics. This is apparently not the case, since some of the claims made by authors boarder or sometimes defy these laws. This leads to erroneous conclusions and recommendations.

It is our conclusion, that besides the mechanics and the “bolts and nuts” of the heaters there is a need in the industry for an educational program directed at the both the basics and the practical approaches to their design, operation and maintenance. The Last chapter of this study addresses such an educational program.

3.2 Analysis of Parameters Addressed in Literature

In the group of topics entitled PARAMETERS ADDRESSED we found the following results:

PARAMETERS ADDRESSED	
Convective Section Heat Absorption	16
Flue-gas Oxygen	16
Flue-gas Combustibles	12
Fuel Composition	10
Heat Flux Rates (surface)	9
Draft Profile	8
Film Temp	8
Fuel HHV/LHV	8
Inlet Process Temp vs. Outlet Flue-Gas Temp	8
Emmissivity of flue gases	7
Stack Velocity	7
Tube Surface Roughness	7
Flue Gas Dew point	7
Bath Temperature	6
Bath Liquid	6
Fouling Resistance	6
Flue-gas CO	5
Heat Flux Rates (cross-section)	5
Fuel-gas Pressure	4
Tube-metal Temp	4
Flame Propagation	4
Temp Between Rad/Conv Zone	3
Tube Velocity	3
Flame to Tube Clearance	2
Limits of Flammability	1

Again, convective heat transfer is at the top of the list along with oxygen in the stack, both were mentioned in 16 out of 44 references. Secondly, are the combustibles in the stack and the fuel composition, followed by standard heat flux rates, discussions about stack draft, film temperature (affecting coking), difference between fuel HHV and LHV, as well as, some mention about correlation between process inlet temperature and stack temperature.

Less “popular” topics include: flue gas emmisivities; stack velocities; tube roughness effect; bath temperature; type of bath liquid; and, fouling resistance.

Further down the list, was flue gas CO; cross-sectional heat flux; impact of fuel pressure; tube metal temperature; and, flame propagation.

The least discussed parameters include: temperature between radiant and convective section; tube velocity; flame to tube clearance; and, limits of flammability.

As a generalization, we noticed that topics related to burner design, operation and physical phenomena occurring at the entrance to the fire tube were rarely addressed. It is worth noting that the vast cross-section of the literature surveyed applies to various other types of combustion equipment and fire-tube heaters are only mentioned occasionally.

3.3 Analysis of Efficiency Measures Proposed in Literature

The final group of topic scores belongs to “EFFICIENCY MEASURES PROPOSED”. In this group we looked for recommendations, which can be directly applied to immersion fire-tube heaters.

Following are the results.

EFFICIENCY MEASURES PROPOSED	
Excess Air Control	14
Enhanced heat transfer	13
Basic Maintenance	11
Extended surface Area	11
Draft Control	9
Preheat Comb Air	9
Reduce Film Resistance	9
Tube Diameter	9
Stack Design	8
Tube Fouling	8
Turbulence Device	8
Convective Zone Configuration	7
Process requirements	7
Reduce Losses (Insulation)	7
Burner Design	6
Flue Gas Dew Point Control	5
Instrumentation	5
Radiant vs Convective Zones	5
Radiant Zone Configuration	5
Education	4
Combustion Volume	2

Flue-gas Distribution	2
Pulsed Combustion	2
Tube-metal Resistance	1

On the top of the proposed efficiency measures are: excess air control and enhanced heat transfer which includes various methods of making the existing fire tube absorb more energy. These topics were followed very closely by recommendations of basic (and regular) maintenance and extended surface area of the fire tube. Next in the frequency are: draft control, air preheat, reduction of film resistance, and specification of tube diameter. Less frequent were suggestions regarding stack design, tube fouling or installation of turbulators.

A very interesting observation is that although convective heat transfer calculations and data are on the top of the two previous lists, the actual configuration of the fire tube in the convective zone is only mentioned in 7 publications. At the same level of frequency is a discussion about process requirements for energy (it was probably assumed to be taken care "by others"), as well as, the recognition of the benefits of insulation.

Even lower on the list were: burner design; flue gas dew point control; additional instrumentation; interaction between the radiant and convective section; and, radiant section configuration. Near the bottom of the list of recommendations were: combustion volume requirements; flue gas distribution; tube metal resistance; and, pulse combustion.

Looking at the above distribution of topics, recommendations and our own experience in the industry, it seems that the subject of efficiency of immersion fire-tube heaters is "stuck" between the traditional "low-tech" approach; lack of power; lack of instrumentation; very competitive nature of the industry; and finally the simple lack of verifiable information related to modern trends in combustion and heat transfer. In this, project we will bring some of these factors into further discussions.

4 HEATER EFFICIENCY PRINCIPLES

In the literature study of Chapter 3, we identified the need for bridging the gap between the science of combustion, heat transfer and the world of “low-tech” immersion fire-tube technology. In doing so, we are hoping to give readers involved in designing, operating, and maintaining this equipment sufficient background information for a better understanding of what makes their systems work more reliably, safely, and more efficiently.

In this chapter, we will address the theoretical principles behind the efficiencies of immersion fire-tube heaters, as well as, a variety of factors, which influence that efficiency. As stated before, it is not our intention to show in this study the exact numerical methods of how to calculate various factors. The equations, factors, and tables found in the referenced literature and a variety of other sources can be quite complicated or confusing.

We have gone through that literature and combined it with our experience in this industry to produce what we believe will be useful charts applicable to immersion fire-tube applications. Additionally, we have provided descriptions of how this data could be interpreted in various fire-tube applications. As explained in our “Shell and Tube Heat Exchanger Analogy” in chapter 3 the thermal design of immersion fire-tube heaters depends on a variety of factors which have a cumulative effect on the overall efficiency, consequently, there is no single “most efficient” fire-tube design which would fit all applications. The fire-tube heater efficiency changes with firing rates, excess air settings, fuel type, mode of control, ambient conditions, etc. The following paragraphs show the magnitude of these changes.

4.1 Laws Of Thermodynamics In Fire-Tube Heater Context

The efficiency of immersion fire-tube heaters has to be viewed in the context of the basic laws of thermodynamics, which dictate the specifics for the movement of heat and work in any type of process involving thermal, mechanical, and chemical energy. Of special interest to our topic are the first two laws of thermodynamics.

4.1.1 First Law Of Thermodynamics

The FIRST LAW OF THERMODYNAMICS also called the law of conservation of energy states that the energy can be changed from one form to another, but it cannot be created or destroyed.

This means that the chemical energy contained in the fuel combined with the energy in the ambient air is changed through a chemical reaction of combustion into heat. This heat is transferred to the bath liquid, steel and insulation of the heater, lost through the external heater and stack surfaces, as well as, partially discharged through the stack with the vent gases. The total sum of the energy that goes into the heater is equal to the total sum of the energy, which leaves the heater. Similarly, the total sum of the mass flow of fuel and air going into the heater is equal to the total mass flow of products of combustion leaving the heater. In the heating process neither the initial total amount of the energy nor the total amount of mass is changed, and although the form of the energy has changed from chemical to thermal, the energy is neither created nor destroyed.

A clear understanding of this first law of thermodynamics is crucial in discussions about the efficiency of immersion fire-tube heaters, the calculation of which relies on mass/energy balances. The term: “mass/energy balance” is just another description for the two equations described above, in which both the mass and the energy remain the same (remain conserved).

4.1.2 Second Law Of Thermodynamics

The SECOND LAW OF THERMODYNAMICS states that in all energy exchanges if no energy enters or leaves the system, the potential energy of the state will always be less than that of the initial state. This is also commonly referred as entropy.

In the context of the immersion fire-tube heaters, this means that if we imagine for a moment the heater as a closed box in which combustion reaction takes place, although the total amount of energy remains the same the potential of this energy to do work diminishes. The transfer of the energy is only possible from a higher state to the lower state, which means from the higher temperature fluid to a lower temperature: from products of combustion to the bath liquid to the process coil. The Second Law implies that this process is unidirectional, irreversible, and that there has to be a difference in this energy potential (entropy) for the energy transfer to take place. It also implies that the smaller the difference in the energy potential, the more difficult it is to transfer the energy. This can be translated into the application of immersion fire-tube heaters through the following examples:

a) the products of combustion must be significantly warmer than the bath liquid, which in turn must be significantly warmer than the process fluid inside the process coil for the heat transfer to occur;

b) the closer these temperatures are together the more fire-tube surface area and conversely, the more process coil area is required, to a point where “infinite” surface areas would be required to transfer the “last BTU” of heat;

c) adding extra mass of excess air to the products of combustion lowers the potential of the energy transfer by reducing the temperature of the products of combustion which in turn reduces the heat transfer to the bath liquid; and,

d) once the fuel flow to the heater is stopped, the energy flow will continue until all temperatures are equalized. Consequently, the heater will keep loosing energy until all of it parts and the bath liquid are cooled to the ambient temperature.

4.1.3 Direct Implication of The 1st and 2nd Law Of Thermodynamics On Fire-Tube Heater Efficiency

Looking at the fire-tube heater efficiency strictly form the point of view of these two basic laws of thermodynamics, we can conclude that in order to maximize the “fixed chemical energy potential contained in the fuel” we should simultaneously:

a) maximize differential temperatures for heat transfer;

b) reduce mass flows; and,

c) eliminate heat losses

- A clear understanding of the application of these three objectives as dictated by the laws of thermodynamics will lead to the more efficient designs of immersion fire-tube heaters.

4.2 Immersion Fire Tube Heater Mass / Energy Balance

The 1st Law of Thermodynamics dictates that both the total energy and the total mass going into the heater remains unchanged and must balance with the total energy and mass leaving the heater. The mass / energy balance which is the key to establishing improved heater efficiency can be represented graphically.

Figure 4.1 shows an energy (and mass) balance in a typical immersion fire-tube heater.

On the INPUT side of the balance there are two components, namely: ambient air and fuel.

On the OUTPUT side flue gases leave through the stack, and thermal energy is given to the process or lost through the heater surfaces to the surroundings.

These mass and energy flows are described in the following paragraphs.

4.2.1 Role of Ambient Air in a Heater Mass/Energy Balance

Ambient air can be characterized by its chemical composition including humidity, temperature, and wind velocity.

Dry air is mostly composed of 21% oxygen and 79% nitrogen with trace amounts of carbon dioxide, hydrogen, argon, neon, helium, krypton, and xenon. From the point of view of mass energy balances only oxygen and nitrogen are of significance while the trace elements can be ignored and considered to be part of the nitrogen stream. Another component, which may have a noticeable impact on the heater mass/energy balance, is water either in vapour form as air humidity or in liquid form, as precipitation. Combined, these components bring to the mass balance energy expressed at a given ambient temperature, as the enthalpy of air. Since the air mass flow amounts to more than 19/20th (based on 10%

excess air) of the total mass flow going into the reaction its enthalpy has a much greater effect on the overall mass balance than that of the fuel. This impact increases with the percentage of excess air going into the reaction.

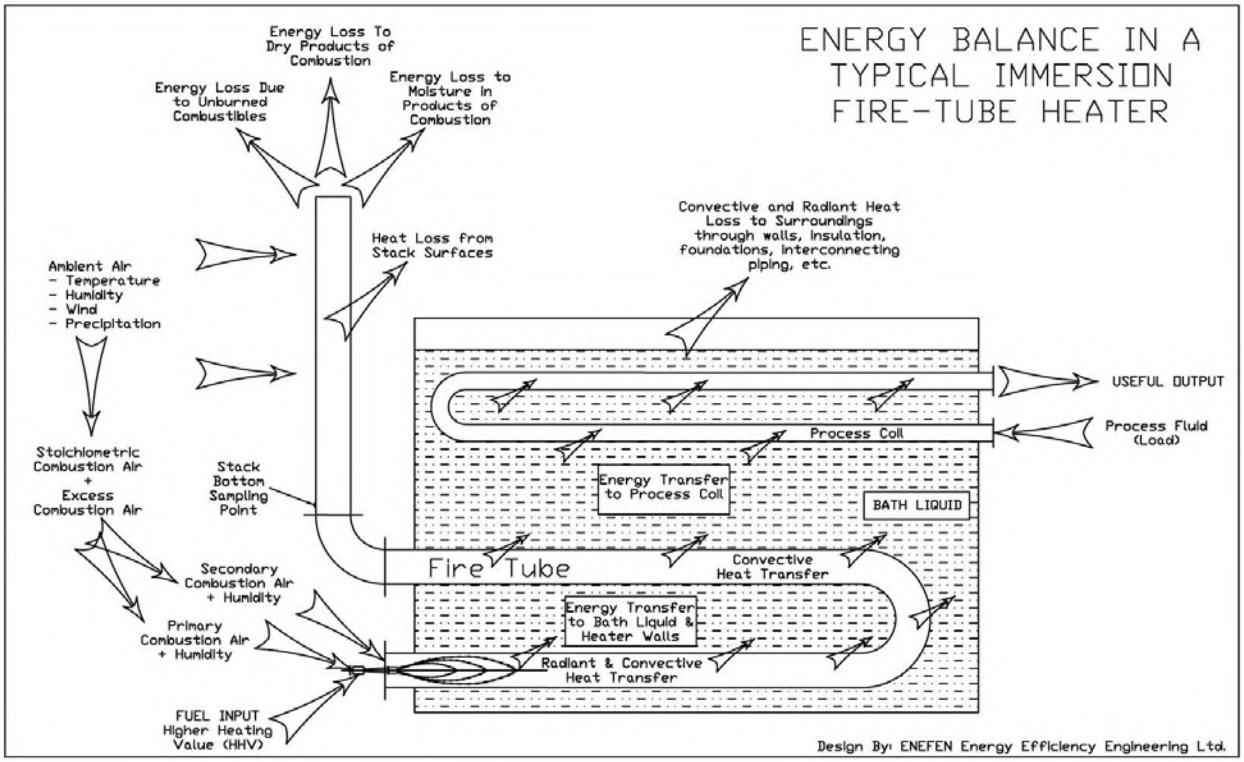

FIGURE 4.1 Energy balance in a typical immersion fire-tube heater

4.2.2 Stoichiometric And Excess Air

In mass/energy balances, air flow is always expressed in terms of the stoichiometric air and excess air. The stoichiometric air is defined as the exact theoretical amount needed to complete the combustion of the given fuel so that no oxygen and no fuel are left over from the reaction. Conversely, substoichiometric combustion occurs when there is not enough air added to the reaction so that all oxygen is used up and some fuel is left over in either its original form or most likely as partially oxidized into carbon monoxide or aldehydes.

In reality, it is difficult to ensure that within a short timeframe of the combustion process all combustible particles will find their oxygen match in a perfect stoichiometric mixture. Consequently, such mixtures tend to result in incomplete combustion. To compensate for this tendency, excess air is added to the process. In a good combustion design excess air can be limited to about 10% to 20% above the stoichiometric air, which based on a formula: ExA% = 1+ O_2%/(21-O_2%) is equivalent to approximately 2% to 3.5% of excess oxygen in the stack gases.

Although excess air helps in fully completing the combustion reaction it also lowers the combustion efficiency by taking what is called a “free-ride” through the heater. This means that the air including its oxygen does not take part in the reaction but absorbs thermal energy needed to heat it from its ambient temperature to the stack temperature.

4.2.3 Role of Burner Primary and Secondary Air on Heater Efficiency

Although in mass / energy balances, the split between the stoichiometric and the excess air is of importance, it is not the case with the burner design. In the case of natural draft Venturi style burners (inspiring air), which are common in the industry, the total amount of air (stoichiometric + excess) is split between the primary air entering the burner’s air/fuel mixer and secondary air induced by stack draft into the tube around the burner.

Despite the fact, that the primary and secondary air, end up eventually in the same place in the fire tube, the route each stream takes is important to the heater performance and its efficiency. Since the objective of the combustion process is to produce the maximum heat with the minimum amount of mass flow (minimum excess air) while oxidizing all of the fuel, thorough mixing of the fuel with air is essential. The chances of this happening are much higher if the air enters though a properly designed and sized fuel /air mixer where the high fuel pressure is utilized to create turbulence and mixing. The quality of such mixing is much higher than that created downstream of the burner nozzle. It is also much easier to mix two gas stream of similar temperatures and specific densities (air = 0.075 lb/cu ft; methane = 0.042 lb/cu ft) inside a mixer than mixing two streams of significantly different temperatures and densities (60 deg F air 0.075 lb/cuft; 3000 deg F products of combustion 0.01 lb/cuft) flowing in parallel to each other along the tube. The first mixing produces a *homogenous flow* of products of combustion; the second mixing produces a *stratified flow*.

From this point of view, the ideal burner solution would have all of the air going through the burner mixer where it could be thoroughly mixed with the fuel.

4.2.4 Role of Fuel In Heater Mass/Energy Balance

Fuel can be characterized by its chemical composition, calorific value, temperature, and pressure.

Unlike most industries, which use clean and dry natural gas or propane purchased from outside sources, the petroleum industry additionally utilizes gas produced from wells (for example casing gas or raw sour gas), or waste fuel from other processes. The use of such unprocessed fuel brings with it safety or operational concerns (such a freezing or corrosion), but is typically dictated by the economics of bringing sweet fuel lines to the heater location. On some sites, the availability of low pressure casing gas offers an attractive source of energy which otherwise would have to be flared. Consequently, the composition of fuel used in the fire-tube heaters can vary from clean and dry natural gas containing mostly methane, to fuels containing heavier hydrocarbons, hydrogen sulfide, and water vapour.

Fuel composition affects calorific value of the fuel expressed in terms of either its Higher Heating Value (HHV) or Lower Heating Value (LHV). Typically the difference between the HHV and LHV is described as the amount of energy used to evaporate water formed during the combustion process from the hydrogen contained in the fuel. However, if the fuel also contains liquid water particles, which have not been removed prior to combustion its LHV must also reflect the energy lost due to evaporation of that water.

Although fuel mass flow usually amounts for less than $1/20^{th}$ (at 10% excess air) of the total mass flow going into the reaction, its temperature is important in the case of fuels containing condensable liquids such as water or heavier hydrocarbons. In a system designed to work with gaseous fuel only, all fuel components should be entering the reaction in a gaseous or vapour form, which is dictated by the fuel temperature. Consequently, although fuel preheat does not have a significant impact on the overall heater energy balance, it may in some cases help eliminate problems associated with burner orifice or mixer freezing and plugging. Fuel preheat may also prevent poor burner performance due to the presence of liquid droplets in the fuel.

Overheating of the fuel may also create problems and should be avoided. This is a common problem, for example, with propane evaporators which when set to an excessive evaporation temperature may actually cause propane cracking.

To summarize, the effect of the fuel temperature on heater efficiency is not as much a function of what the enthalpy of the fuel brings to the overall energy balance, but more a function of optimal fuel temperature required for proper burner performance. Both low and excessive fuel temperature may create combustion problems through poor fuel/air mixing.

The final characteristic of the fuel is its pressure. Although the fuel pressure does not have a direct impact on the mass / energy balances, it is commonly used in the fire tube heaters to induce combustion air and to provide thorough mixing of air with fuel inside the burner mixer. Creating that homogeneous mix is crucial to complete combustion and optimized efficiency. The design of the Venturi air mixer can greatly affect the burner's ability to aspirate primary combustion air and the burner's turndown capability.

Conversely, with low-pressure fuels such as casing gas, the induction of combustion air is limited, and the mixing ability of the burner is significantly reduced. Consequently, complete and efficient combustion is more difficult to achieve.

4.2.5 What Happens with the Energy from Air and Fuel in the Heater

The two components to the reaction: combustion air and fuel are mixed by the burner and ignited to promote an oxidation reaction called combustion. In this rapidly progressing chemical conversion, chemical energy contained in the combustible compounds is released in a series of reactions, which lead to the conversion of carbon atoms contained in the fuel to carbon dioxide, hydrogen to water; and, sulfur to sulfur dioxide, all accompanied by the release of electromagnetic energy mostly in the infrared range (heat) but also in the visible part of spectrum (light) or ultraviolet radiation (UV flame signal). Sufficient excess air, fuel/air **t**urbulent mixing, **t**emperature, and retention **t**ime (3 T's of combustion) are essential to the combustion process.

4.2.6 Combustion is a Multi-Step Reaction

Combustion reactions occur in stages. Although extremely fast, violent and difficult to measure the completion of oxidation reaction in the combustion process is by no means guaranteed. Combustion involves very fast and very complicated multi-step reactions determined by diffusion, heat transfer near the flame, and by distortion, disruption, and blending of the flame front by turbulence, a process, which is very often described as a series of mini-explosions.

Without getting too deeply into the theory of the combustion process, we would like to mention two examples of many theories explaining the combustion reaction:

a) free radical reaction mechanism theory, and,

b) hydroxylation theory.

Free radical reaction mechanism theory assumes that combustion is controlled through hydrogen atoms and is proportional to the formation and destruction of formaldehyde in the following stages:

I. $HCHO + O_2$? free radicals

II. OH (hydroxyl radical) + CH_4 ? $H_2O + CH_3$ (methyl radical)

III. $CH_3 + O_2$? HCHO + OH

IV. OH + HCHO ? H_2O + CHO

V. OH and CHO are destroyed

Hydroxylation theory assumes that combustion is controlled through oxygen atoms, which added to hydrocarbon molecule produces unstable compounds, then aldehydes and formaldehydes, to CO and water, then CO_2 and water

$CH_4 + O_2$? H_2O + HCHO ? CO + H_2O ? $CO_2 + H_2O$

Although the exact mechanism of the combustion reaction is not known, its multi-step nature has far reaching consequences on the mass energy balances and the efficiency calculations and performance of immersion fire-tube heaters. By disrupting the kinetics of the reaction, for example by flame quenching, the reaction may be stopped at one of the intermediate stages. These consequences are described in the following paragraphs.

4.2.7 Complete and Partial (or Incomplete) Combustion

Most literature, calculations, and evaluation procedures assume a complete combustion based on a simplified conversion of carbon to carbon dioxide, and of hydrogen to water:

$C + O_2$? CO_2
$H_2 + ½ O_2$? H_2O
$CH_4 + 2 O_2$? $2 H_2O + CO_2$

Under this assumption there are no combustibles left in the tube after the combustion is complete, and water and carbon dioxide are discharged into the atmosphere.

Although the ultimate goal of proper combustion is to achieve such complete reaction through fire-tube design, burner setup, and unit operation and maintenance, the reality of fire-tube heaters is often different due to partial (incomplete) combustion.

During incomplete combustion, not all of the hydrogen and carbon atoms are converted to water and carbon dioxide. Here are some of the possible scenarios:

a) $C + ½\ O_2$? CO

b) $H + ½\ O_2$? OH (unstable hydroxyl radical)

c) $CH_4 + ½\ O_2$? $CO + 2H_2$ (methane to carbon monoxide and hydrogen)

d) $CH_4 + ½\ O_2$? CH_3OH (methane to methyl alcohol)

e) $CH_4 + O_2$? $HCHO + H_2O$ (methane to formaldehyde)

f) $CH_4 + {}^3/_2\ O_2$? $HCOOH + H_2O$ (methane to formic acid)

Although many of these reactions are associated with insufficient combustion air during substoichiometric combustion, they can also be the result of other factors such as poor fuel and air mixing, flame impingement on a cold tube surface, or flame quenching with excessive amount of cold air. In either case, the combustion reaction is interrupted.

In extreme cases, which are common in fire-tube heater operations, incomplete combustion leads to carbon (soot) deposits inside the fire tube and in the stack, tube corrosion, and can also result in the discharge of unburned fuel through the stack.

4.2.8 Heat Transfer of Energy Through the Tube Wall into the Bath Liquid.

The energy released from the combustion process is transferred through the tube wall into the surrounding bath liquid mostly through radiant and convective heat transfer, but also through conduction. This heat transfer is described in detail in the following chapters.

4.2.9 Energy Transfer Through the Bath Liquid

The energy, which reaches the bath liquid, is transferred through conduction but also through natural or forced convection (depending on the heater type) from the immediate vicinity of the fire tube outside wall through the vessel. The ability of the bath to effectively exchange heat from the fire tube to the bath and then to the process coil is affected by the bath circulation due to natural or forced convection. This energy not only heats the process coil but also heats the bath liquid itself as well as heater walls, insulation, attached piping and related equipment.

4.2.10 Energy Transfer to the Process = USEFUL OUTPUT

As the thermal energy reaches the process coil (or multiple coils), it is transferred through its walls by convection into the process liquid (indirect heating). In applications where the heating is direct such as oil treaters or oil storage tanks, the energy is transferred directly to the process medium. Whether this energy transfer is direct or indirect the final amount of energy going into the process medium is defined as "useful output".

In our investigation of fire tube efficiency, we assumed that the ability for this final energy transfer was not inhibited by insufficient surface area in the process coil, or by insufficient differential temperature for the energy transfer to take place.

We have however identified, that insufficient flow of the process medium was one of the main reasons for poor efficiency. Although the process medium is not in direct contact with the fire tube, its low flow may result in cyclic operation of the heater. Also the volume of the bath fluid or process fluid operates much like a battery that stores heat. As the bath temperature fluctuates it demands cyclic firing of the burner.

In the case of direct heat transfer applications, where the process fluid is in direct contact with the fire tube, the energy transfer may be limited by the external fouling of the tube by either the nature of the solids (for example sand), or by a bath fluid such as glycol or hydrocarbons coking on the fire tube surface.

4.2.11 Heat Loss to the Surroundings

Many of the immersion fire tube heaters used by the petroleum industry are located outdoors and directly exposed to the weather. It is therefore obvious that factors such as ambient air temperature, wind velocity and precipitation have an effect on the convective and radiant energy loss from the bath liquid through the metal walls, insulation, and cladding. There is also a heat loss due to connected piping and related equipment and its foundations. In many heater calculations, these factors are not addressed in detail, and a simple 4 to 5% heat loss is assumed to these surroundings. This assumed heat loss is based on typical boiler applications, which are located inside buildings and equipped with adequate insulation. The heat loss from immersion-fire tube heaters exposed to weather may be higher.

It is also important to recognize that this energy loss continues as long as there is a differential temperature between the inside of the heater and the outside air (2^{nd} law of thermodynamics), regardless if the burner is firing or is off.

This would include losses up the stack due to draft through the fire tube when the burner if off in the cyclic service. With the cyclic nature of operation of the fire-tube heaters this effect must be carefully considered. In some cases draft control may help reduce this loss.

4.2.12 Heat Loss to Stack

The energy flow and heat losses described in the previous paragraphs have a direct impact on the available USEFUL OUTPUT which was defined as that energy portion used directly in the process. By far the largest energy loss, in any fired equipment is the energy lost out the stack with the flue gases when the burner is operating. This loss is due to three components:

a) dry products of combustion (sensible heat);

b) moisture (latent heat) in stack gases; and,

c) unburned combustibles (poor combustion).

These components are described in the following paragraphs.

4.2.12.1 Energy Loss to Dry Products of Combustion

Loss to dry products of combustion is directly related to the amount of air allowed into the heater and the stack temperature. Under ideal theoretical conditions, in order to maximize the combustion efficiency, one would like to use a stoichiometric mixture of pure oxygen with the fuel. The combustion would result in the formation of water and carbon dioxide with no other components taking part in the reaction.

Although such combustion is used in specialized applications such as some metallurgical processes or even in an acetylene torch, it is not practical in conventional heating applications. This is due to the fact that the combustion air consists of only 21% oxygen and 79% of nitrogen. The nitrogen, which is an inert gas, does not take part in the combustion reaction and yet it is being heated by the energy released in the reaction.

As we will explain later in this report, nitrogen does not contribute to the radiative heat transfer in the fire-tube, as it is transparent to the infrared radiation. By absorbing part of the heat energy, nitrogen lowers however the temperature of the other products of combustion thus reducing their ability to transfer radiant heat. The more excess air that is added to the combustion, the more nitrogen comes with it and the more effect it has on the energy loss to dry products of combustion and on the reduction in the radiative heat transfer.

The other dry products include carbon dioxide and unused oxygen from the excess air. The carbon dioxide originates from the fuel and is directly proportional to its flow. Relative to the nitrogen, mass flow of the carbon dioxide and of the excess oxygen is relatively low, and so is their effect on the efficiency.

Since we cannot avoid the participation of the nitrogen in the combustion reaction, the only way we can decrease the heat loss associated with its presence is by minimizing the amount of excess air. We further want to maximize heat recovery by reducing the differential temperature between ambient air and the stack temperature, while respecting the concern for the flue gas dew point temperature. This is consistent with our objectives defined from the 1^{st} and 2^{nd} law of thermodynamics.

Additionally, from a theoretical point of view, if we could discharge the stack gases from the heater at the same temperature as the incoming ambient air, there would be no heat loss to the dry products of combustion and the amount of excess air would not matter. This goal however, based on the 2nd law of thermodynamics is impossible because there has to be a differential energy potential between the gas and liquid side of the tube for the energy transfer to take place. In other words, an infinite heat transfer surface would be required to transfer the last “bit” of energy.

4.2.12.2 “Economical Differential” (Approach) Temperature to Minimize Energy Loss to Dry Products of Combustion

In practical terms of immersion fire-tube heater applications, there is an “economical differential temperature”, between the gas and liquid bath side, which results in “economically reasonable” fire-tube sizes. This differential temperature is often referred to as “approach temperature”. Based on our previous experience and study of higher efficiency heaters from their manufacturers’ literature, this approach temperature is between 180 and 270 deg F (100 and 150 deg C). This means, that in fire-tube heater applications stack temperature target should be 100 to 150 deg C above the average bath liquid temperature while the excess air should be as close to zero (stoichiometric) as possible.

The effects of stack temperature and excess air will be discussed later in this report.

4.2.12.3 Energy Loss to Moisture in Products of Combustion

As discussed previously, the moisture in the products of combustion originates from three sources: hydrogen in the fuel, humidity in the air and humidity (free water) in the fuel. There is also the potential that under certain atmospheric conditions precipitation from atmosphere in form of rain, mist, ice fog, or snow is induced into the burner as liquid water increase the heat loss to moisture in the products of combustion. Although the mass flow of water vapour in the products of combustion is relatively small compared to the nitrogen flow described in the previous paragraphs, its effect on the energy loss is quite significant. This is due to a large difference between the latent and sensible heat of water vapour. It takes only 1 BTU to heat 1 lb of water by 1 deg F, but it takes 1000 BTU’s to convert this 1 lb of water at the same temperature from liquid to the vapour state.

That latent energy is the energy difference between water vapour and condensed water. During the combustion process latent energy is scavenged from the combustion reaction to produce water vapour in the products of combustion, which, without being condensed, is discharged to the atmosphere. This lost energy potential depends on the proportion between the carbon and hydrogen contained in the fuel and is expressed by its Higher or Lower Heating Value (HHV and LHV). In case of methane firing, this energy loss to latent heat in the products of combustion is approximately 10%, in case of propane firing 8%. We will show this relationship later in the report.

In addition, the specific heat of water is about double that of the specific heat of nitrogen, which means that the energy loss due to the high stack temperature, compared on a pound for pound basis increases twice as fast for water vapour as it does for the dry products of combustion.

Since the amount of water vapour in the products of combustion is related mostly to the fuel flow it is constant for any given firing rate. This is assuming that the fuel is as dry as possible and any potential water carry-over has been removed before the fuel is injected into the burner. The excess air, however, has an impact on the amount of humidity which enters the heater and conversely on the amount of fuel which has to be burned in order to heat this excess air and humidity to the stack temperature.

Consequently, the design goals outlined under the 1st and 2nd law of thermodynamics of reducing the mass flows and increasing the differential temperatures as much as possible apply also to the analysis of stack energy loss due to moisture in the products of combustion.

The above analysis does not take under consideration a possibility of condensing water vapour out of the products of combustion. Although practiced on some residential style high efficiency condensing furnaces available today, the vapour condensing techniques are considered not practical in the context of immersion fire-tube heaters due to inherent problems with corrosion and disposal of the condensate.

4.2.12.4 Energy Loss to Unburned Combustibles

This topic has been already discussed previously under the incomplete combustion.

With incomplete combustion not only is some of the energy available from the fuel not fully utilized but there is also a potential for increased fouling and corrosion of the tube, impeding heat transfer, and raising safety concern in case of high CO levels. Unburned fuel also scavenges sensible heat that is lost out the stack.

One of the primary goals of efficient fire-tube designs is to avoid the possibility of incomplete (partial) combustion. Later in this report, we will quantify the energy loss due to unburned combustibles in the products of combustion.

4.2.12.5 Heat Loss from Stack Surfaces

The final topic within the stack energy group of losses, is the heat loss from stack surfaces as shown in the Figure 4.1. We identified it as a separate item in this energy diagram to shows its indirect impact on the overall heater performance and efficiency. This energy loss is unlike all other losses, which we discussed previously, because it occurs downstream of (after) the energy that is transferred to the bath liquid, and therefore it should not be added to all the other heat losses in the efficiency calculation.

The stack surface energy loss is affected by the ambient temperature and wind velocity, but equally by the stack gas temperature and velocity. In other words, uninsulated stack acts in a similar way to a shell and tube heat exchanger, with stack gases inside the tube and the ambient air and its “wind” on the “shell side”.

Although stack surface heat transfer does not “steal” energy directly from the heater, it cools the products of combustion thereby reducing the natural draft and potentially causing condensation and freezing of moisture from the products of combustion inside the stack. In extreme cases, this may lead to “flooding” of the fire tube with condensed and accumulated liquid water. This accumulated water boils off and is re-condensed, essentially refluxing within the fire tube and stack leading to corrosion and in larger quantities to flooding of the firebox. Due to this potential, there is a tendency in the industry to run the stack at high temperatures just to avoid this condensation problem. This tendency leads to reduced heater efficiencies.

The common practice of running high stack temperatures in order to avoid condensation addresses the problem by dealing with its symptoms rather than its root cause, which is the energy loss from the stack surface itself. In other words, if we eliminate the heat loss, there will not be any condensation in the stack and no concern for tube flooding, and the natural draft will be maintained. As a result, the products of the combustion will leave the stack at the same temperature (or close to) as they leave the fire-tube.

Possible solutions include stack insulation or a wind shroud, which would minimize the heat loss from stack surface.

Popular concern here is that these two measures will cause stack overheating and oxidation. Again, this concern is based on the symptom and not on the root cause. The root cause of stack overheating is due to inadequate heat transfer of the fire-tube to remove sufficient energy from the products of combustion before they are discharged into the stack.

Carbon steel stack can be reliably used with temperatures up to 600 deg F without loosing its mechanical strength or excessive oxidation. As long as the fire tube and firing rate are designed so that the entrance temperature to the stack is less then 600 deg F, the stack can be safely insulated without concerns for its overheating. Taking under consideration the economic approach temperature defined in the previous paragraphs of between 180 and 270 deg F, a fire tube could be used with bath liquid temperatures as high at 330 to 420 deg F (165 to 215 deg C). This covers most of the bath temperature applications except for some of the salt bath, or high temperature oil applications. For these applications, a stainless steel stack could be used, and still insulated to avoid condensate accumulation.

The understanding of energy loss from stack surfaces and overall effects of stack and fire-tube interaction is important to the proper design of high efficiency immersion fire-tube heaters.

4.2.12.6 Where to Measure Stack Temperature

Based on the observation that the stack surface heat loss does not directly affect the efficiency calculation of a heater, it is important to emphasize that the stack temperature used to calculate the heater efficiency should be measured immediately after products of combustion leave the fire tube and before more energy is lost through the stack surfaces. This temperature is often referred to as the “stack bottom temperature". This is why the sampling port for the products of combustion should be located near the stack bottom, as well as, for convenient access.

4.3 Immersion Fire Tube Heater With Heat Recovery Options Mass / Energy Balance

Figure 4.2 shows the energy balance diagram in an Immersion fire-tube heater with an air and/or fuel preheat. In this section, we will discuss the advantages and feasibility of both of these approaches.

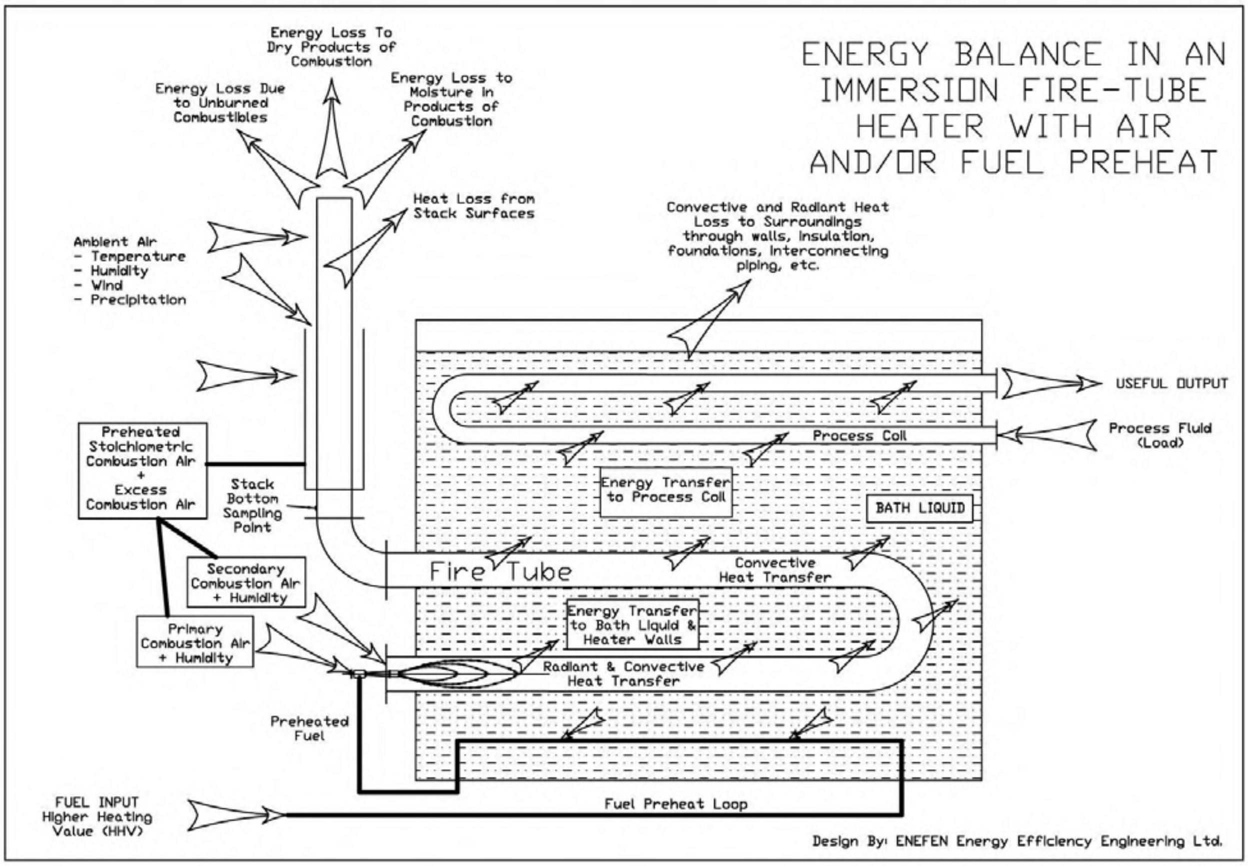

FIGURE 4.2 Energy balance in an immersion fire-tube heater with air and/or fuel preheat

4.3.1 Fuel Preheat

The common approach to fuel preheat used on many installations is a short run of pipe entering through the heater shell running through the bath liquid, then exiting the shell near the fuel train connection. A fuel preheat coil is shown in the black solid line in the Figure 4.2. and also illustrated in the Figure 4.3.

As the fuel flows though the pipe immersed in the bath liquid, heat is transferred from the bath to the fuel preheating it in the process. This approach should not be construed as a heat recovery method since the energy is being subtracted from the useful source of energy and not from a source of waste energy.

As an alternative, to fuel coil location in the bath, a possible fuel preheat with stack gas could be considered, although this should be done with caution not to overheat the fuel. The problems associated with too low or too high fuel temperature were discussed previously in this chapter. In addition, we pointed out that the mass flow of fuel is very small compared to air mass flow; therefore any changes to fuel temperature have only a small impact on the overall energy balance. We will quantify this energy later in this chapter.

FIGURE 4.3 Immersion fire-tube heater with fuel preheat using pipe coil immersed in the bath liquid.

4.3.2 Combustion Air Preheat

A much higher potential for heat recovery and a big impact on the overall energy balance of a heater is in combustion air preheating. Figure 4.4 shows one possible approach using a sleeve mounted around the bottom portion of the stack. Combustion air is pulled through the gap formed between this sleeve and the stack outside wall preheating air in the process. The preheated outlet from the sleeve is connected to the heater's windbox. The idea of heat recovery from stacks is very common with forced draft heating systems, however, with natural draft systems this approach has both positive and negative effects.

To start with, this approach can only be used with heaters, which already operate at high stack temperatures and there is sensible heat to be recovered. On the positive side moderate air preheat will protect the windbox, as well as, wet fuel in the burner from freezing and will recover some of the stack energy in the process.

On the negative side, the preheat sleeve should not be too "high" as it will create its own natural draft, or not too "tight" as it will create pressure restriction, counteracting the draft and air flow through the fire tube. Additional length of stack maybe required in order to compensate for this effect. Preheat sleeve may also create a "permanent" wind around the stack surface resulting in cooling and condensation. Also, the external sleeve should be insulated to eliminate energy loss from the preheated air to the surroundings.

In summary stack heat recovery has limited applications in natural draft heaters and should be applied with due care. Between heat recovery from the stack and a proper combination of the fire tube, burner, and an insulated stack, the latter approach has the better probability of success.

FIGURE 4.4 Immersion Fire-Tube Heater With Combustion Air Preheat Sleeve Installed Around the Stack.

4.4 Modified Sankey Diagram for Immersion Fire-Tube Heater

Another useful way to visualize the energy balance in fired heater is through the use of Sankey diagrams. A modified Sankey diagram for heat balance in an immersion fire-tube heater is shown in Figure 4.5.

This diagram corresponds to the energy balances previously shown in Figures 4.1 and 4.2. Energy flow represented in the diagram can be followed from the left side of the diagram to the right. The concept of the diagram is based on the analysis of “Inputs” to, and “Outputs” from the process (in our case fire-tube heater) represented in the diagram as the thick black box outline. The arrows pointing towards the box are the “energy inputs”, the arrows pointing away from the box are the “energy outputs”.

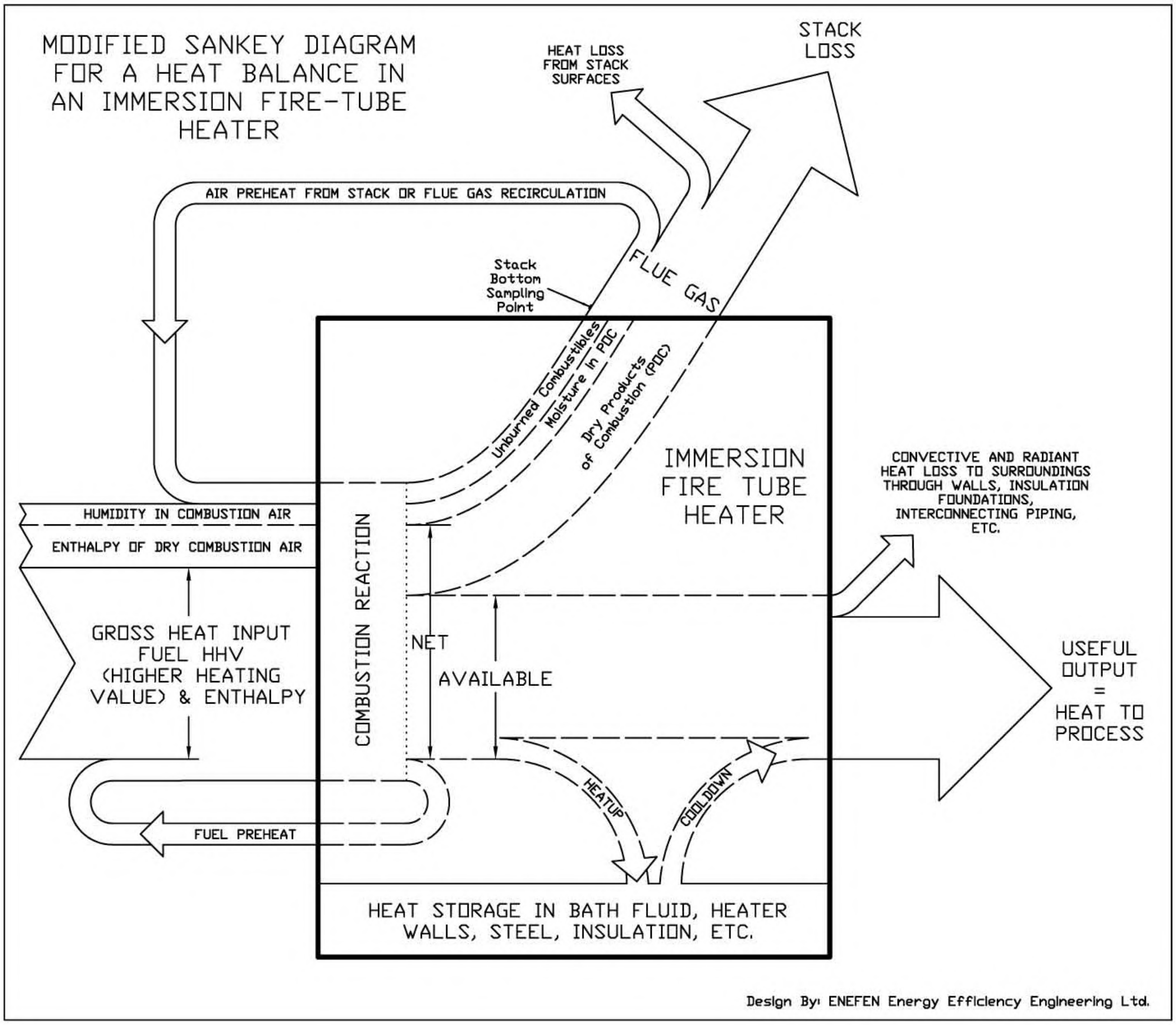

FIGURE 4.5 Modified Sankey Diagram For a Heat Balance In An Immersion Fire-Tube Heater.

On the left hand side of the Sankey diagram the fuel energy input is represented by its Higher Heating Value (HHV). The other inputs include the enthalpy of dry combustion air, air humidity, enthalpy of the fuel itself, as well as, the potential for air and fuel preheat.

Unlike the air preheat using energy recovered from the stack, fuel preheat is removed from the heater bath and then returned to the fire tube.

All of these input energy streams enter into the combustion reaction. Some of the energy is turned into a loss due to the dry products of combustion; moisture in the products of combustion; and, unburned combustibles which are ejected with the flue gas from the heater.

If combustion air-preheat is incorporated into the system design, some of the flue gas energy can by recovered and returned to the input as demonstrated in the diagram. The remaining flue gas energy is carried with the flue gases up through the stack. After the heat losses through stack surfaces are subtracted, the final stack loss can be determined.

The energy portion left after correcting for the losses in the flue gases is called AVAILABLE ENERGY. In a typical efficiency analysis, the available energy is further subdivided into convective and radiant heat losses to the surroundings. The remainder is assumed to go to the process and is called the USEFUL OUTPUT Energy. It must be emphasized that the concept of AVAILABLE ENERGY is based on an assumption that no energy transfer has taken place during the combustion process, which in reality is not possible. Nevertheless, the AVAILABLE ENERGY is useful in describing all of the energy, which is not lost to the flue.

The most important aspect of the Sankey diagram is that, in addition to, showing the direction of energy flows it also graphically shows the relative magnitude either additive or subtractive. This is illustrated through the thickness or width of the individual arrows. This concept clearly demonstrates the 1st law of thermodynamics as the sum of the widths of all input arrows is identical to the sum of the widths of all the output arrows. Therefore, the diagram shows that the energy in the heater is neither created nor destroyed, it is simply converted to a different form through the combustion process and then redistributed.

The understanding of the Sankey diagram concept is very useful in assessing the efficiency of immersion fire-tube heaters.

4.4.1 Difference between Fuel Higher Heating Value (HHV) and Lower Heating Value (LHV)

Looking back on the Sankey diagram at the heater boundary, after subtracting the energy potential lost to unburned combustibles, the rest of the energy potential from the fuel is split into NET sensible energy and energy lost due to the latent heat of moisture in the products of combustion. This split corresponds to the definition of the fuel Lower Heating Value (LHV). Fuel HHV is defined as its total calorific value potential which could be recovered if the products of combustion were cooled to the ambient temperature and all of the vapour formed during combustion was condensed. LHV is equal to HHV less that latent energy, which could be recovered by the condensation of water vapour.

The distinction between fuel HHV and LHV is useful when assessing the combustion processes, which may or may not involve condensation of the products of combustion.

4.4.2 How Is the Efficiency Calculated?

From the point of view of thermodynamics, the efficiency calculation is a simple division of the useful output energy by the total input energy

$$EFFICIENCY[\%] = \frac{USEFUL\_OUTPUT}{TOTAL\_INPUT} * 100$$

Looking at the Sankey diagram and based on the 1st law of thermodynamics:

$$USEFUL\_OUTPUT = TOTAL\_INPUT - TOTAL\_LOSSES$$

If we substitute this USEFUL OUTPUT expression in the first equation we get:

$$EFFICIENCY[\%] = \frac{(TOTAL\_INPUT - TOTAL\_LOSSES)}{TOTAL\_INPUT} * 100$$

Based on the 2nd law of thermodynamics there must be a difference in energy potential for the energy transfer to take place, and 100% energy transfer is impossible, therefore:

$$TOTAL\_LOSSES > 0$$

$$EFFICIENCY[\%] < 100$$

These simple soundings theoretical principles of efficiency calculation are difficult to apply and verify in real-life applications because “total energy inputs”, “useful energy output” and “total energy losses” are not only difficult to accurately measure but also sometimes even difficult to identify. These challenges lead to an array of “practical” efficiency definitions found in the literature.

4.4.3 How Many Types of Efficiency are there?

There is only <u>one</u> theoretical definition of efficiency from the point of view of laws of thermodynamics, however, there are many definitions of efficiency related to fired equipment. All of these definitions are based on assumptions that the magnitude of certain inputs, outputs and losses in the heat balance is negligible or relatively not important to the calculation and therefore it can be ignored.

The plurality of these definitions and their possible meaning is perhaps the most common source of discussions and misunderstandings related to this subject.

Among these definitions, we can find, (in alphabetical order) the following efficiency definitions:

a) Combustion Efficiency -in some cases describes either HHV or LHV, Gross or Net efficiency, or sometimes refers to the effectiveness of the oxidation, where 100% means a complete combustion, and say 95% means that there are 5% unburned combustibles left in the products of combustion. One of the sources defines combustion efficiency as the portion of the total energy (fed to the combustion chamber) that is available in the combustion chamber after the combustion (assuming that no heat transfer has taken place);

b) Economic Efficiency – refers to the percent of fuel cost recovered in form of useful energy;

c) Fuel Efficiency – similar in meaning to economic efficiency;

d) Furnace Efficiency – described in the literature as the portion of the combustion energy which can finally be applied to the process of interest;

e) Gross Efficiency used interchangeably with HHV Efficiency describes the useful output as a percent of fuel gross (higher) heating value (HHV)

$$GROSS(HHV)EFFICIENCY[\%] = \frac{USEFUL\_OUTPUT}{FUEL\_GROSS(HHV)INPUT} * 100$$

Gross efficiency is similar in the meaning to economic efficiency or fuel efficiency;

f) HHV Efficiency used interchangeably with gross efficiency;

g) LHV Efficiency used interchangeably with net efficiency;

h) NET Efficiency used interchangeably with LHV Efficiency describes the useful output as a percent of fuel net (lower) heating value (LHV)

$$NET(LHV)EFFICIENCY[\%] = \frac{USEFUL\_OUTPUT}{FUEL\_NET(LHV)INPUT} * 100$$

i) Thermal Efficiency – this definition used commonly with heat exchangers refers to the percent of total energy entering the heater which is transferred to the heated medium; and,

j) Total Efficiency – used sometimes to described the product of thermal efficiency and combustion efficiency (describing the % of complete combustion), or alternately as a combination of combustion and furnace efficiency.

In comparing these efficiency definitions, we come to a conclusion that basically they all try to describe, in different ways, the one and only “true” thermodynamic definition with various “twists” or simplifications to it. Some of these “sub-definitions” of efficiency (such as available heat calculation) are not measurable in real life. An interesting observation from our study, is that even the most reputable references use various efficiency terms interchangeably and mix them liberally in their publications.

What becomes clear, is that this plurality of efficiency definitions and their inherent ambiguities make the comparison of efficiency claims by various heater manufacturers very difficult unless they use a standard calculation method and that calculation is clearly documented. A good example of such calculations (rating sheets) can be found as used by reputable industrial boiler manufacturers.

Of specific interest to our report are the terms of “gross” and “net efficiency” because they are the most commonly used in the relevant literature, reports or equipment manuals. For additional clarity in this report, we will refer to the Gross (HHV) efficiency and the Net (LHV) efficiency. We will further address these two efficiency definitions in the next section.

4.4.4 Should the GROSS(HHV) or NET(LHV) Efficiency Calculation be Used For Evaluation Of Immersion Fire-Tube Heaters?

As explained in the previous section of this report, there is only one theoretical definition of heater efficiency based on the laws of thermodynamics, which as shown in the Sankey diagram includes all energy inputs, outputs, and losses. All other definitions are simplifications of this definition under the assumption that some of these energy inputs, outputs, or losses can be ignored. This is true in many cases, where some of the values are very small or constant, or simply cannot be measured. For example, in case of conventional boilers with standard insulation, and located inside heated buildings, the radiant and convective losses from the boiler exterior wall are assumed to be 4 to 5% of the total HHV of the heat input. In many cases it is too difficult or cumbersome to measure these losses in practice. Therefore, most boiler manufacturers will show that value on their datasheets as a constant and subtract it from the measured efficiency to obtain the final guaranteed efficiency.

One very distinctive variation to the “true” definition of efficiency is shown by the difference between gross(HHV) and net(LHV) efficiency. The first definition is based on the ratio between the useful output and the fuel higher heating value (HHV), the latter on the ratio of the useful output to the fuel lower heating value (LHV).

Of the two efficiencies, the gross efficiency is closer to the “true” thermodynamic efficiency because it includes in the calculation a more complete picture of energy inputs.

This raises the question of: “why is the net (LHV) efficiency used?”

Most of its proponents would argue that since most furnaces do not condense the water vapour out of the products of combustion, so why include that water vapour in the calculation. And indeed, as can be found in the older literature (in the slide rule era) it was easier to perform internal calculations of mass/energy flows and balances within the combustion process using “specific heats” while “parking off to the side” the latent heat of the water vapor. This was done under the assumption that this latent heat will not change within the heater boundaries and can be added back at the end of the process. In today’s computerized calculations, a similar calculation can be comfortably performed using enthalpies instead of specific heats, in which case such exclusion of the latent energy is of little or no benefit.

One of the reason’s that the “net (LHV) efficiency” is still used today is for commercial reasons in that it simply sounds better.

The LHV is lower than HHV for all fuels containing hydrogen. For methane that difference is approximately 10% based on LHV of 911 BTU/cuft and HHV of 1012 BTU/cuft. Consequently, the LHV efficiency of the same heater is 10% higher than the HHV efficiency.

If an “unaware” buyer was considering the purchase of a gas fired appliance rated at 70% efficiency (HHV), or 77% efficiency (LHV), he would more likely choose the appliance rated at 77%, without realizing that both ratings are identical. This difference in perception has been exploited in the past, primarily by manufacturers of smaller (mostly residential) fired appliances who would simply state the “efficiency” figure in their advertising without explaining what this efficiency is based on. Historically, LHV efficiency has been used commonly in the US and some parts of Europe and was not very common in Canada except where appliances were imported from the US.

The introduction to the market of residential high efficiency condensing furnaces, which cool the exhaust gas to close to the ambient temperatures and condense the water from the flue gases in the process, led to claims of heaters being able to operate with efficiencies in excess of 100%. Taken out of the context of peculiarities of LHV efficiency calculations, this of course would indicate to the reader that the heater produces more energy than it consumes, which, is misleading and technically incorrect.

The most compelling reason to use gross (HHV) efficiency calculations when comparing efficiencies of immersion fire-tube heaters is the fact that the natural gas used commonly in these heaters is sold and accounted for on the basis of its higher heating value (HHV). Although the meters are set to measure the corrected volumetric flows of gas, for accounting/billing purposes those readings are converted to GJ(HHV) or MMBTU(HHV). When it comes to discussing the cost of heater operation of and potential savings, it is much easier to use gross (HHV) efficiencies multiplied by the fuel cost than figuring it out from net (LHV) efficiencies.

Later in this report, we will show the differences of various fuels and stack temperatures on both gross and net efficiency, however, for the rest of this report, the software program and tube performance charts are all based on gross (HHV) efficiencies. This report recommends for the purpose of the efficiency evaluation, that only the gross (HHV) efficiencies be used.

4.4.5 Effect of Energy Stored inside the Heater on Efficiency

A portion of the available energy in the fire tube is used to heat the bath fluid, heater walls, insulation and other connected equipment. In most indirect heater applications, the bath liquid contained within the heater does not leave its physical boundaries. In oil treaters or storage tanks, there maybe a continuous flow rate of liquid moving through the heater. In either case, the volume of the liquid present in the heater at any time and all heater materials must be treated in mass energy balances as an energy accumulator, which either stores or returns portion of the available energy. This is why a line heater keeps working after the burner is turned off, and until the liquid temperature decreases enough for the burner to be restarted. The heater fluid works like a battery to store energy between firing cycles. Conversely, when the bath temperature is too low it will take time to preheat the unit and store enough energy for the process side to start working properly.

This energy storage (accumulator) function is shown in the Sankey diagram Figure 4.5 as the heat-up and cool-down energy stream. These energy flows within the heater boundary are not shown directly in typical efficiency calculations, however, they can influence its accuracy or verification.

4.4.6 Effect of Heater ON/OFF operation on Heater Efficiency

Typical efficiency calculations are based on steady state energy flows and equalized temperature gradients in a heater. As one of the sources defines it: “Combustion efficiency is a value determined from input and output data of a combustion process at constant operational conditions”. This approach is used commonly for example, in steam boilers, which under normal conditions produce a constant flow of steam with all temperature gradients stabilized. In these installations, startup and shutdown are not considered part of the normal operation and usually are not considered in efficiency investigations. Instead, certain turndown to the boiler operation is defined and efficiency measured at various stages of such turndown.

The operation of immersion fire-tube heaters is significantly different from a boiler operation. Due to their ON/OFF control, heater operation consists of many starts and stops which define their ON/OFF duty cycle. The duty cycle can be expressed as a ratio between the ON time and a total of ON+OFF time before the next ON cycle starts. For example, if a heater stays on for 5 minutes and then stops for 5 minutes its duty cycle is 5/(5+5) = 50%, if it stays on for 5 minutes and then stops for 10 minutes, its duty cycle is 5/(5+10)=33%.

Figures 4.6 and 4.7 illustrate actual data of stack bottom temperature during such cyclic heater operation. In addition to energy loss during the short ON period, there is also a continuous energy loss during the OFF period, due to the presence of the continuous pilot and the reverse heat transfer from the bath liquid to the ambient air drafted through the tube. The stack bottom temperature stays close to bath liquid temperature.

The higher the duty cycle, the more the heater operation resembles a boiler operation, and the more stable the efficiency becomes. Low duty cycles are an indication of an excess of available energy for the process requirements. In other words, the energy input is mismatched with useful energy output.

Based on the 2nd law of thermodynamics, not only are the mass flows in the fire-tube and losses not minimized during the ON-cycle, but also there is an energy loss during the OFF-cycle due to the differential energy potential between the energy stored in the bath liquid and the ambient air in the tube. The stack continues to draft air through the fire tube heating the air in the process and losing energy from the bath liquid.

Consequently, the average heater efficiency with ON/OFF firing will be lower than heater’s with continuous firing. In addition, there are negative effects of ON/OFF or cyclic firing such as natural draft fluctuations, or tube thermal shocking and overheating.

These conclusions strengthen the argument for efficiency optimization through the matching of the useful output requirement with a continuous and stabilized minimum possible input, which results in minimal losses and maximum efficiency.

Translating this thermodynamics jargon into simple terms, we can state with a high confidence level that the average heater efficiency can be increased by reducing its firing rate to a point where it "percolates" continuously, thereby providing just the right amount of energy for the process requirement. To make it work, we need to reduce the mass flow by controlling the secondary air and modulating the fuel input.

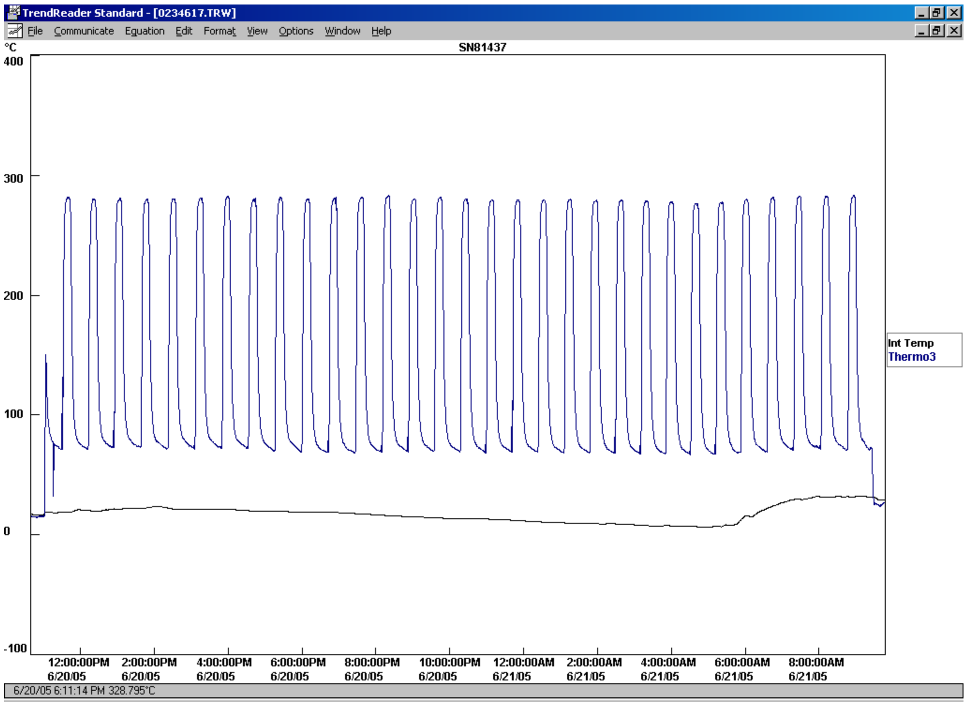

FIGURE 4.6 Example of a cyclic operation of a line heater (actual data)

ON/OFF cycle = 42 minutes, 21% ON Time, Stack bottom temp 285 deg C during ON time, 75 deg C during OFF time. Natural draft is maintained during OFF time

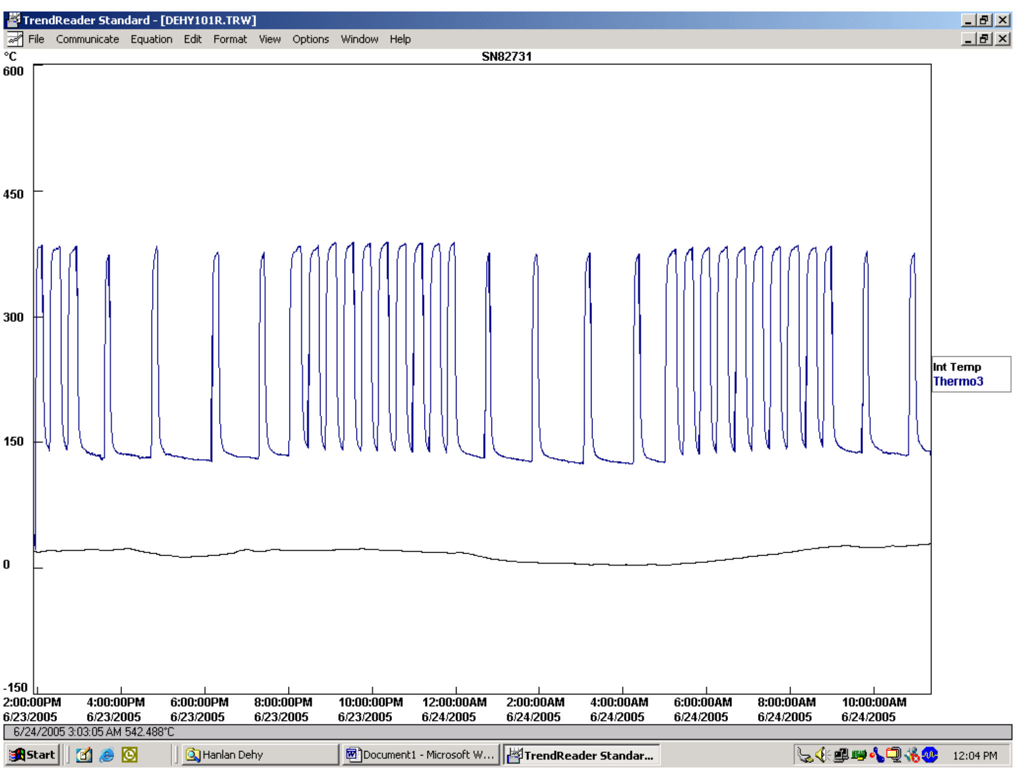

FIGURE 4.7 Example of a cyclic operation of a salt bath heater (actual data)

Cycle changes with process load, Stack bottom temp 350 deg C during ON time, 145 deg C during OFF time. Natural draft is maintained during OFF time.

4.4.7 Useful Output Efficiency Pitfall

The efficiency calculation of a heater is based on the ratio of "useful output" to the total input energy used to produce the useful output.

In this section, we briefly address the impact of this "useful output" on the heater efficiency. It the context of the energy efficiency it is a rather odd topic and rarely addressed in the literature. It has been simply assumed that the "useful output" just "is" and "is required". Consequently, the heater sizing and its performance are being matched to produce this "useful output requirement".

Lets consider a more "holistic" approach to the fire-tube heater efficiency problem. Based on our knowledge of the industry and combined with field experience and literature studies, the subject of the energy requirement for a given process is quite often unpredictable and variable. In the case of line heaters, it is common for the production rates from new wells to quickly decrease after their initial start and continue this decrease as they become depleted. As a result, over time, heaters become grossly oversized for the process requirement and cycle. In addition, there are issues related to the process heat utilization, insulation, and the overall energy conscious process design. Although these issues are outside of the scope of this investigation, they are actually the most important aspect of the energy efficiency analysis.

It may not make sense, for example, to try to improve the efficiency of a heater by say 10% to 15% if we haven't addressed the heat energy utilization first. If for example, 50% of useful output is being wasted in the process we should address this waste before trying to make the appliance more efficient. It is more effective to make the process more energy efficient so that the demand for the energy is reduced.

Using an analogy of heating a home, the installation of a new high efficiency furnace is not the most important solution, if the house has no insulation, or if those living in the house always left doors and windows open.

A further extreme example of this would be to shut down a line heater on a gathering system if the operating pressure and temperature are such that the process fluid no longer has a tendency to hydrate. Bypassing or removing the heater also reduces the pressure drop and saves compression energy.

The same holistic approach to energy conservation may point in the direction of heat recovery from waste-heat sources or the use of waste fuel gas which otherwise would be flared.

In the context of this investigation, the pitfall of predefined useful output (heater rating) requirements must be avoided by looking first at the actual process requirements.

When dealing with existing or new installations, the question of useful output required from a heater can be viewed in the following two different ways:

a) how to make this heater work most efficiently ?; or

b) how can we make this process work most efficiently?.

Although both questions sound similar, the answers could be quite different. To answer the first question, we could start by adding to the heater surface area, controls, or other measures aimed at making it as efficient as possible. To answer the second question, we could simply turn the heater down or perhaps by making some process changes, we could eliminate the need for the heat so we could turn the heater off.

Some of the answers may be very simple. For example, a simple relocation of the thermocouple, which controls the heater temperature control loop to a spot, more directly affected by the process may stop the heater from constant firing which could result in significant fuel savings.

An excellent case for this approach is presented in the reference A29, where the authors looked at the thermal overrun in a line heater operation. The concept of thermal overrun is based on the assumption that in an indirect heating system with a fixed bath temperature setpoint, the bath temperature must be set to handle the maximum process flow. If the process flow decreases, the heat transfer from a fixed process coil surface area will not decrease proportionally to the process flow, but it will remain higher thus effectively overheating the reduced process flow. Therefore, although energy is transferred to the process, some of it can be considered as a “thermal overrun” and therefore a loss.

There are numerous solutions to the thermal overrun problem such as:

a) relocating the temperature thermocouple to the process side of the heater;

b) reducing the glycol volume stored in the heater to make it respond faster to load changes; or,

c) bypassing some of the process gas around the heater, so that only part of the gas is heated and then blended back with the cold gas.

The important goal in avoiding the useful output efficiency pitfall is to change the traditional paradigm used to evaluate energy systems, so that it is based on the actual process needs and not on its maximum ratings which may not be valid.

4.4.8 How to Measure Heater Efficiency

Both the measurement and verification of a heaters performance is difficult. Taking into consideration the variables of the cyclic operation, energy storage effect of the bath and equipment, practical limitations of sensor technology (measurement) and the availability of instruments complicate the task.

In order to make the mass/energy balance work in practical terms, all the energy inputs and useful output would have to be steady state be precisely measured. Even in lab conditions, it would be difficult, unless the heater was left operating for an extended period of time at a constant process flow, fuel and combustion air input. Based on our tests in a small heater, it takes over one hour of continuous firing for all temperatures to stabilize, so that a proper energy/ mass balance can be established. In an oil treater or similar processes with a large liquid storage capacity and a constant in-feed creating slow changing liquid temperature gradients across the heater, a “precise measurement” of useful energy is not only virtually impossible but also process dependent.

A more suitable approach to efficiency measurements can be determined from the 1st law of thermodynamics. Based on the energy conservation principle and an observation that the flue gas losses generally account for the majority of the total losses in the heater, efficiency can be calculated from the following equation:

$$EFFICIENCY[\%] = \frac{(TOTAL\_INPUT - TOTAL\_LOSSES)}{TOTAL\_INPUT} * 100$$

In this equation it is not necessary to actually measure all the total inputs and total losses, but instead mass/energy balances based on a unit of fuel burned can be used. Five values must be known to establish these balances, namely:

a) fuel type;

b) stack excess oxygen;

c) stack CO;

d) stack bottom temperature; and,

e) ambient temperature.

From excess oxygen, the excess air and basic mass balance can be calculated for a given fuel type and corrected for unburned fuel from the CO measurement. From differential temperature between stack bottom and the ambient air, the final energy balance and energy loss to flue gas can be determined. Using this energy loss to flue gas and fuel higher heating value in the above equation, the heater efficiency can be calculated.

The above method is used for efficiency calculations in combustion analyzers.

Although this method is based on a number of assumptions, the flue gas analysis method is by far the fastest and simplest measurement technique used for efficiency measurements of fired heaters. It is widely accepted in the industry for boiler and heater efficiency evaluations. To obtain even more realistic efficiency figures, a nominal value for radiant and convective heat losses from heater surfaces can be subtracted, although frequently this value is ignored.

This flue-gas analysis method was used in this report for the measurement of immersion fire-tube heater efficiencies.

4.5 Types of Heat Transfer in A Fire Tube Heater and their Simultaneous Nature

There are three modes of heat transfer, which occur simultaneously in fire-tube applications. They are: conductive, convective and radiative heat transfer.

Conduction heat transfer refers to the transfer of energy from the more energetic to less energetic particles of a substance, resulting from the interaction between particles through random molecular motion. Conduction applies to either stationary or moving gases, liquids or solids but it occurs in somewhat different ways due to the spacing of molecules.

Convection heat transfer occurs in fluids and is influenced by molecular conduction and macroscopic fluid motion and it takes place adjacent to heated surfaces as a result of fluid motion past the surface.

Radiation heat transfer occurs through the movement of energy by electromagnetic waves in the wavelength between 0.1 to 100 micrometers and does not require any medium between the two bodies to occur.

Many of the simplified heat transfer calculations treat these three heat transfer methods separately, based on the assumption that one of the methods is prevalent and the other two have negligible impact on the overall solution. Although this may be true with simple shell and tube heat exchanger problems, it is not the case with immersion fire-tube heat transfer, where all three heat transfer methods are of significance and influence each other.

Looking from the burner end, in the so-called "flame zone", the inside of the fire-tube contains a reacting and turbulent mixture of fuel and air which is rapidly changing its chemical composition, temperature and volume through a combustion reaction. Subject to the physical arrangement of the tube entrance, the burner type, the primary and secondary air control, and the stack draft, this process is neither homogenous nor fully predictable. As the stream of the burning fuel/air mixture exits the burner nozzle at high temperature (3500 deg R), it interacts with the cold (500 deg R) stream of secondary air. Taking under consideration the parallel flow of these two streams and the large 7:1 ratio of two gas stream densities this interaction is neither fully controllable nor assured.

Although significant amounts of radiation energy are emitted by the flame in that zone, which might directly reach the metal of the tube wall, there may be a tendency for that energy to be transferred by convection to the cold secondary air stream moving parallel to the flame. It is not unusual however to see lower tube wall temperatures at the first few feet from the tube entrance due to this cooling effect and the time (tube length) it takes for the combustion process to complete.

Depending on the capacity rating, tube diameter and length, as well as, burner setup, these simultaneously reacting and mixing streams forming the flame can often reach far into the tube, and sometimes to the end of the first pass. Along the way the combustion process continues raising the bulk gas temperature and with it both the convective and radiant heat transfer.

It is also possible that the two gas streams may remain stratified with the hot and lighter gases lifted by buoyancy towards the top tangent of the fire tube and the cold air moving along the bottom of the tube.

As the products of combustion travel along the tube they are cooled through simultaneous radiant and convective heat transfer to the cold tube wall.

The complexity of the dynamics of these chemical reactions, flow velocities, temperature gradients and gas mixing are very complicated and can only be fully predicted with sophisticated finite element computer models such as FLUENT, output of which was shown previously in Figure 2.9.

In general, we can assume that in the first tube pass the gas temperatures are typically high enough to maintain a combination of radiative heat transfer and convective heat transfer. The key to successful modeling of these two heat transfer methods is that they must be integrated together along the tube length as the both affect each other.

In a properly sized heater, the combustion process should be complete somewhere along the first tube path. The turbulence created by each elbow helps in mixing of any potentially stratified gas flow.

As the gas travels along the tube, it cools down to a point where the radiative heat transfer component diminishes. The remainder of the fire-tube works mainly in the convective heat transfer mode. This is similar to a conventional shell and tube heat exchanger with the hot gas on the inside of the tube and a cold liquid on the outside.

Although the focus in heat transfer calculations is on the radiant and convective components the conductive heat transfer is also present with the other two all the time. There is conductive heat transfer within the gas stream, conduction through the tube wall, conduction and convection through the bath liquid, and finally, conduction through the process coil to the process fluid.

Due to the nature of the combustion process occurring inside the fire tube, all three heat transfer methods must be considered along with the simultaneous interaction on each other.

4.5.1 Conductive Heat Transfer

Although conductive heat transfer is typically considered as a secondary concern in fire-tube calculations, the knowledge of its interaction and principles may help in understanding the overall heat transfer concept.

The background of the conductive heat transfer is in the 2nd law of thermodynamics, which was explained earlier indicates that the heat flows in the direction of decreasing temperature.

4.5.1.1 Understanding Thermal Conductivity

The heat conduction theory assumes that the rate of heat transfer in a material is proportional to the temperature gradient and to a constant called thermal conductivity (k). This constant which is expressed in BTU/hr/ft/deg F is different for each type of material.

Typical ranges in BTU/hr/ft/deg F of thermal conductivity are as follows:

- Gases at atmospheric pressure	0.004 to 0.70
- **Products of combustion**	**0.022 to 0.03**
- Insulating materials	0.01 to 0.12
- Non-metallic liquids	0.05 to 0.40
- **Water**	**0.32**
- Non-metallic solids	0.02 to 1.5
- Liquid metals	5.0 to 45
- Alloys	8.0 to 70
- **Carbon steel**	**25**
- **Stainless steel**	**9.4**
- Pure metals	30 to 240

In the context of fire-tube heaters, the understanding of these differences in thermal conductivity values helps in interpreting the heat transfer phenomena occurring in the heater and impacting on its efficiency.

4.5.1.2 Examples Of Thermal Conductivity Comparisons

In conductive heat transfer the ability to transfer heat is directly proportional to thermal conductivity (k) and the temperature gradient from hot to cold. Materials with higher k-values transfer heat well while other materials have insulating properties.

In the case of fire-tube if we look at the overall heat transfer relationship between the combustion gases, the fire-tube and the liquid bath we see that following:

a) products of combustion k=0.022 and a carbon steel fire tube k=25. The products of combustion are able to transfer 1136 times less heat through conduction than the fire tube

b) the liquid bath in the heater (assume water) k=0.32 compared to carbon steel fire tube k=25. The bath is able to transfer 78 times less heat through conduction than the (clean) fire tube

c) when we compare the products of combustion k=0.022 to 0.03 to water bath k=0.32, the products of combustion are able to transfer 10 to 15 times less heat than the bath

d) thermal conductivity of products of combustion (k=0.022 to 0.03) is comparable to the thermal conductivity of best insulating materials (k=0.01 to 0.12)

The conclusion from the above is that the fire-tube heat transfer performance due to conduction is fundamentally limited on the gas side.

4.5.1.3 Implications of Thermal Conductivity

Based on the above explanation, we can appreciate that the fire-tube wall material has a negligible effect on the resistance to conduct heat as the surrounding liquid's resistance is 78 times greater, and the gas resistance inside the fire tube is1136 times greater than that of the fire tube material.

Similarly, we can see that if the heater had to rely only on the conductive heat transfer, it would be 10 to 15 times more difficult to do it on the gas side than on the liquid side. This observation can lead us to a conclusion that the gas side in the fire-tube is controlling (restricting) a large portion of the heat transfer.

Another example of the effects of the conductive heat transfer on the overall heater performance can be found when the inside of the fire-tube is fouled with soot (carbon) or oxides due to rust of thermal metal oxidation in flame impinged areas, or alternatively covered on the outside with coked material and/or sand (such as in oil treaters). In these cases, the deposited materials form insulating layers with low conductivity on the metal surfaces. These insulating layers impede the other two methods of heat transfer.

Since our study is directed at preventing situations such as soot deposits, oxidized tube "hot-spots" or coked material on the outside of the tube, we will treat all of them as abnormal and undesirable conditions which must be avoided. The only solution to these problems is to restore its original heat transfer capabilities through cleaning or replacing the fire tube.

For the purpose of this study we assume that the resistance to conductive heat transfer through a clean tube is negligible.

A clear understanding of the relationship between the radiative, convective and conductive heat transfer in the fire-tube and their simultaneous interdependence is essential to this study and it is the basis of our investigation.

4.5.2 Radiative Heat Transfer

Industry's common belief, that in order to have radiative heat transfer, there must be a visible flame is incorrect. The idea of such "flame radiation" is based on an assumption that there is some special mechanism at work within the flame zone emitting radiant energy towards the fire tube.

In reality, the radiative heat transfer is related to the emmisivity of the bulk of products of combustion based on their temperature, composition, and "dimension" of the gas volume, and not on the presence of the visible flame.

Although a visible flame is a good indication of the presence of radiative heat transfer, this heat transfer method actually continues past the flame zone until the temperature of the products of combustion is reduced to about 1100 deg F. This is the point where the emmisivity of the gases is low enough that the radiative heat transfer component becomes negligible.

4.5.2.1 Mechanism of Radiative Heat Transfer

Radiant energy is emitted only by gases and solids and particularly by carbon molecules, which when present in the flame, emit broadband radiation. The more carbon there is in the flame, the more yellow or luminous it becomes. Consequently, fuels with higher C/H ratio such as fuel oil, butane or propane produce more radiant flames than methane.

The energy released in the process of combustion is carried through the fire-tube by the products of combustion. Since the emission of radiation occurs in the infrared region of the spectrum, and is different for individual compounds, it is the gas composition, which dictates the radiant heat transfer properties of the gas mixture. The inert gases and diatomic gases of symmetrical composition, such as O2, N2 or H2, are transparent to thermal radiation. The gases that absorb and emit radiation are polyatomic gases such as CO2 and H2O and asymmetric molecules such as CO.

Our goal in the combustion process should be **not** to produce any CO. It is therefore, the water vapour and the carbon dioxide, which produce most of the radiant "heat transfer work" inside a fire tube. If we ignore the small amount of humidity which enters the combustion process with the combustion air, the only sources of these compounds is the hydrocarbon fuel, and depending on the particular burner setting, this amount of fuel is fixed by the gas pressure and the orifice size in the burner.

Consequently, based on any given fixed fuel flow rate, the ability of the products of combustion to emit radiant heat is limited by the fixed amount of CO2 and H2O and their temperature.

4.5.2.2 Impact of Excess Air on the Radiative Heat Transfer

The temperature of the products of combustion as produced by the flame is directly related to the amount of air used for combustion. The more air that is added to the combustion (generally through secondary air ports), the lower the temperature of the flame and the resulting products of combustion, and the lower their ability to emit radiant energy will be.

In order to maximize the radiant heat transfer, the products of combustion should therefore be kept as hot as possible by reducing the amount of excess air.

This is consistent with our three design goals defined earlier from the laws of thermodynamics of increasing differential temperatures, minimizing mass flows and eliminating losses.

4.5.2.3 "Dimension" of the Gas Volume in Radiative Heat Transfer

There is another aspect of the radiative heat transfer that is described in literature as the "dimension of the gas volume". Although somewhat confusing, this expression refers basically to the distance between the gas and the tube wall and the angle (view factor) at which radiation reaches that wall. This is significant in situations where the hot products of combustion do not fill the entire fire tube in its entirety but due to the effect of buoyancy flow only along its top tangent. In this top area where the gas actually "touches" the tube, the radiant heat transfer component can be considered perpendicular to the wall and therefore maximized. As the tube wall geometry transitions from "horizontal" (along top of tube) to "vertical" on the tube sides, the radiation from a smaller source (less than full volume) along its top tangent becomes almost parallel to the metal surface and diminishes. However, on the tube bottom, the radiation is perpendicular to the metal surface and is maximized from the angle point of view, but at the same time it is minimized due to the greater distance from the source.

The impact of the angle on the radiative heat transfer can be best described by an analogy to sun tanning. As we turn our body towards the sun we feel its radiant heat mostly on the parts of the skin, which are perpendicular to the sun rays. The parts, which are parallel to or face in the opposite direction are not affected by the direct radiation of the sun.

The impact of the distance between the source of radiation and the heated surface can also be described by an analogy to a candle flame. If we hold our finger to the side of the flame we can move it as close as ½" to ¼" away from the visible flame without feeling any heat. If however, we try to move the finger above the candle flame we will have to allow 4" to 5" to avoid getting burned get burned. This is however, not the result of the heat radiation from the flame but the result of the combination of radiative and convective heat transfer from the rising products of combustion to our skin.

4.5.2.4 Radiative Heat Transfer in a Fire-Tube

As the above examples demonstrate, the radiative heat transfer is a very powerful and concentrated way of transferring the energy in a fire tube to the surrounding bath liquid but it is also very sensitive to the distance between the body of the gas (which tends to rise by its buoyancy towards the tube top tangent) and the tube circumference, and the angle at which radiation impacts the tube wall.

From a fire-tube design point of view, this means that in order to maximize the radiative heat transfer we have to “fill” the tube with the hot products of combustion as much as possible so that both the distance from the heat source is minimized and the angle of the tube surface exposure to the radiation is made as close to 90 degrees as possible. It should also be emphasized that this guideline applies not only to the flame zone portion of the fire tube where the flame is visible but also to the remaining tube length where the radiative component is of significance (i.e. down to the point where gas temperature decreases below approximately 1100 deg F).

4.5.2.5 What to Avoid In the Radiative Heat Transfer

This guideline should not be construed as an encouragement for direct flame impingement on the fire tube wall, which should be avoided at all cost. Direct flame impingement causes thermal tube wall damage and oxidation, which may lead to liquid boiling and coking on the outside of the tube. In addition, the direct flame impingement of reacting compounds in the flame on the cooler tube surface (relative to flame temperature) interrupts the chemical kinetics of the reaction of combustion leaving deposits of soot (carbon) on the tube surface and unburned CO and aldehydes in the products of combustion stream.

We also want to dispel the myth that an orange flame in a fire tube improves the transfer of radiant heat. As explained above, although the yellow flames are indeed more luminescent and emit more radiation than blue flame it is only due to the higher content of carbon in the fuel. With combustion of light paraffin hydrocarbons such as methane, the only way to produce an orange flame is through substoichiometric (partial) combustion. Such partial combustion can be caused either by insufficient air, poor mixing or by direct flame impingement (impact) on a cold tube surface quenching the combustion reaction. Either way, there is more to be lost by the partial burning of the fuel than can be gained by trying to make the normally blue flame of natural gas to turn to an orange colour.

4.5.2.6 Burner Guidelines for Maximized Radiative Heat Transfer

To combine our conclusion:

e) the radiative heat transfer is **not** a function of how visible the flame is, but a function of emmisivity of the products of combustion;

f) products of combustion should be as hot as possible and with the least mass (lowest excess air) to maximize radiative heat transfer;

g) the impingement on the tube walls should not be allowed by ensuring that there is a minimum 3” gap visible between the flame bushel and the tube wall, all around the flame;

h) the fire tube should be “filled” with products of combustion as much as possible, through proper matching of the maximum fire rate, the flame diameter, and the tube diameter; and,

i) complete combustion of all of the fuel with minimum excess air (2% to 3% excess oxygen in the stack)

Based of the above conclusions we formulated the following recommendations for the burner design which would maximize radiative heat transfer:

a) the burner should work reliably with the air/fuel mixture closest to the stoichiometric;

b) the burner should provide a thorough premixing of the combustion air with the fuel before the combustion process by maximizing the primary air induction;

c) the burner should produce a sharp and short flame, which does not impinge on the fire tube. (as opposed to a long and “lazy” flame which may lift by buoyancy and impinge on the tube surface); and,

d) the burner flame size and the tube size should be matched to effectively “fill” the tube with hot gas without creating a flame impingement problem.

Radiant heat transfer calculations are very complex, however in this study we attempted to calculate the radiant heat flux rates using various approximations. We also looked at the impact of the flame shape, the primary and secondary air control and the burner design on the radiative heat transfer component.

4.5.3 Convective Heat Transfer

In addition to the radiative heat transfer in the first pass of the fire-tube, there is also a simultaneous convective heat transfer. As the products of combustion are cooled below approximately 1100 deg F, the radiant heat transfer diminishes and convective heat transfer becomes prevalent.

Convective heat transfer can be greatly influenced by a laminar sub-layer (boundary layer) formed by the flowing fluid in the immediate vicinity of the solid surface. As we approach the fire tube wall, the flow slows down forming a boundary layer at the edge of the turbulent flow. As we go further through a transition zone, the flow slows even more until it becomes laminar. In this laminar sub-layer, heat transfer is through molecular conduction. The thicker the layer, the more resistance there is to the heat transfer. In other words, the laminar sub-layer effectively insulates the tube surface from heat transfer.

The method of counteracting this effect is to maintain a turbulent flow and high velocities of the fluid in order to “scrub” the boundary layer off the surface of the tube.

4.5.3.1 “Controlling” Role of the fire-tube gas side on the heater efficiency

The boundary layer effect is particularly severe with gas to liquid heat transfer where the resistance to the heat transfer on the gas side is much larger than on the liquid side. This can be demonstrated through a comparison of typical heat transfer coefficients on both sides of the tube and their effect on the overall heat transfer coefficient “U”.

Let’s assume that the gas side heat transfer coefficient is equal to 5 and the liquid side coefficient is equal to 100. The overall $U = 1 / (1/5+1/100) = 4.76$.

Even if we could **increase the liquid side coefficient by tenfold** to say 1000 the U would be only equal to $U = 1 / (1/5+1/1000) = 4.98$ which is equivalent to a **4.5% increase**.

On the other hand, if we could **increase the gas heat transfer coefficient by 50%** to 7.5, the U value would be: $U = 1 / (1/7.5+1/100) = 6.98$, a **40% increase**.

This simple example illustrates the importance of the gas side of the fire tube on the overall heater performance. There is a lot to be gained by optimizing the gas side of the fire tube than by improving the liquid side (including the properties of the heat transfer liquid itself), which in most calculations can be simply ignored. Conversely, redesigning the liquid side components or changing the type of the heat transfer liquid will not significantly improve the efficiency of the immersion fire-tube heater.

This is not to say that the liquid side of the heater is not important. There are operational and safety issues involved with having the liquid column separated from the hot products of combustion. Especially with oil tank heaters, the problem of coking on the outside of the tube can seriously impact the heater performance.

In general however, the likelihood of coking diminishes, if the flame is properly shaped and does not impinge on the inside of the tube, and also when the heater temperature control minimizes overfiring. In applications where silt or sand settlement is a problem there are also other heater design techniques, which could minimize this problem.

4.6 Combustion HHV and LHV Efficiencies

In this section we will look at the impact of excess air and the stack bottom temperature on heater efficiencies. To illustrate this impact, we included three charts based on the combustion of methane in air. It is important to understand that these charts, as well as, most of the other charts presented in the subsequent sections are fuel specific and change with fuel composition.

The first chart in Figure 4.8 was constructed to illustrate the gross (HHV) thermal efficiency as a function of temperature difference between stack bottom and combustion air in the range of 200 deg F to 1500 deg F, and excess air between 0% (stoichiometric combustion) and 500%.

A low reported efficiency of 30% would be equivalent, according to this chart, to the operation of the heater with 530 deg F and 500% excess air, up to 1450 deg F and 100% excess air, in all cases indicating severe tube overfiring with uncontrolled secondary air.

Figure 4.9 shows the same relationship except it is expressed in net (LHV) thermal efficiency.

Figure 4.10 illustrates the difference between LHV and HHV efficiency. It is important to understand, that the difference between the HHV and LHV efficiency should not be used in the combustion calculations as a fixed value for example: 9% efficiency difference for methane. As the excess air and stack temperature increase the impact of the latent heat on the overall energy balance decreases. For example: at 20% excess air and 1000 deg F stack temperature, the difference between HHV and LHV efficiency is 7.1%.

The LHV efficiency are shown for comparison only and are not used anywhere else in this report.

All references in this report are to HHV efficiency values.

4.7 Understanding O_2 and CO_2 Analyzer Readings

Figure 4.11 illustrates the relationship between the analyzer reading and the excess air. It is important to understand that the curves change for different fuels and their mixtures due to the changing C/H (carbon to hydrogen ratio). The presented curve is for methane and assumes complete combustion. The curve is limited to 0% to 100% excess air since neither substoichiometric firing nor high excess air firing is of interest to this study and its guidelines.

With stoichiometric mixture, the excess oxygen is zero and the carbon dioxide is 11.8%. As the excess air increases so does the oxygen, however, the percent of carbon dioxide in the mixture decreases due to the dilution with air. The actual amount of carbon dioxide does not change at a given firing rate since it originates from the carbon in the fuel. Most combustion analyzers do not actually measure the CO2, but derive it mathematically from the oxygen and CO measurements.

The relationship between the excess air and the excess oxygen can be approximated for combustion of methane from the following equation: $ExA\% = 1 + O_2\%/(21 - O_2\%)$, where: ExA% is the percent excess air, and O_2% is the percent of excess oxygen in the stack. Note that the exact calculation is more complex and changes with the fuel composition.

The high efficiency goal requires that excess air be minimized, with the stack oxygen level kept as close to zero as possible without creating excessive CO. In practical terms, stack O_2 values between 2% and 5% are achievable. This translates to between 9.5% and 28.1% excess air. Heater operation above these excess air levels would be considered inefficient.

This combustion calibration method using stack O_2 differs from older methods using CO_2, which are still found in the literature. The objective of these older methods was to adjust the burner to obtain CO2 readings as close to 11.8% as possible. Modern portable analyzers commonly use O2, CO, NO, NO2 and SO2 cells for more complete stack gas analysis.

Another important aspect of combustion analyzer readings is that similar to a chromatographic analysis their readings are based on a dry volume (molar) basis. This means that the values cannot be used directly in the combustion mass balances without first mathematically correcting for the water content.

A common characteristic of burners used in immersion fire-tube heaters is that they rely on secondary air to be able to complete combustion, some significantly more than others. Since this secondary air is induced by the draft action of the stack, it is somewhat independent of the firing rate. Therefore, as the burner fuel flow is turned down the amount of excess air seen by the analyzer increases, thereby reflecting this uncontrolled flow of secondary air. Burners with higher primary air capability allow for the reduction of the secondary air flow to minimize the effect of the high excess air at turndown.

4.8 Percent O_2,CO_2 and H_2O in the Products of Combustion

Figure 4.12 illustrates the change in percent of O_2, CO_2, and H_2O as wet and dry, both % weights and % volumes (molar basis) when firing with methane between 0% and 500% excess air. The graph is designed as a tool to help in conversion of dry-base combustion analyzer readings into wet-base values, which can be more readily used in the combustion calculations. Note that the curves presented will change for different fuel compositions.

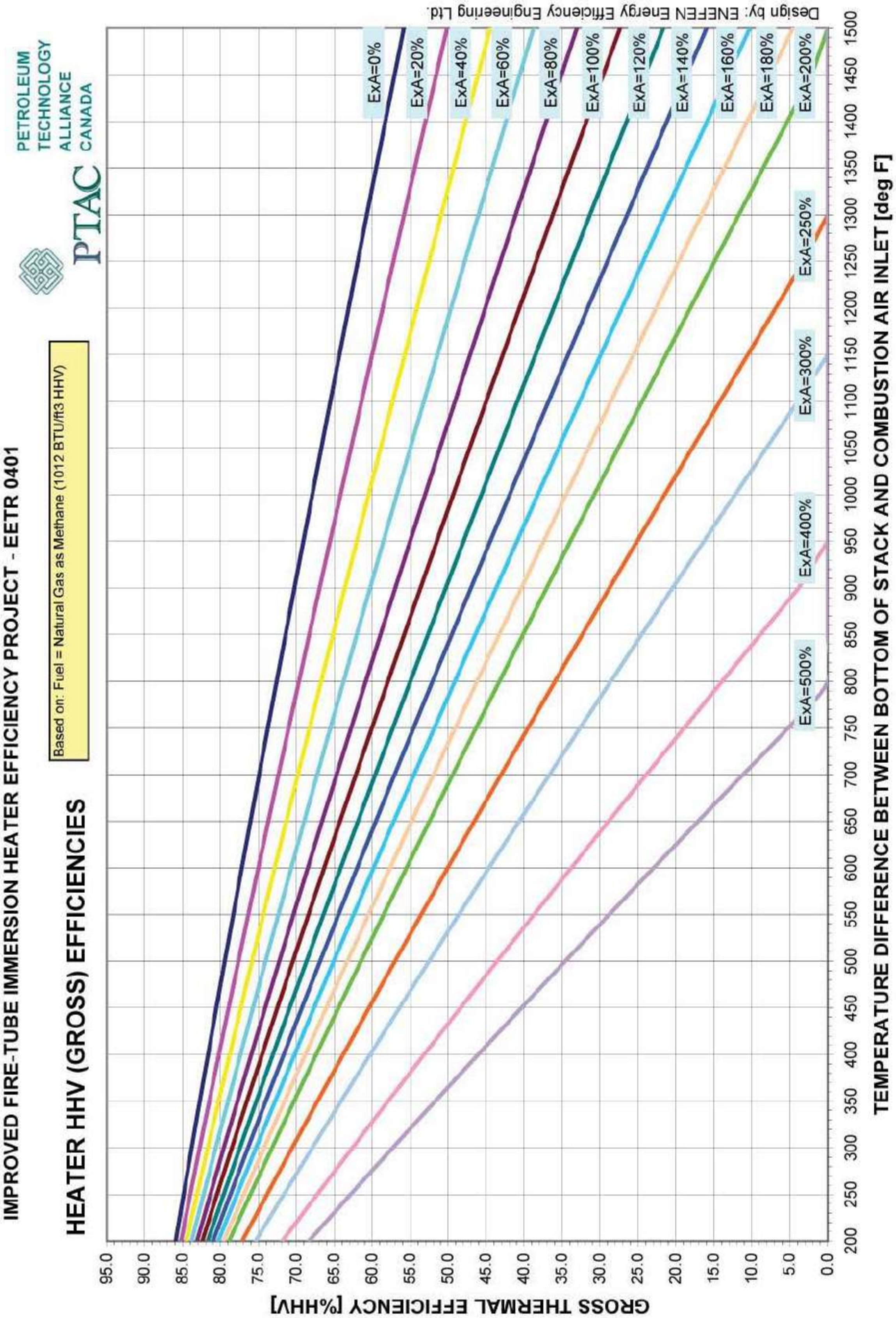

FIGURE 4.8 Heater HHV (GROSS) Efficiencies

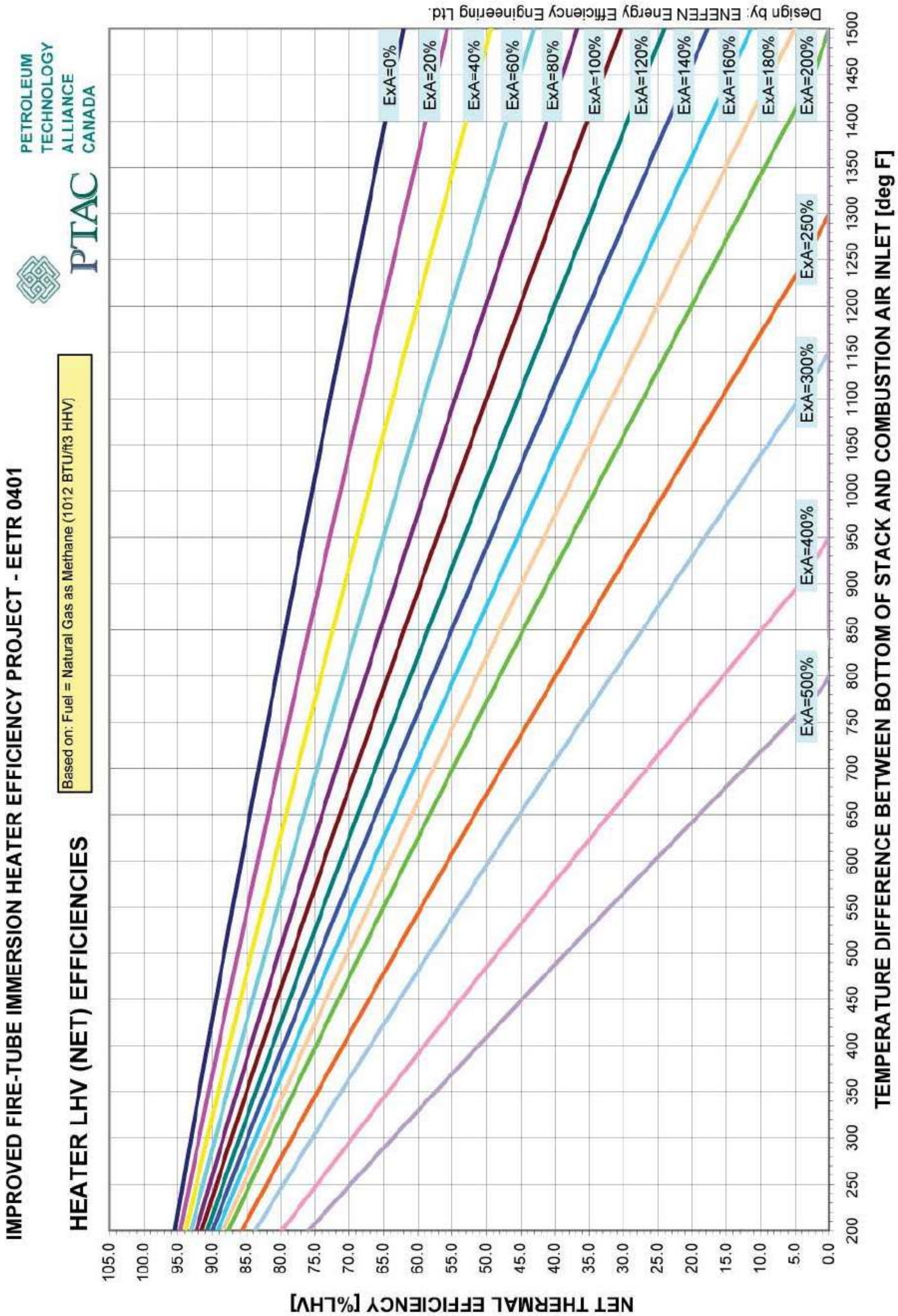

FIGURE 4.9 Heater LHV (NET) Efficiencies

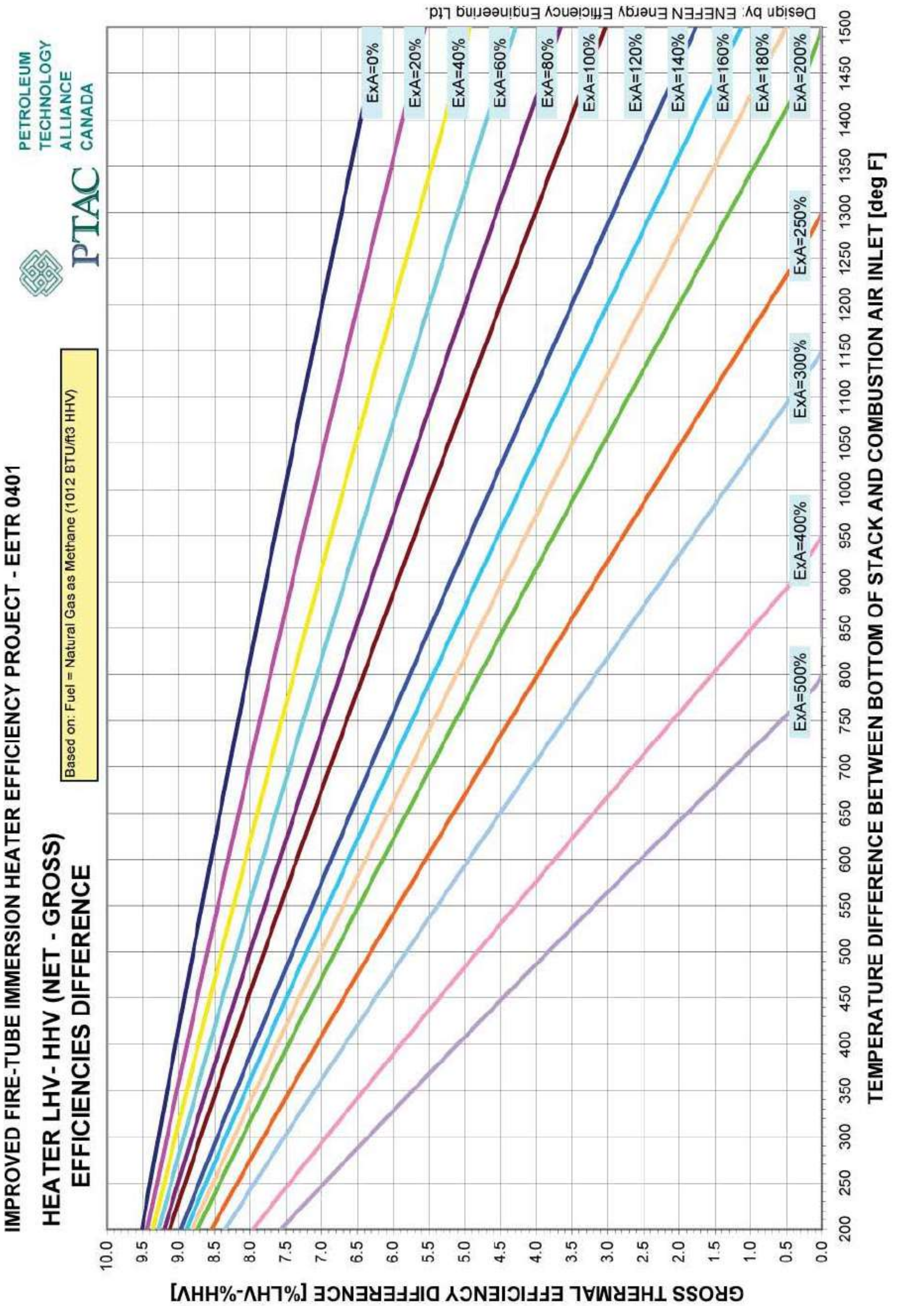

FIGURE 4.10 Heater LHV-HHV (Net-Gross) Efficiencies Difference

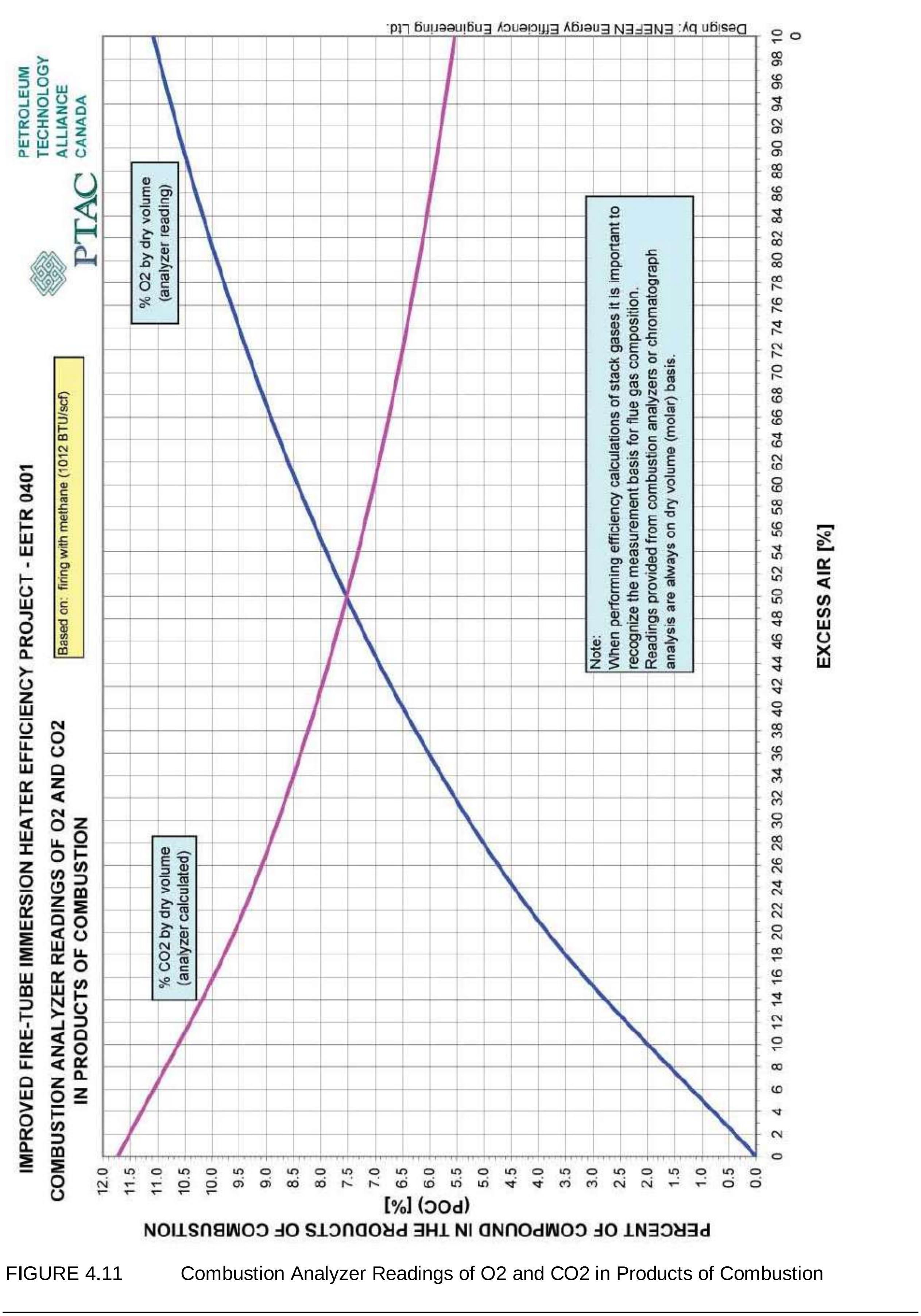

FIGURE 4.11 Combustion Analyzer Readings of O2 and CO2 in Products of Combustion

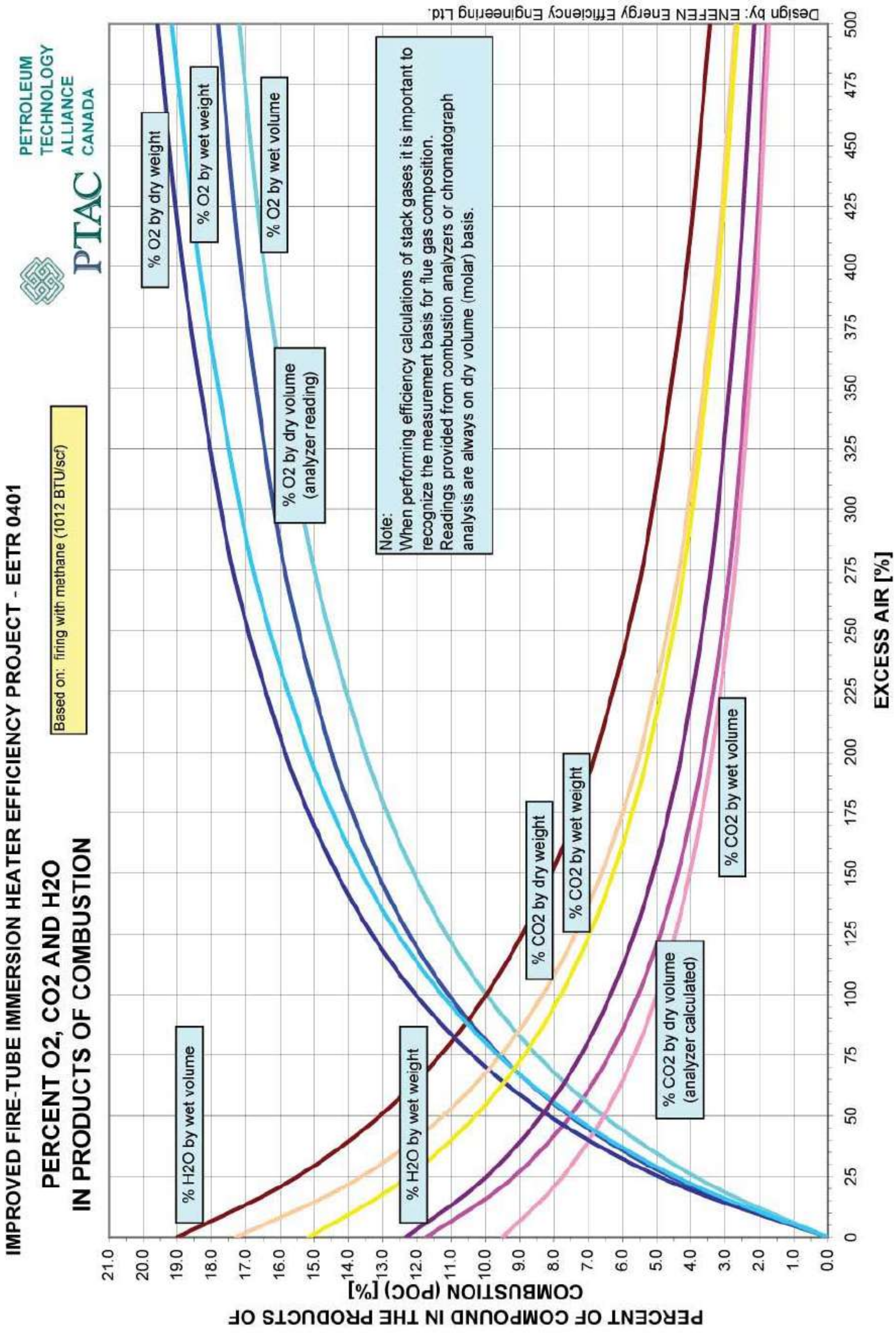

FIGURE 4.12 Percent O2, CO2, H2O in Products of Combustion

4.9 Impact Of Bath Liquid Temperature On Heater Efficiency

Figure 4.13 illustrates the impact of bath temperature on heater efficiency, as if this same heater could be filled with different liquids and ran to a different temperature setpoint. This chart is constructed to allow for estimating efficiency losses resulting from changes in the bath temperature with a fixed fire tube surface area. The horizontal X-axis shows bath temperature starting from 60 deg F up to 800 deg F. The 60 deg F bath temperature is used as a nominal temperature efficiency to which efficiencies at other temperatures are compared. The vertical Y-axis shows the differential efficiency loss compared to 60 deg F performance.

Typical ranges of the bath temperature for various applications (reference A23) are shown on the chart as red bars.

Examples of efficiency comparisons are as follows:

a) Line heater with 50% EG bath operating at 140 deg F setpoint is approximately 0.5% less efficient than the above nominal 60 deg F efficiency;

b) Line heater with 50%EG bath operating at 205 deg F setpoint is approximately 0.8% less efficient than the nominal efficiency;

c) Consequently, any changes to the temperature setpoint of a line-heater using 50%EG affect the heater efficiency by maximum 0.3% (0.8%-0.5%);

d) Amine reboiler operating at 270 deg F is approximately 0.6% less efficient than a line heater (1.4%-0.8%);

e) TEG reboiler operating at 400 deg F is approximately 1.6% less efficient than a line heater (2.4%-0.8%); and,

f) Salt bath heater operating a 800 deg F is approximately 6.7% less efficient than a line heater (7.5%-0.8%).

Although the above comparisons were calculated based on a theoretical performance of an 18” dia – 2 pass – 20 ft long fire tube, methane firing, 15 deg C ambient, 2.5% O2 in the stack, they can all be generalized to show the relative impact of various bath liquid temperature with any fire-tube size.

4.10 Impact of Stack CO on Heater Efficiency

CO in the stack results from incomplete combustion either due to poor air/fuel mixing, inadequate or excessive amount of combustion air, or to flame impingement on a cold surface such as fire-tube metal wall. Compared to flame temperature, the tube wall is considered cold regardless of the bath temperature. Figure 4.14 shows the impact of CO in the stack on heater efficiency. The chart was constructed based on firing with methane and stoichiometric 0% excess air.

Good operating practice for burners is based on less than 100 ppm CO tuning, and a maximum allowable safety limit of 400 ppm. Most portable combustion analyzers are limited to 0 to 5,000 ppm CO range. Some analyzers can be purchased with 0-10,000 or 0-30,000 ppm cells. Caution must be exercised when exposing chemical CO cell analyzers to high CO levels as permanent damage may occur.

The parallel curves shown in the chart represent various CO readings starting from 0 ppm first in 1,000 ppm then 10,000 ppm increments. The CO value is treated in the computation as a loss of the calorific value in the fuel, as if CO could be further oxidized to CO_2 to deliver more energy.

For example: at 500 deg F stack temperature differential (stack bottom minus ambient temperature) at CO=0 ppm efficiency is 79.5%; at CO=10,000 ppm (1% by volume) the comparable efficiency is 76%. Consequently 1% CO in stack corresponds to 79.5-76 = 3.5% efficiency loss due to incomplete combustion of fuel. Conversely, normal 100 ppm CO level affects the efficiency by only 0.0375%.

Due to safety concerns, operation with the CO exceeding 400 ppm should not be allowed.

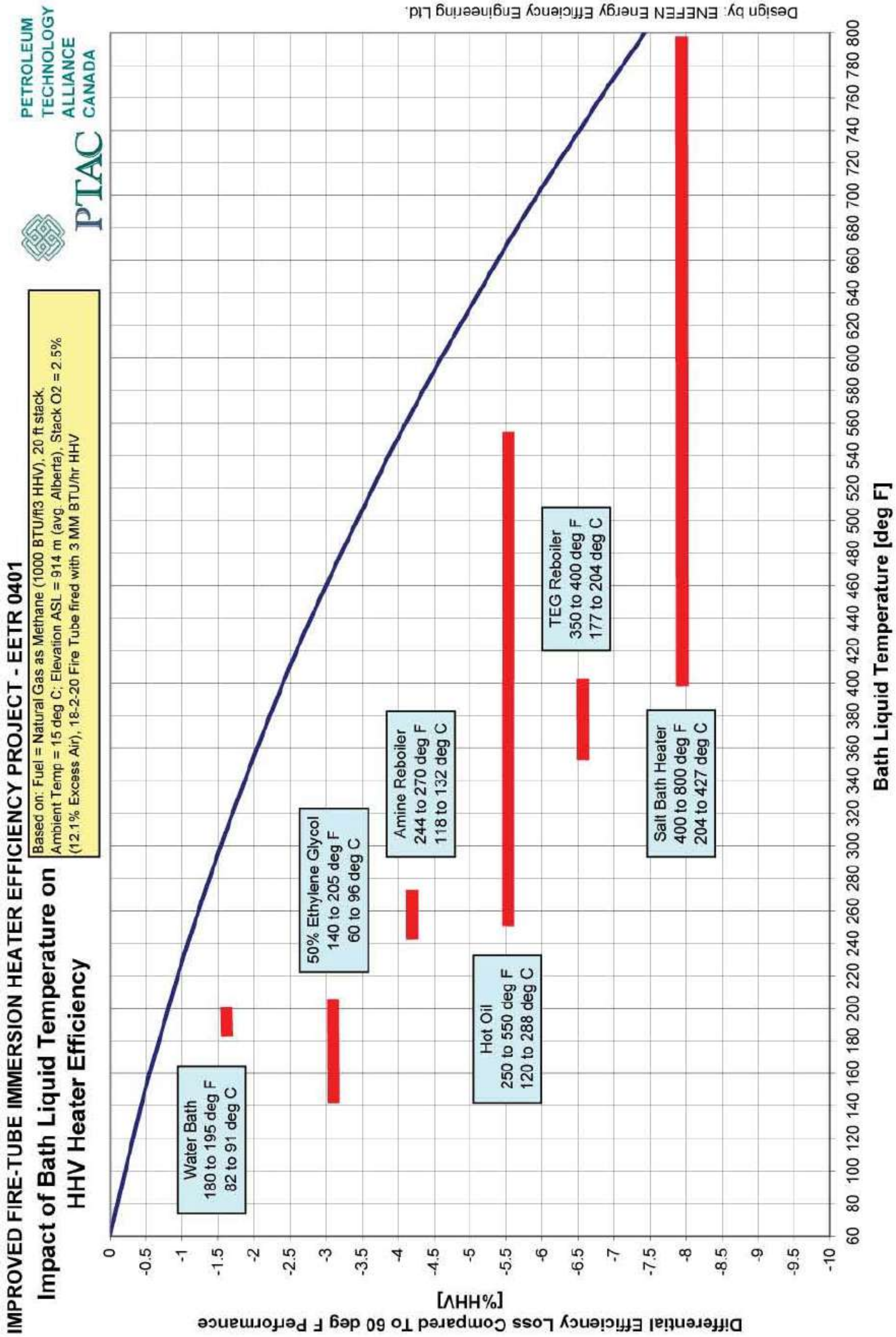

FIGURE 4.13 Impact of Bath Liquid Temperature on HHV Heater Efficiency

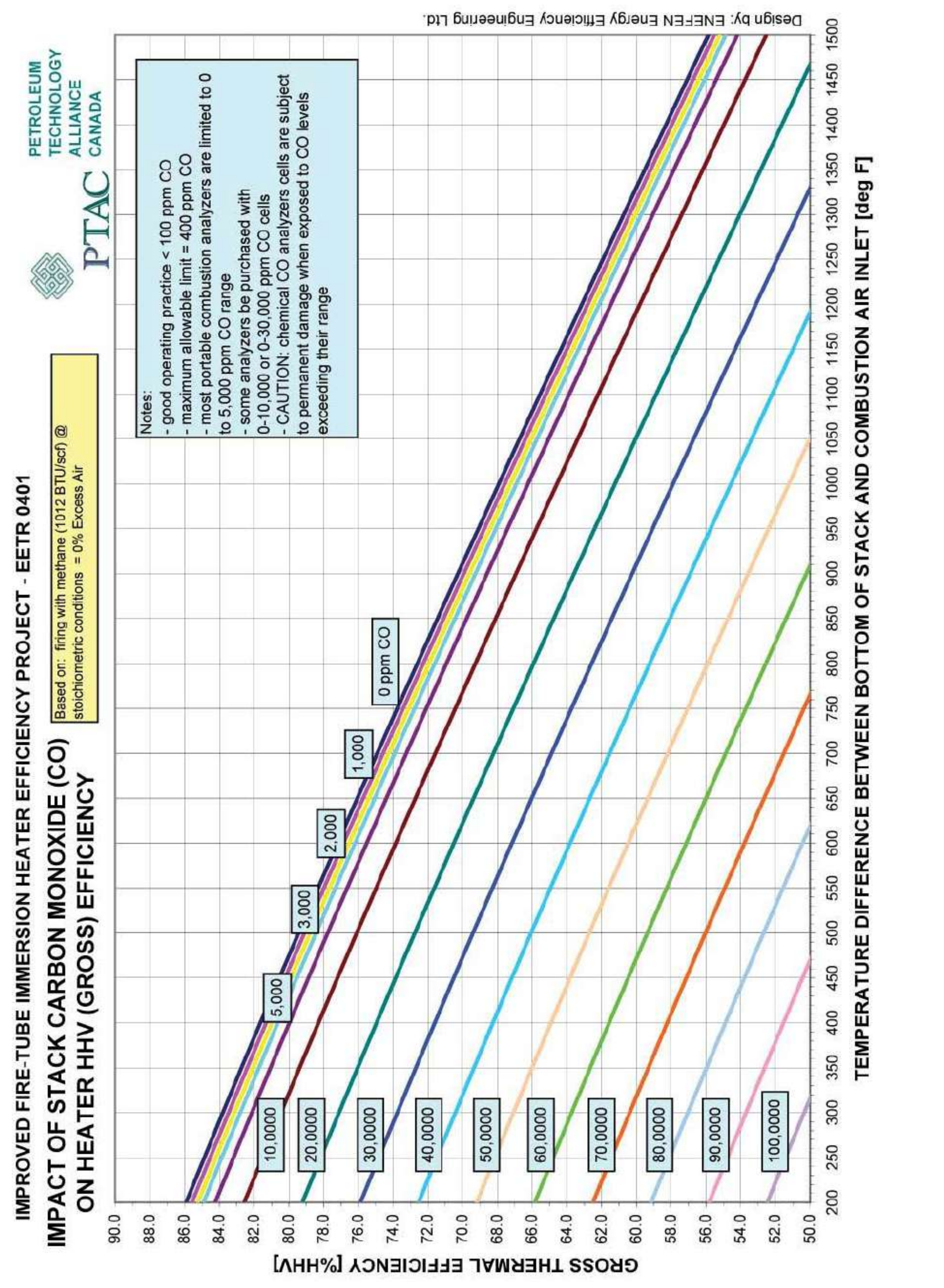

FIGURE 4.14 Impact of Stack CO on Heater HHV (Gross) Efficiency

4.11 Impact Of Fuel Composition On Heater Gross (HHV) Efficiency

Figure 4.15 illustrates the impact of various fuels on heater HHV (Gross) Efficiency when firing with that fuel at stoichiometric condition. Similar curves can be constructed for various fuel mixtures and excess air levels, however, the objective of this chart is to show the relative impact of fuel composition on efficiency. Individual curves are shown for C1, C2, and C3, C4, C5, C6, H2S, H2, and CO. The differences between C4, C5, and C6 are very small consequently, the curves overlap.

H2 and CO curves are shown for comparison to demonstrate the impact of the hydrogen content in the fuel on the efficiency. Hydrogen firing produces the lowest HHV efficiencies due to the highest amount of water created in the process (100%). Conversely the CO firing produces the highest HHV efficiencies because it has no hydrogen in its composition, and it converts to 100% CO2. The difference between these two curves at 500 deg stack differential is 90-75.5 = 14.5%. Hydrocarbons fall within this CO-H2 range with the lightest C1 producing the lowest efficiency at 500 deg F of 79.5%. In comparison, C1 combustion is only 4% more efficient than pure hydrogen and 10.5% less efficient than CO firing. The difference between C1 and C4 efficiency is approximately 2.5%. Typical sour field gas is shown as a light green line produces efficiencies close to methane. H2S combustion is shown for comparison as a dark green line, which at 500 deg F differential stack temperature produces approximately the same efficiencies as C1, but at 1100 deg F has an efficiency 2% lower than C1.

4.12 Impact of Fuel Composition on Heater Net (LHV) Efficiency

Figure 4.16 illustrates a similar relationship to Figure 4.13 except that it is expressed in LHV net efficiencies. Here the results are not influenced by the water formation during the combustion reaction, but by the sensible heat content of the individual compounds in the products of combustion.

CO combustion produces the highest efficiencies while H2S combustion produces the lowest. All hydrocarbons LHV efficiencies are very similar.

4.13 Impact of Ambient Air Temperature on Heater Efficiency

Figure 4.17, illustrates the impact of ambient air temperature on heater HHV (gross) efficiency. The curve was constructed based on firing methane at 20% excess air and 500 deg F stack temperature. Similar curves could be constructed for other conditions, however, we selected 500 deg F stack temperature and 20% as representative to a reasonable efficiency goal for a fire tube heater. The efficiency is affected by the fact that the ambient air has to be heated to produce the equivalent temperature of products of combustion in the fire tube, and therefore similar heat transfer.

At –40 deg F the efficiency is estimated at 78.73% and at 100 deg F ambient at 79.35%. Consequently, there is only a 0.82% HHV efficiency loss between the heater “summer” and “winter” operation. With a higher excess air, these efficiency losses increase, however the **ambient air temperature is not a major source of the efficiency losses**.

4.14 Impact of Combustion Air Pre-Heat on Heater Efficiency

The Impact of combustion air preheat on heater efficiency can be readily estimated using heater HHV (Gross) efficiency chart in Figure 4.8. The procedure is the same as with ambient air operation except that we use air preheat temperature when establishing the temperature difference between bottom of stack and combustion air inlet.

For example, an ambient temperature of 50 deg F and a stack bottom temperature of 550 deg F, the temperature difference is 500 deg F. At 20% excess air this corresponds to gross (HHV) efficiency of 78.5%.

If we use preheated combustion air to 250 deg F, then the temperature difference between the 550 deg F stack and this preheated air is reduced to 300 deg F, and the resulting gross (HHV) efficiency is 83%.

Hence the 250 deg F air preheat at 20% excess air corresponds to 4.5% increase in efficiency.

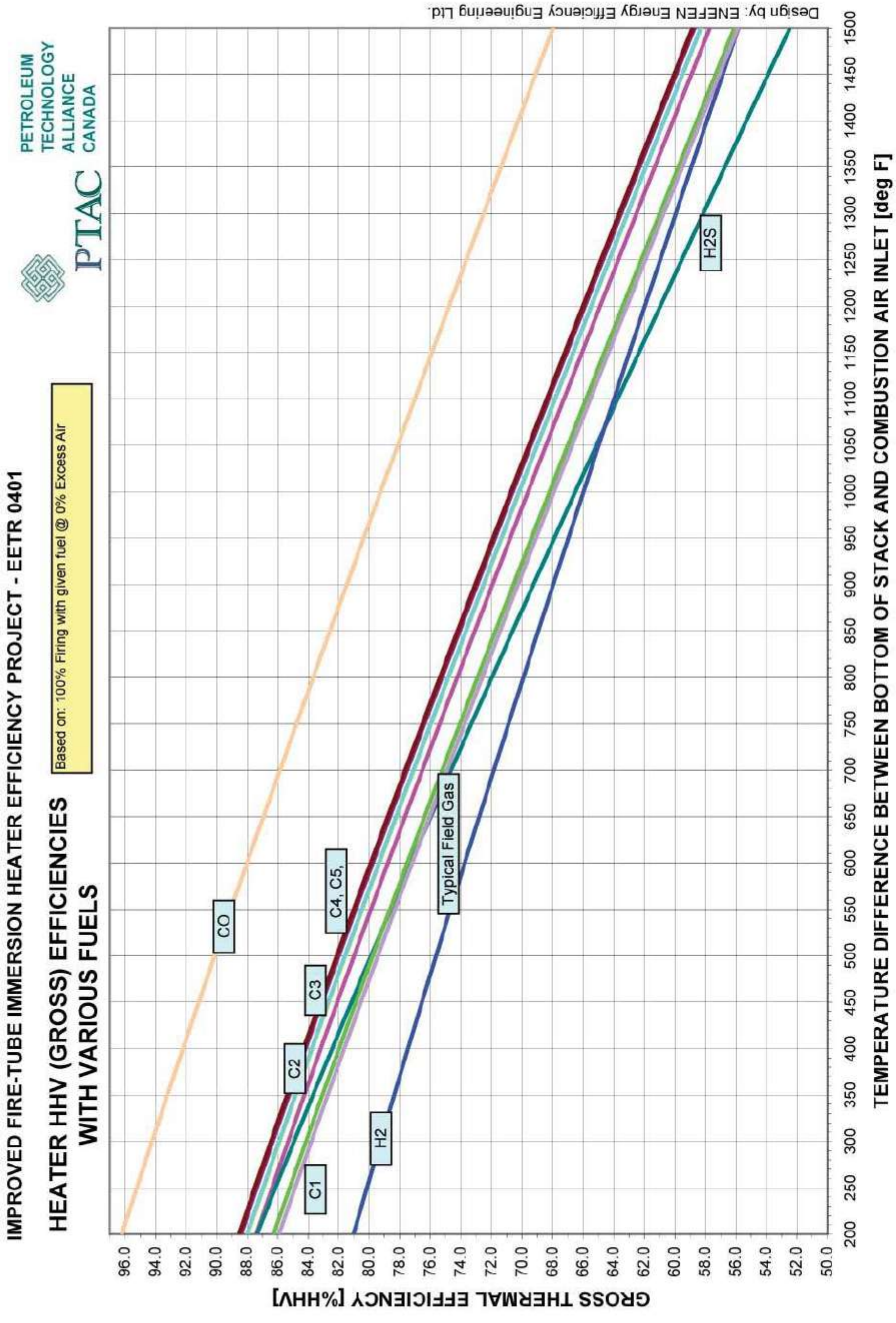

FIGURE 4.15 Heater HHV (Gross) Efficiencies With Various Fuels

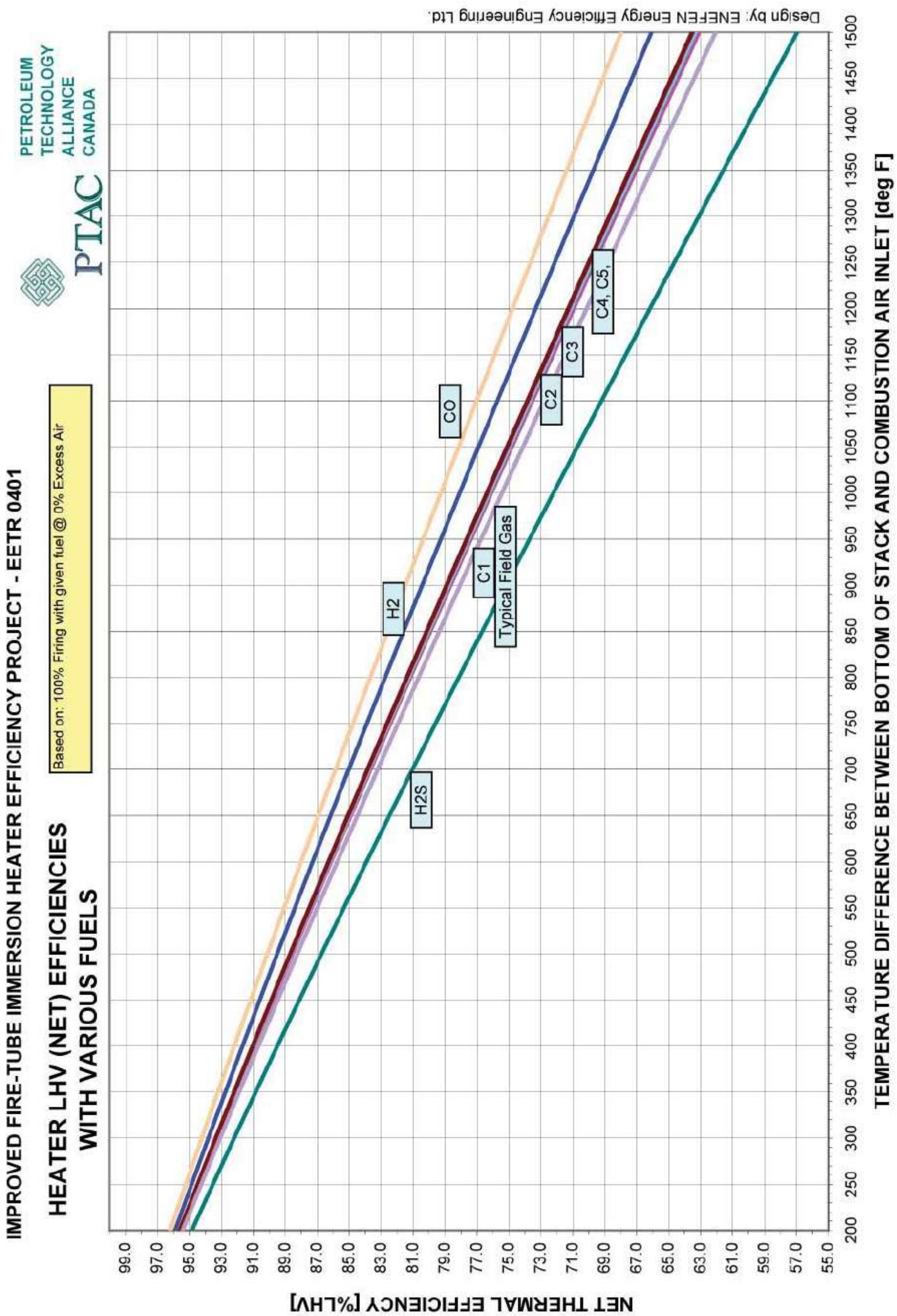

FIGURE 4.16 Heater LHV (NET) Efficiencies With Various Fuels

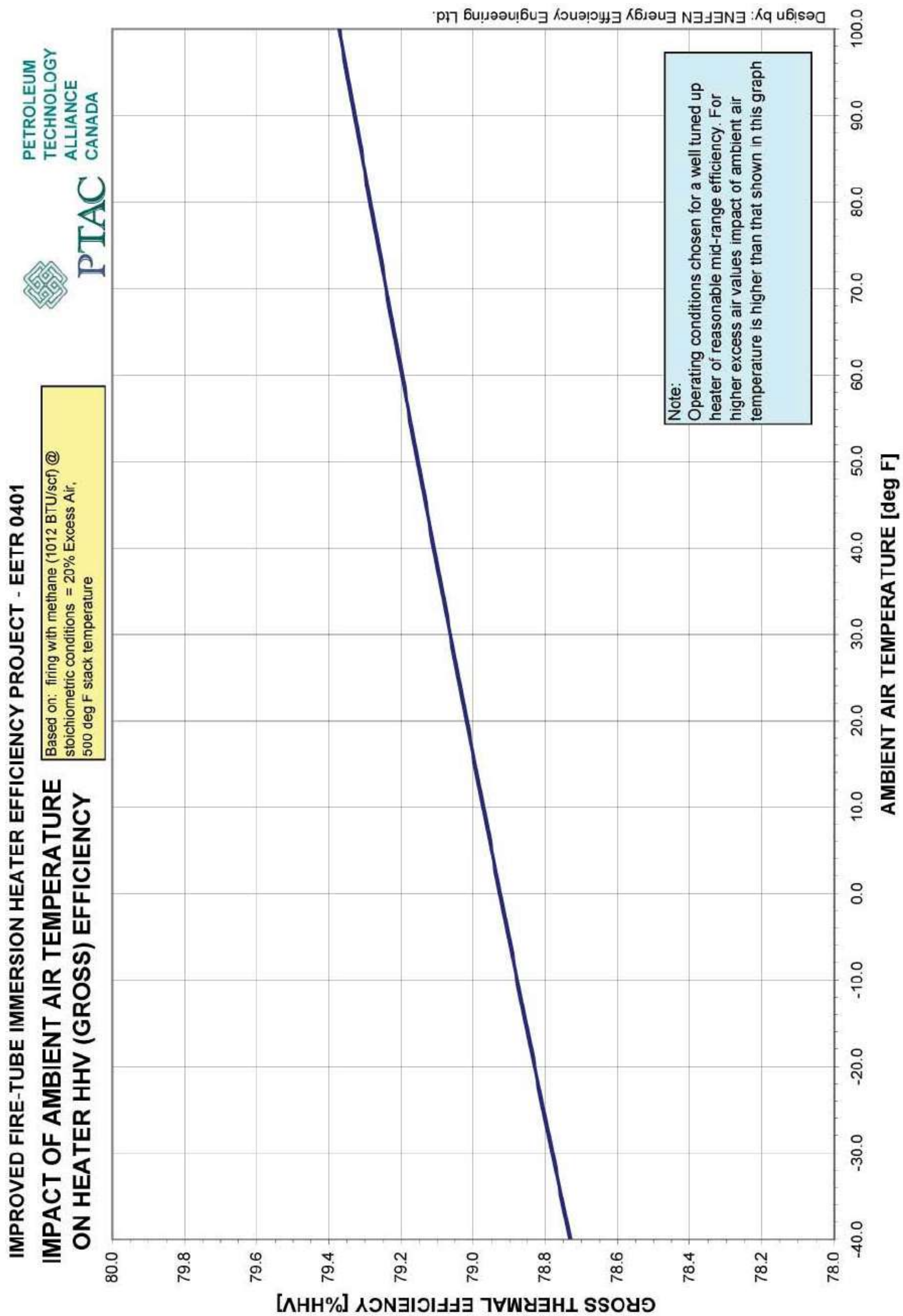

FIGURE 4.17 Impact of Ambient Air Temperature on Heater HHV (Gross) Efficiency

4.15 Impact of Ambient Air Humidity on Heater Efficiency

Figure 4.18 illustrates the efficiency curve, which was constructed based on firing with methane at 20% excess air, 500 deg stack temperature, and 100 deg F ambient summer condition. At 0% relative humidity efficiency is 79.37%, at 100% it is 79.17%. This translates to a small 0.2% change in efficiency between dry and humid air operation.

4.16 Impact of Fuel Temperature on Heater Efficiency

Figure 4.19 was constructed to research the impact of fuel temperature on the overall heater efficiency. This subject was previously discussed under 4.2.4.

The fuel preheat temperature range of 0 to 350 deg F is deliberately exaggerated on the chart to show the negligible impact on overall heater efficiency. The chart was based on firing with methane at 0% excess air and a 500 deg F stack temperature. With 0 deg F fuel gross (HHV) efficiency was calculated at 79.41%, at 350 deg F the efficiency increased to 79.56%, for a total increase of 0.15%. As the mass flow of fuel is low compared to that of combustion air, little sensible heat is added to increase efficiency.

4.17 Flame (Hot Mix) Temperature

Figure 4.20 illustrates the impact of excess air on the flame temperature, also called the “hot mix” temperature. The chart is based on firing with methane. Although the adiabatic flame temperature of methane combustion can be calculated at 3,484 deg F, the actual flame temperature is lower than that value and it is actually unknown. The flame temperature cannot be accurately measured because the flame is emitting radiant heat. Some sources estimate that by the time combustion is completed flame looses between 15% and 25% percent of the original energy contained in the fuel via radiation. Consequently, the measured temperatures are much lower than those calculated and for stoichiometric flames are typically in the range between 2,500 to 2,800 deg F. Excess air has a great impact on the “hot mix” temperature as part of the energy is used to heat excess nitrogen and excess oxygen, which do not take part in the reaction.

Disregarding the discrepancy between the actual and the theoretical measured flame temperatures, we can use the curve to see the relative drop in the temperature caused by excess air. At 50% excess air the flame “looses” 800 deg F; at 100% 1,300 deg F; and at 150% 1,700 deg F. This corresponds to between 11 to 16 deg F flame temperature loss for each 1% of excess air. This temperature drop, results in a great reduction in the radiative heat transfer, as well as, in the LMTD of the convective heat transfer. In an extreme case, such a pilot firing with a large flow of excess air, the flame temperature loss is in excess of 2,500 deg F, hence the products of combustion are too cold to provide effective heating of the bath liquid. In addition, combustion reaction is interrupted and flame produces high CO levels.

4.18 Stack Draft

Figure 4.21 illustrates the effect of stack height and the ambient air temperature on natural draft. All graphs were based on methane firing with 15% excess air at 3000 ft. A.S.L. typical Alberta elevation, and show the natural draft effect in three groups: for 10ft, 20ft and 30ft high stack. Each group of graphs consists of five ambient temperature-based curves for: -40, -5, +30, +65, and +100 deg F.

The impact of stack height on the draft is readily visible. For example at 500 deg F stack temperature on a hot summer day (worst case at +100 deg F) a 10 ft stack produces only 0.053” W.C. (inches water column) theoretical draft, a 20 ft stack 0.11” W.C, and 30’ stack, 0.165” draft. This means that every 10’ of stack length adds approximately 0.054” W.C to the theoretical draft.

Since ambient air also affects the natural draft, we can look at a combined impact of stack height and ambient air temperature through the following correlation: ambient temperature change produces parallel curves which at the above conditions are spaced by approximately 0.0038” W.C/10deg F/ 10ft of stack height.

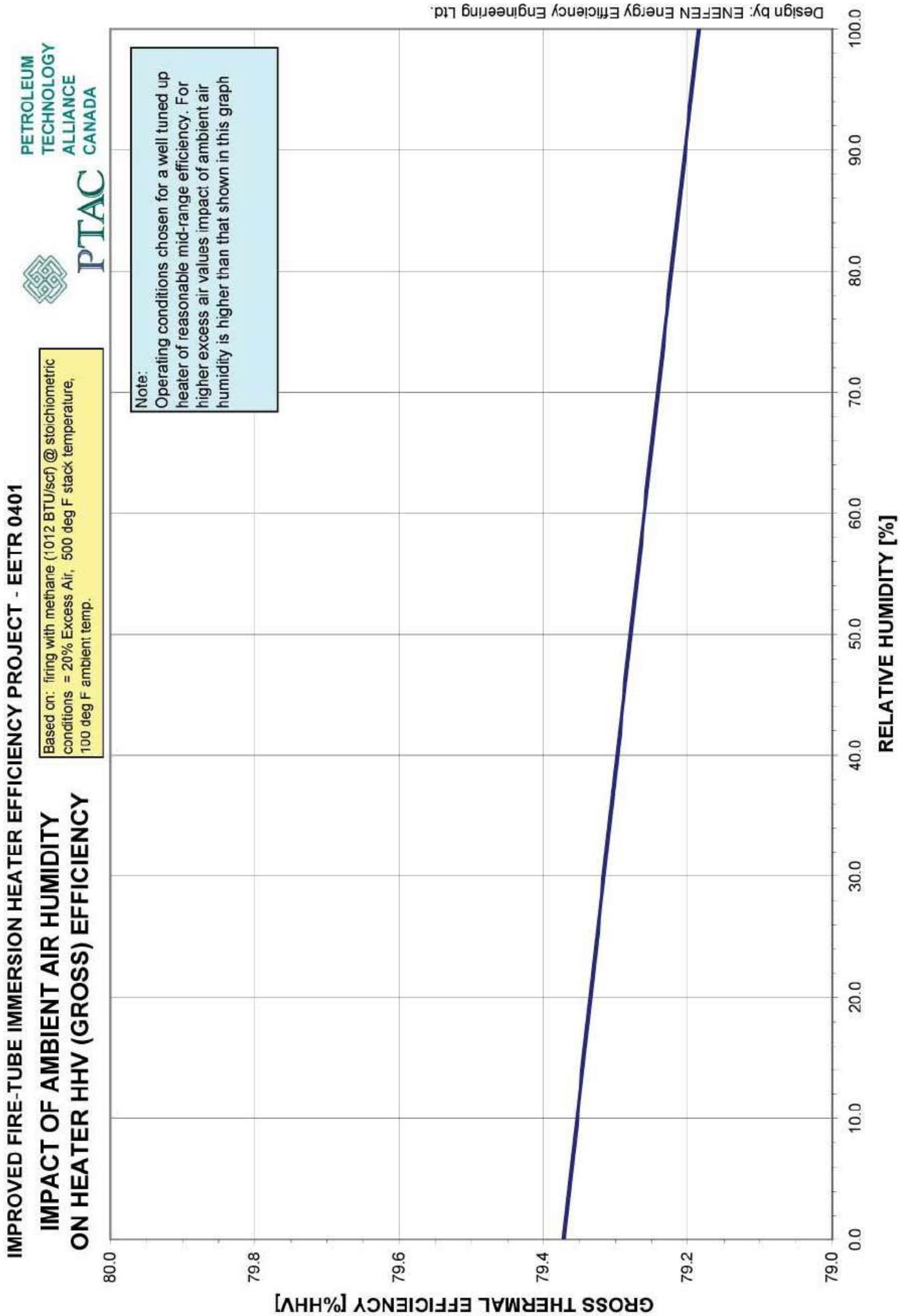

FIGURE 4.18 Impact of Ambient Air Humidity on Heater HHV (Gross) Efficiency

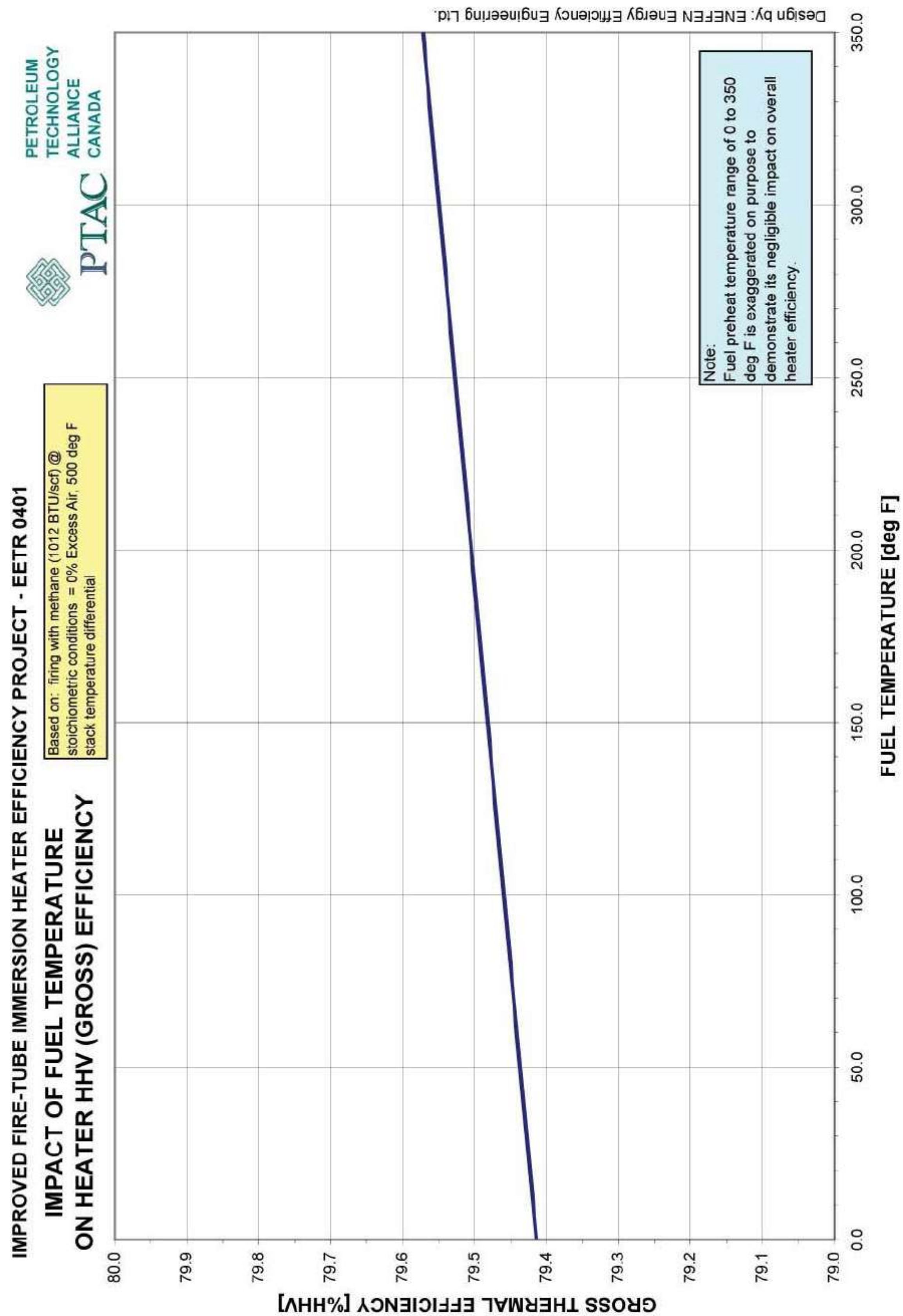

FIGURE 4.19 Impact of Fuel Temperature on Heater HHV (Gross) Efficiency

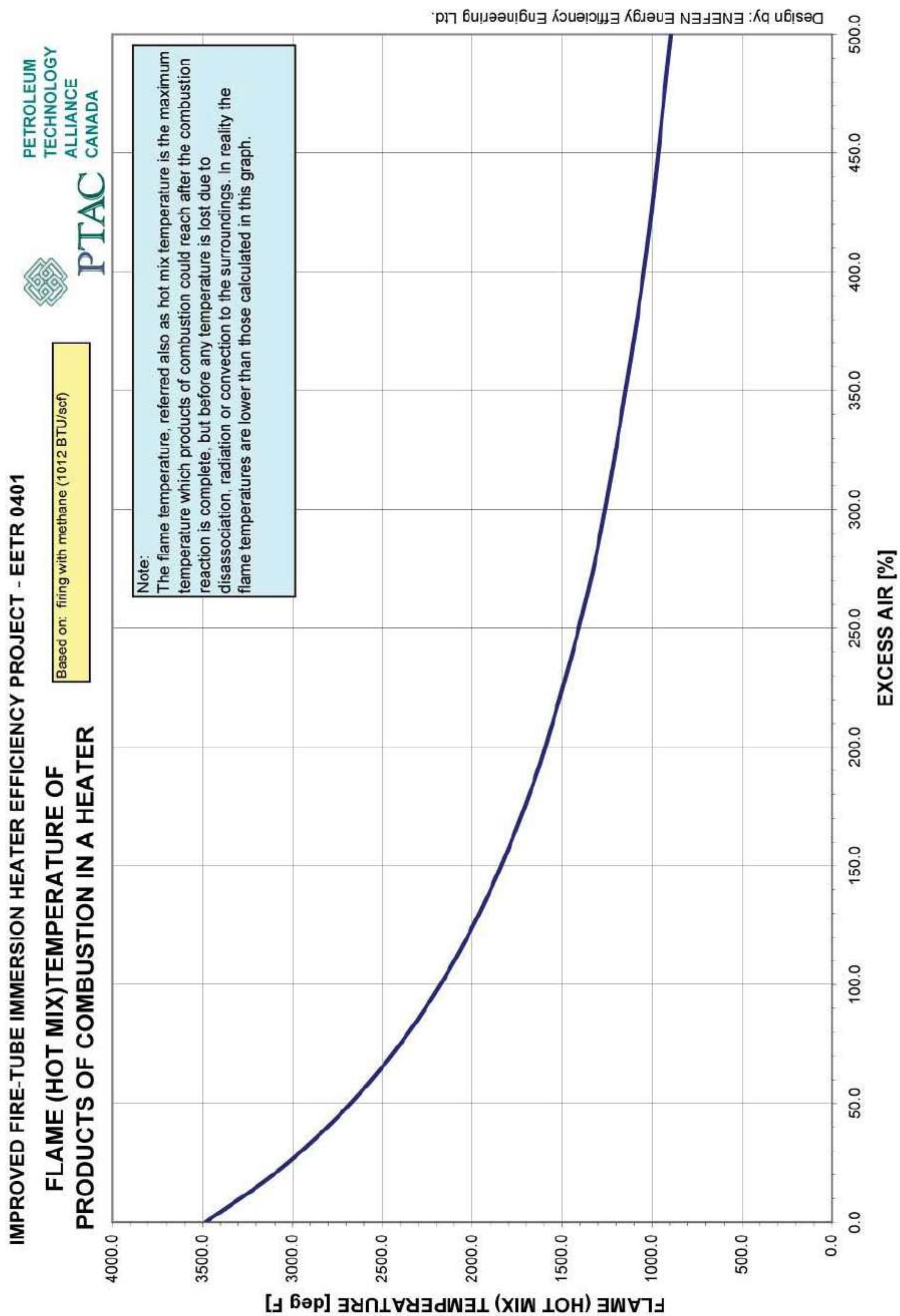

FIGURE 4.20 Flame (Hot Mix) Temperature of Products of Combustion in a Heater.

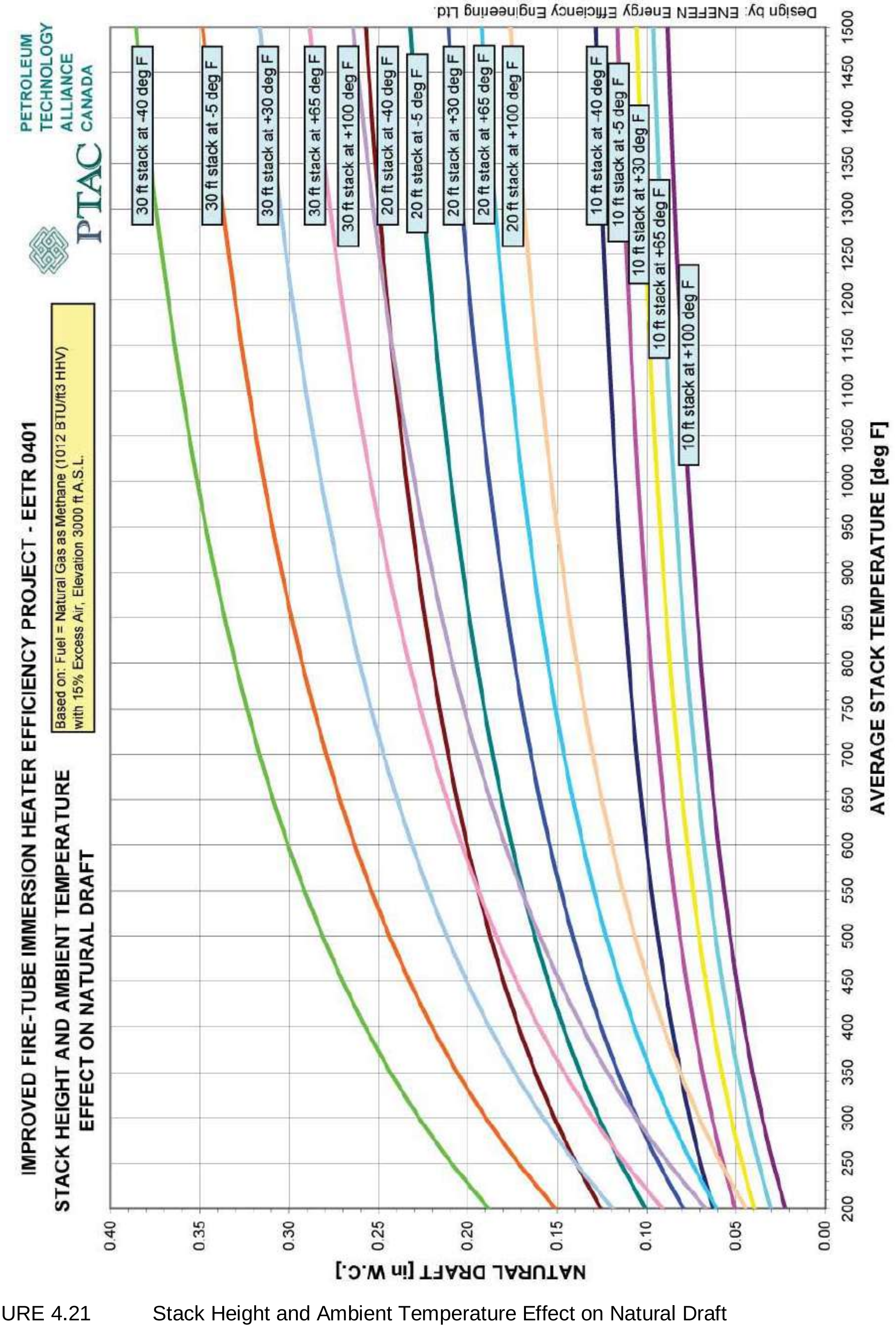

FIGURE 4.21 Stack Height and Ambient Temperature Effect on Natural Draft

4.19 Shell Heat Loss

Figure 4.22 illustrates the heat loss from the heater shell per ft2 of surface area. Graphs are constructed to show the comparison of no insulation to either 1" or 2" thickness of 1,000 deg F mineral fibre insulation with an aluminum jacket.

In each group, graphs illustrate the difference of ambient temperature and wind velocity on the heat loss: -40 deg F @ 20 mph wind, -40 deg F @ 0 mph wind, 100 deg F @ 20 mph wind, and 100 deg F @ 0 mph wind.

The chart clearly shows a dramatic improvement between an uninsulated surface and an insulated surface, however, the difference in insulation thickness does not show significant improvements. A conclusion could be drawn from this correlation that insulating the end heads on the heater may have a better effect on the overall efficiency than increasing the insulation thickness on the rest of the shell. The differences are especially large for high shell temperature such as in salt bath application.

For lower bath ranges such as in a line heater application the heat losses from insulated surfaces are less than 100 BTU/hr/ft2, and vary between 200 BTU/hr/ft2 for uninsulated surface in summer with no wind, to 1100 BTU/hr/ft2 in winter with 20 mph wind.

The graphs were created with the help of a 3EPLUS insulation rating program available as freeware on the Internet (www.naima.org) from North American Insulation Manufacturers Association (NAIMA). Flat plate approximation with base metal emmittance of 0.8 were chosen for the calculations.

4.20 Stack Heat Loss

Figure 4.23 illustrates the heat loss from the stack per ft2 of surface area. Graphs are constructed to show the comparison of no insulation to either 1" or 2" thickness of 1,200 deg F mineral fibre insulation with an aluminum jacket.

In each group, graphs illustrate the difference of ambient temperature and wind velocity on the heat loss: -40 deg F @ 20 mph wind, -40 deg F @ 0 mph wind, 100 deg F @ 20 mph wind, and 100 deg F @ 0 mph wind. The graphs are shown for 4", 20" and 36" diameter stack.

Similar to the shell heat loss graphs discussed previously, this chart demonstrates a dramatic improvement between an uninsulated surface and an insulated surface, however the difference in insulation thickness does not produce any significant improvements. Taking under consideration the benefits of stack insulation, a thin, 1" insulation could easily produce the desired results.

There is also a significant difference of the uninsulated stack diameter on the heat loss, with smaller stacks having a lower heat loss per ft2 of surface area than larger stacks in similar operating conditions.

For a stack temperature of 500 deg F the heat loss varies between 1,200 BTU/hr/ft2 for uninsulated surface in summer with no wind, to 3100 BTU/hr/ft2 in winter with a 20 mph wind.

For a stack temperature of 1,000 deg F the heat loss varies between 1,800 BTU/hr/ft2 for 4" dia uninsulated surface in summer with no wind, to 9,600 BTU/hr/ft2 for 36" dia uninsulated surface in winter with a 20 mph wind.

The graphs were created with the help of a 3EPLUS insulation rating program available as a freeware on the Internet (www.naima.org) from North American Insulation Manufacturers Association (NAIMA). Base metal emmittance of 0.8 was chosen for our calculations.

The main difference between shell and stack heat losses is that the shell losses directly affect the efficiency of the heater as they use energy already stored in the liquid bath.

Stack losses occur after the products of combustion leave the heat transfer surfaces inside the heater (the fire tube). So unless there is a heat recovery system in place, which would return part of this energy back to the heater, the energy in the stack is already considered lost to the process. The heat losses in the stack have however, other indirect adverse effects on the process such as condensation, freezing, loss of draft or increased corrosion.

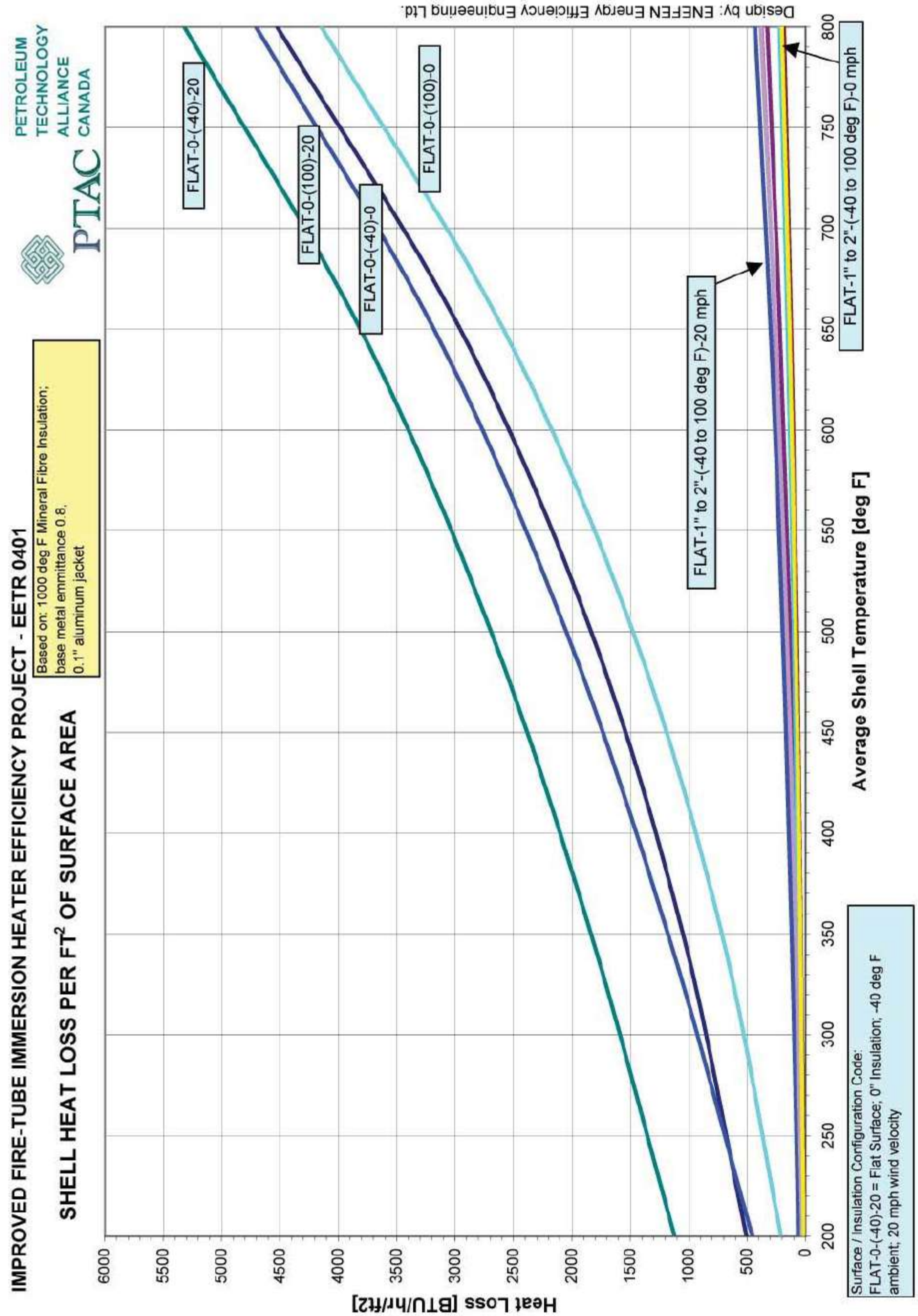

FIGURE 4.22 Shell Heat Loss Per ft2 of Surface Area

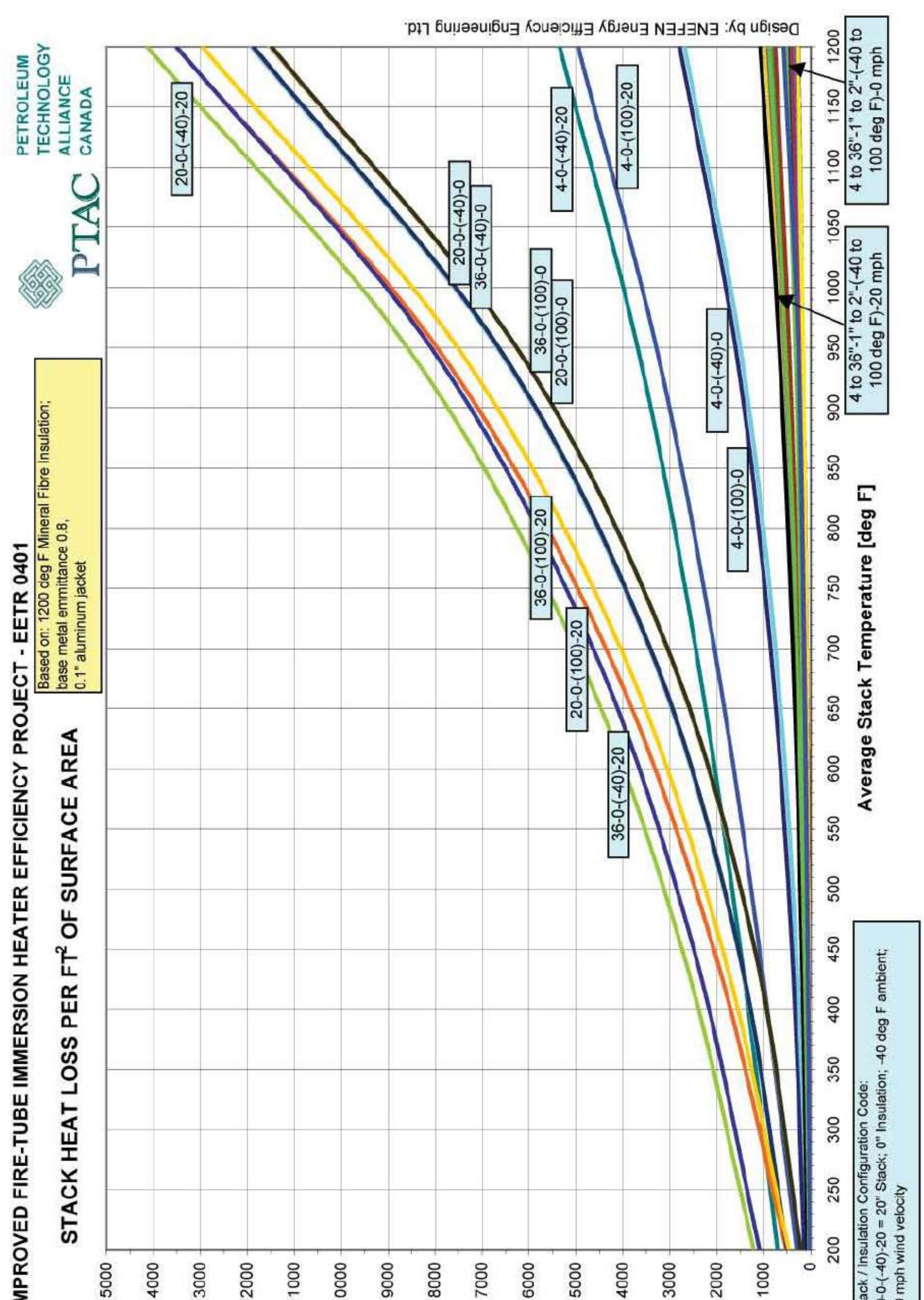

FIGURE 4.23 Stack Heat Loss Per ft2 of Surface Area

An important aspect to understand with stack losses, is that although the above stack heat loss curves show dramatic heat losses per ft2. of surface area, it does not necessarily mean that the stack gas has the actual heat capacity, and thermodynamic ability to satisfy these losses. Similar to the fire tube performance, the heat transfer through the stack is controlled by laminar boundary layers on both sides of the stack metal surface. Since the flow through a natural draft stack is more of a plug flow or laminar type than a turbulent type, the heat transfer from the bulk of the products of combustion is impeded. In an uninsulated stack the products of combustion may lose about 75 to 125 deg F.

The great ability of the uninsulated surface to lose the heat to the surrounding air as demonstrated in the graphs, may however, create significant condensation and possibly freezing on the stack's internal surfaces.

4.21 Dew Point of Products of Combustion

Figure 4.24 illustrates the impact of excess air on the dew point of the product of combustion. The graph is based on methane firing and changes with different fuel compositions.

Dew point is defined as the temperature at which moisture contained in a gas mixture starts to condense.

At stoichiometric conditions, with 0% excess air the dew point of the products of combustion of methane is 139 deg F. As the excess air increases the dew point temperature decreases. At 50% excess air, it is 126 deg F, at 100% excess air 116 deg F. This can be translated to an average rate of decrease of: 2.3 deg F / 10% excess air change.

Since the goal of this efficiency project is to minimize heat losses by maintaining low excess air in the combustion below 30%, we are concerned with dew point temperatures between 130 and 139 deg F.

Some sources suggest using a so called "dew point suppression technique" which is based on deliberately increasing the excess air in order to lower the dew point of the stack gases thus minimizing the possibility of condensation in the stack. Although this technique may be effective in solving corrosion problems in boiler applications with preheated air, in immersion fire-tube heaters the use of cold ambient air is counterproductive to the higher efficiency goals and therefore, should **not** be considered.

The condensation of water from the products of combustion is not isolated to the stack but can occur also inside the fire-tube if the tube wall temperature drops below the dew point. It is a common occurrence during startups with a cold bath liquid or after prolonged shutdown that certain amount of water is condensed out inside the fire tube. The more frequent this occurs the more corrosion damage can be experienced in the tube

The dew point consideration becomes especially important when dealing with fuels containing sulfur, which changes the vapour pressure of the condensate. Although there is conflicting information on this subject in the literature, following are some common guidelines related to this subject.

One of the sources states that the presence of sulfur increases the dew point temperature by 25 to 75 deg F (164 to 214 deg F); another source suggests that the dew point may be as high as 350 deg F due to a catalytic conversion of SO_2 to SO_3 followed by formation of sulfuric acid (H_2SO_4). The common industry practice is to maintain the stack temperature above 300 deg F when dealing with fuels containing sulfur.

The large differences between sweet and sour fuel firing effects on dew point temperature is especially acute in the case of line-heaters with bath temperatures in the range between 60 to 80 deg C (140 to 176 deg F). Low bath temperatures, frequent cycling, and high excess air keep the tube wall temperature low which results in surface condensation. This may occur even if the bulk of the products of combustion is warmer than the dew point. As with sweet fuel firing the corrosion problems may be small, with the sour fuel firing corrosion problems are a certainty.

A clear understanding of the dew point concept and applications is essential in proper heater design and maintenance.

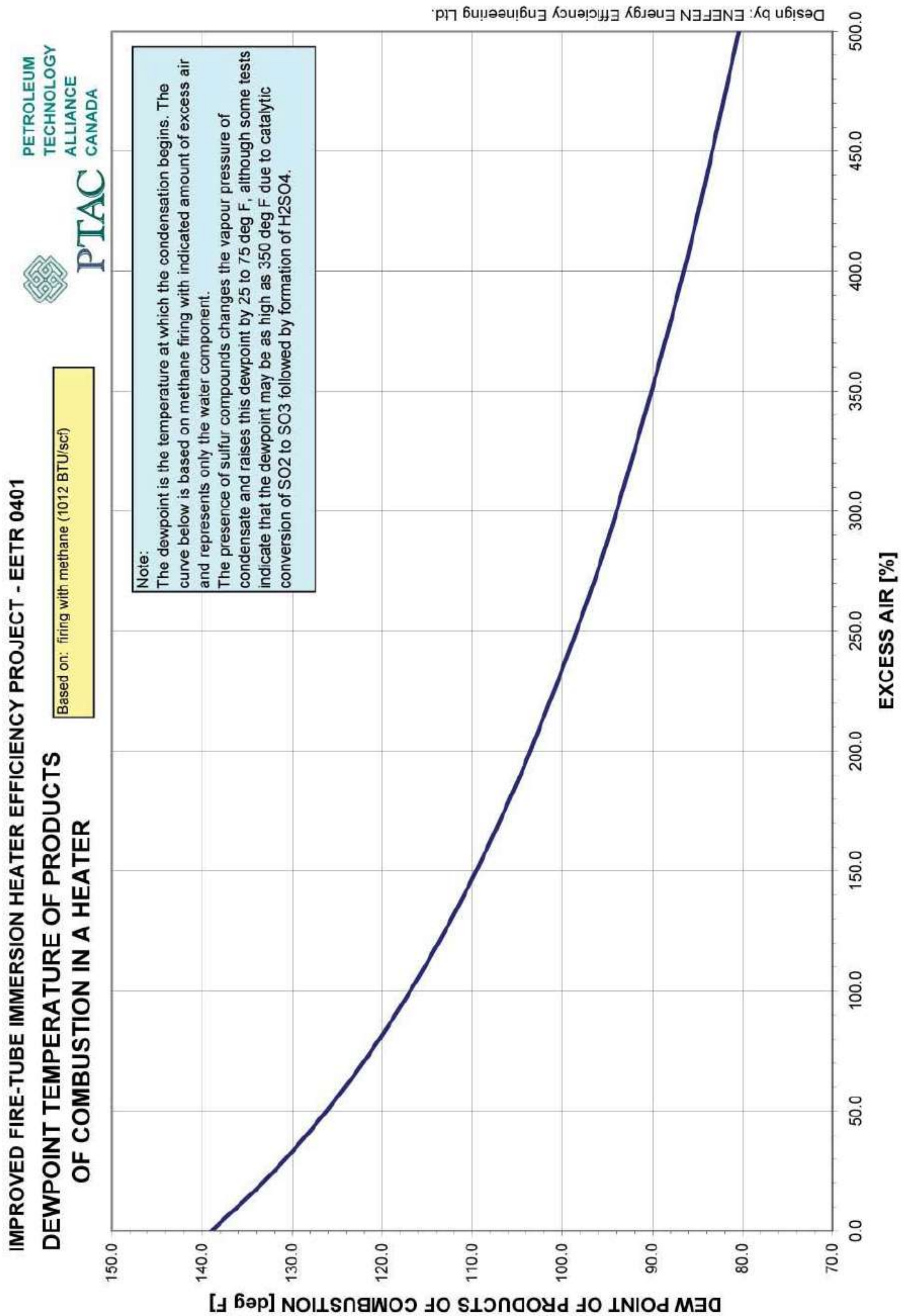

FIGURE 4.24 Dew point Temperature of Products of Combustion in a Heater

5 FIRE TUBE RATING SOFTWARE DEVELOPMENT

In order to help with the task of optimizing fire-tube performance for a specific process application, we collaborated with COEN Company of Burlingame, CA, in creating a practical and easy to apply software program. The program was designed to predict thermal performance of an immersion fire-tube heater by specifying type of fuel, heat input, tube configuration and stack height, burner flame type, as well as boundary conditions such as ambient air temperature and humidity, wind velocity or stack insulation. The program (Figure 5.1) takes under consideration both the radiative and convective heat transfer and calculates fire tube heat flux profile, temperature profile and pressure drop profile.

FIGURE 5.1 COEN Fire-Tube Rating Program – Welcome Screen

5.1 Coen's Approach to Heat Transfer Calculations

Based on the literature sources presented in the previous chapters COEN proposed the following approach to calculating the above data:

a) use modified stirred reaction model (SR) defined as FEGT + delta

b) use delta method for the reaction zone

c) account for both convection and radiation transfer occurring simultaneously with the gas emmisivity changing as a function of temperature and mean beam length

d) account for changing convection coefficient with decreasing density and temperature (instead LMTD method)

e) use "marching solution" downstream of the reaction zone – by dividing convection section into 100+ zones

f) calculate enthalpy for each zone considering it as a stirred reactor

g) this method is well suited to changing tube geometry, possible enhancements with turbulizers and calculation of fluid pressure losses.

h) use gas turbine calculation models to define radiant heat transfer.

5.2 Main Program Data Screen

The main program data screen is shown in Figure 5.2

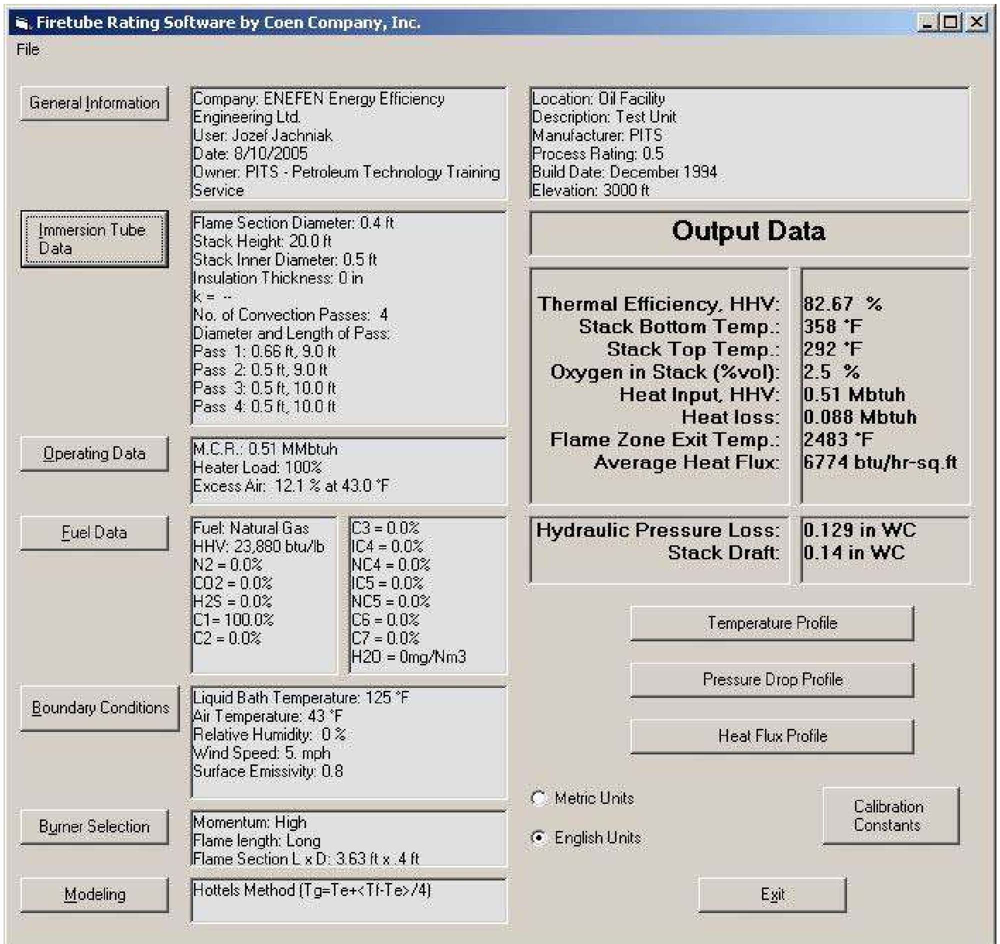

FIGURE 5.2 COEN Fire-Tube Rating Program – Main Data Screen

5.3 INPUTS to Coen Program

The INPUTS to the Coen Program include:

a) General Info Button (Figure 5.3): Company Name User Name, Date, Owner Name, Facility Name, Heater Location, Description, Tag No., Manufacture, Date Built, Elevation;

b) Immersion Tube Data Button (Figure 5.4): Stack ID and height, # of convection sections each with ID and length, stack insulation, thermal conductivity;

c) Operating Data Button (Figure 5.5): Heat input, Percent Load, Excess Air (EA);

d) Fuel Data Button (Figure 5.6): Select Natural Gas or #2 Oil, or user defined fuel;

e) Boundary Conditions Button (Figure 5.7): Liquid Bath Temperature, Air Temperature, Relative Humidity, Wind Speed and Surface Emmissivity;

f) Burner Button (Figure 5.8): select high/low momentum burner, narrow/wide, long/short;

g) Model Button (Figure 5.9): Stirred Model, Weighted Average, Normalized Zone, Hottels Method, Constant Delta Model, Blizard's Model. Square Root Model. Long's Method, Saunder's LMTD Model, Anson's Model, or Auto Gas Zone Model;

h) Calibration Button (Figure 5.10): Convective Coefficient Modifier, Radiation Coefficient Modifier, Flame Zone Modifiers: Aspect Ratio L/D for Short Flame and Long Flame, Momentum Low and

Momentum High. For the best match apply under Calibration constants: Convective Coefficient Modifier = 1.3 and Radiation Coefficient Modifier = 2.0.; and,

i) There is also a choice of Metric or English Units.

FIGURE 5.3 COEN Fire-Tube Rating Program – General Information Screen

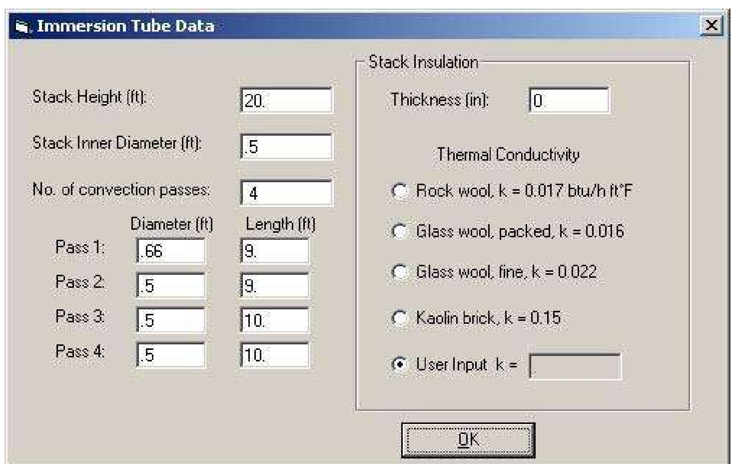

FIGURE 5.4 COEN Fire-Tube Rating Program – Immersion Tube Data Screen

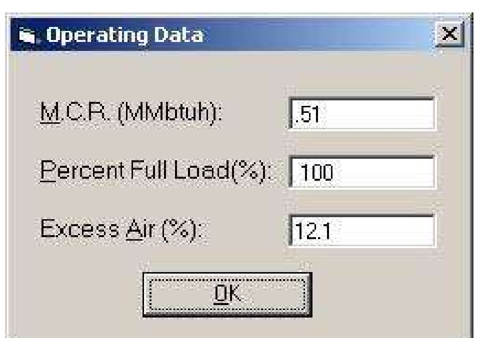

FIGURE 5.5 COEN Fire-Tube Rating Program – Operating Data Screen

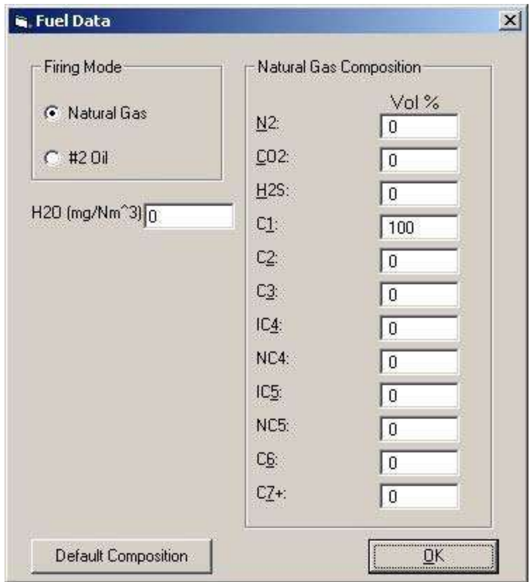

FIGURE 5.6 COEN Fire-Tube Rating Program – Fuel Data Screen

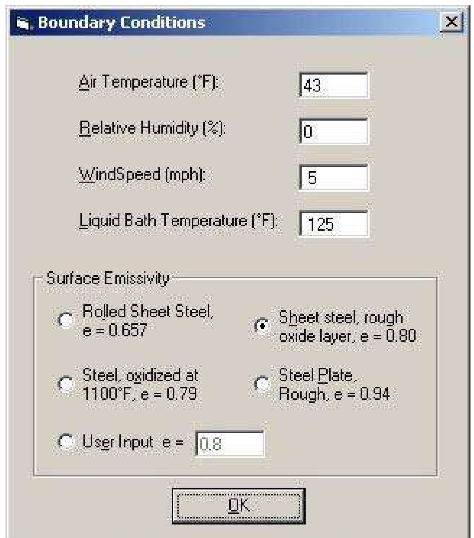

FIGURE 5.7 COEN Fire-Tube Rating Program– Boundary Conditions Screen

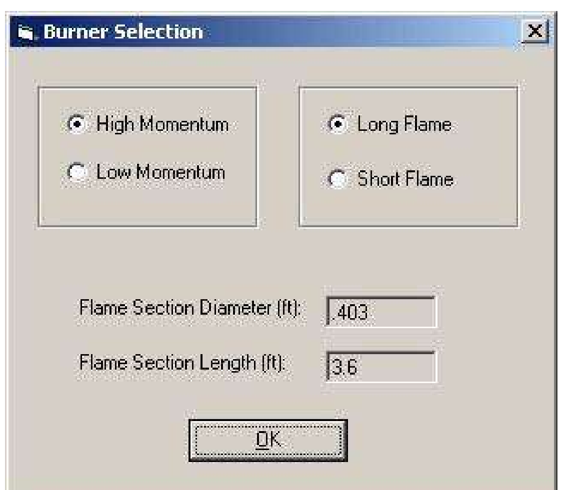

FIGURE 5.8 COEN Fire-Tube Rating Program – Burner Selection Screen

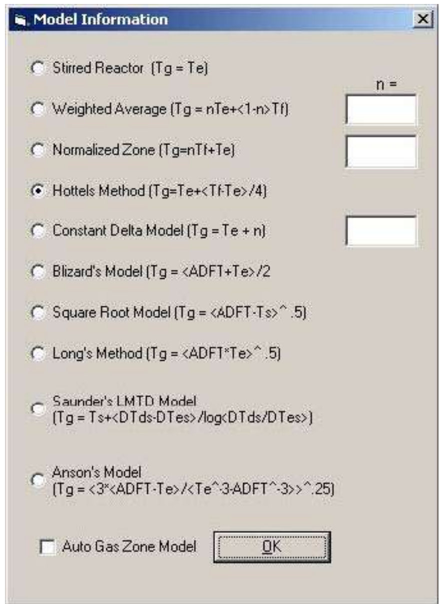

FIGURE 5.9 COEN Fire-Tube Rating Program – Model Information Screen

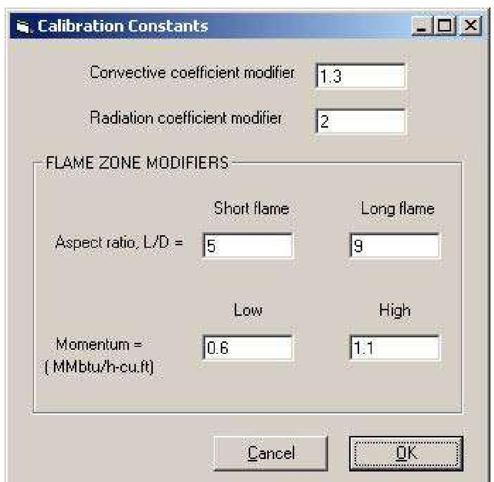

FIGURE 5.10 COEN Fire-Tube Rating Program –Calibration Constants Screen

5.4 Outputs from Coen Program

The OUTPUTS from the Coen Program include (Figure 5.2):

a) Thermal Efficiency %HHV;

b) Stack Bottom Temperature;

c) Stack Top Temperature;

d) Oxygen in Stack %;

e) Heat Input, HHV;

f) Heat Loss;

g) Flame Zone Exit Temperature;

h) Average Heat Flux;

i) Hydraulic Pressure Loss; and,

j) Stack Draft.

5.5 Temperature, Pressure and Heat Flux Profile Graphs

- In addition, Coen program displays the following graphs:

a) Tube Temperature Profile (Figure 5.11);

b) Pressure Drop Profile (Figure 5.12); and,

c) Heat Flux Profile (Figure 5.13)

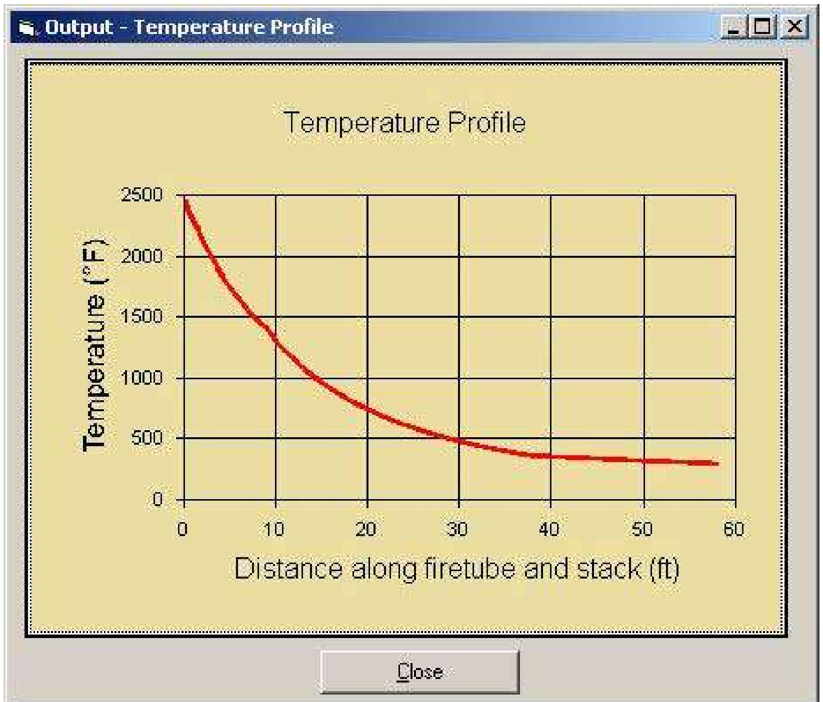

FIGURE 5.11 COEN Fire-Tube Rating Program – Temperature Profile Graph

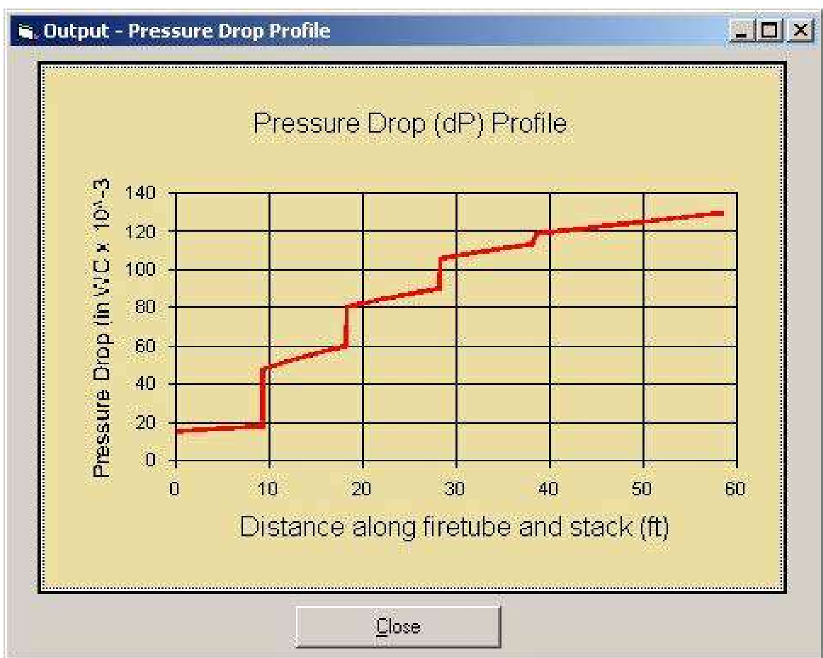

FIGURE 5.12 COEN Fire-Tube Rating Program– Pressure Drop Profile Graph

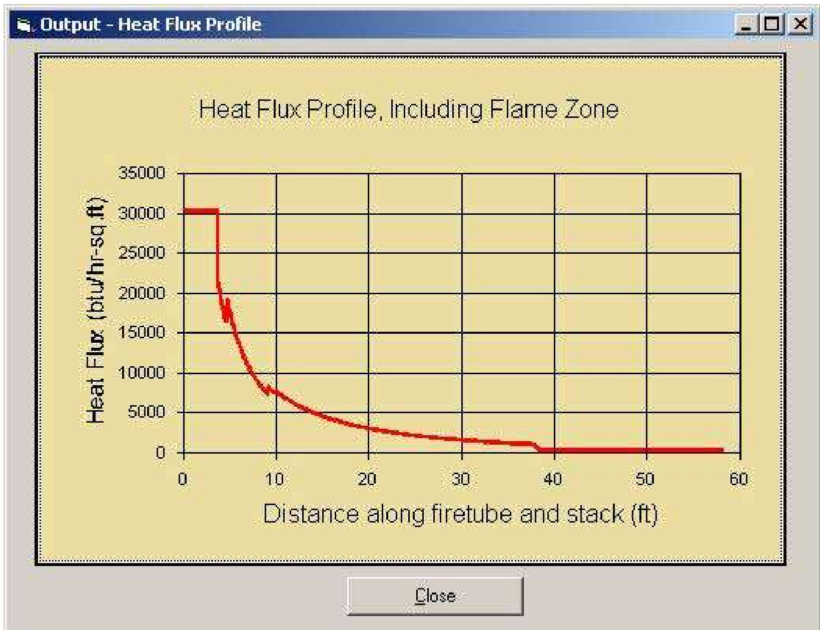

FIGURE 5.13 COEN Fire-Tube Rating Program – Heat Flux Profile Graph

6 FIELD DATA COLLECTION AND ANALYSIS

In order to get a better understanding of the current technology design and performance data from a number of actual field installations of immersion fire-tube heaters were collected

6.1 Heater Field Inspection and Efficiency Evaluation Report

To facilitate the data collection we designed a spreadsheet entitled: "Immersion Heater Field Inspection and Efficiency Evaluation Report."

The format of the report is illustrated in Figures 6.1 through 6.5 below and its goal is to facilitate and standardize data collection and on-the-spot evaluation in the field. A similar report was prepared for

The first page of the report aids in the collection of the following data:

a) Owner information;

b) Manufacturer information;

c) Heater and process information; and,

d) Heater design.

Second page of the report addresses the following topics:

a) Fire tube and stack design;

b) Combustion system design;

c) Fuel gas data; and,

d) Combustion air data.

Third page of the report helps in estimating and recording the following data:

a) Heat loss and thermal energy potential;

b) Field measurements "as found"; and,

c) Thermal efficiency "as found".

Fourth page of the report calculates potential energy savings in the following categories:

a) Sensible heat;

b) Latent heat;

c) Unburned CO; and,

d) Insulation losses

The magnitude of potential savings is expressed both in terms of GJ/A and in $/A based on a specified cost of fuel for GJ. The calculation allows also correction based on measured duty cycle of the heater.

Fifth page of the report shows a summary of:

a) Corrective actions taken;

b) Maintenance recommendations; and,

c) Recommended modifications.

By using the above report in the field not only will the pertinent data of the heater be recorded but also an on-the-spot evaluation possible of possible upgrades or corrective actions.

We have used the report on all the surveyed heaters in order to prioritize their upgrades based on two criteria: worst performance and safety concerns and biggest potential for savings.

IMMERSION HEATER FIELD INSPECTION AND EFFICIENCY EVALUATION REPORT

PTAC

PETROLEUM TECHNOLOGY ALLIANCE CANADA

Design by: ENEFEN Energy Efficiency Engineering Ltd.

00-00-00-00-W5

OWNER INFORMATION	
Name	
Area	
Heater Location (LSD or description)	00-00-00-00-W5
Equipment Tag Number	Salt Bath Heater 102
Altitude [meters A.S.L.]	925
Other Comments	

MANUFACTURER INFORMATION	
Name	Brown & Root
Location	
Model Number	
Serial Number	SS0003
Built MM/YY	1996
CRN Number	4003.2
Project Reference Number(s)	
Other Comments	

HEATER AND PROCESS INFORMATION	
Process Description	Salt Bath Heater
Appliance Type	Natural Draft Immersion Tube Heater
Number of process loads	1
Process Fluid(s)	
Total Process Duty	3.00 MM BTU/hr
Design Thermal Efficiency (HHV)	65%
Maximum Burner Input (HHV)	4.62 MM BTU/hr
Bath Liquid	Salt Bath
Bath Temperatue Setpoint	275.0 deg C
Other Comments	design efficiency assumed as typical

HEATER DESIGN	
Fuel Train location	Enclosed
Control Power	
Valve actuation medium	Sweet fuel gas
Process temperature control	ON/OFF
Bath LO Level switch	YES
Bath HI temp switch	YES
LO fuel gas pressure switch	NO
HI fuel gas pressure switch	NO
Flame detection	YES / Thermocouple
Main fuel automatic shutoff	YES
Pilot fuel automatic shutoff	NO
Burner Management System Model	
B149.3 approval	NO
Other Comments	Thermocouple based flame detection not compliant

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FIGURE 6.1 Immersion Heater Field Inspection And Efficiency Evaluation Report Page 1 of 5

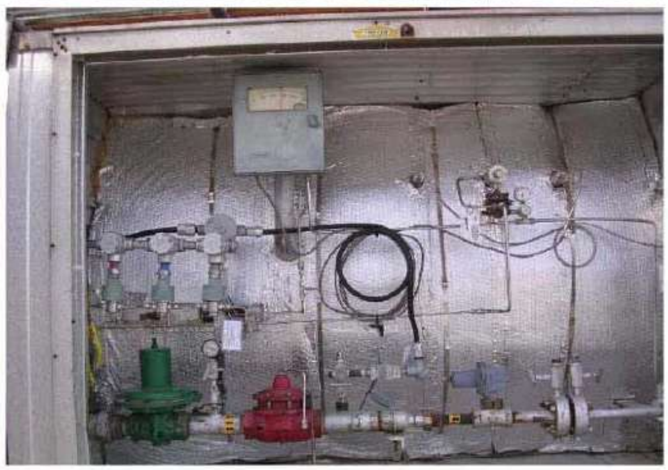
IMMERSION HEATER FIELD INSPECTION AND EFFICIENCY EVALUATION REPORT

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA

00-00-00-00-W5

Design by: ENEFEN Energy Efficiency Engineering Ltd.

FIRE TUBE AND STACK DESIGN	
Fire Tube Circumference	7.92 ft
Fire Tube O.D.	30.2 in
Number of tube passes	2
Tube length (each pass)	34.00 ft
Tube immersed surface area	538.3 ft2
Design Average Heat Flux	5,573 BTU/hr-ft2
Stack Circumference	7.92 ft
Stack O.D.	30.2 in
Stack Height	12.00 ft
Other Comments	tube length measurement based on the outside heater dimension
COMBUSTION SYSTEM DESIGN	
Burner Make	
Burner Size / Model	
Gas Orifice Size	
Gas Adjuster Needle Valve	
Maximum Burner Fuel Pressure	
	0.0 PSIG
Other Comments	
FUEL GAS	
Fuel Type	Sweet Natural Gas
Fuel Higher Heating Value (HHV)	37.71 MJ/Nm3
	1,012 BTU/scf
Maximum fuel flow	129.20 Nm3/hr
	4,561 SCFH
Fuel Inlet Pressure	
	0.0 PSIG
Other Comments	fuel flow back calculated from performance
COMBUSTION AIR	
Ambient temperature	22.7 deg C
Theoretical Excess Air	15.0%
Theoretical Excess Oxygen in the Stack (dry basis)	3.0%
Combustion Air Flow	783 SCFM
Other Comments	burner oversized running too lean



Page 2 of 5

FIGURE 6.2 Immersion Heater Field Inspection And Efficiency Evaluation Report Page 2 of 5

IMMERSION HEATER FIELD INSPECTION AND EFFICIENCY EVALUATION REPORT

00-00-00-00-W5

PTAC

PETROLEUM TECHNOLOGY ALLIANCE CANADA

Design by: ENEFEN Energy Efficiency Engineering Ltd.

HEAT LOSS AND THERMAL EFFICIENCY POTENTIAL	
Theoretical Stack Bottom Temperature	425.0 deg C
Thoretical Sensible Energy Loss Through Stack (HHV)	14.96%
Theoretical Latent Energy Loss Through Stack (HHV)	9.00%
Theoretical Energy Lost Through Insulation (HHV) (assumed)	5.00%
Total Energy Lost (HHV)	28.96%
Theoretical Obtainable Thermal Efficiency (HHV)	71.0%
Other Comments	Calculation based on 150 deg C stack bottom to bath approach temperature
FIELD MEASUREMENTS "AS FOUND"	
Measured Stack Bottom Temperature	379.0 deg C
Measured Excess Oxygen is Stack (V/V Dry)	9.0%
Measured CO in Stack	4 ppm
Measured NOx in Stack	34 ppm
Measured Combustion Efficiency	67.2%
Fuel flow	
	0 SCFH
Firing Rate (HHV)	0.00 MM BTU/hr
Burner ON Time	10.0 minutes
Burner OFF Time	10.0 minutes
Heater Duty Cycle	50.0%
Other Comments	Fuel flow and duty cycle not measured
THERMAL EFFICIENCY "AS FOUND"	
Calculated Excess Air	67.4%
Sensible Energy Stack Flue Gas Loss (HHV)	20.61%
Latent Energy Loss Through Stack (HHV)	9.00%
Energy Lost Through Unburned CO (HHV)	0.00%
Energy Lost Through Insulation (HHV) (assumed)	5.00%
Total Energy Lost (HHV)	34.61%
Calculated Thermal Efficiency (HHV)	65.4%
Other Comments	

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FIGURE 6.3 Immersion Heater Field Inspection And Efficiency Evaluation Report Page 3 of 5

IMMERSION HEATER FIELD INSPECTION AND EFFICIENCY EVALUATION REPORT

00-00-00-00-W5

PTAC

PETROLEUM TECHNOLOGY ALLIANCE CANADA

Design by: ENEFEN Energy Efficiency Engineering Ltd.

POTENTIAL EFFICIENCY SAVINGS			
Fuel Cost $/GJ HHV	6.0 $/GJ		
Sensible Energy Savings	0.31 MM BTU/hr	0.33 GJ/hr	17,381 $/A
Latent Energy Savings	0.03 MM BTU/hr	0.03 GJ/hr	1,819 $/A
Unburned CO Savings	0.00 MM BTU/hr	0.00 GJ/hr	3 $/A
Insulation loss savings	0.02 MM BTU/hr	0.02 GJ/hr	1,011 $/A
Total Energy Savings (HHV)	0.36 MM BTU/hr	0.38 GJ/hr	20,214 $/A
100% Duty Cycle	3,193 MM BTU/A	3,369.04 GJ/A	20,214 $/A
Measured Duty Cycle	1,597 MM BTU/A	1,684.52 GJ/A	10,107 $/A
Other Comments	Burner is oversized and set to run too lean. Some improvement potential if duty cycle is low.		

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FIGURE 6.4 Immersion Heater Field Inspection And Efficiency Evaluation Report Page 4 of 5

IMMERSION HEATER FIELD INSPECTION AND EFFICIENCY EVALUATION REPORT

PTAC

PETROLEUM TECHNOLOGY ALLIANCE CANADA

00-00-00-00-W5

Design by: ENEFEN Energy Efficiency Engineering Ltd

CORRECTIVE ACTION TAKEN		COMMENTS
	Burner pressure changed	
	Primary air flow adjusted	
	Burner gas needle valve position adjusted	
	Burner gas orifice changed	
	Burner size changed	
	Flame cells cleaned	
	Secondary air flow adjusted	

MAINTENANCE RECOMMENDATIONS

X	Measure heater duty cycle and if less than 100%, decrease the burner firing rate in order to decrease stack temperature
X	Reduce burner firing rate (smaller orifice or smaller burner size) in order to extend burner duty cycle
X	Tune up burner on a regular basis
	Clean fire tube and stack
	Clean flame cell(s)
	Service fuel train

RECOMMENDED MODIFICATIONS

X	Install fuel meter
	Install flame detection
X	Install main fuel automatic shutoff
X	Install pilot fuel automatic shutoff
X	Install certified Burner Management System using flame rod detection (thermocouple based flame detection is not approvable)
	Insulate stack
	Insulate heater body
X	Install secondary air adjustable control
X	Increase stack height
	Modify fire tube
	Recertify the heater after alteration or relocation

Page 5 of 5

FIGURE 6.5 Immersion Heater Field Inspection And Efficiency Evaluation Report Page 5 of 5

6.2 Scope and Objectives of Heater Survey

We have surveyed in the field 43 heaters and collected detailed information regarding their design, condition, and performance. The collected data is too voluminous to include in this report (over 300 pages) and the small details of individual installations are outside of the scope of this project. In collecting this data we had however, the following objectives in mind:

a) Develop the data collection method (Heater Field Inspection and Efficiency Evaluation Report);

b) Test the data collection method on a number of heater installations;

c) Learn more about the trends in heater performance, average condition, efficiency, etc;

d) Identify common problems with heaters and reasons for low heater efficiency;

e) Develop and test simple methods of efficiency improvements; and,

f) Test larger-scale (multiple installations) data collection, recording, and heater evaluation process.

Hence, the emphasis of this work was more on identifying the trends with low heater efficiencies and on development of methodology to deal with these trends than on repairing individual heaters.

6.3 Photo Gallery of Surveyed Heaters

To demonstrate the scope of work conducted in this part of the project we have included a photo gallery of 43 surveyed heaters (Figures 6.6 through 6.10).

6.4 Surveyed Heaters Data Summaries

Data collected in individual heater surveys was assembled into data summaries shown in Figures 6.11 through 6.15. The basic structure and content of the summaries is similar to the individual reports, except, having multiple heaters data listed side by side allows observation of trends and establishing of priorities.

Summaries are organized by geographical/operational areas in order to simplify asset management / maintenance within the plant. The surveyed heaters were used for the following applications:

a) Well site gas heater;

b) Line gas heater;

c) Glycol heating medium heater;

d) Diesel oil hot string medium heater;

e) Amine reboiler;

f) Salt bath regen gas heater; and,

g) Salt bath amine reboiler;

In addition, we included in our analysis and research selected data from approximately 60 other installations involving the following immersion fire-tube heater applications:

a) Oil treater;

b) Conversion of oil treater from natural draft to forced draft;

c) Oil storage tank; and,

d) Dehy TEG reboiler.

This wide crossection of application allowed us to draw generalized conclusions about fire-tube efficiencies and potential areas for their improvement.

FIGURE 6.6 Photo Gallery "A" of Surveyed Heaters

FIGURE 6.7 Photo Gallery “B” of Surveyed Heaters

FIGURE 6.8 Photo Gallery “C” of Surveyed Heaters

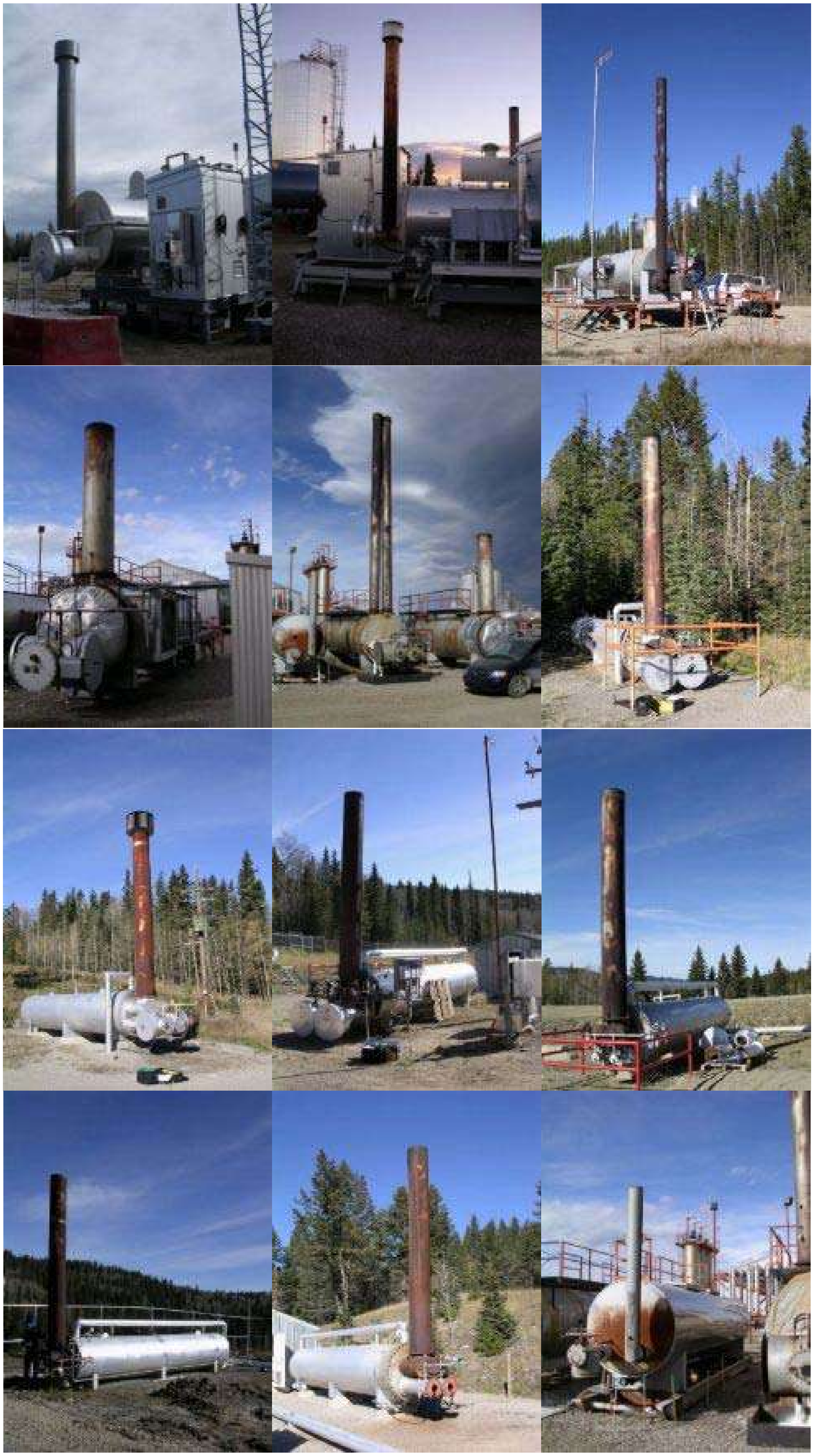
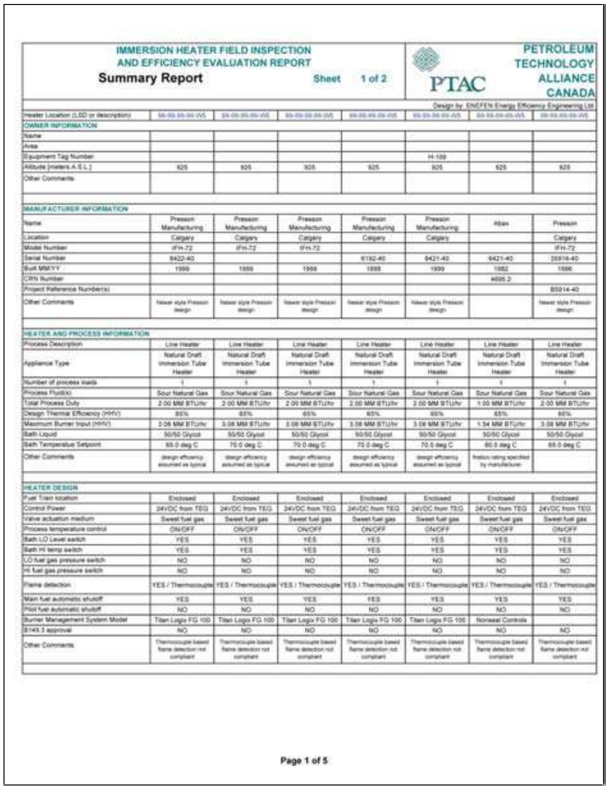


FIGURE 6.9 Photo Gallery "D" of Surveyed Heaters

FIGURE 6.10 Photo Gallery “E” of Surveyed Heaters



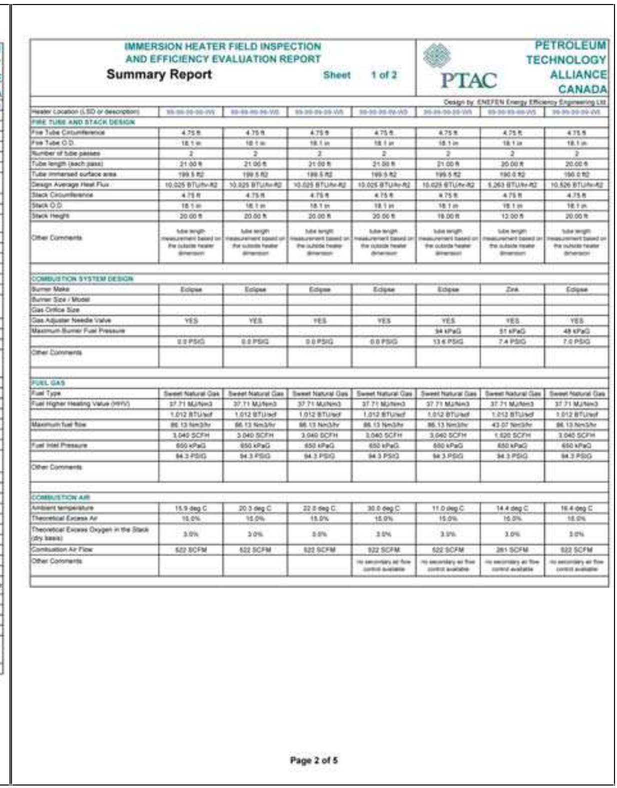
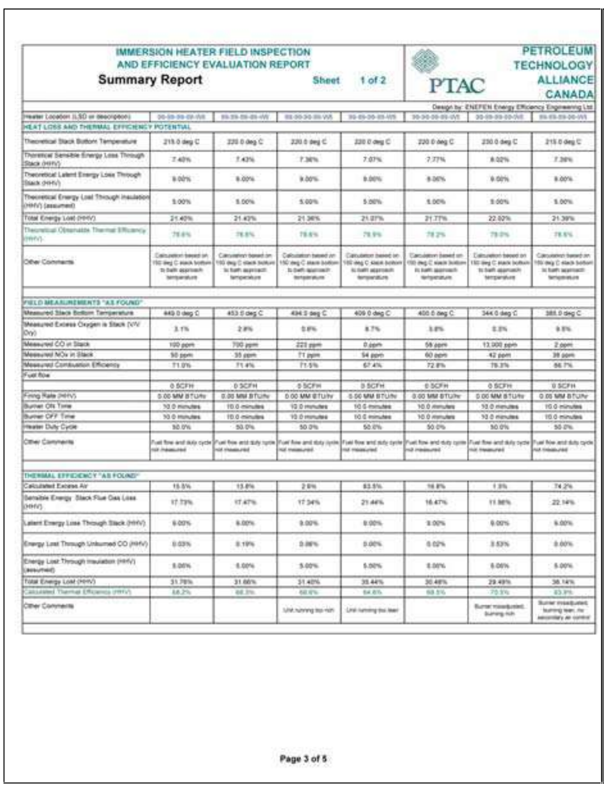


FIGURE 6.11/6.12 Heater Field Inspection and Efficiency Evaluation Summary Report – P 1/2 of 5



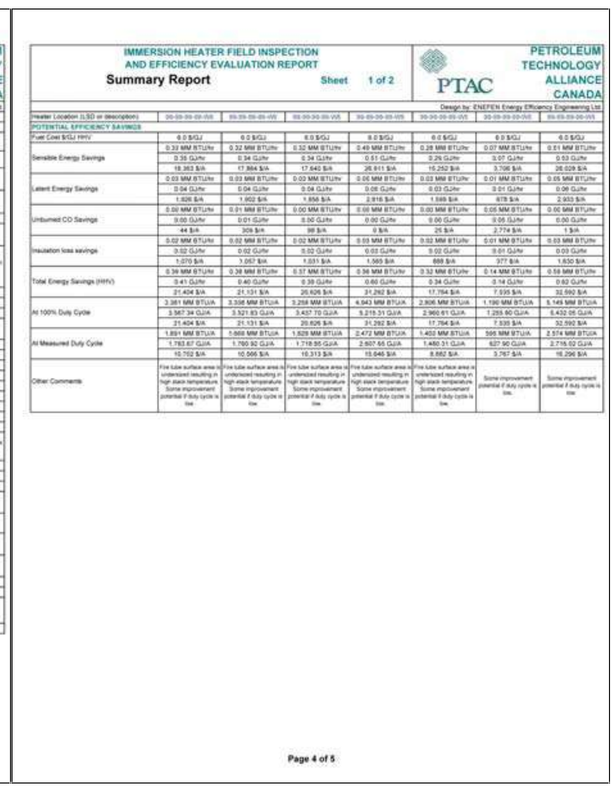
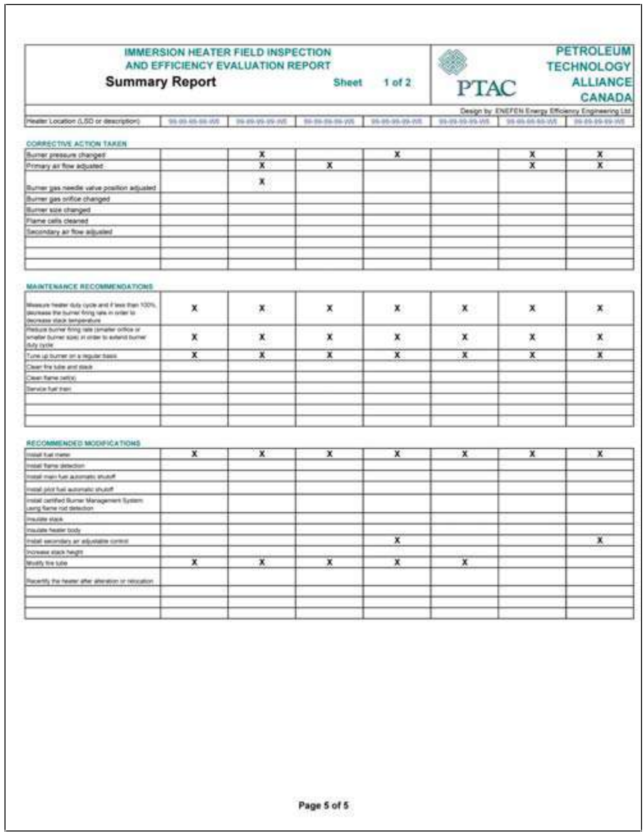


FIGURE 6.13/6.14 Heater Field Inspection and Efficiency Evaluation Summary Report - P 3/4 of 5



IMMERSION HEATER FIELD INSPECTION AND EFFICIENCY EVALUATION REPORT

Summary Report Sheet 1 of 2

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA

Design by: ENEFEN Energy Efficiency Engineering Ltd

Heater Location (LSD or description)	99-99-99-99-W5	99-99-99-99-W5	99-99-99-99-W5	99-99-99-99-W5	99-99-99-99-W5	99-99-99-99-W5	99-99-99-99-W5
CORRECTIVE ACTION TAKEN							
Burner pressure changed		X		X		X	X
Primary air flow adjusted		X	X			X	X
Burner gas needle valve position adjusted		X					
Burner gas orifice changed							
Burner size changed							
Flame cells cleaned							
Secondary air flow adjusted							
MAINTENANCE RECOMMENDATIONS							
Measure heater duty cycle and if less than 100%, decrease the burner firing rate in order to decrease stack temperature	X	X	X	X	X	X	X
Reduce burner firing rate (smaller orifice or smaller burner size) in order to extend burner duty cycle	X	X	X	X	X	X	X
Tune up burner on a regular basis	X	X	X	X	X	X	X
Clean fire tube and stack							
Clean flame cell(s)							
Service fuel train							
RECOMMENDED MODIFICATIONS							
Install fuel meter	X	X	X	X	X	X	X
Install flame detection							
Install main fuel automatic shutoff							
Install pilot fuel automatic shutoff							
Install certified Burner Management System using flame rod detection							
Insulate stack							
Insulate heater body							
Install secondary air adjustable control				X			X
Increase stack height							
Modify fire tube	X	X	X	X	X		
Recertify the heater after alteration or relocation							

Page 5 of 5

FIGURE 6.15 Heater Field Inspection and Efficiency Evaluation Summary Report - P 5 of 5

6.5 Summary Synopsis

- The data from 43 surveyed heaters (45 fire tubes) was summarized. The results were then graphically analyzed (Figure 6.16 through 6.19) for trends and distribution patterns. The following paragraphs are the result of this analysis:

a) Figure 6.16 illustrates the distribution of rated capacities of surveyed heaters:
- between 0.5 to 4.5 MM BTU/hr. At nominal rated efficiency of 65%, these heaters were designed to fire between .7 and 6.9 MM BTU/hr;
- 44% of heaters rated at between 1.5 and 2 MM BTU/hr;
- 20% of heaters rated at less than 1 MM BTU/hr;
- 22% heaters rated above 2 MM BTU/hr;
- Maximum single fire tube rating: 4.5 MM BTU/hr;
Although this capacity distribution does not represent the overall industry cross-section, it covers most of the range of heater sizes discussed in this study;

b) Figure 6.17 illustrates the distribution of stack bottom temperatures in surveyed heaters:
- between 180 deg C and 530 deg C;
- curve shows a relatively even distribution of results, indicating that the stack bottom temperature is a rather random result of heater setup rather than a pre-engineered operating parameter;
- 62% of heaters operated above the maximum target temperature of 350 deg C most likely due to inadequate surface area;
- none of the heaters operated below the minimum target of 150 deg C i.e. significantly above the dew point temperature of 60 deg C (139 deg F);
- average measured stack bottom temperature was 366 deg C

c) Figure 6.18 illustrates the distribution of stack excess O_2 levels in surveyed heaters:
- between 0% and 13% stack O_2;
- only 20% of heaters running within the target excess O_2 range between 2% and 3.5%;

- 49% of heaters running with excessive O_2;
- 31% of heaters running with inadequate excess air;
- the data does not show 8 heaters which were found firing substoichiometrically and were re-adjusted during survey but prior to recording the data;
- average excess O_2 was 4.5%

d) Figure 6.19 illustrates the distribution of gross HHV efficiencies of surveyed heaters:
- between 64 % and 82% HHV;
- uniform result distribution indicate that the efficiency is a random result of the system setup rather than pre-designed and maintained value;
- 51% of heaters operated below the minimum efficiency target of 72%;
- disregarding a few really misadjusted units none of the heaters run below the 64%HHV efficiency;
- **- average thermal efficiency was 72.3%HHV.**

6.6 Final Conclusions from Field Tests

Following were the final conclusions from the field tests of 43 heaters (45 fire-tubes):

a) The range of heater sizes (between 0.4 and 4.5 MM BTU/hr rating), their number (43), and variety of process application provided a valid cross-section of data for analysis in this study;

b) 8 heaters had very high stack CO in excess of 2%+ and were running substoichiometrically. Simply burner adjustment during survey was sufficient to reduce these CO levels to acceptable limits below 400 ppm;

c) thermal efficiency of all heaters was between 64% and 82% with average 72.3%, thus confirming validity of our theoretical target efficiency range between 72% and 82%. **No** really low efficiency examples (down to 30%) were found; average thermal efficiency of all heaters was 72.3%.

d) over half of all heaters were running below the 72% minimum target, thus providing good potential for improvement;

e) 62% of the heaters were running with stack bottom temperature above 350 deg C target, indicating most likely inadequately sized fire tube;

f) None of the heaters measured was found running close to the dew point temperature;

g) Almost half of all heaters were found running with excessive air levels, and 30% were running with inadequate air levels. Only 20% of heaters were set to the optimum stack O_2 levels between 2% and 3.5%

h) Flame cells were plugged up on 3 heaters;

i) Burner was misadjusted on 16 heaters;

j) Burner was overfiring on 5 heaters;

k) Fire tubes needs cleaning on 6 heaters;

l) Heater was grossly oversized on 3 heaters; and,

m) No flame detection on 14 heaters.

Field testing phase of this project, and the collected data, confirmed the validity of heater efficiency range target of **between 72% and 82%**, and the stack bottom temperature range between **150 and 350 deg C**. All heaters running with high CO were easily readjusted during the survey to provide reasonable combustion data with at least 64% HHV efficiency. There is a definite room for further improvement to operate heaters closer to the 82% optimum efficiency point. At the same time there were no heaters found running at really low efficiencies as claimed in some of the references.

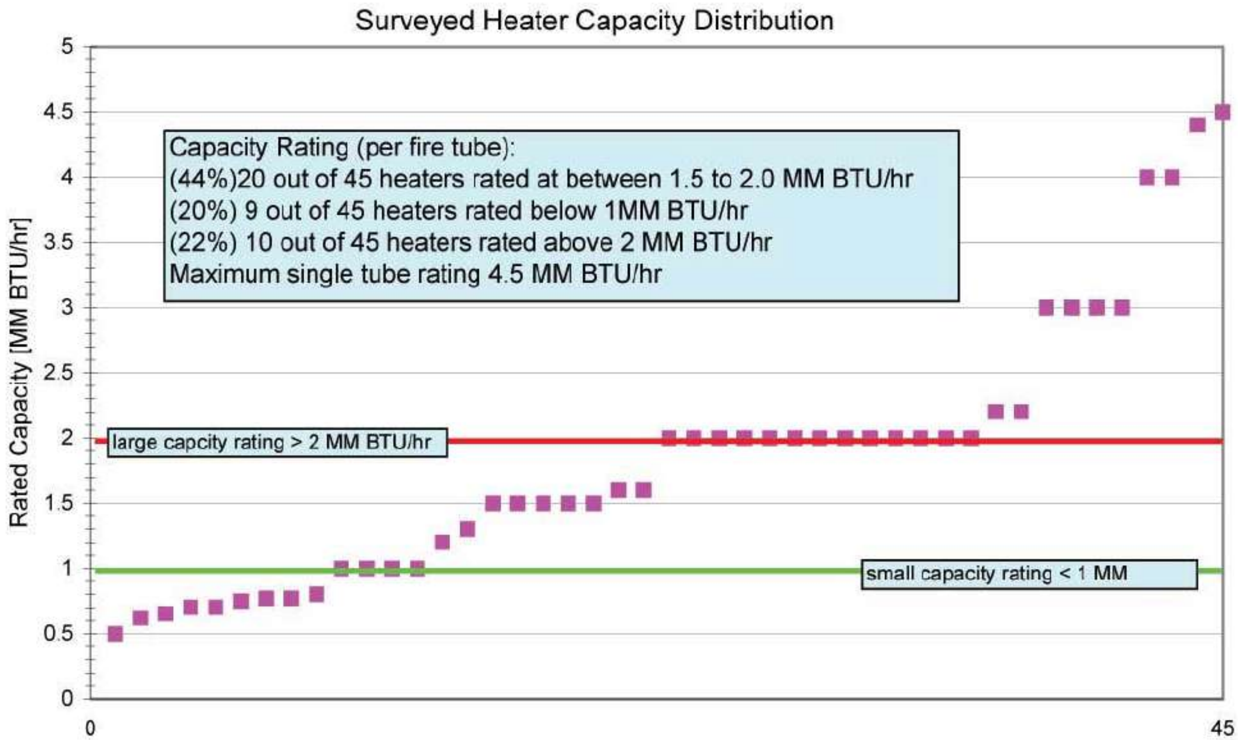


FIGURE 6.16 Surveyed Heater Rated Capacity Distribution

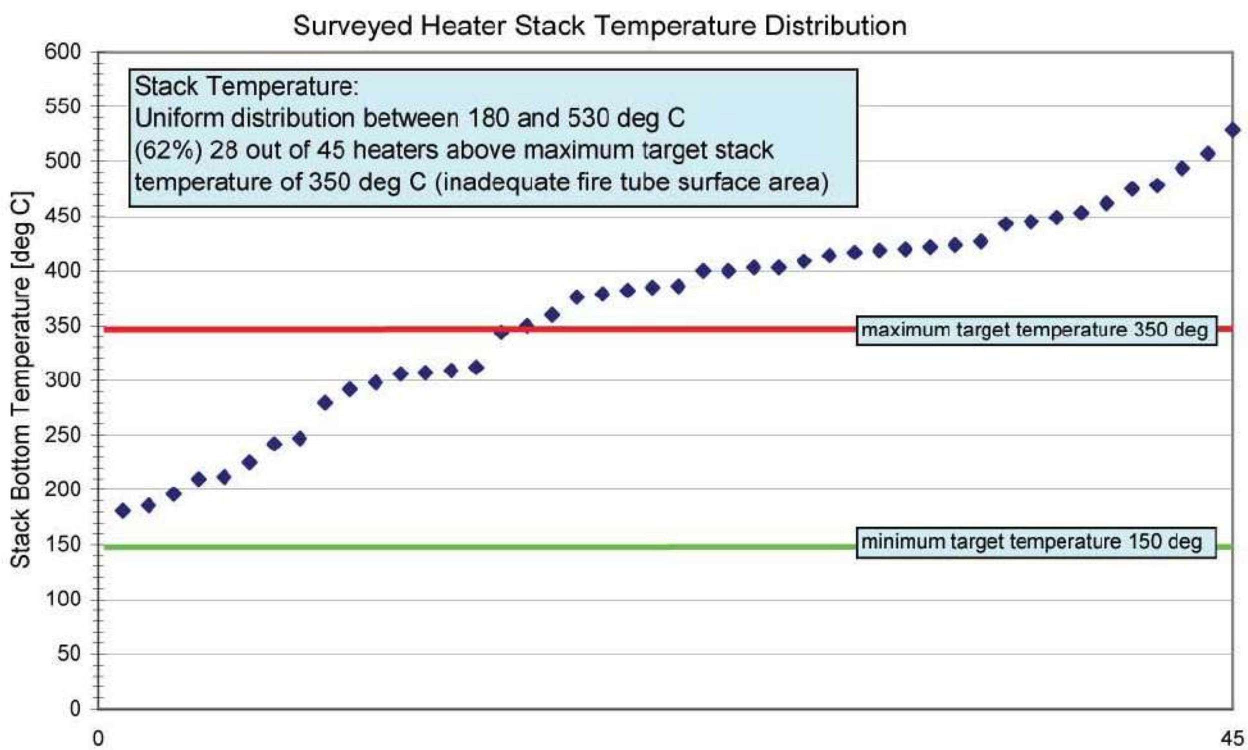


FIGURE 6.17 Surveyed Heater Stack Temperature Distribution

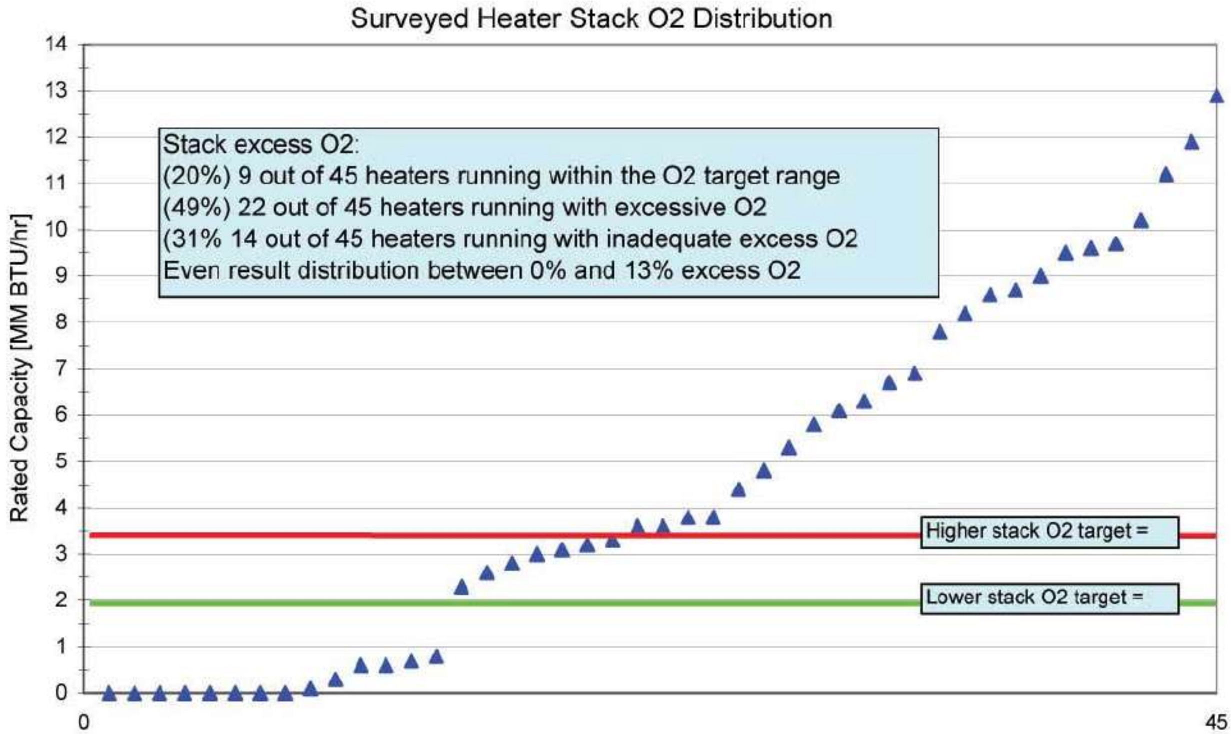


FIGURE 6.18 Surveyed Heater Stack Excess O2 Distribution

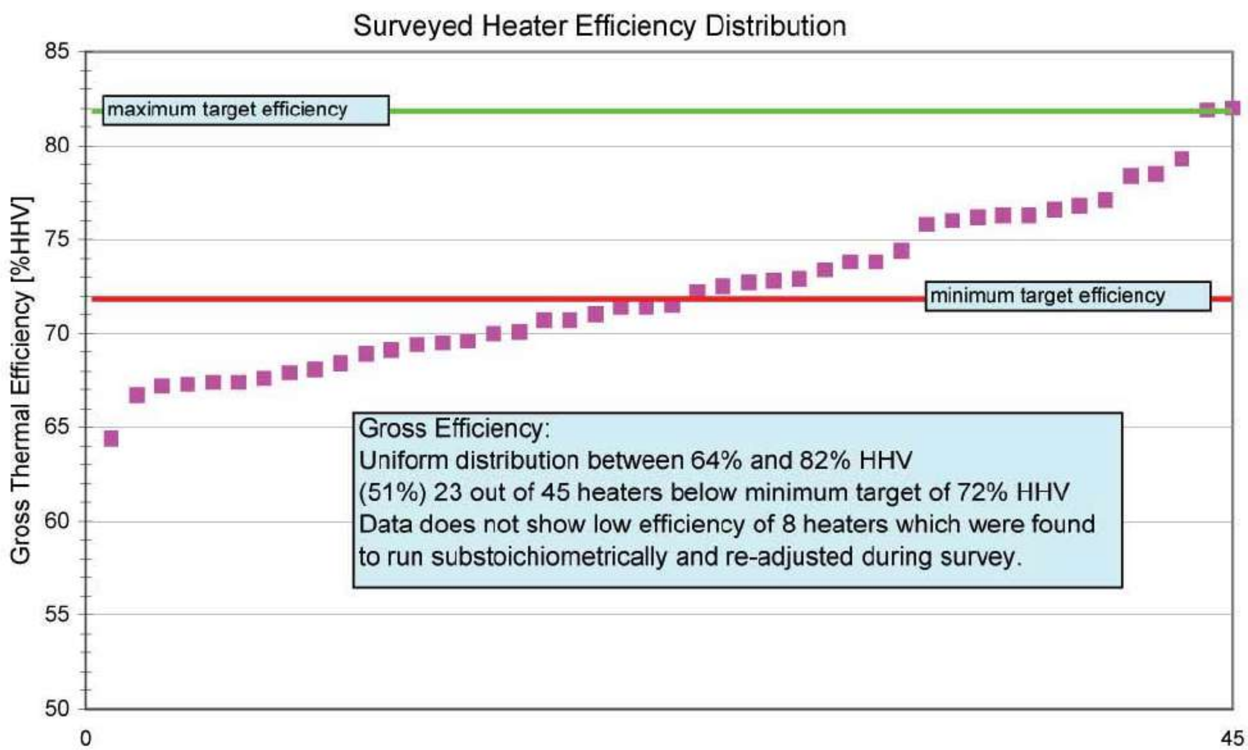


FIGURE 6.19 Surveyed Heater Gross Efficiency Distribution

7 TEST UNIT DESIGN AND CONSTRUCTION

In order to test and calibrate Coen program and also obtain further insights into the operation and behavior of immersion fire tube heaters we conducted laboratory tests in field environment. Although this term sounds like a contradiction of terms, this unique opportunity was made possible by a partnership with the Petroleum Industry Training Service (PITS) Training Centre in Nisku, AB. (Figure 7.1)

7.1 Test Facilities at PITS

For readers unfamiliar with PITS activities, following is a brief overview:

a) Training arm of the Canadian petroleum industry

b) Owned, directed and partially funded by six petroleum associations

c) Non-profit

d) Internationally recognized for high quality training in petroleum technologies

e) Over 8000 students trained per year

f) Owns fully operational and instrumented training and testing facility in Nisku

g) Mandate to identify training needs, develop and offer training, provide advice and guidance and help establish standards

h) PITS mandate is: TRAINING – TESTING –STANDARDS DEVELOPMENT in technology areas related to the Alberta oil & gas Industry operations.

To fulfill this need PITS training facility in Nisku includes besides classrooms a truly fascinating fully functional petroleum “mini” plant including drilling rigs, well control centre, compression and gas processing facility (Figure 7.2), and, oil facility (Figure 7.3). The equipment used in these facilities is real petroleum equipment, which has been either donated to PITS by the industry or acquired from decommissioned plants. For space reasons and process load restrictions the capacities of individual equipment are small, however the equipment is fully functional and part of the training offered by PITS includes its actual hands-on operation. For safety reasons the training centre does not use sour gas or any other processes containing possibly lethal chemicals. Fore example: fuel gas used for training purposes is sweet sales gas and oil processing facility stores oil in tanks, mixes it with water and nitrogen to produce oil/water emulsion. The mixing process is precisely controlled by the DCS and any specific oil/water ratio can be simulated. The emulsion is the processed through a treater where oil and water are separated and returned back to the storage tanks.

FIGURE 7.1 Petroleum Industry Training Service in Nisku

The entire training facility is fully instrumented with latest technology sensors and controlled by OPTO DCS (distributed control system) (Figure 7.8). Not only can the process by demonstrated and operated by the students, but also upset and failure conditions can be safely simulated. Such is for example the purpose of the well control facility, which is regularly used to deliver the well blow-up prevention training program.

FIGURE 7.2 PITS Gas Facility

FIGURE 7.3 PITS Drilling Rig and Oil Facility

FIGURE 7.4 PITS amine reboiler in Gas Processing Facility

FIGURE 7.5 PITS Line Heater at the Sweet Gas Let Down Station

FIGURE 7.6 PITS oil treater controls in the Oil Processing Facility

FIGURE 7.7 PITS Heater controls and the Gas Processing Facility

FIGURE 7.8 PITS DCS interface panel in the Gas Processing Facility

FIGURE 7.9 PITS horizontal oil treater and site to immersion fire-tube test unit at the Oil Processing Facility

7.2 Test Objectives

Thanks to the courtesy of PITS and with their tremendous support we were able to build the prototype of a fully instrumented multipass immersion fire-tube heater and test it for a period of 1 month with various burners fluids and at various operational conditions.

To start this process we identified the following objectives:

a) Build test stand

b) Install instrumentation

c) Configure data collection hardware

d) Procure burners for tests (9 burners planned – 25 burners received)

e) Burner stand test (flame shape, noise, primary air, stack data, temperature profile)

f) Test first with water, then glycol, and oil (Specific Gravity SG=0.88, Specific Heat cp=0.4365)

g) Test 2, 3, 4 pass configuration

h) Test turbulator effectiveness

7.3 Test Unit Configuration

Various configurations of the test unit were considered (Figure 7.10), and a decision was made to proceed with configuration E (Figure 7.11), which incorporated 8" diameter first pass, 6" dia second, third and fourth pass, configurable elbows to change number of passes from between 2, 3, and 4, and 2x10'section stack which could be configured for either 10' or 20' operation.

Figure 7.12 shows the unit P&ID, Figure 7.13 Bill of Materials – Mechanical, and Figure 7.14 Bill of Materials – Instrumentation.

A photo gallery of the test unit and its construction and instrumentation details follows these figures.

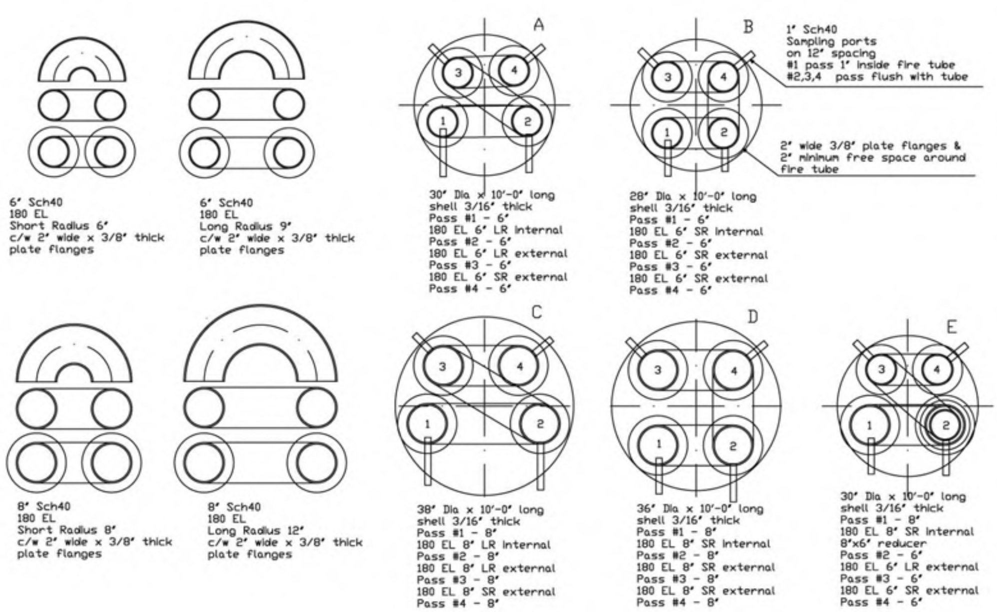


FIGURE 7.10 Various prototype configurations considered

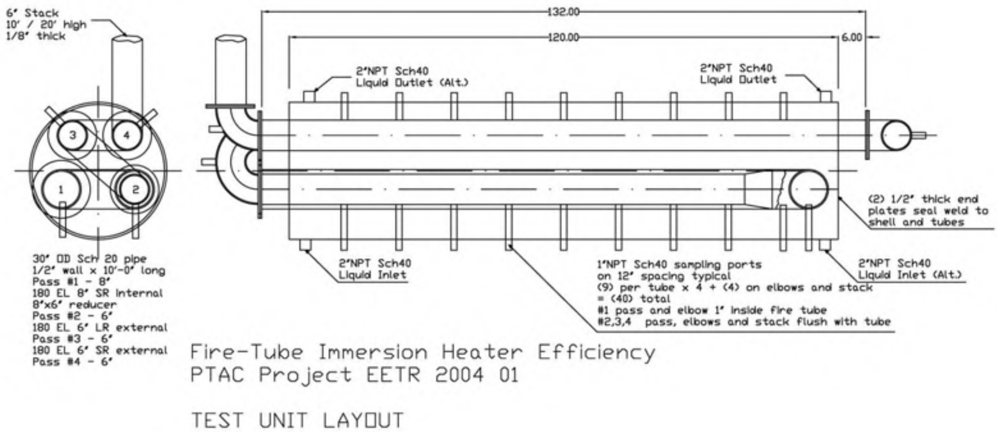


FIGURE 7.11 Final test unit configuration E, which was implemented

7.4 Test Unit P&ID

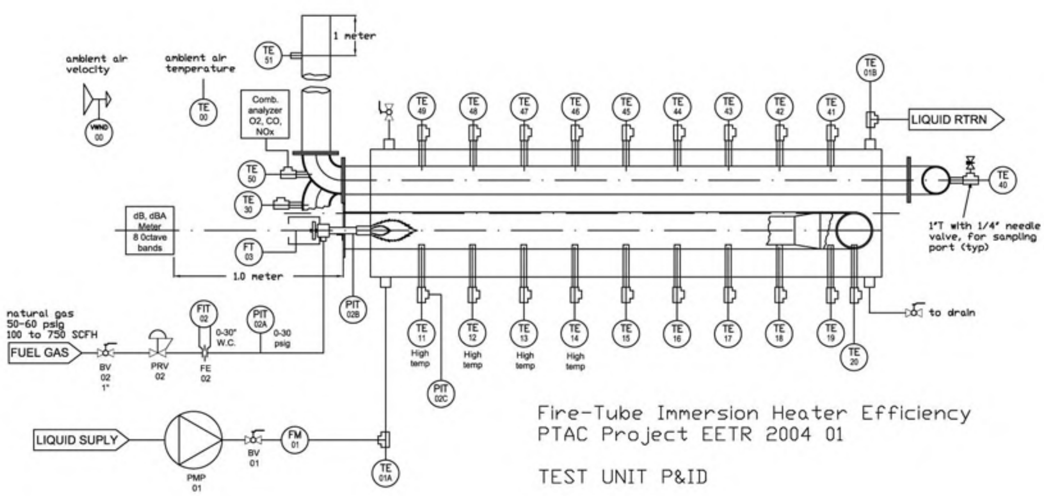


FIGURE 7.12 Test Unit P&ID

7.5 Test Unit Bill of Materials (BOM)

Fire-Tube Immersion Heater Efficiency
PTAC Project EETR 2004 01

BILL OF MATERIALS		Rev 2	3-Mar-04
TAG#	NAME	Qty	DESCRIPTION
HEATER - MECHANICAL			
N/A	Shell	1	30"OD, 1/2" wall Sch20 pipe x 120" long
N/A	End plates	2	29"OD, 1/2" thick plate
N/A	8" plate flange	1	1/2" plate x 12.625 OD
N/A	1st pass tube	1	8" Sch40 pipe 0.322" wall x 112" long
N/A	1st elbow	1	8" Sch40 x 180 EL Short Radius
N/A	Reducer	1	8"x6" Sch40 concentric reducer
N/A	2nd pass tube	1	6" Sch40 pipe 0.280" wall x 106" long
N/A	6" plate flanges	12	1/2" plate x 10.625 OD
N/A	2nd elbow	1	6" Sch40 x 180 EL Long Radius
N/A	3rd and 4th tube pass	2	6" Sch40 pipe 0.280" wall x 132" long
N/A	3rd elbow	1	6" Sch40 x 180 EL Short Radius
N/A	Stack elbow	1	6" Sch40 x 90 EL Short Radius
N/A	Stack	2	6"OD x 1/8" wall tube x 10' long (each)
N/A	Liquid connections	4	2" half-couplings
N/A	Liquid valves	4	2" NPT ball valves
N/A	Sampling ports (bottom tubes)	19	1"NPT Sch40 pipe 8" long,
N/A	Sampling ports (top tubes), 2-nd and 3rd elbow, stack elbow	21	1"NPT Sch40 pipe 4" long,
N/A	Sampling Couplings	40	1"NPT Coupling
	Labour to fabricate burner mount	1	
	Labour to assemble piping	1	
	Fabrication	1	Fabricate unit
	Painting	1	Painting

FIGURE 7.13 Test Unit BOM - Mechanical

Fire-Tube Immersion Heater Efficiency
PTAC Project EETR 2004 01

BILL OF MATERIALS		Rev 2	3-Mar-04
TAG#	NAME	Qty	DESCRIPTION

INSTRUMENTATION			
PMP01	Liquid pump	1	Existing
FM01	Liquid flow meter	1	Floco 2" c/w pulse transmitter
TE01A, TE01B, TE00, TE51	Liquid inlet/outlet, ambient air TC, stack top temperature	4	Type K (-331 to 2510 deg F) Inconel sheath, 11" long, 3/4"NPT compression fitting for adjustable insertion length
TE11-14	1st Pass tube flame zone high temperature thermocouples	4	Type S (32-3218 deg F) Inconel sheath, 19" long, 3/4"NPT compression fitting for adjustable insertion length with 10' connecting cable
TE15-20	1st Pass tube (lower temperature) and 1st elbow thermocouples	6	Type K (-331 to 2510 deg F) Inconel sheath, 19" long, 3/4"NPT compression fitting for adjustable insertion length with 10' connecting cable
TE21 - 29	2nd Pass tube thermocouples	9	Type K (-331 to 2510 deg F) Inconel sheath, 19" long, 3/4"NPT compression fitting for adjustable insertion length with 10' connecting cable
TE30-50	2nd and 3rd elbow, 3rd and 4th tube pass, and stack thermocouple	21	Type K (-331 to 2510 deg F) Inconel sheath, 11" long, 3/4"NPT compression fitting for adjustable insertion length with 10' connecting cable
BV02	Gas shutoff ball valve	3	1" ball valve
PRV02	Gas pressure regulator	1	Fisher 627
FE02	Gas flow orifice	3	1" orifice flanges, c/w orifice plate ???? Bore (various sizes TBA)
FIT02	Fuel flow indicating transmitter	1	Rosemount Multivariable Flow transmitter
PIT02A	Burner gas pressure	2	Pressure transmitter 0-60 PSIG
PIT0B	Burner mixture pressure	1	DP 0-50" WC (Rosemount)
PIT02C	Tube draft transmitter	1	DP -3 to +3 "WC (Rosemount)
FT03	Primary air flow transmitter	1	Air flow transmitter with pilot tube
dBM	dB, dBA meter, 8 octave	1	
CMBA	Combustion analyzer	1	TESTO - existing
VWND	Wind velocity meter	1	
N/A	Primary air flow isolation tube	??	To fit individual burners
PSV03	Liquid side pressure safety valve	1	Set at 15 PSIG max shell test pressure
IGNX	Ignition transformer	1	Part of BMS system
IGN	spark plug, flame rod, pilot assembly	1	Profire
BMS1	Burner Management System	1	Profire
BMS2	Burner Management System	1	ACL500
	Labour to design instrumentation	1	
	Labour to install instruments	1	
	Labour to connect instruments	1	
	Misc Wiring components	1	

FIGURE 7.14 Test Unit BOM - Instrumentation

Fire-Tube Immersion Heater Efficiency
PTAC Project EETR 2004 01

BILL OF MATERIALS		Rev 2	3-Mar-04
TAG#	NAME	Qty	DESCRIPTION
DCS Control System Componenets			
	Controller	1	OPTO22 LCM4
	Ethernet Interface	1	OPTO22MSENET-100
	Ethernet Brain	2	OTPO22 B3000 Enet Brain
	Rack	2	OTPO22 SNAP 16 channel Rack
	5 VDC Power Supply	1	OPTO22 PS5
	24 VDC Power Supply	1	OMRON 50 Watt
	Eithernet Switch	1	Dlink 8 port
	Temperature Modules	24	OPTO22 AITM-4
	Discrete Input Modules	1	OPTO22 SNAP IDC5
	Descrete Output Modules	1	OPTO22 SNAP ODC5
	Analogue Input Modules	1	OPTO22 SNAP IAMA-4
	Analogue Output Modules	1	OPTO22 SNAP AOMA-2
	Misc Wiring components	1	Cat 5, 110 VAC outlet, Strain reliefs, etc
PNL	Data acquisition panel	1	NEMA 12 panel
	Single board PC	1	
	Touch Screen Control Station	1	Dolch 19" Div 2
	Labour to design DCS	1	
	Labour to design instrumentation		
	Labour to assemble DCS Panel		
PNL	Labour to program controls	1	

FIGURE 7.15 Test Unit BOM – DCS Control System Components

Fire-Tube Immersion Heater Efficiency
PTAC Project EETR 2004 01

BILL OF MATERIALS		Rev 2	3-Mar-04
TAG#	NAME	Qty	DESCRIPTION
BURNERS (various makes)			
BRNR-01	Main Burner Assembly	1	Maxon
BRNR-02	Main Burner Assembly	1	Maxon
BRNR-03	Main Burner Assembly	1	Maxon
BRNR-04	Main Burner Assembly	1	Hauck
BRNR-05	Main Burner Assembly	1	North American
BRNR-06	Main Burner Assembly	1	Pyronics
BRNR-07	Main Burner Assembly	1	Pyronics
BRNR-08	Main Burner Assembly	1	Pyronics
BRNR-09	Main Burner Assembly	1	Pyronics
BRNR-10	Main Burner Assembly	1	Eclipse
BRNR-11	Main Burner Assembly	1	ACL
BRNR-12	Main Burner Assembly	1	A-Fire
BRNR-13	Main Burner Assembly	1	Pro-Fire
BRNR-14	Main Burner Assembly	1	Kenilworth
BRNR-15	Main Burner Assembly	1	MCI
BRNR-16	Main Burner Assembly	1	MCI

FIGURE 7.16 Test Unit BOM – Burners

7.6 Test Unit Construction

FIGURE 7.17 Test unit shell under construction (return end)

FIGURE 7.18 Test unit shell under construction (burner end)

7.7 Test Unit Installation at the PITS Oil Facility

FIGURE 7.19 Finished test unit installed outside of the PITS Oil Facility

7.8 Test Unit Instrumentation Details

FIGURE 7.20 High Temperature S-type thermocouples in the 1st pass

FIGURE 7.21 K-type thermocouples in 2^{nd}, 3^{rd} and 4^{th} pass

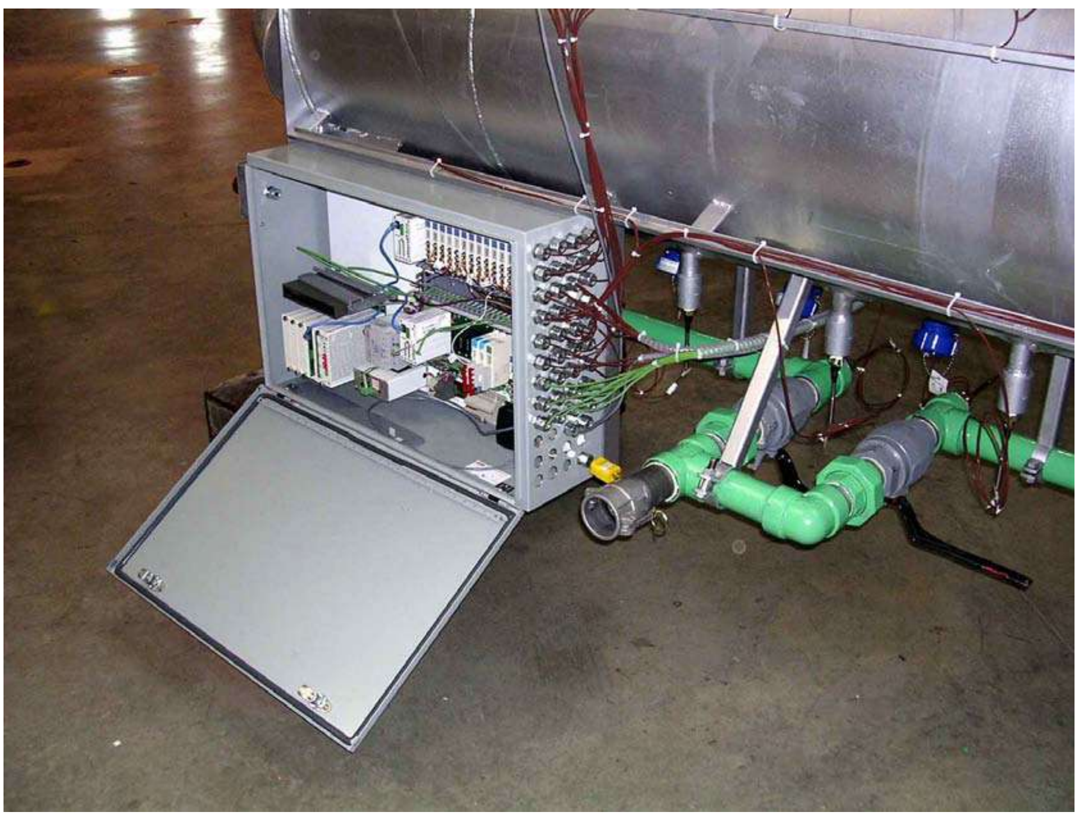


FIGURE 7.22 Wired control panel and liquid inlet

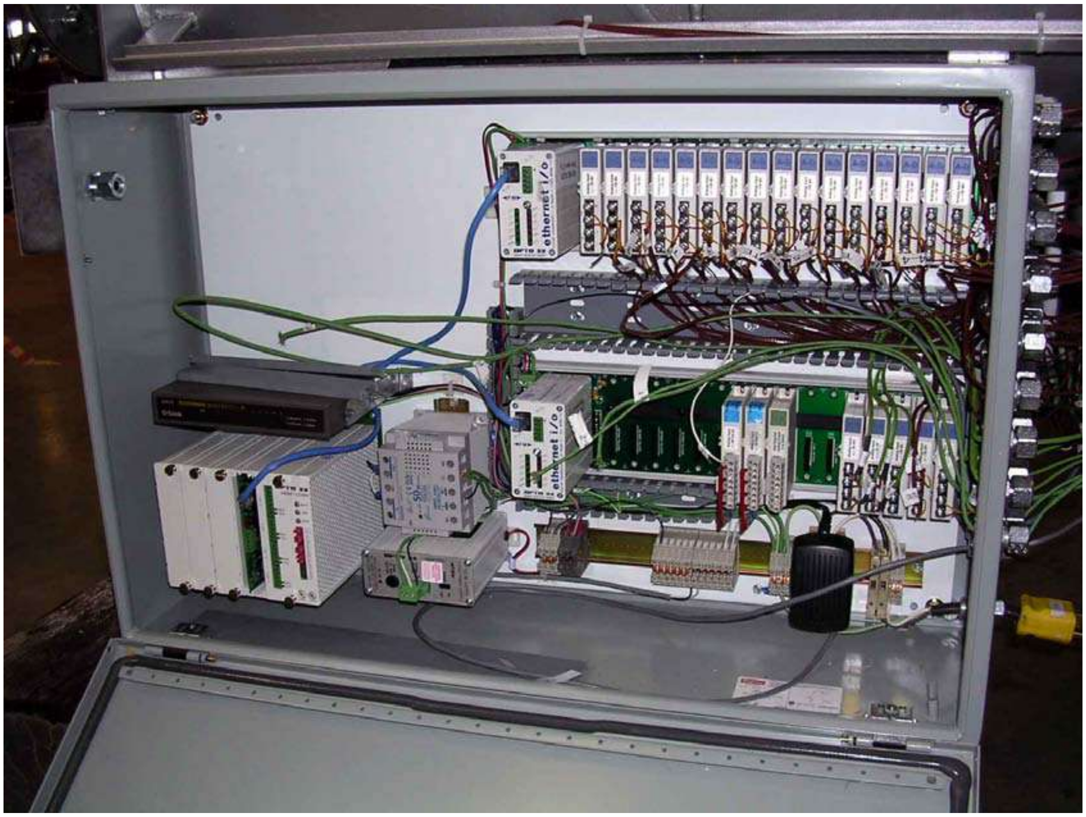


FIGURE 7.23 Interface to plant DCS

FIGURE 7.24 Fuel train

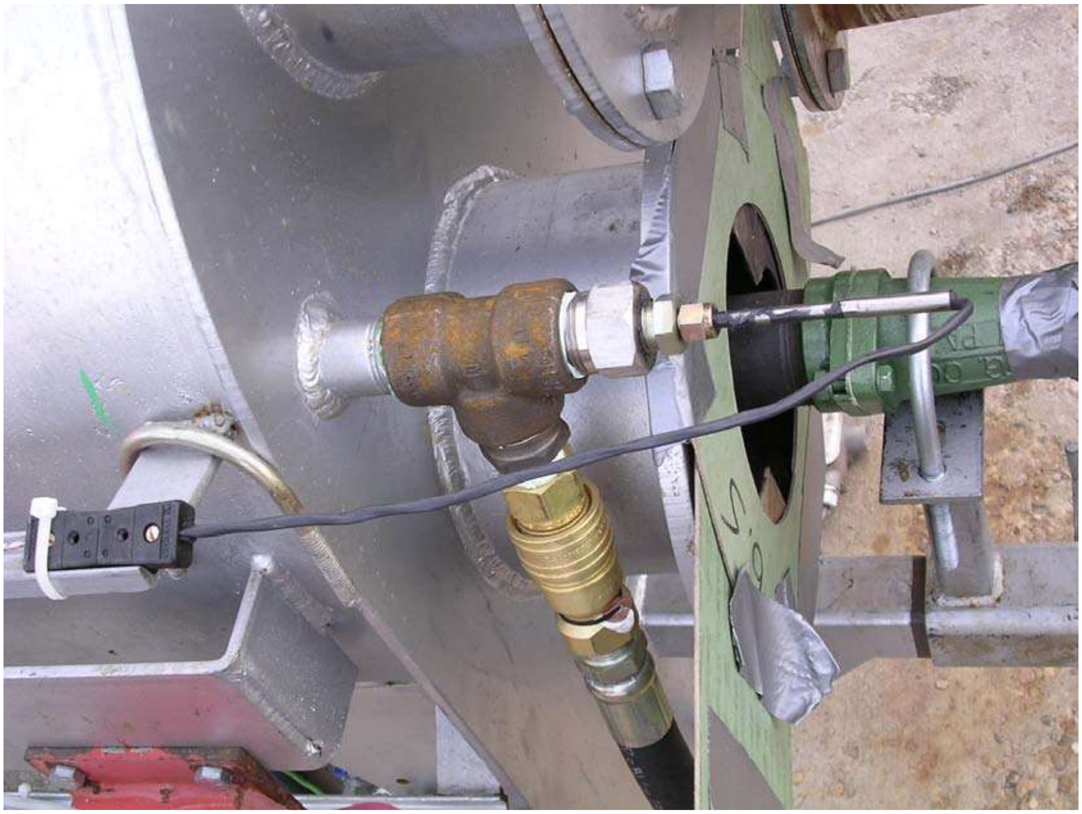


FIGURE 7.25 Fuel gas outlet from preheat coil with TC

FIGURE 7.26 Fuel gas inlet to preheat coil with TC

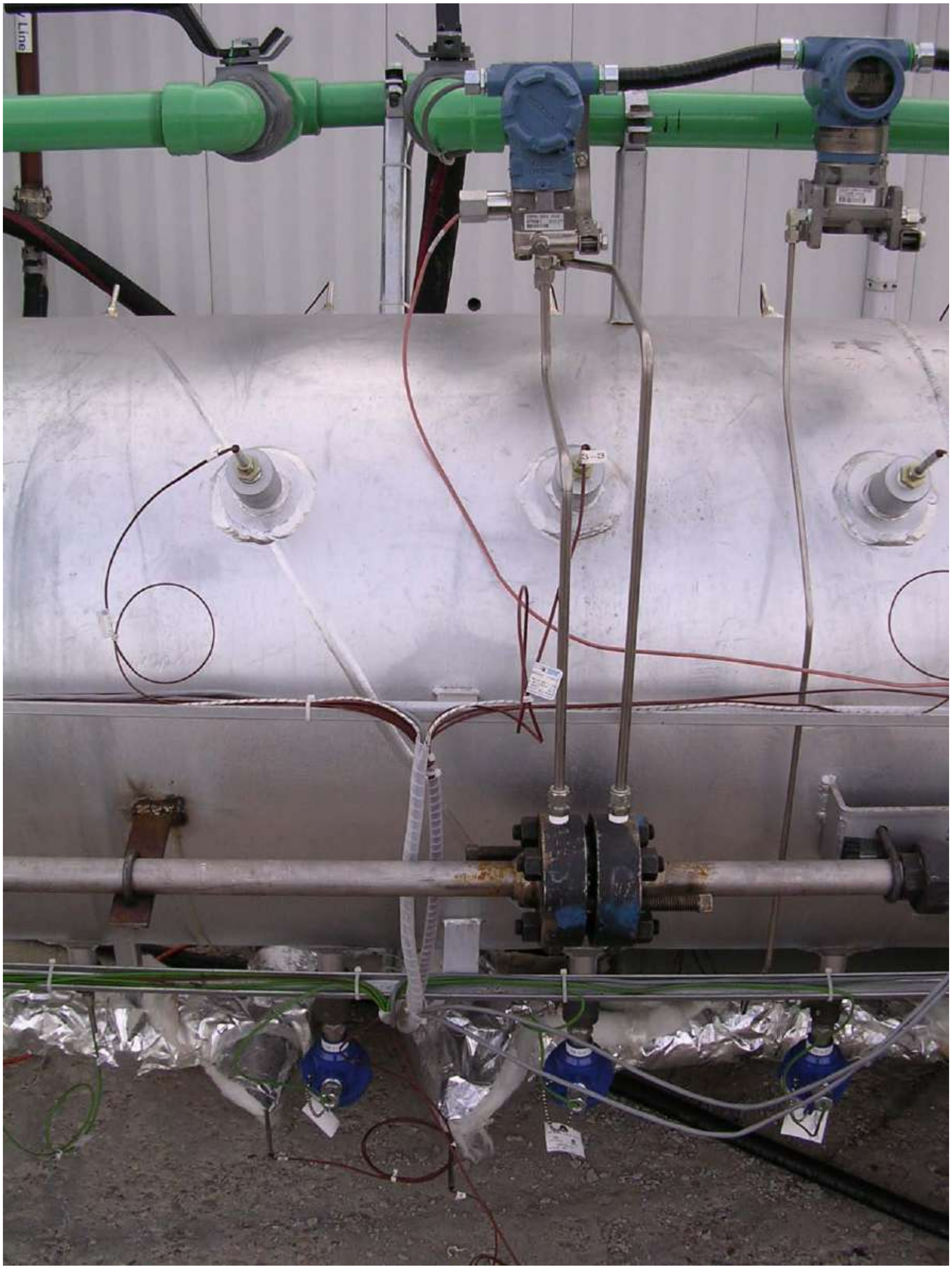


FIGURE 7.27 Calibrated fuel metering flow run with temperature and pressure compensation

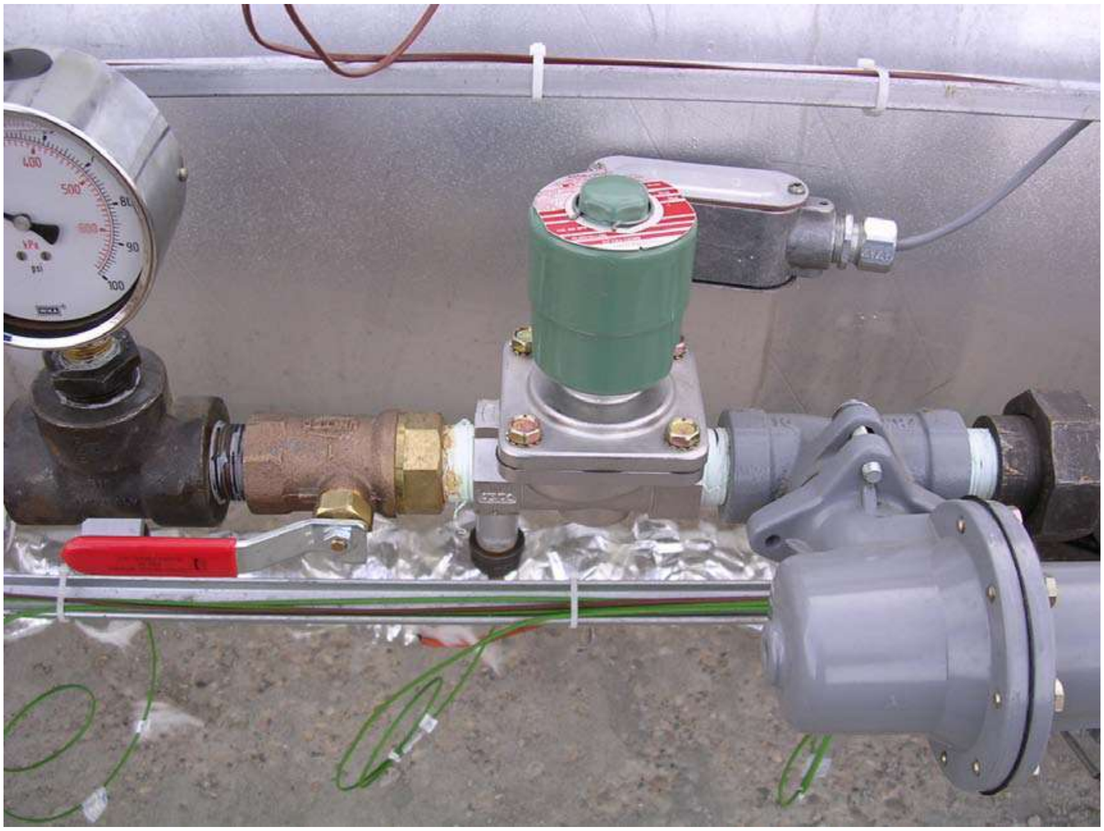


FIGURE 7.28 Automatic Gas Safety Shutoff Valve

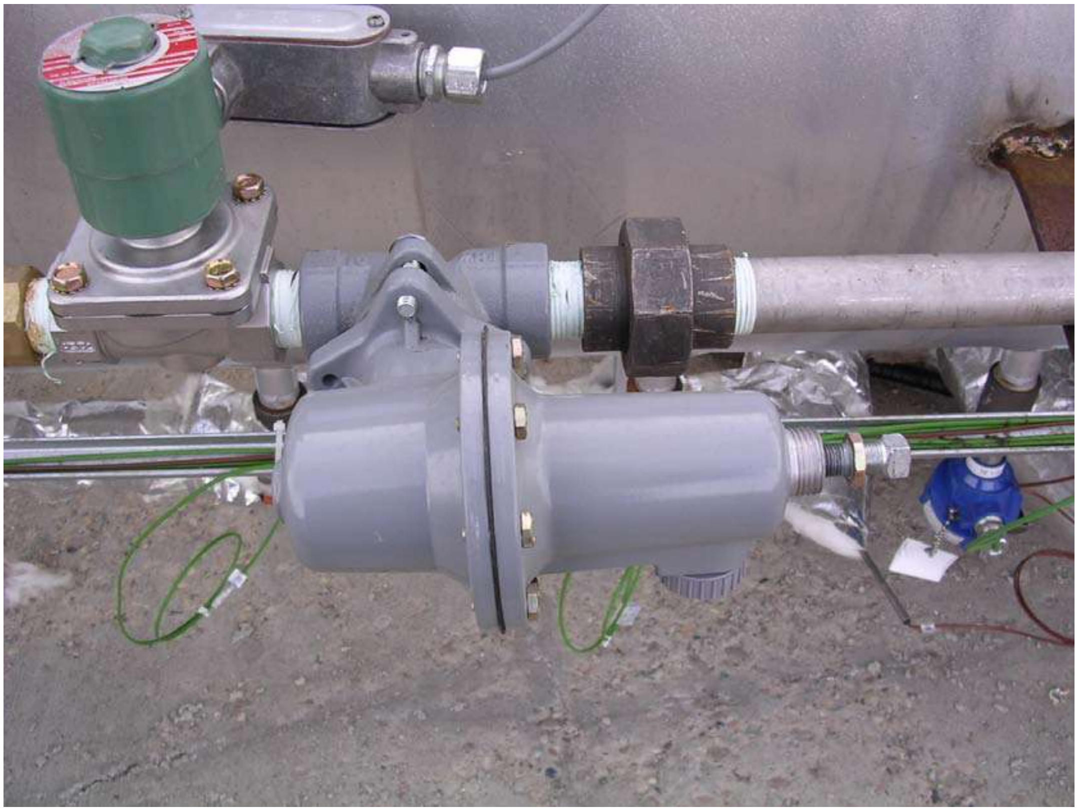


FIGURE 7.29 Main gas pressure regulator

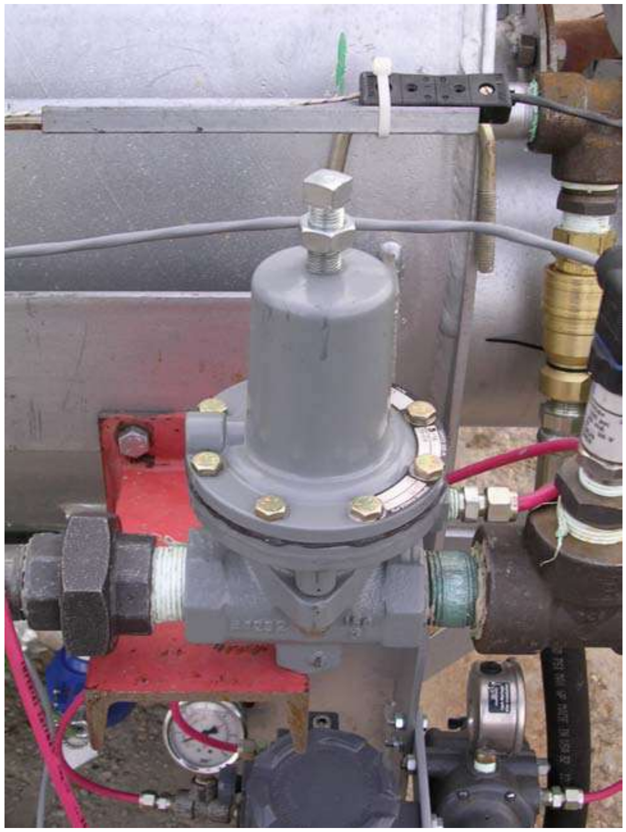


FIGURE 7.30 Fisher type 119 regulator used for control valve

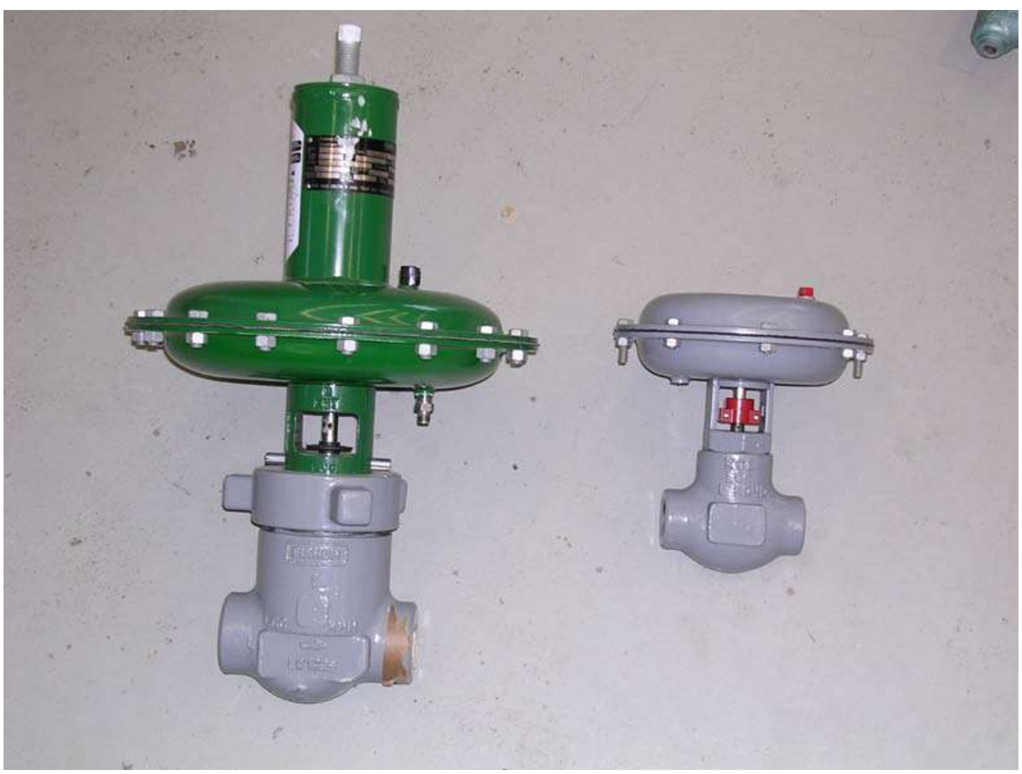


FIGURE 7.31 Alternative Fisher D2 and D4 control valves tested

FIGURE 7.32 Fisher I/P transducer

FIGURE 7.33 Fisher new “I2P” transducer

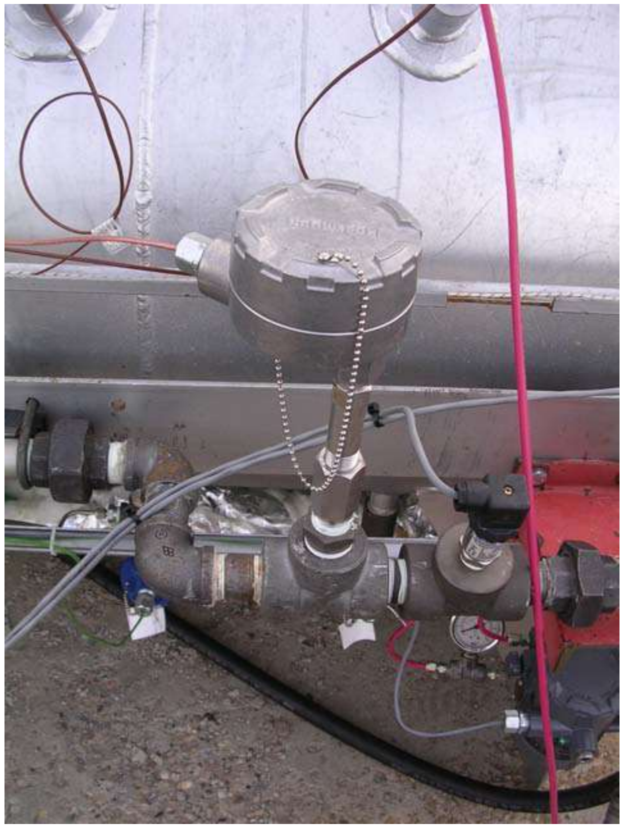


FIGURE 7.34 Fuel temperature TC for temperature correction

FIGURE 7.35 Fuel pressure PT upstream of control valve

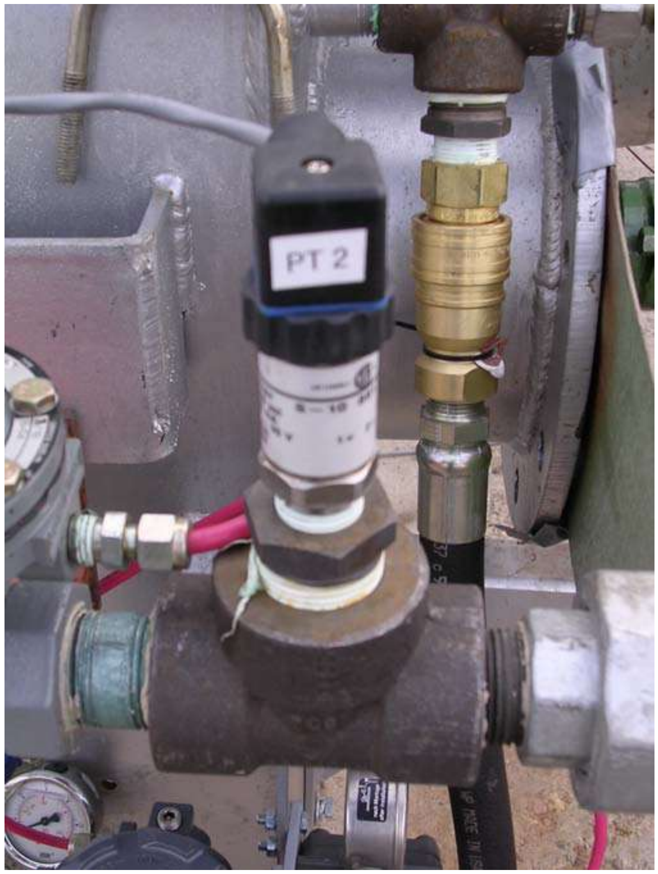


FIGURE 7.36 Fuel pressure PT downstream of control valve

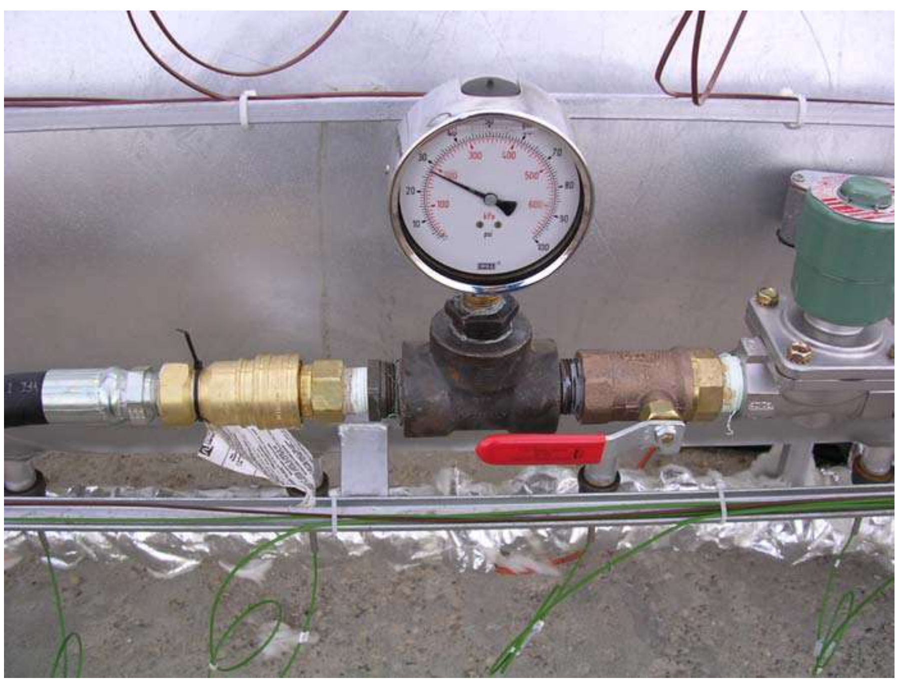


FIGURE 7.37 Fuel inlet pressure gauge

FIGURE 7.38 Fuel pressure to burner pressure gauge

FIGURE 7.39 Burner mixture pressure PT

FIGURE 7.40 Fire tube draft PT

FIGURE 7.41 Primary Air Flow Measurement – Isolation Tube

FIGURE 7.42 Primary Air Flow Measurement - Sensor

FIGURE 7.43 Primary Air Flow Measurement - Readout

FIGURE 7.44 Liquid outlet 1 with TC and pressure gauge

FIGURE 7.45 Liquid outlet switchover valves

FIGURE 7.46 Liquid outlet 2 with TC and pressure relief valve

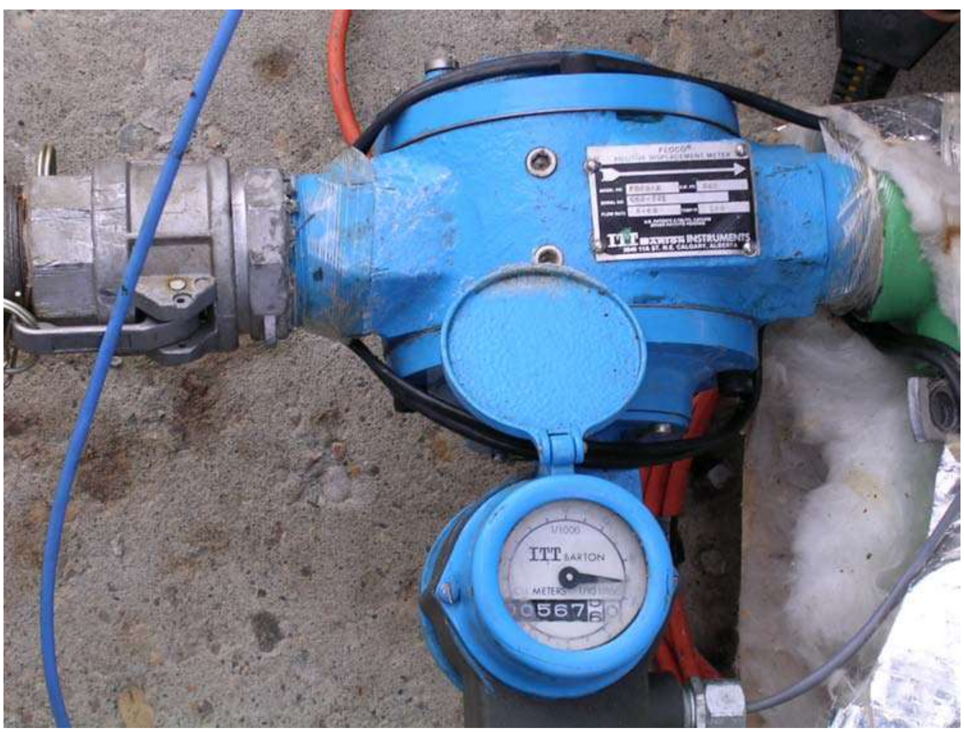


FIGURE 7.47 Liquid FLOCO flow meter

FIGURE 7.48 Return elbow between 3rd and 4th pass with TC

FIGURE 7.49 Return elbow between 2nd and 3rd pass with TC

FIGURE 7.50 Stack Connected to 4th pass outlet, with stack bottom TC

FIGURE 7.51 Stack assembled to 20ft height with middle and top TC

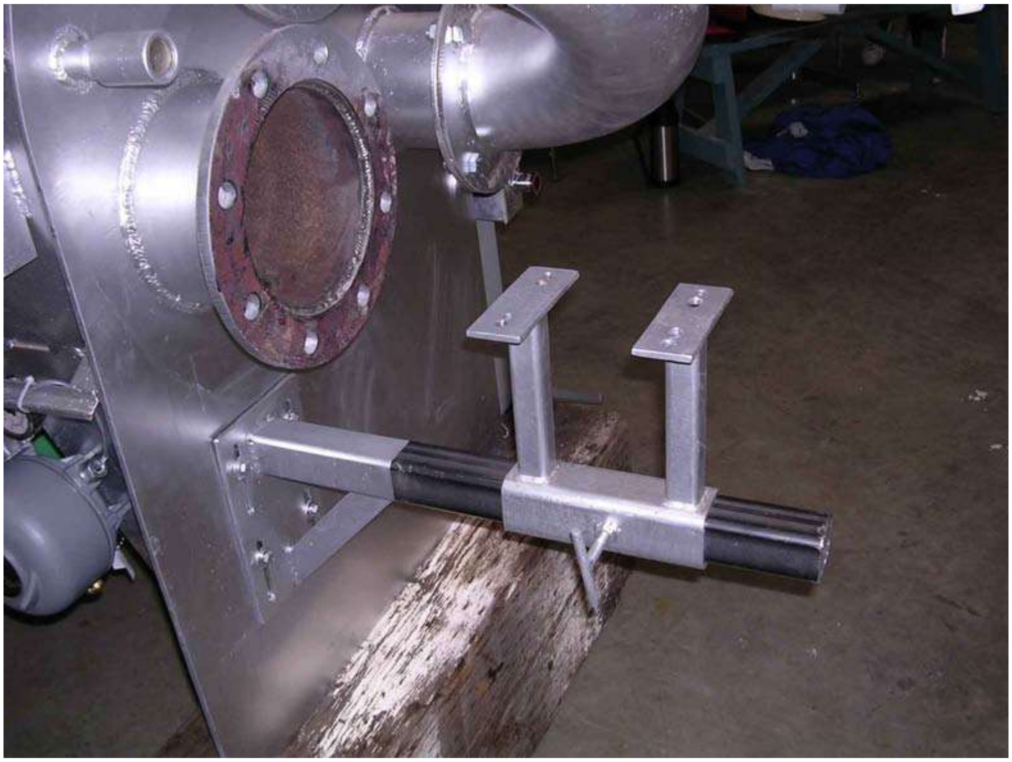


FIGURE 7.52 Adjustable burner mounting bracket at the 1st pass inlet

7.9 Test Unit DCS Operator Interface

FIGURE 7.53 Main test unit control DCS screen and operator interface

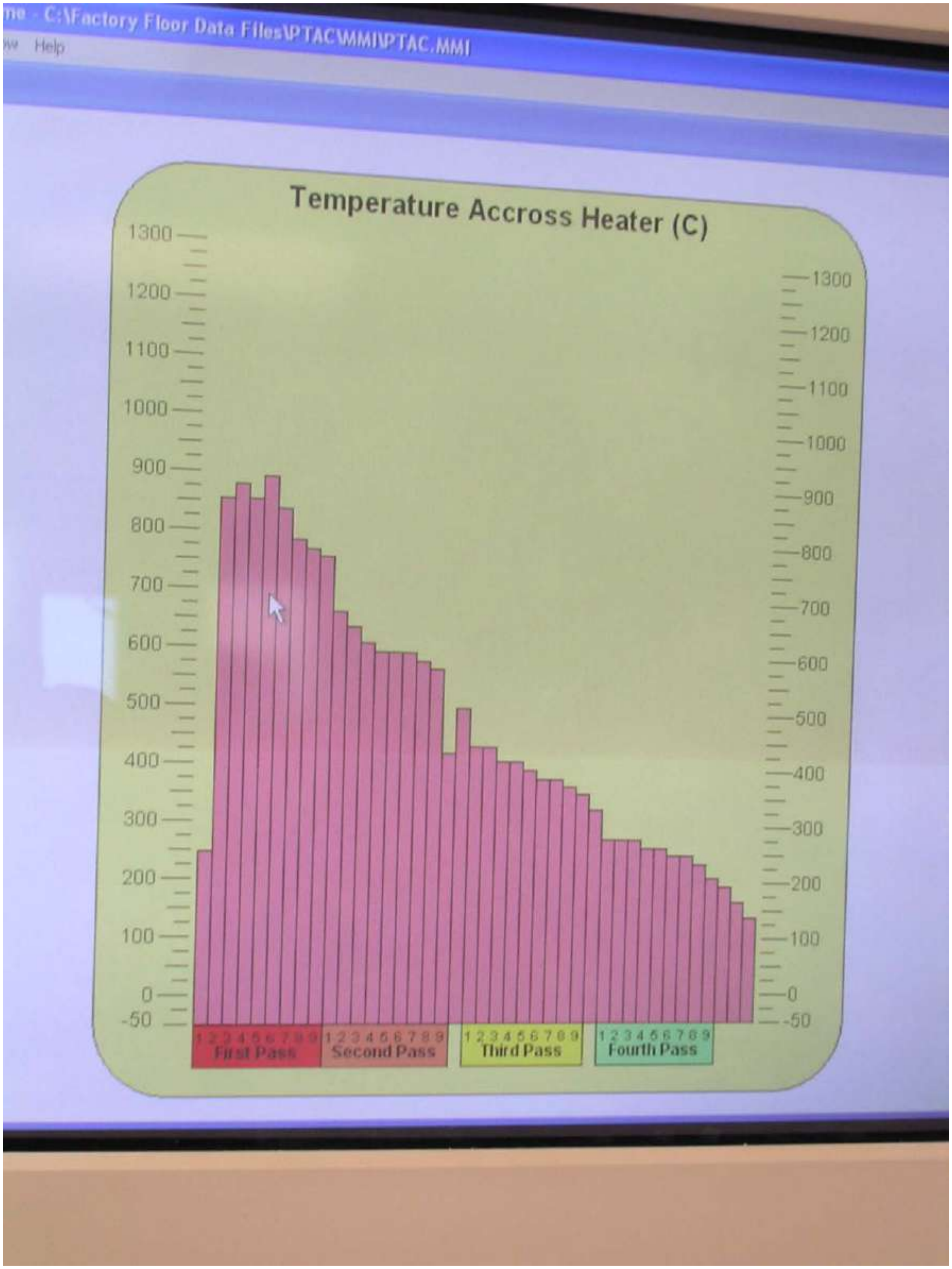


FIGURE 7.54 DCS graph of temperature profile in the tube

7.10 Test Unit Final As-Built Features

The following objectives were achieved in the construction of the immersion fire-tube heater prototype

a) 2-, 3-, and 4-pass tube operation;

b) Stack extendable from 10’ to 20’;

c) Fuel preheat / no-preheat selectable;

d) Adjustable burner mount for various burners;

e) Can accommodate turbulators;

f) Liquid flow direction (counter- vs. co-current);

g) Liquids: water – glycol – oil;

h) Automatic fuel flow adjustment; and,

i) 65 channels of process data recording to plant DCS

8 BURNER BENCH TESTS

This chapter contains summary of the bench testing of the burners at the PITS facility in Nisku, AB.

Figure 8.1 illustrates side-by-side some of the burners provided by various burner manufacturers and used in the bench tests. These manufacturers include:

a) ACL Manufacturing;

b) A-Fire Holdings;

c) Bekaert;

d) Eclipse;

e) Hauck Manufacturing;

f) Kenilworth;

g) Maxon Corporation;

h) North American;

i) Pro-Fire; and,

j) Pyronics.

Except for one small 1" Maxon burner, all of the other burners in the photograph were sized and recommended by their vendors in response to the same specification of 500,000 BTU/hr HHV burner output which was to be released in an 8" diameter first path of fire tube of the test heater. The striking differences in the burner physical sizes and their design illustrate alternative concepts used by manufacturers. As part of this project we looked at various aspects of the burner design and performance and its impact on the fire-tube heater efficiency.

FIGURE 8.1 Various burners used in the bench tests.

Figures 8.2, 8.3, and 8.3 illustrate the arrangement of the test stand used for bench testing.

The bench tests included firing of each burner with natural gas in “open flame” tests. The gas was being modulated by the DCS while the following data was being recorded:

a) fuel gas flow, pressure and temperature;

b) primary air flow and temperature;

c) burner gas/air mixture pressure;

d) burner sound pressure level at 1m to the side and 1m behind the burner; and,

e) flame length and diameter.

FIGURE 8.2 Bench test stand– primary air flow measurement.

An 8” PVC pipe was sealed around the mixer inlet to guide the primary flow to the burner’s mixer, a velocity meter installed in the pipe was used to measure the air flow at various firing rates.

FIGURE 8.3 Bench test stand – burner mount

Each burner was mounted leveled on the burner mount so that flame could be freely observed.

Air/fuel mixture pressure was measured upstream of the burner nozzle.

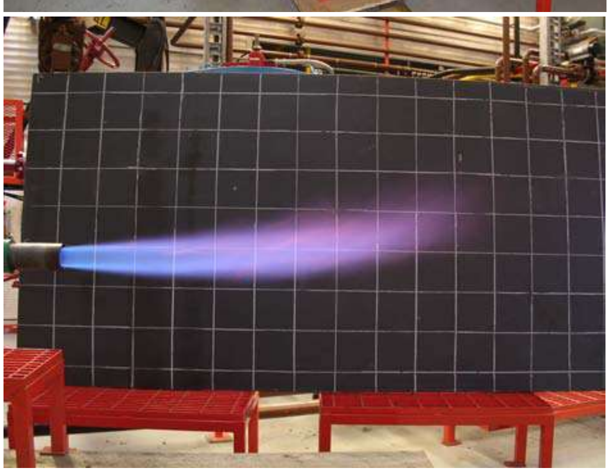


FIGURE 8.4 Bench test stand – reference grid for flame size measurement.

Burner test stand was located in front of a 6”x6” grid used as a background for photos, and as a reference of flame, length, diameter and trajectory.

In addition, flame size was physically measured at each firing rate using a tape measure.

Flame in this photograph is approximately 5’ long and 5” in diameter.

8.1 ACL 1” Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.5;
- self-centering in the tube;
- flame view obstructed by spinner;
- spinner blades maybe difficult to adjust and subject to breaking, misalignment may cause flame instability in the tube;
- flame nozzle with limited spin and flame anchoring;
- small mixer with low air entrance coefficient, and low primary air capability;
- small diameter straight barrel with stepped entry resulting in high mixture pressure drop and therefore limited air induction capability.

Open Flame Tests

- see Figure 8.6;
- flame suspended aerodynamically stabilized, may cause higher noise, pulsation and problems with flame rod signal due to lack of grounding at the flame base;
- Reddish flame coloring indicates low primary air in this rich flame and reliance on secondary airflow;
- Small perimeter gas ports produce individual “flower” like flames with angular trajectory;
- Long and wide flame due to low primary air indicates that the burner is too small for the tested capacity.
- Tube soot deposits and hot spots due to impingement possible.

Bench Test results

- See figure 8.7;
- Stoichiometric air in primary air at less than 20%, qualifies this burner as mostly raw gas burner;
- Gas pressure at 20 PSIG not used effectively for primary air induction and fuel air mixing;
- Burner mixture pressure high up to 4.5”W.C. mostly due to raw gas flow;
- sound pressure level high (back measurement) between 90 and 95 dBA;
- Large flame volume with low Q/V (BTU/volume) = 262,000 BTU/ft3 due to low primary air;
- Low L/D (length/diameter) ratio = 4.2.

PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT Project EETR 0401 **Burner Characteristics** Design by: ENEFEN Energy Efficiency Engineering Ltd.	
Manufacturer:	ACL MANUFACTURING	Address:	Box 2002 805 Main Avenue West
Description:	1" ACL Burner		
		City, Province, Code:	Sundre AB T0M 1X0
Orifice:	1/8"	Telephone / Fax	(403) 638-5234 / (403) 638-4973
Overall Length:	17"	Web Site:	www.acl-manufacturing.com


General Arrangement

Combination burner with secondary air control, sparkplug / flame rod, and connection for pilot. Assembly is self-centering upon adjustment of two bolts at the bottom of the secondary air spinner. View of the flame is blocked by the spinner.

Gas Nozzle

Centre gas port with 8 angled ports on the perimeter and external conical air deflector. Open nozzle with limited flame anchoring

Gas Mixer & Primary Air Adjustment

Small mixer with 1/8"NPT gas connection. Straight mixing tube with internal diameter step (no cone).


Secondary Air Adjustment

Secondary air adjustment is achieved by bending the angle of the blades

FIGURE 8.5 ACL – 1" burner characteristics.

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	ACL MANUFACTURING
Description:	1" ACL Burner
Orifice:	1/8"
Date:	17-Mar-05

501,000 BTU/hr ; 1 turn

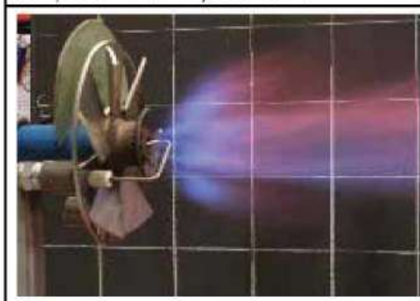
337,000 BTU/hr ; 1turn

176,000 BTU/hr ; 1 turn

501,000 BTU/hr ; 0.5 turns

373,000 BTU/hr ; 0.5 turns

141,000 BTU/hr ; 0.5 turns



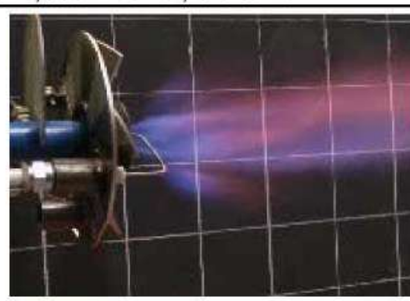
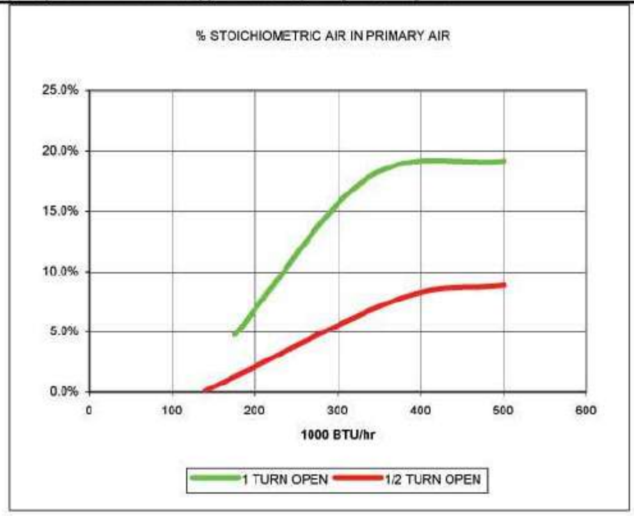
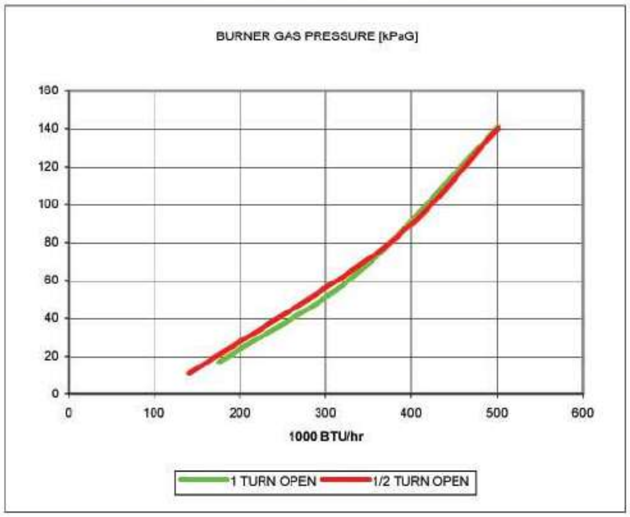


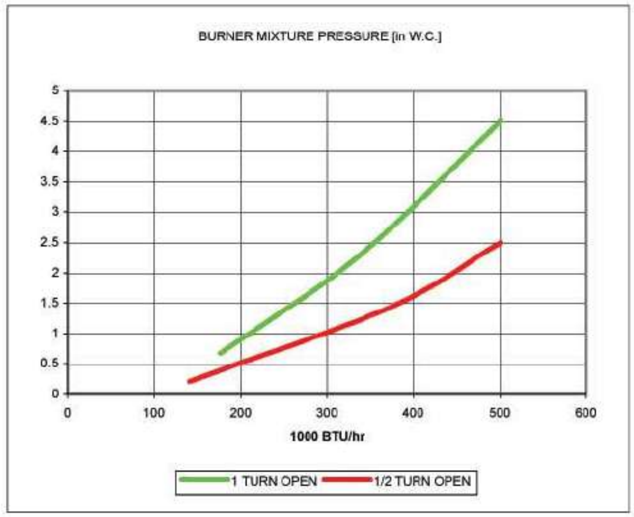
FIGURE 8.6 ACL – 1" burner open flame tests.

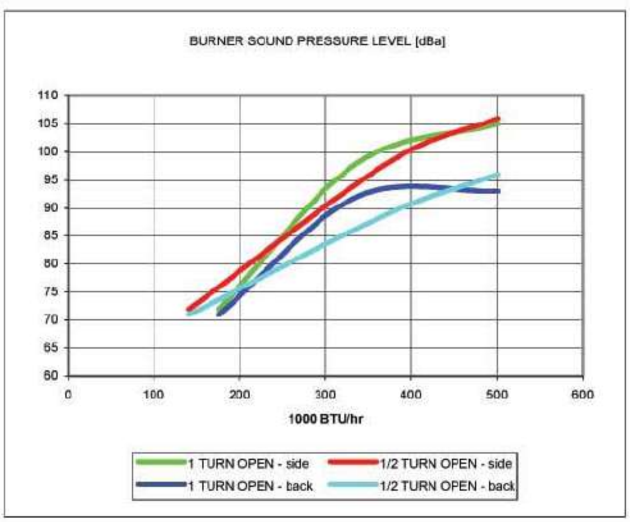
PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
		Project EETR 0401
		Burner Bench Test Performance Summary
		Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	ACL MANUFACTURING
Description:	1" ACL Burner
Orifice:	1/8"
Date:	17-Mar-05









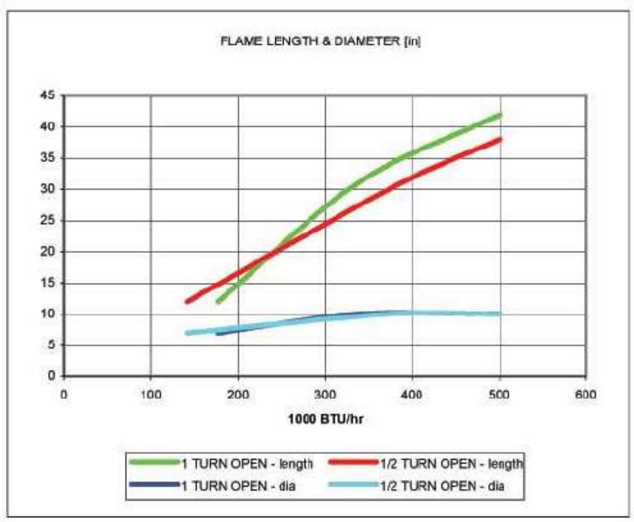


FIGURE 8.7 ACL – 1" burner bench test performance summary.

8.2 A-Fire 1" Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.8;
- good quality NC machined stainless construction
- flame nozzle with limited spin and flame anchoring;
- small mixer with higher entrance coefficient, but low primary air capability
- easily adjustable primary air louvers visible form the back, supplied as an option;
- small diameter straight barrel with stepped entry resulting in high mixture pressure drop and therefore limited air induction capability.

Open Flame Tests

- see Figure 8.9;
- flame suspended aerodynamically stabilized, may cause higher noise, pulsation and problems with flame rod signal due to lack of grounding at the flame base;
- Reddish flame coloring indicates low primary air in this rich flame and reliance on secondary airflow;
- Small perimeter gas ports produce individual "flower" like flames with angular trajectory;
- Tube soot deposits and hot spots due to impingement possible.

Bench Test results

- See figure 8.10;
- Stoichiometric air in primary air at less than 45%, qualifies this burner as low primary air burner;
- Gas pressure at 20 PSIG not used effectively for primary air induction and fuel air mixing;
- Burner mixture pressure – could not be measured;
- sound pressure level high (back measurement) at 95 dBA;
- Low flame volume with high Q/V (BTU/volume) = 1,936,000 BTU/ft3;
- Acceptable L/D (length/diameter) ratio = 9.0.

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT		
	Project EETR 0401		
	Burner Characteristics		
	Design by: ENEFEN Energy Efficiency Engineering Ltd.		
Manufacturer:	A-Fire	Address:	5508-59th Avenue
Description:	1" A-Fire Burner	City, Province, Code:	Lloydminster, AB T9V 3A8
Orifice:	11/64"	Telephone / Fax:	(780) 875-0672/(780) 808-8415
Overall Length:	12"	Web Site:	http://www.a-fire.ca
 			General Arrangement Burner nozzle and mixer combination. High quality machined components
			Gas Nozzle "Bell" type gas nozzle with large centre port and 16 angled side ports in two sizes. Stainless steel construction
			Gas Mixer & Primary Air Adjustment Primary adjustment achieved through rotating of the external shutter which is offered as an option. Knurled locking screw provided to secure shutter in its position.
			Secondary Air Adjustment No secondary air adjustment incorporated

FIGURE 8.8 A-Fire – 1" burner characteristics.

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	A-Fire
Description:	1" A-Fire Burner
Orifice:	11/64"
Date:	17-Mar-05



507,000 BTU/hr ; 100% open

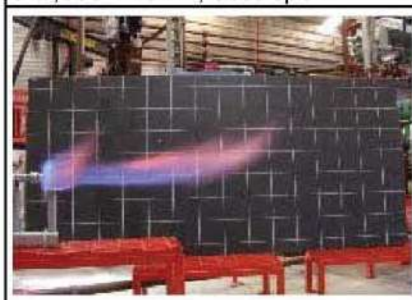

254,000 BTU/hr ; 100% open


77,000 BTU/hr ; 100% open


518,000 BTU/hr ; 50% open


227,000 BTU/hr ; 50% open


167,000 BTU/hr ; 50% open


503,000 BTU/hr ; 10% open

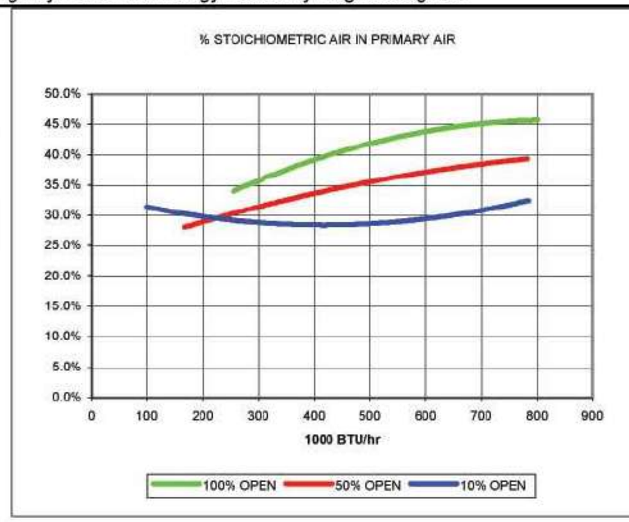

214,000 BTU/hr ; 10% open


100,000 BTU/hr ; 10% open

FIGURE 8.9 A-Fire – 1” burner open flame tests.

PETROLEUM TECHNOLOGY ALLIANCE CANADA (PTAC)	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Bench Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	A-Fire
Description:	1" A-Fire Burner
Orifice:	11/64"
Date:	17-Mar-05



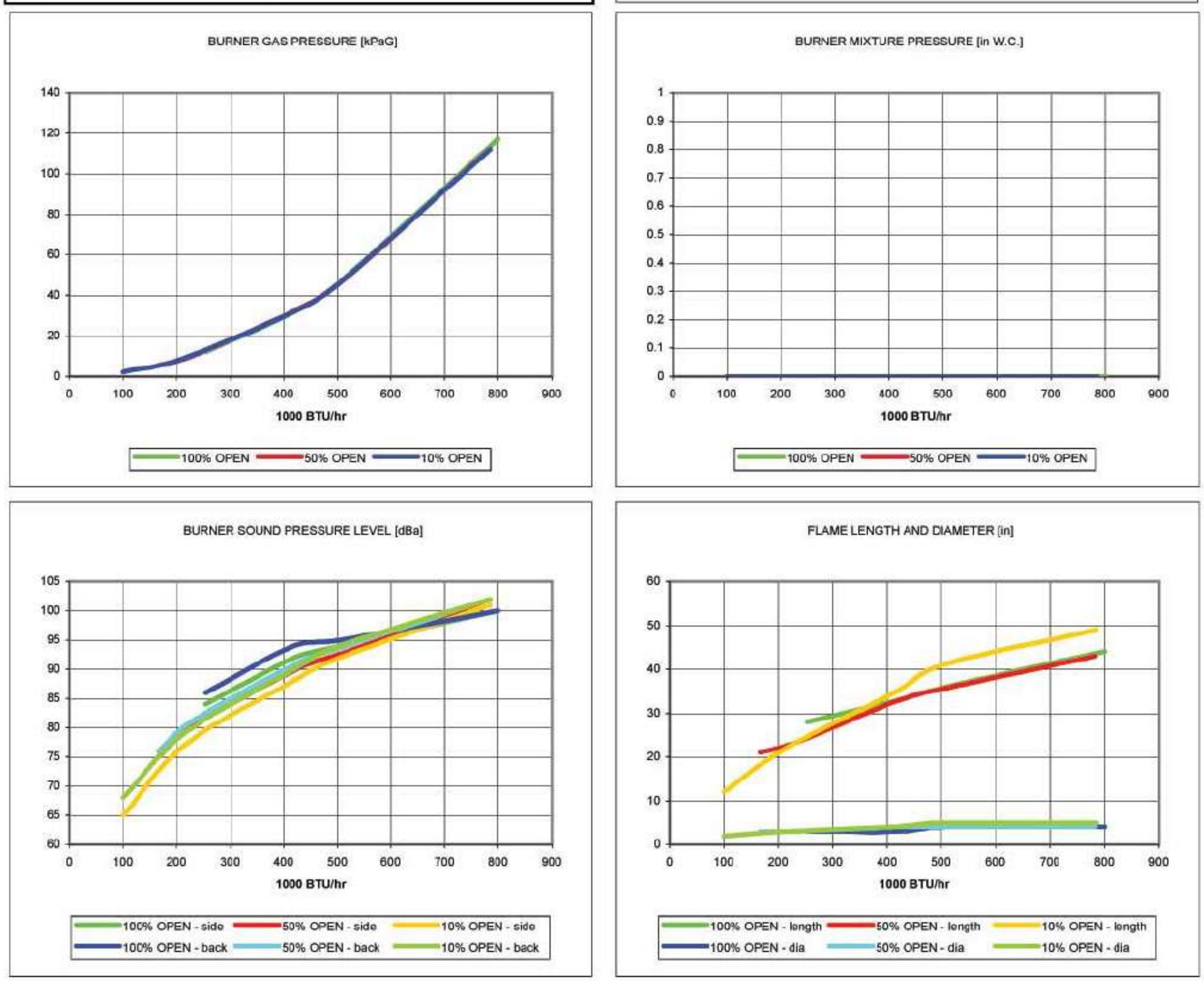


FIGURE 8.10 A-Fire – 1" burner bench test performance summary.

8.3 Bekaert 3"x12" (Config. A) Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.11;
- innovative design with good quality, NC machined stainless construction and external high temperature metal mesh
- pressure drop of the nozzle and fuel/air mixture distribution to the mesh controlled by perforated screen on the inside;
- nozzle was supplied together with a standard Eclipse mixer but without compound barrel of Venturi sleeve and with a recommendation that a straight pipe nipple be installed in between the two components
- to the best of our knowledge the two components were not tested as an assembly prior to the delivery for evaluation

Open Flame Tests

- see Figure 8.12;
- although both the "radiant" and the "blue flame" mode of operation was achieved, it was not without a large "lazy" external flame present at all firing rates;
- The external flame was raising vertically up from the mesh surface in an uncontrollable fashion;
- This burner has no forward momentum and must rely on other means of directing the flame such as a strong natural draft or a combustion air blower
- Tube soot deposits and hot spots due to impingement around the burner will lead to a premature tube failure.
- This flame shape is <u>not suitable</u> for fire tube application.

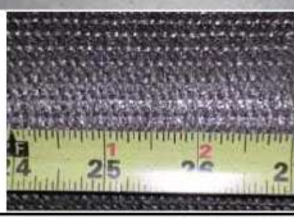
Bench Test results

- See figure 8.13;
- Stoichiometric air in primary air high at over 80%;
- Gas pressure at 20 PSIG produces good air induction in the Eclipse mixer;
- Burner mixture pressure – could not be measured;
- Sound pressure level low (back measurement) at 85 to 87 dBA;
- Large flame volume due to external flame with low Q/V (BTU/volume) = 109,000 BTU/ft3;
- L/D (length/diameter) ratio = 0.4 - difficult to measure due to external free flowing flame

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT		
	Project EETR 0401		
	Burner Characteristics		
	Design by: ENEFEN Energy Efficiency Engineering Ltd.		
Manufacturer:	Bekaert (Config Short A)	Address:	1200 Chastain Rd.
Description:	3"dia x12" mesh burner with 2-1/2" Eclipse Mixer, No Compound Barrel, 2-1/2" Nipple		Building 200, Suite 210
		City, Province, Code:	Kennesaw, GA 30144
Orifice:	1/8"	Telephone / Fax:	(800)241-4126/(770) 423-9181
Overall Length:	12" mesh + pipe nipple and mixer to suit	Web Site:	http://www.bekaert.com/BCT


General Arrangement

Metal fibre media flame nozzle only supply fro burner manufacturer. Mixer and other components are by others.


Gas Nozzle

Metal fibre media supported by an internal perforated stainless steel screen. Manufacture can vary the perforation sizes for various pressure drops. This nozzle relies on fuel/air pre-mixing. End plate could be either blank or mesh.

Gas Mixer & Primary Air Adjustment

Mixer supplied with the burner was a standard Eclipse 2-1/2" mixer. Straight 2-1/2" nipple was used to connect mixer to nozzle

Secondary Air Adjustment

No secondary air adjustment incorporated

FIGURE 8.11 Bekaert – 3"x12" (Config. A) burner characteristics.

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
PTAC	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Bekaert (Config Short A)
Description:	3"dia x12" mesh burner with 2-1/2" Eclipse Mixer, No Compund Barel, 2-1/2" Nipple
Orifice:	1/8"
Date:	19-Mar-05

497,000 BTU/hr ; 100% open

293,000 BTU/hr ; 100% open

155,000 BTU/hr ; 100% open

500,000 BTU/hr ; 4 turns

293,000 BTU/hr ; 4 turns

147,000 BTU/hr ; 4 turns

498,000 BTU/hr ; 3 turns

291,000 BTU/hr ; 3 turns

147,000 BTU/hr ; 3 turns

FIGURE 8.12 Bekaert – 3"x12" (Config. A) burner open flame tests.

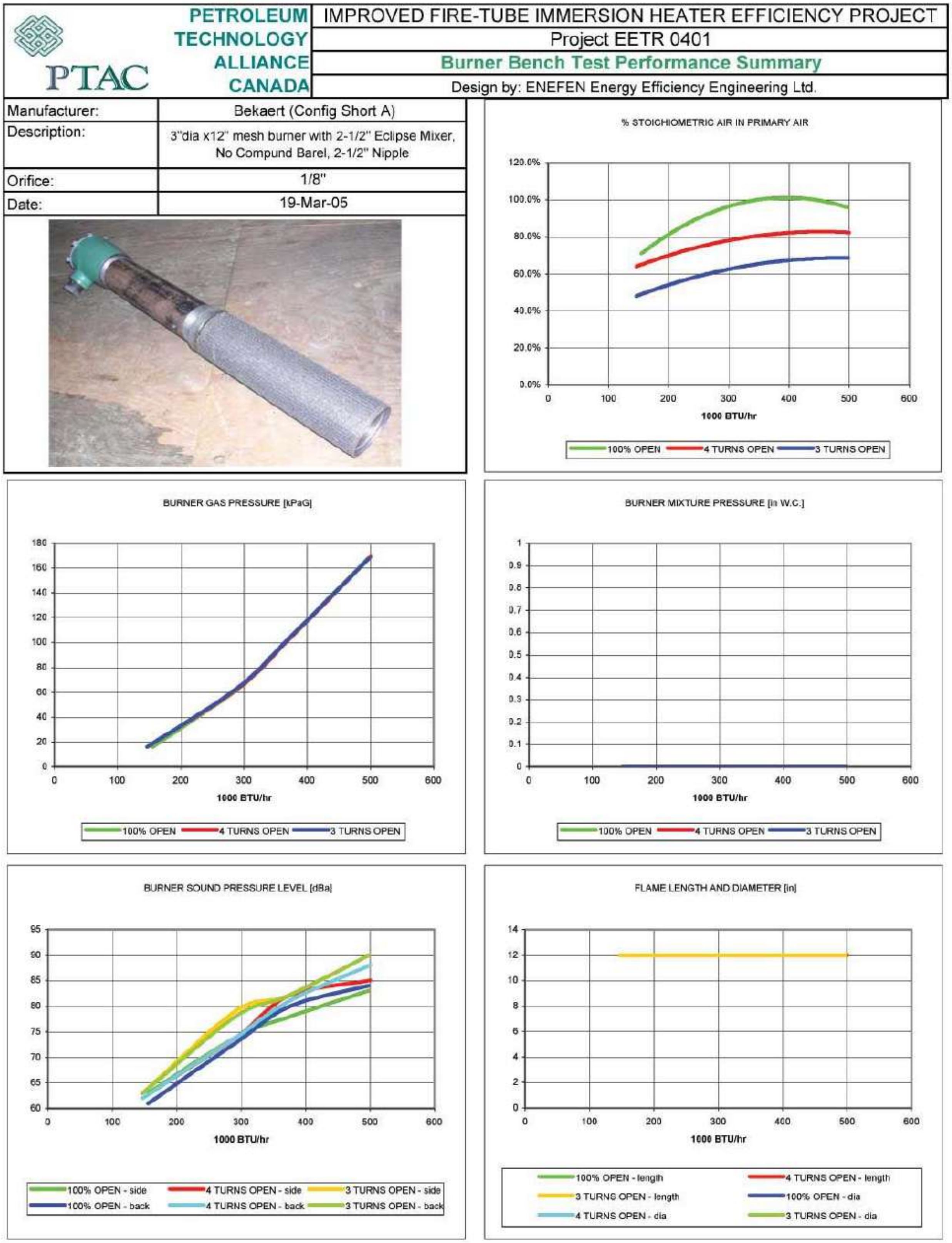


FIGURE 8.13 Bekaert – 3"x12" (Config. A) burner bench test performance summary.

8.4 Bekaert 3”x12” (Config. B) Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.14;
- same nozzle as used in Config. A
- pressure drop of the nozzle and fuel/air mixture distribution to the mesh controlled by perforated screen on the inside;
- nozzle was tested with available on site smaller Eclipse mixer and Venturi sleeve in an attempt to improve performance compared to test of Config. A

Open Flame Tests

- see Figure 8.15;
- flame performance was improved for both the “radiant” and the “blue flame” mode of operation, but a smaller “lazy” external flame was still present at most firing rates;
- The external flame was raising vertically up from the mesh surface in an uncontrollable fashion;
- This burner has no forward momentum and must rely on other means of directing the flame such as a strong natural draft or a combustion air blower
- Tube soot deposits and hot spots due to impingement around the burner will lead to a premature tube failure.
- This flame shape is not suitable for fire tube application.

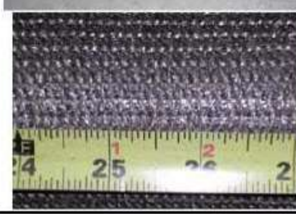
Bench Test results

- See figure 8.16;
- Stoichiometric air in primary air good at over 110%;
- Gas pressure at 20 PSIG produces good air induction in the Eclipse mixer with Venturi sleeve;
- Burner mixture pressure 0.2” W.C.;
- Sound pressure level (back measurement) at 90 dBA;
- Large flame volume due to external flame with low Q/V (BTU/volume) = 100,800 BTU/ft3;
- L/D (length/diameter) ratio = 0.4 - difficult to measure due to external free flowing flame

PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT	
		Project EETR 0401	
		Burner Characteristics	
		Design by: ENEFEN Energy Efficiency Engineering Ltd.	
Manufacturer:	Bekaert (Config Short B)	Address:	1200 Chastain Rd.
Description:	3"dia x12" mesh burner with 1-1/2" Eclipse Mixer, No Compound Barrel, 1-1/2"x2-1/2" Venturi		Building 200, Suite 210
		City, Province, Code:	Kennesaw, GA 30144
Orifice:	1/8"	Telephone / Fax:	(800)241-4126/(770) 423-9181
Overall Length:	12" mesh+mixer+venturi+ nipple = 47"	Web Site:	http://www.bekaert.com/BCT


General Arrangement

Metal fibre media flame nozzle only supply fro burner manufacturer. Mixer and other components are by others.


Gas Nozzle

Metal fibre media supported by an internal perforated stainless steel screen. Manufacture can vary the perforation sizes for various pressure drops. This nozzle relies on fuel/air pre-mixing. End plate could be either blank o mesh.

Gas Mixer & Primary Air Adjustment

Nozzle tested with 1-1/2" standard Eclipse mixer and 1-1/2"x2-1/2" Venturi.

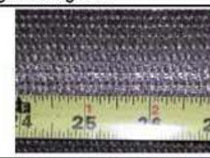
Secondary Air Adjustment

No secondary air adjustment incorporated

FIGURE 8.14 Bekaert – 3”x12” (Config. B) burner characteristics.

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

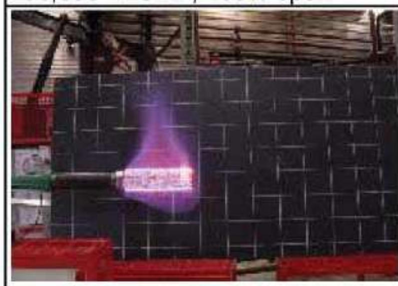
Manufacturer:	Bekaert (Config Short B)
Description:	3"dia x12" mesh burner with 1-1/2" Eclipse Mixer, No Compound Barel, 1-1/2"x2-1/2" Venturi
Orifice:	1/8"
Date:	15-Mar-05



496,000 BTU/hr ; 100% open

307,000 BTU/hr ; 100% open

72,000 BTU/hr ; 100% open



495,000 BTU/hr ; 3 turns

310,000 BTU/hr ; 3 turns

72,000 BTU/hr ; 3 turns

495,000 BTU/hr ; 2.5 turns

311,000 BTU/hr ; 2.5 turns

81,000 BTU/hr ; 2.5 turns

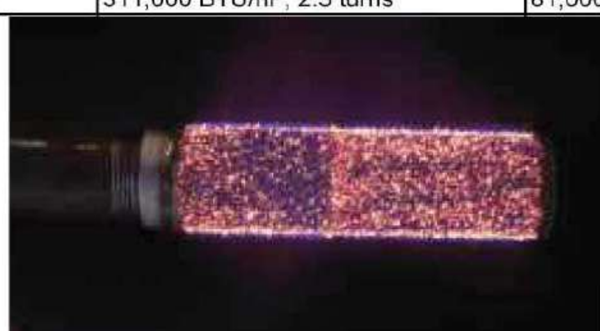
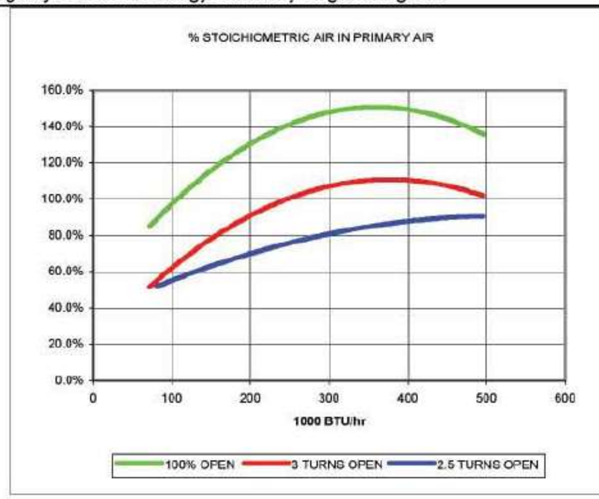
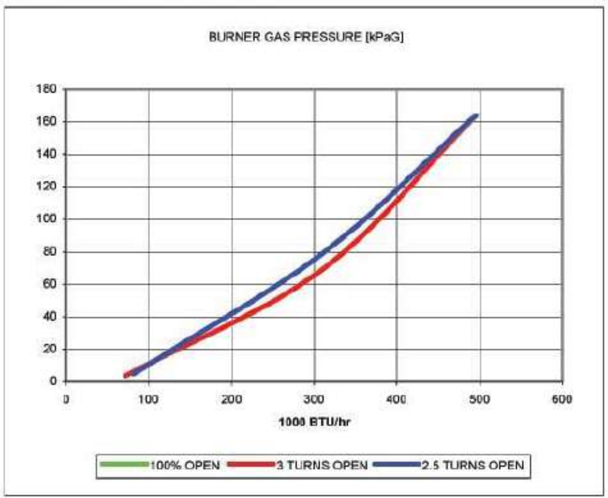


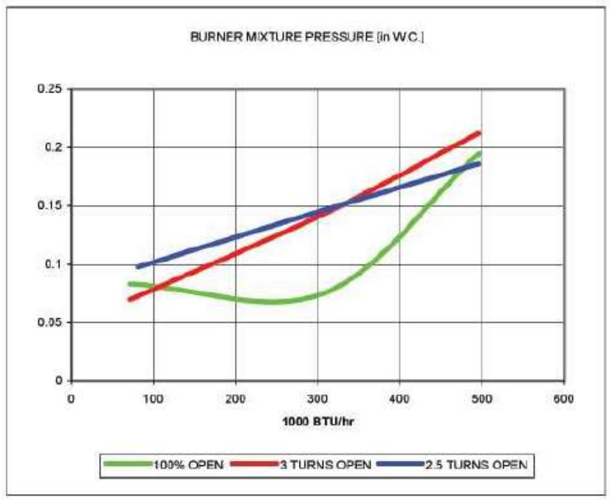
FIGURE 8.15 Bekaert – 3”x12” (Config. B) burner open flame tests.

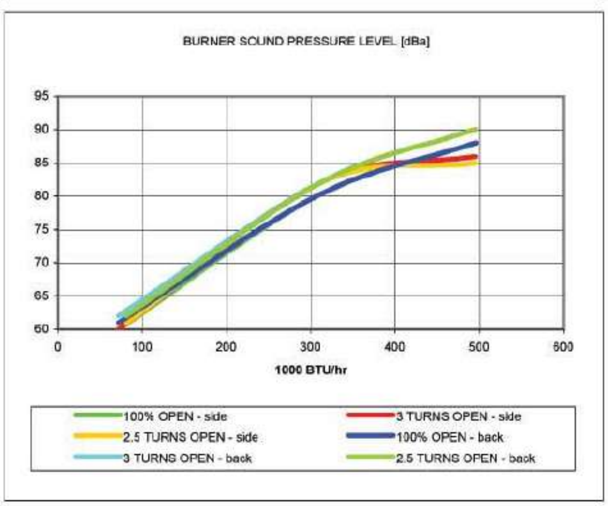
PETROLEUM TECHNOLOGY ALLIANCE CANADA (PTAC)	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Bench Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Bekaert (Config Short B)
Description:	3"dia x12" mesh burner with 1-1/2" Eclipse Mixer, No Compound Barel, 1-1/2"x2-1/2" Venturi
Orifice:	1/8"
Date:	15-Mar-05









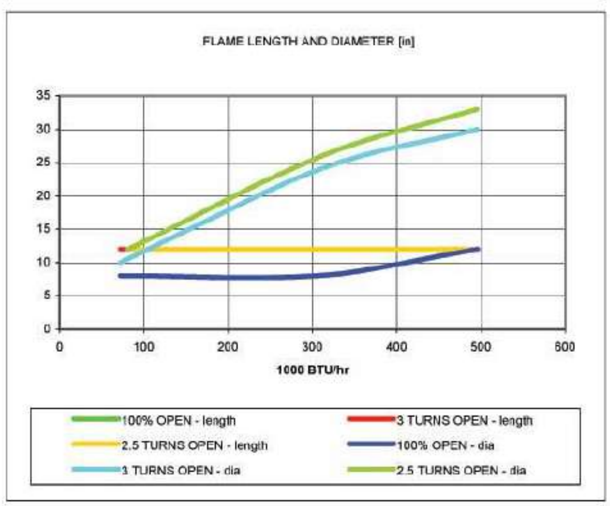


FIGURE 8.16 Bekaert – 3"x12" (Config. B) burner bench test performance summary.

8.5 Bekaert 3"x12" (Config. C) Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.17;
- same nozzle as used in Config. A, and B
- pressure drop of the nozzle and fuel/air mixture distribution to the mesh controlled by perforated screen on the inside;
- nozzle was tested with available on site Eclipse compound barrel in an attempt to improve performance compared to test of Config. A and B

Open Flame Tests

- see Figure 8.18;
- flame performance was similar to configuration "A" with "lazy" external flame present at most firing rates;
- The external flame was raising vertically up from the mesh surface in an uncontrollable fashion;
- This burner has no forward momentum and must rely on other means of directing the flame such as a strong natural draft or a combustion air blower
- Tube soot deposits and hot spots due to impingement around the burner will lead to a premature tube failure.
- This flame shape is not suitable for fire tube application.

Bench Test results

- See figure 8.19;
- Stoichiometric air in primary air high at approximately 90%;
- Gas pressure at 20 PSIG produces good air induction in the Eclipse mixer with compound barrel;
- Burner mixture pressure could not be measured;
- Sound pressure level (back measurement) low at 87 dBA;
- Large flame volume due to external flame with low Q/V (BTU/volume) = 144,900 BTU/ft3;
- L/D (length/diameter) ratio = 0.5 - difficult to measure due to external free flowing flame

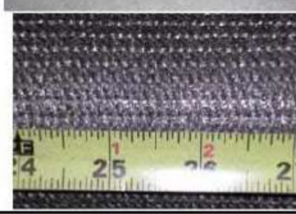
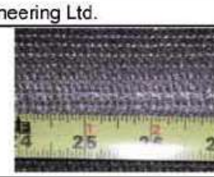
PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT Project EETR 0401 **Burner Characteristics** Design by: ENEFEN Energy Efficiency Engineering Ltd.	
Manufacturer:	Bekaert (Config Short C)	Address:	1200 Chastain Rd.
Description:	3"dia x12" mesh burner with 2-1/2" Eclipse Mixer, With 2-1/2" Compound Barrel, 2-1/2" Nipple		Building 200, Suite 210
		City, Province, Code:	Kennesaw, GA 30144
Orifice:	1/8"	Telephone / Fax:	(800)241-4126/(770) 423-9181
Overall Length:	12" mesh+mixer+barrel+nipple = 38"	Web Site:	http://www.bekaert.com/BCT
			General Arrangement Metal fibre media flame nozzle only supply fro burner manufacturer. Mixer and other components are by others.
 			Gas Nozzle Metal fibre media supported by an internal perforated stainless steel screen. Manufacture can vary the perforation sizes for various pressure drops. This nozzle relies on fuel/air pre-mixing. End plate could be either blank o mesh.
			Gas Mixer & Primary Air Adjustment Nozzle tested with 2-1/2" standard Eclipse mixer, 2-1/2" compound barrel and 2-1/2" straight nipple.
			Secondary Air Adjustment No secondary air adjustment incorporated

FIGURE 8.17 Bekaert – 3"x12" (Config. C) burner characteristics.

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Bekaert (Config Short C)
Description:	3"dia x12" mesh burner with 2-1/2" Eclipse Mixer, With 2-1/2" Compound Barel, 2-1/2" Nipple
Orifice:	1/8"
Date:	19-Mar-05



498,000 BTU/hr ; 15.5 turns

290,000 BTU/hr ; 15.5 turns

146,000 BTU/hr ; 15.5 turns

494,000 BTU/hr ; 4 turns

289,000 BTU/hr ; 4 turns

143,000 BTU/hr ; 4 turns

497,000 BTU/hr ; 3 turns

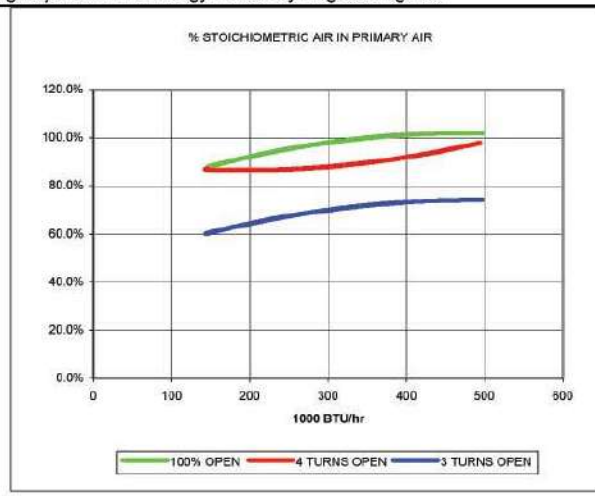
287,000 BTU/hr ; 3 turns

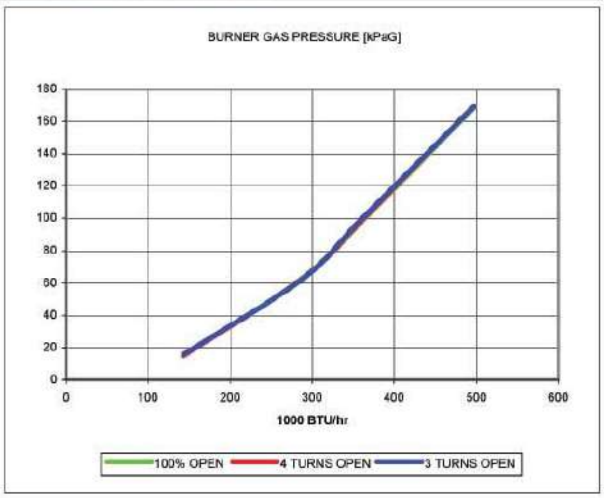
144,000 BTU/hr ; 3 turns

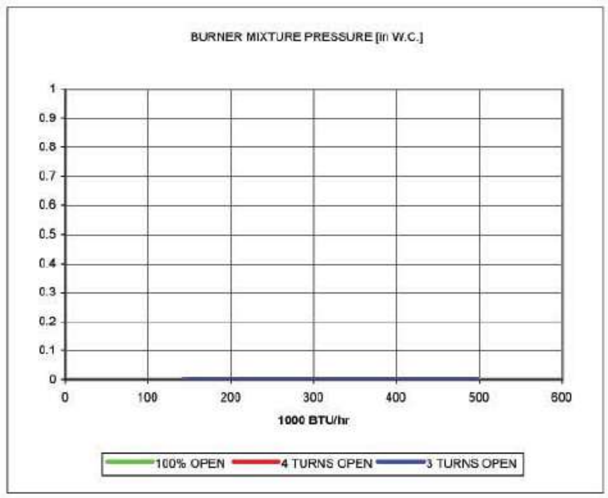
FIGURE 8.18 Bekaert – 3”x12” (Config. C) burner open flame tests.

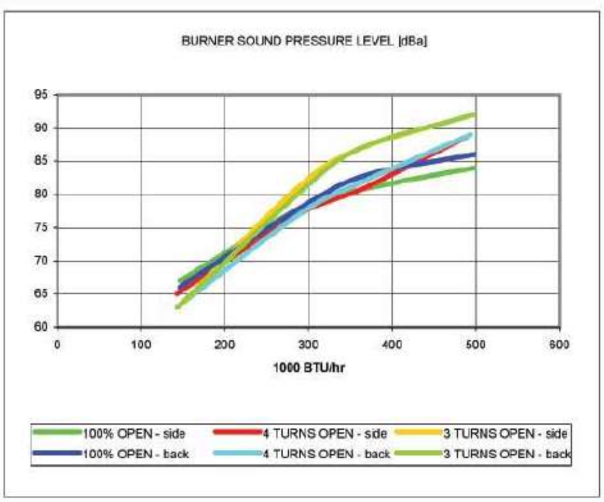
PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Bench Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Bekaert (Config Short C)
Description:	3"dia x12" mesh burner with 2-1/2" Eclipse Mixer, With 2-1/2" Compound Barel, 2-1/2" Nipple
Orifice:	1/8"
Date:	19-Mar-05









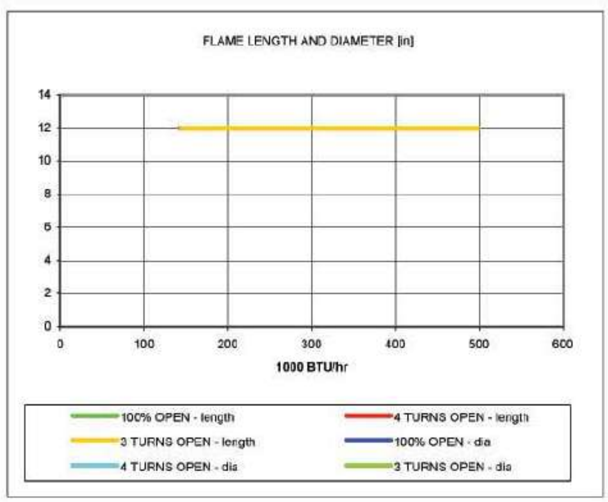


FIGURE 8.19 Bekaert – 3"x12" (Config. C) burner bench test performance summary.

8.6 Bekaert 3”x18” (Config. D) Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.20;
- same diameter bur longer nozzle than used in Config. A, B, and C
- pressure drop of the nozzle and fuel/air mixture distribution to the mesh controlled by perforated screen on the inside;
- nozzle was tested with available on site Eclipse mixer and Venturi sleeve

Open Flame Tests

- see Figure 8.21;
- flame performance was similar to configuration “B”, “lazy” external flames still present at higher firing rates, best performance out of all three configurations due to the use of a proper Venturi.;
- The external flame was raising vertically up from the mesh surface in an uncontrollable fashion;
- This burner has no forward momentum and must rely on other means of directing the flame such as a strong natural draft or a combustion air blower
- Tube soot deposits and hot spots due to impingement around the burner will lead to a premature tube failure.
- This flame shape is not suitable for fire tube application.

Bench Test results

- See figure 8.22;
- Stoichiometric air in primary air high at approximately 100%;
- Gas pressure at 20 PSIG produces good air induction in the Eclipse mixer with Venturi;
- Burner mixture pressure could not be measured;
- Sound pressure level (back measurement) low at 87 dBA;
- Large flame volume due to external flame with low Q/V (BTU/volume) = 67,000 BTU/ft3;
- L/D (length/diameter) ratio = 0.6 - difficult to measure due to external free flowing flame

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT		
	Project EETR 0401		
	Burner Characteristics		
	Design by: ENEFEN Energy Efficiency Engineering Ltd.		
Manufacturer:	Bekaert (Config Medium D)	Address:	1200 Chastain Rd.
Description:	3"dia x18" mesh burner with 1-1/2" Eclipse Mixer, No Compound Barrel, 1-1/2" x 2-1/2" Venturi		Building 200, Suite 210
		City, Province, Code:	Kennesaw, GA 30144
Orifice:	1/8"	Telephone / Fax:	(800)241-4126/(770) 423-9181
Overall Length:	12" mesh+mixer+venturi+ nipple = 53"	Web Site:	http://www.bekaert.com/BCT


General Arrangement

Metal fibre media flame nozzle only supply fro burner manufacturer. Mixer and other components are by others.



Gas Nozzle

Metal fibre media supported by an internal perforated stainless steel screen. Manufacture can vary the perforation sizes for various pressure drops. This nozzle relies on fuel/air pre-mixing. End plate could be either blank o mesh.

Gas Mixer & Primary Air Adjustment

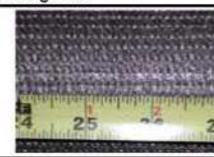
Nozzle tested with 1-1/2" standard Eclipse mixer and 1-1/2"x2-1/2" Venturi.

Secondary Air Adjustment

No secondary air adjustment incorporated

FIGURE 8.20 Bekaert – 3”x18” (Config. D) burner characteristics.

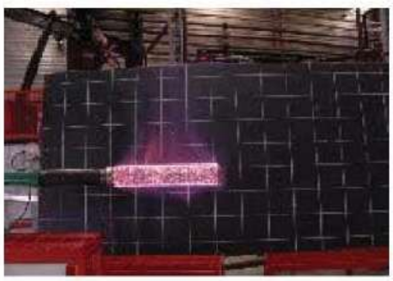
PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.
Manufacturer:	Bekaert (Config Medium D)
Description:	3"dia x18" mesh burner with 1-1/2" Eclipse Mixer, No Compound Barel, 1-1/2" x 2-1/2" Venturi
Orifice:	1/8"
Date:	15-Mar-05



500,000 BTU/hr ; 15.5 turns

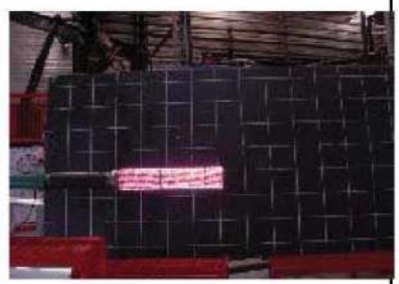
354,000 BTU/hr ; 15.5 turns

188,000 BTU/hr ; 15.5 turns



500,000 BTU/hr ; 3 turns

365,000 BTU/hr ; 3 turns



165,000 BTU/hr ; 3 turns

501,000 BTU/hr ; 2 turns

388,000 BTU/hr ; 2 turns

179,000 BTU/hr ; 2 turns

500,000 BTU/hr ; 0.5 turns

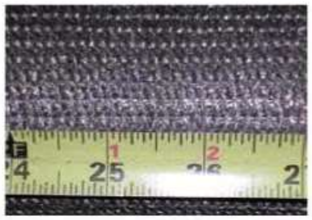
356,000 BTU/hr ; 0.5 turns

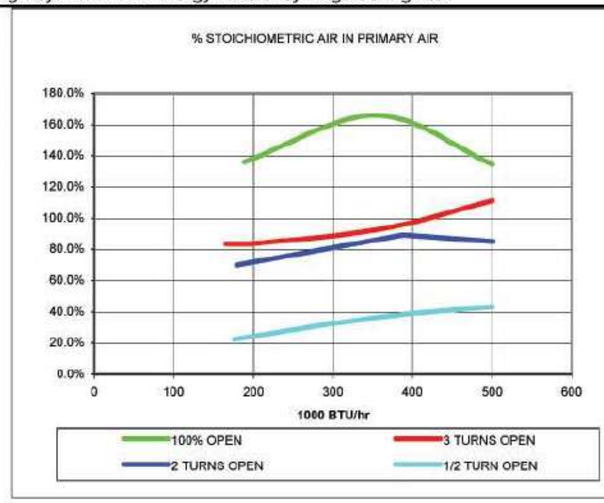
176,000 BTU/hr ; 0.5 turns

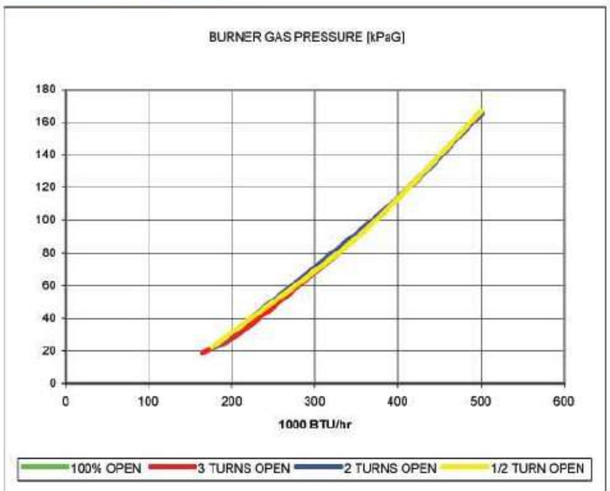
FIGURE 8.21 Bekaert – 3"x18" (Config. D) burner open flame tests.

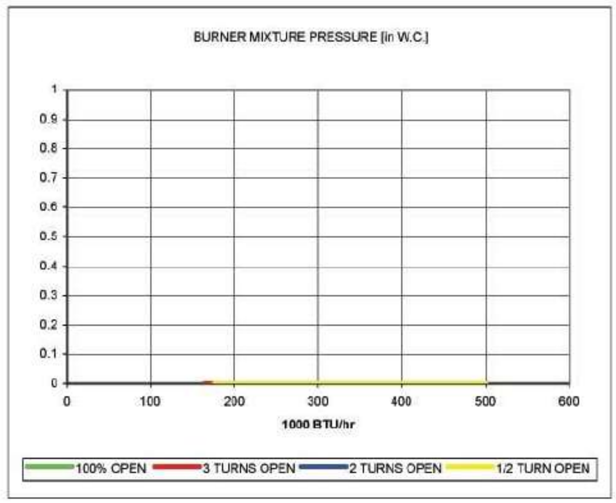
PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
		Project EETR 0401
		Burner Bench Test Performance Summary
		Design by: ENEFEN Energy Efficiency Engineering Ltd.

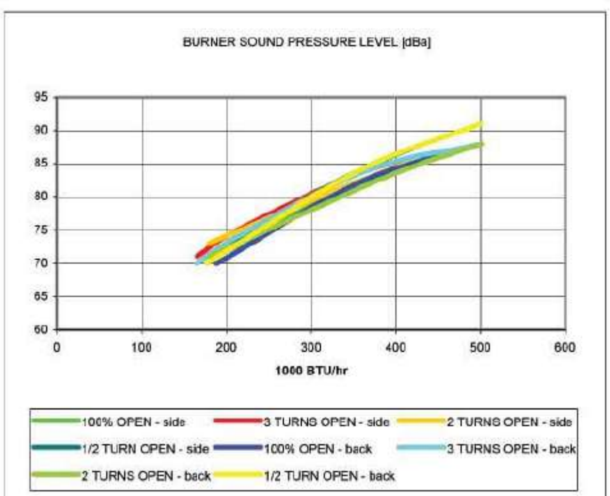
Manufacturer:	Bekaert (Config Medium D)
Description:	3"dia x18" mesh burner with 1-1/2" Eclipse Mixer, No Compound Barel, 1-1/2" x 2-1/2" Venturi
Orifice:	1/8"
Date:	15-Mar-05











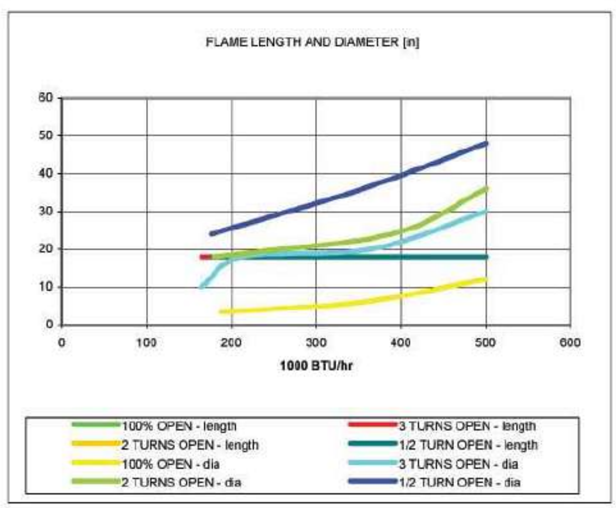


FIGURE 8.22 Bekaert – 3"x18" (Config. D) burner bench test performance summary.

8.7 Bekaert 3”x18” (Config. E) Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.23;
- same nozzle as used in Config. D
- pressure drop of the nozzle and fuel/air mixture distribution to the mesh controlled by perforated screen on the inside;
- nozzle was tested with available on site Eclipse compound barrel

Open Flame Tests

- see Figure 8.24;
- flame performance was similar to configuration “C”, “lazy” external flames still present at higher firing rates;
- The external flame was raising vertically up from the mesh surface in an uncontrollable fashion;
- This burner has no forward momentum and must rely on other means of directing the flame such as a strong natural draft or a combustion air blower
- Tube soot deposits and hot spots due to impingement around the burner will lead to a premature tube failure.
- This flame shape is not suitable for fire tube application.

Bench Test results

- See figure 8.25;
- Stoichiometric air in primary air high at approximately 100%;
- Gas pressure at 20 PSIG produces good air induction in the Eclipse mixer with compound barrel;
- Burner mixture pressure could not be measured;
- Sound pressure level (back measurement) low at 85 dBA;
- Large flame volume due to external flame with low Q/V (BTU/volume) = 72,000 BTU/ft3;
- L/D (length/diameter) ratio = 0.6 - difficult to measure due to external free flowing flame

PTAC — PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT		
	Project EETR 0401		
	Burner Characteristics		
	Design by: ENEFEN Energy Efficiency Engineering Ltd.		
Manufacturer:	Bekaert (Config Medium E)	Address:	1200 Chastain Rd.
Description:	3"dia x18" mesh burner with 2-1/2" Eclipse Mixer, With 2-1/2" Compound Barrel, 2-1/2" Nipple		Building 200, Suite 210
		City, Province, Code:	Kennesaw, GA 30144
Orifice:	1/8"	Telephone / Fax:	(800)241-4126/(770) 423-9181
Overall Length:	12" mesh+mixer+barrel+nipple = 46"	Web Site:	http://www.bekaert.com/BCT
 			General Arrangement Metal fibre media flame nozzle only supply fro burner manufacturer. Mixer and other components are by others.
  			Gas Nozzle Metal fibre media supported by an internal perforated stainless steel screen. Manufacture can vary the perforation sizes for various pressure drops. This nozzle relies on fuel/air pre-mixing. End plate could be either blank o mesh.
			Gas Mixer & Primary Air Adjustment Nozzle tested with 2-1/2" standard Eclipse mixer, 2-1/2" compound barrel and 2-1/2" straight nipple.
			Secondary Air Adjustment No secondary air adjustment incorporated

FIGURE 8.23 Bekaert – 3”x18” (Config. E) burner characteristics.

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.
Manufacturer:	Bekaert (Config Medium E)
Description:	3"dia x18" mesh burner with 2-1/2" Eclipse Mixer, With 2-1/2" Compound Barel, 2-1/2" Nipple
Orifice:	1/8"
Date:	19-Mar-05

		
498,000 BTU/hr ; 15.5	291,000 BTU/hr ; 15.5 turns	146,000 BTU/hr ; 15.5 turns
		
496,000 BTU/hr ; 4 turns	288,000 BTU/hr ; 4 turns	146,000 BTU/hr ; 4 turns
		
496,000 BTU/hr ; 3 turns	288,000 BTU/hr ; 3 turns	146,000 BTU/hr ; 3 turns

FIGURE 8.24 Bekaert – 3"x18" (Config. E) burner open flame tests.

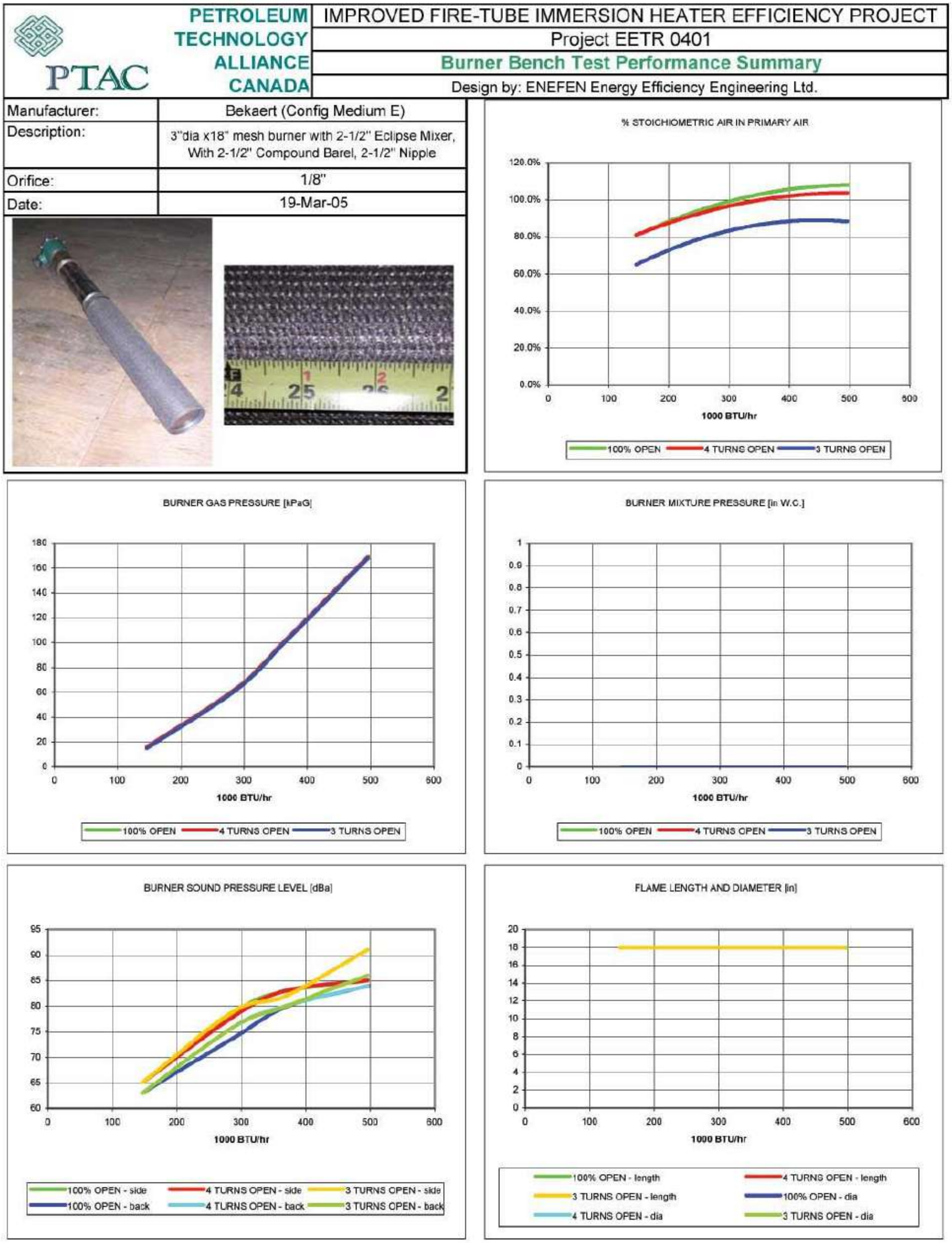


FIGURE 8.25 Bekaert – 3"x18" (Config. E) burner bench test performance summary.

8.8 Bekaert 3"x18" (Config. F) Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.26;
- same nozzle as used in Config. D and E
- pressure drop of the nozzle and fuel/air mixture distribution to the mesh controlled by perforated screen on the inside;
- nozzle was tested with Eclipse mixer and pipe nipple as supplied by manufacturer

Open Flame Tests

- see Figure 8.27;
- flame performance was similar to configuration "A", "lazy" external flames present at all firing rates, worst performance out of D, E, F configurations;
- The external flame was raising vertically up from the mesh surface in an uncontrollable fashion;
- This burner has no forward momentum and must rely on other means of directing the flame such as a strong natural draft or a combustion air blower
- Tube soot deposits and hot spots due to impingement around the burner will lead to a premature tube failure.
- This flame shape is not suitable for fire tube application.

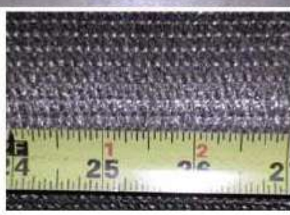
Bench Test results

- See figure 8.28;
- Stoichiometric air in primary air high at approximately 100%;
- Gas pressure at 20 PSIG produces good air induction in the Eclipse mixer;
- Burner mixture pressure could not be measured;
- Sound pressure level (back measurement) low at 83 dBA;
- Large flame volume due to external flame with low Q/V (BTU/volume) = 97,000 BTU/ft3;
- L/D (length/diameter) ratio = 0.7 - difficult to measure due to external free flowing flame

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT		
	Project EETR 0401		
	Burner Characteristics		
	Design by: ENEFEN Energy Efficiency Engineering Ltd.		
Manufacturer:	Bekaert (Config Medium F)	Address:	1200 Chastain Rd.
Description:	3"dia x18" mesh burner with 2-1/2" Eclipse Mixer, No Compound Barrel, 2-1/2" Nipple		Building 200, Suite 210
		City, Province, Code:	Kennesaw, GA 30144
Orifice:	1/8"	Telephone / Fax:	(800)241-4126/(770) 423-9181
Overall Length:	12" mesh+mixer+ nipple to suit = 41"	Web Site:	http://www.bekaert.com/BCT


General Arrangement

Metal fibre media flame nozzle only supply fro burner manufacturer. Mixer and other components are by others.


Gas Nozzle

Metal fibre media supported by an internal perforated stainless steel screen. Manufacture can vary the perforation sizes for various pressure drops. This nozzle relies on fuel/air pre-mixing. End plate could be either blank o mesh.

Gas Mixer & Primary Air Adjustment

Mixer supplied with the burner was a standard Eclipse 2-1/2" mixer. Straight 2-1/2" nipple wa used to connect mixer to nozzle

Secondary Air Adjustment

No secondary air adjustment incorporated

FIGURE 8.26 Bekaert – 3"x18" (Config. F) burner characteristics.

PTAC — PETROLEUM TECHNOLOGY ALLIANCE CANADA

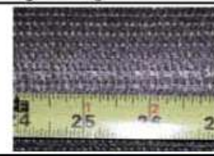
IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT

Project EETR 0401

Burner Open Flame Tests

Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Bekaert (Config Medium F)
Description:	3"dia x18" mesh burner with 2-1/2" Eclipse Mixer, No Compound Barel, 2-1/2" Nipple
Orifice:	1/8"
Date:	19-Mar-05



495,000 BTU/hr ; 15.5 turns

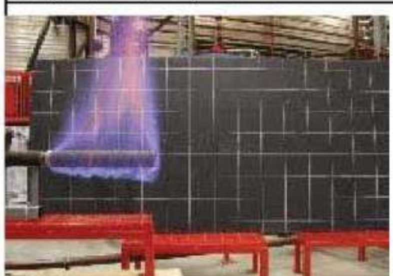
376,000 BTU/hr ; 15.5turns

148,000 BTU/hr ; 15.5 turns

497,000 BTU/hr ; 4 turns

295,000 BTU/hr ; 4 turns

151,000 BTU/hr ; 4 turns



497,000 BTU/hr ; 3 turns

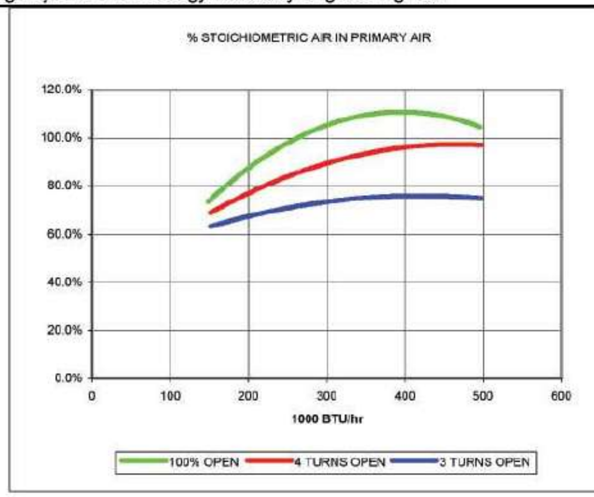
297,000 BTU/hr ; 3 turns

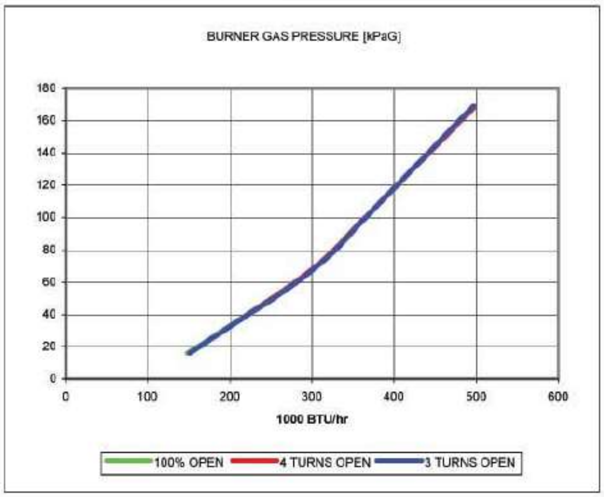
151,000 BTU/hr ; 3 turns

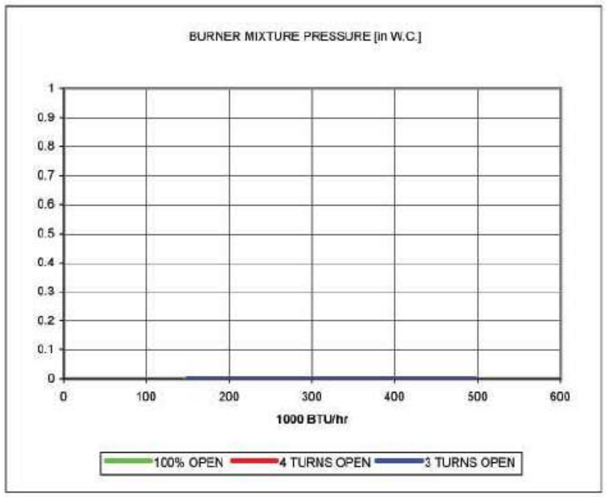
FIGURE 8.27 Bekaert – 3”x18” (Config. F) burner open flame tests.

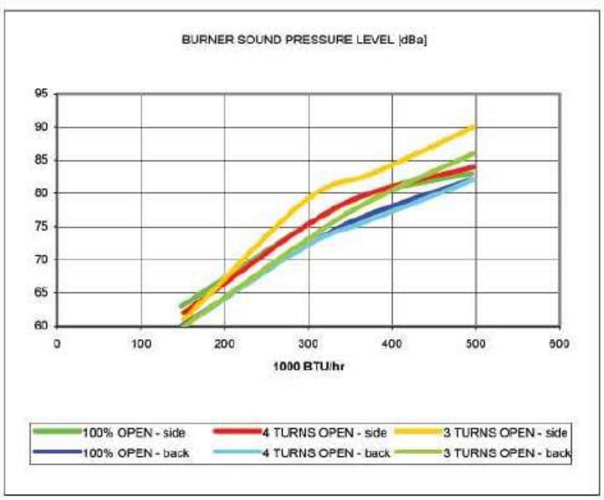
PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
PTAC	Project EETR 0401
	Burner Bench Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Bekaert (Config Medium F)
Description:	3"dia x18" mesh burner with 2-1/2" Eclipse Mixer, No Compound Barel, 2-1/2" Nipple
Orifice:	1/8"
Date:	19-Mar-05









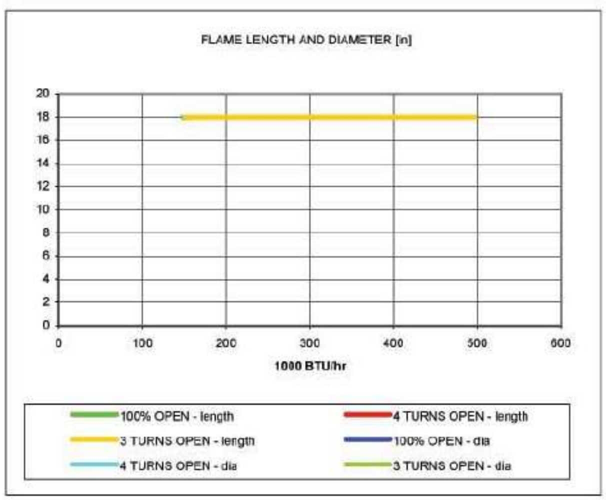


FIGURE 8.28 Bekaert – 3”x18” (Config. F) burner bench test performance summary.

8.9 Bekaert 4”x24” (Config. G) Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.29;
- largest 4” nozzle submitted for evaluation
- pressure drop of the nozzle and fuel/air mixture distribution to the mesh controlled by perforated screen on the inside;
- nozzle was tested with Eclipse mixer, compound barrel, and Venturi sleeve.

Open Flame Tests

- see Figure 8.30;
- flame performance was similar to smaller nozzles, “lazy” external flames present at firing rates close to stoichiometric, some improvement with fully open mixer and high excess air;
- top row of photos demonstrate well burner performance with high primary air (140% stoichiometric), middle row burner performance close to stoichiometric (90%) and bottom row partial primary air (40%).
- The external flame was raising vertically up from the mesh surface in an uncontrollable fashion;
- This burner has no forward momentum and must rely on other means of directing the flame such as a strong natural draft or a combustion air blower;
- Radiant heat from nozzle was overheating connecting nipple and Venturi sleeve (see dark discoloration in the photograph)
- Tube soot deposits and hot spots due to impingement around the burner will lead to a premature tube failure.
- This flame shape is not suitable for fire tube application.

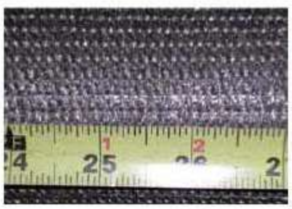
Bench Test results

- See figure 8.31;
- Stoichiometric air in primary air high at approximately 90% with controlled air flow, and 140% with fully open mixer;
- Gas pressure at 20 PSIG produces good air induction in the Eclipse mixer with Venturi;
- Burner mixture pressure could not be measured;
- Sound pressure level (back measurement) low at 85 dBA;
- Large flame volume due to external flame with low Q/V (BTU/volume) = 97,000 BTU/ft3;
- L/D (length/diameter) ratio = 0.7 - difficult to measure due to external free flowing flame

PETROLEUM TECHNOLOGY ALLIANCE CANADA (PTAC)	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT		
	Project EETR 0401		
	Burner Characteristics		
	Design by: ENEFEN Energy Efficiency Engineering Ltd.		
Manufacturer:	Bekaert (Config Long G)	Address:	1200 Chastain Rd.
Description:	4"dia x24" mesh burner with 2-1/2" Eclipse Mixer, With 2-1/2" Compound Barrel, 2-1/2" x 3" Venturi		Building 200, Suite 210
		City, Province, Code:	Kennesaw, GA 30144
Orifice:	1/8"	Telephone / Fax:	(800)241-4126/(770) 423-9181
Overall Length:	24" mesh+mixer+compound barrel+Venturi = 57"	Web Site:	http://www.bekaert.com/BCT

General Arrangement

Metal fibre media flame nozzle only supply fro burner manufacturer. Mixer and other components are by others.



Gas Nozzle

Metal fibre media supported by an internal perforated stainless steel screen. Manufacture can vary the perforation sizes for various pressure drops. This nozzle relies on fuel/air pre-mixing. End plate could be either blank o mesh.

Gas Mixer & Primary Air Adjustment

Nozzle tested with 2-1/2" standard Eclipse mixer, 2-1/2" compound barrel and 2-1/2"x3" Venturi.

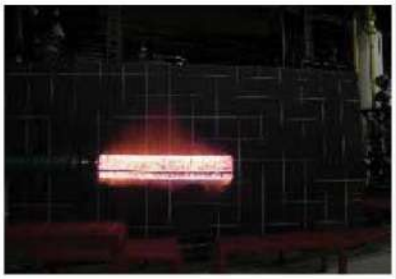
Secondary Air Adjustment

No secondary air adjustment incorporated

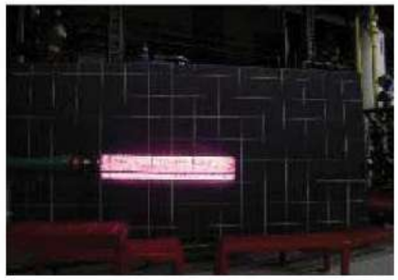
FIGURE 8.29 Bekaert – 4”x24” burner characteristics.

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

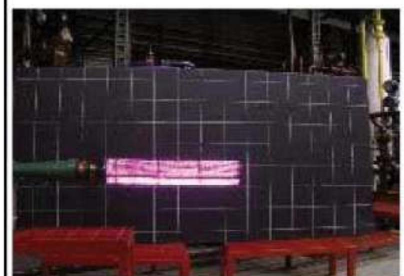
Manufacturer:	Bekaert (Config Long G)
Description:	4"dia x24" mesh burner with 2-1/2" Eclipse Mixer, With 2-1/2" Compound Barel, 2-1/2" x 3" Venturi
Orifice:	1/8"
Date:	30-Mar-05



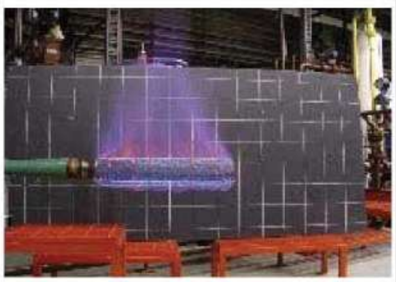
478,000 BTU/hr ; 5 turns



299,000 BTU/hr ; 5 turns

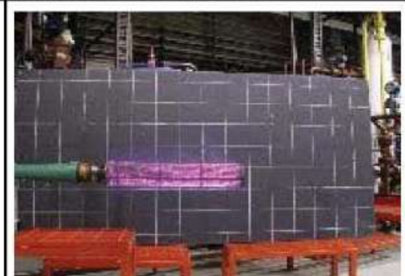


112,000 BTU/hr ; 5 turns



477,000 BTU/hr ; 2 turns

291,000 BTU/hr ; 2 turns



113,000 BTU/hr ; 2 turns

479,000 BTU/hr ; 1 turn

299,000 BTU/hr ; 1 turn

114,000 BTU/hr ; 1 turn

FIGURE 8.30 Bekaert – 4”x24” burner open flame tests.

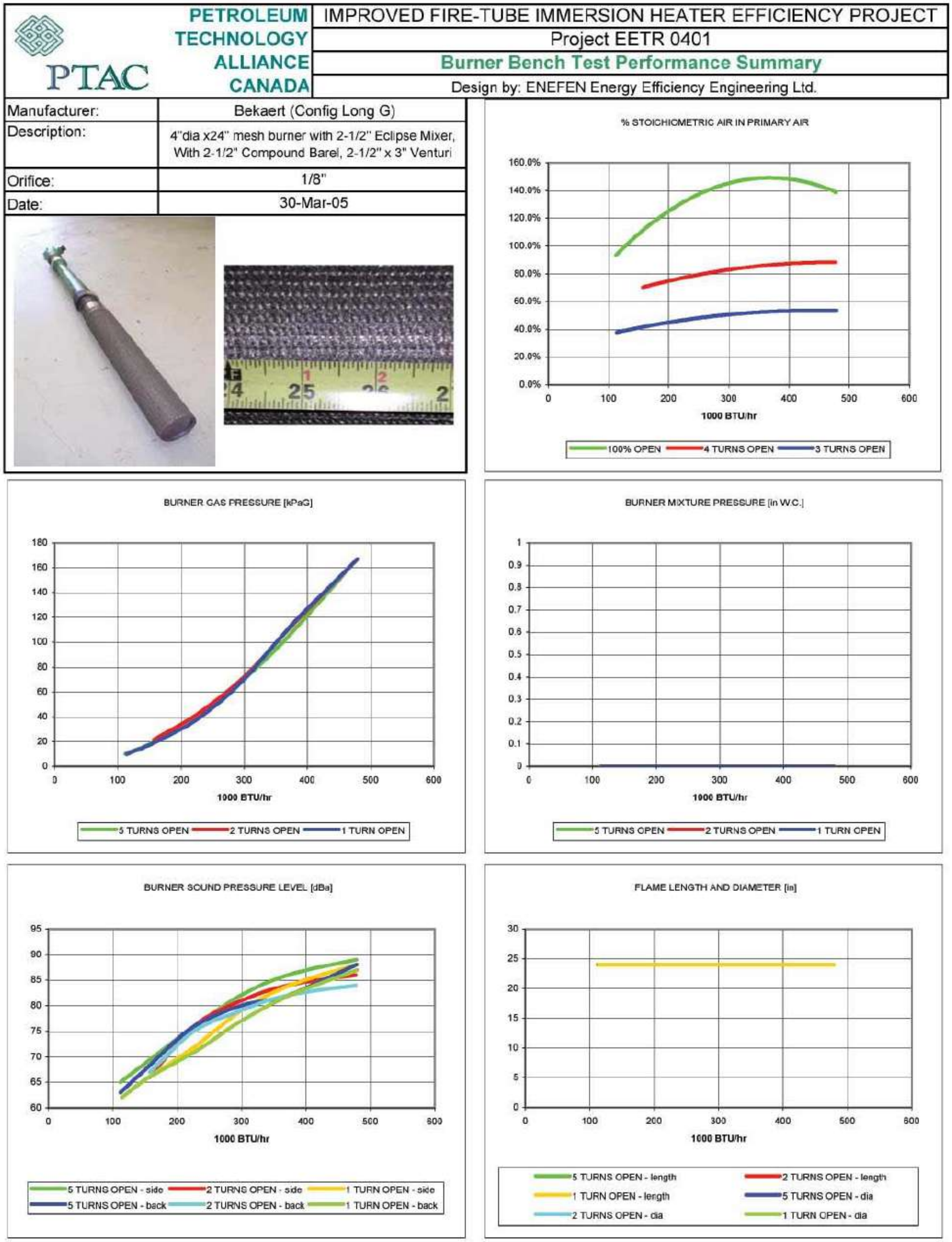


FIGURE 8.31 Bekaert – 4"x24" burner bench test performance summary.

8.10 Eclipse 1-1/2" Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.32;
- most common burner in fire tube heaters in Alberta
- Ferrofix nozzle producing narrow flame more suitable for this application than a Sticktite nozzle with wider flame which has a tendency to produce rumble and pulsations;
- Complete assembly consisting of air/fuel mixer, compound barrel, Venturi sleeve, and Ferrofix gas nozzle.
- Somewhat difficult to reach gas orifice, which requires the removal of the mixer.
- Primary air louver lock using electric crown nut does not provide secure locking

Open Flame Tests

- see Figure 8.33; three flame type are clearly visible:
- typical high momentum/intensity premix burner. Good flame stability, although may become unstable at low firing rates, good match for the fire tube application.
- top row of photographs illustrates 120% stoichiometric air/fuel ratio homogeneously premixed inside the mixer; resulting in a fully aerated short and straight flame; blue, purple and white in colour; ideal for the fire tube application; will not impinge on the tube surface and will also result in the highest radiative heat transfer.
- Middle row of photographs illustrates 70% stoichiometric air/fuel ratio; resulting in an air deficient flame; blue and reddish in colour; bending upwards due to buoyancy, not recommended for fire tube application; as it will impinge on the tube surface, some soot deposit and local tube overheating/thermal oxidation probable.
- Bottom row of photographs illustrates 30% stoichiometric air/fuel ratio, resulting in a mostly raw gas flame; blue and yellow in colour; unburned fuel searching for oxygen turns into uncontrollable yellow flame tips impinging on the tube surface. Not recommended to the fire tube application. Will lead to soot deposits, tube overheating oxidation and premature failure.

Bench Test results

- See figure 8.34;
- Stoichiometric air in primary air high at approximately 120% ideal for fire tube application but it may create flame stability at turndown;
- Gas pressure at 20 PSIG produces good air induction in the Eclipse mixer with compound barrel and Venturi;
- Burner mixture pressure 1.8" W.C.;
- Sound pressure level (back measurement) high at 100 dBA;
- small flame volume with high Q/V (BTU/volume) = 5,052,000 BTU/ft3;
- L/D (length/diameter) ratio = 8

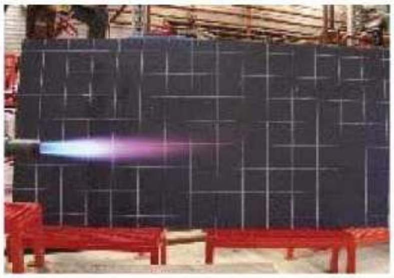
PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT		
	Project EETR 0401		
	Burner Characteristics		
	Design by: ENEFEN Energy Efficiency Engineering Ltd.		
Manufacturer:	Eclipse	Address:	#5,3530-11A Street N.E.
Description:	1-1/2" Eclipse Mixer, With 1-1/2" Compound Barrel, 1-1/2" x 2-1/2" Venturi, 2-1/2" Nozzle	City, Province, Code:	Calgary, AB T2E 6M7
Orifice:	1/8"	Telephone / Fax:	(403) 291-9211/(403) 291-9214
Overall Length:	30"	Web Site:	www.eclipsenet.com

	General Arrangement Typical complete assembly of Eclipse burner common in the industry. Assembly consists of a mixer, compound barrel, Venturi, and gas nozzle.
	Gas Nozzle Eclipse Ferrofix Nozzle with built-in flame retention feature. Nozzle produces long and narrow flame pattern as compared to a wider flame available with Sticktite nozzles.
	Gas Mixer & Primary Air Adjustment Eclipse mixer commonly used in the industry also by some of the other burner manufacturers. Basic mixer features cast iron body with gas orifice and primary air shutter. Also supplied with the burner is a needle valve which allows fine adjustment to the orifice opening. The optional compound barrel is used to enhance fuel/air mixing, and is recommended for heavier fuel gases.
	Secondary Air Adjustment No secondary air adjustment incorporated

FIGURE 8.32 Eclipse – 1-1/2" burner characteristics.

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Eclipse
Description:	1-1/2" Eclipse Mixer, With 1-1/2" Compound Barel, 1-1/2" x 2-1/2" Venturi, 2-1/2" Nozzle
Orifice:	1/8"
Date:	14-Mar-05



496,000 BTU/hr ; 100% open

353,000 BTU/hr ; 100% open

224,000 BTU/hr ; 100% open

497,000 BTU/hr ; 2 turns

212,000 BTU/hr ; 2 turns

119,000 BTU/hr ; 2 turns

497,000 BTU/hr ; 0.5 turns

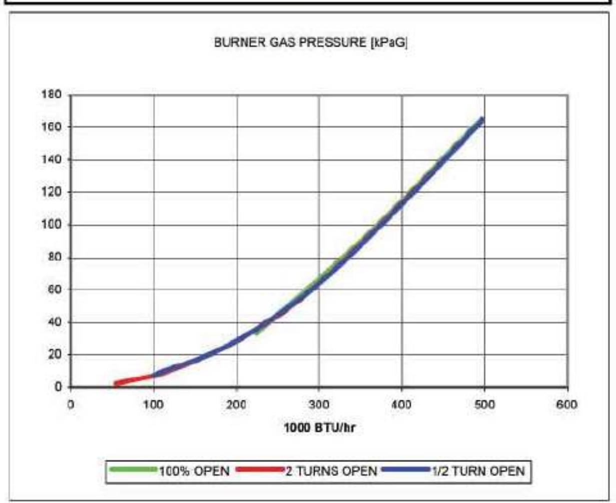
320,000 BTU/hr ; 0.5 turns

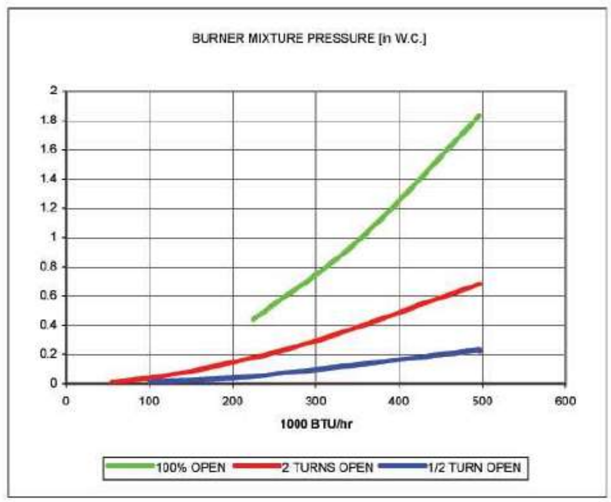
198,000 BTU/hr ; 0.5 turns

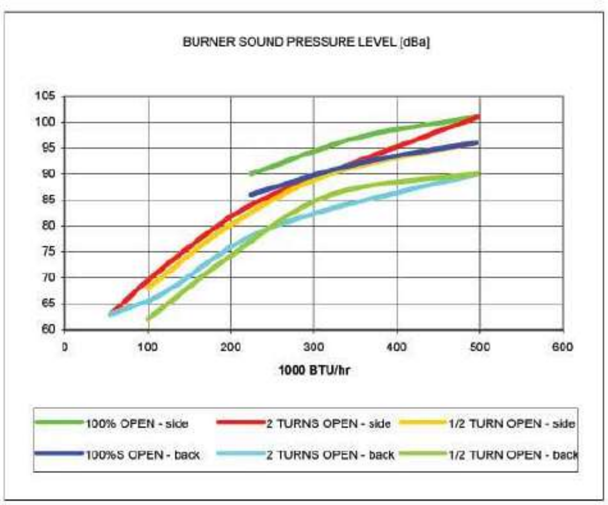
FIGURE 8.33 Eclipse – 1-1/2" burner open flame tests.

PETROLEUM TECHNOLOGY ALLIANCE CANADA	Project EETR 0401
PTAC	**Burner Bench Test Performance Summary**
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Eclipse
Description:	1-1/2" Eclipse Mixer, With 1-1/2" Compound Barel, 1-1/2" x 2-1/2" Venturi, 2-1/2" Nozzle
Orifice:	1/8"
Date:	14-Mar-05







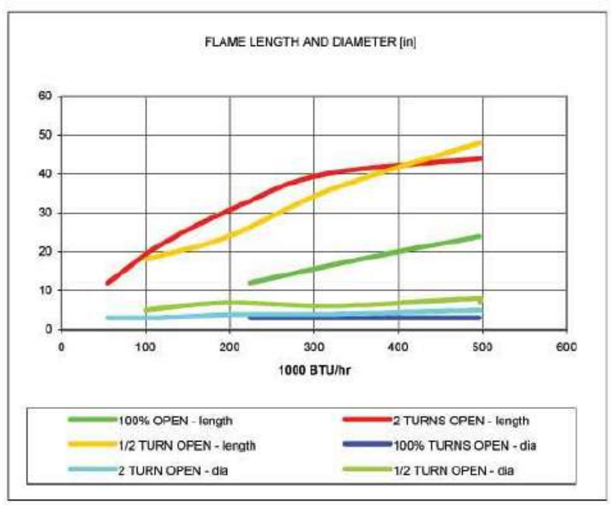


FIGURE 8.34 Eclipse – 1-1/2" burner bench test performance summary.

8.11 Hauck 2" Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.35;
- very un-common burner in Alberta
- Excellent, heavy duty cast gas nozzle design with good flame retention capability
- Simple assembly with integral mixer and Venturi sleeve with low air inlet coefficient.
- Easy to reach gas orifice.
- Secure locking mechanism of the primary air.

Open Flame Tests

- see Figure 8.36;
- excellent high momentum/intensity premix burner. Good flame stability, for all firing ranges and most primary air settings.
- Top three rows of photographs illustrate between 80% and 110% stoichiometric air/fuel ratio homogeneously premixed inside the mixer; resulting in a fully aerated short and straight flame; blue, purple and white in colour; ideal for the fire tube application; will not impinge on the tube surface and will also result in the highest radiative heat transfer.

Bench Test results

- See figure 8.37;
- Stoichiometric air in primary air high at approximately 110% ideal for fire tube application;
- Gas pressure at 20 PSIG produces good air induction in this high efficiency Venturi;
- Burner mixture pressure measured at .1" W.C (? possibly in error);
- Sound pressure level (back measurement) high at between 95 and 100 dBA;
- small flame volume flame with high Q/V (BTU/volume) = 1,677,000 BTU/ft3;
- L/D (length/diameter) ratio = 7.5

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT		
	Project EETR 0401		
	Burner Characteristics		
	Design by: ENEFEN Energy Efficiency Engineering Ltd.		
Manufacturer:	Hauck Manufacturing	Address:	PO Box 90
Description:	2" Venturi with RAF nozzle	City, Province, Code:	Lebanon, PA 17042
Orifice:	3/32" (redrilled to 1/8")	Telephone / Fax:	(717) 272-3051
Overall Length:	20"	Web Site:	http://www.hauckburner.com

	General Arrangement Burner assembly features gas nozzle, venturi mixer, and primary air shutter combination. Cast iron components
	Gas Nozzle Heavy duty cast iron nozzle includes internal flame retention device with large main gas orifice and 8 smaller holes located around its perimeter
	Gas Mixer & Primary Air Adjustment Gas mixer features a low entrance loss bell shaped inlet and perpendicular flow of combustion air relative to gas flow, for enhanced mixing. Heavy duty cast iron shutter includes a locking screw. Gas Connection through the back of the mixer.
	Secondary Air Adjustment No secondary air adjustment incorporated

FIGURE 8.35 Hauck – 2" burner characteristics.

PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
		Project EETR 0401
		Burner Open Flame Tests
		Design by: ENEFEN Energy Efficiency Engineering Ltd.
Manufacturer:	Hauck Manufacturing	
Description:	2" Venturi with RAF nozzle	
Orifice:	3/32" (drilled later to 1/8" for 500,000)	
Date:	15-Mar-05	

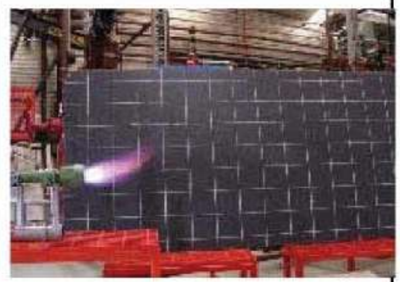
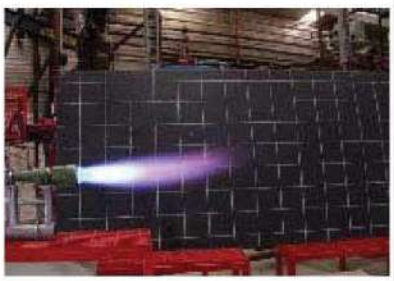
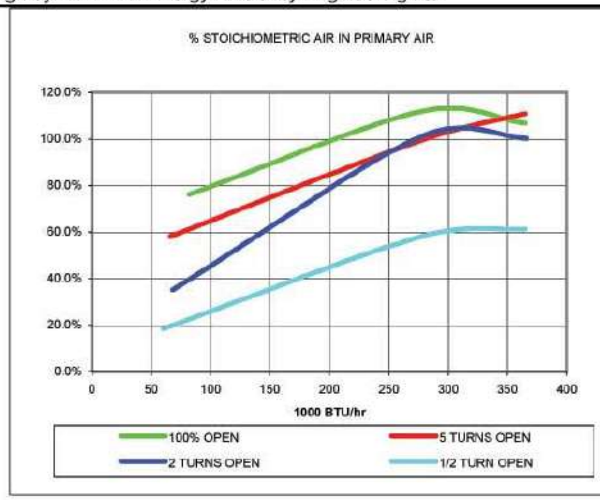
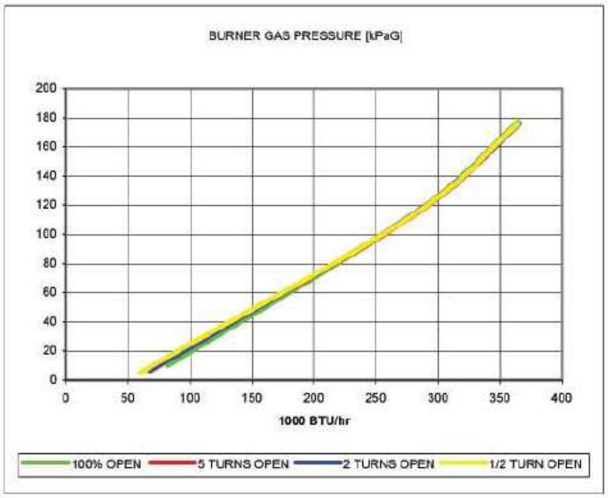
		
365,000 BTU/hr ; 11.5 turns	278,000 BTU/hr ; 11.5 turns	82,000 BTU/hr ; 11.5 turns
		
365,000 BTU/hr ; 5 turns	279,000 BTU/hr ; 5 turns	66,000 BTU/hr ; 5 turns
		
336,000 BTU/hr ; 2 turns	277,000 BTU/hr ; 2 turns	68,000 BTU/hr ; 2 turns
		
365,000 BTU/hr ; 0.5 turns	278,000 BTU/hr ; 0.5 turns	60,000 BTU/hr ; 0.5 turns

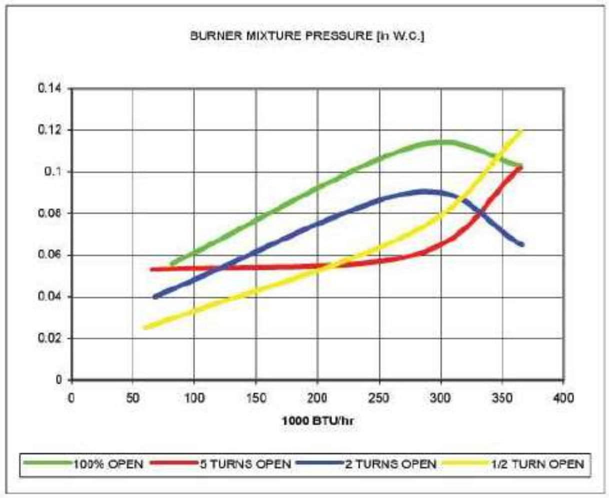
FIGURE 8.36 Hauck – 2” burner open flame tests.

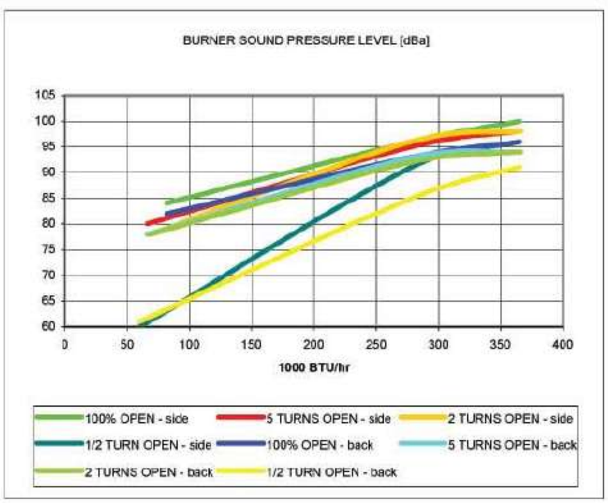
PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Bench Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Hauck Manufacturing
Description:	2" Venturi with RAF nozzle
Orifice:	3/32"
Date:	15-Mar-05









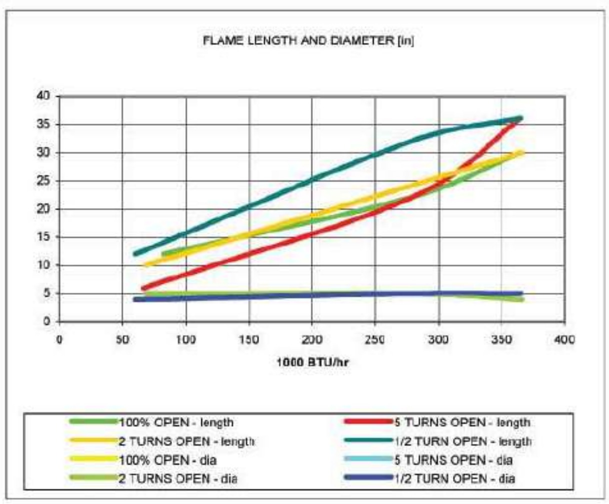


FIGURE 8.37 Hauck – 2" burner bench test performance summary.

8.12 Kenilworth 1-1/2" (Config. 101) Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.38;
- combination of gas nozzle with secondary air spinner and external burner sleeve
- good flame retention capability
- large non-plugging burner orifices
- Simplified "stepped" small diameter and lower efficiency "Venturi"
- Modified small Eclipse mixer, with low air entrance coefficient, and difficult to reach gas orifice, but redrilled internally to accommodate flue gas recirculation
- Secure locking mechanism of the primary air, plus adjusting plate drilled to ensure sufficient airflow.
- Unique "scavenger" flue gas recirculation arrangement designed to preheat wet fuel gas using hot products of combustion.
- Self-centering bracket

Open Flame Tests

- see Figure 8.39;
- long but relatively straight flame shaped by the external burner sleeve.
- Reddish flame colour indicates soot caused by insufficient primary combustion air, internal burner flame impingement, and/or carbon from local overheating of steel burner surfaces. High burner sleeve temperature indicated by red glow, and sleeve discoloration, may lead to premature oxidation of the sleeve.

Bench Test results

- See figure 8.40;
- Stoichiometric air in primary air low at approximately 50%;
- Gas pressure at 10 PSIG not fully utilized for primary air induction;
- Burner mixture pressure measured at 1.4" W.C;
- Sound pressure level (back measurement) high at between 95 dBA;
- small flame volume with high Q/V (BTU/volume) = 1,062,000 BTU/ft3;
- L/D (length/diameter) ratio = 8.4

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT		
	Project EETR 0401		
	Burner Characteristics		
	Design by: ENEFEN Energy Efficiency Engineering Ltd.		
Manufacturer:	Kenilworth (Config. 101)	Address:	Box 12118
Description:	1-1/2" low pressure with flame scavenger, 1-1/2"x5" turbulator	City, Province, Code:	Lloydminster, AB T9V 3C4
Orifice:	#23	Telephone / Fax:	780 853 7775
Overall Length:	32"	Web Site:	www.kenilworth.ca


General Arrangement

Burner assembly features gas nozzle / secondary air spinner combination, "simplified" venturi, mixer with primary air shutter air flue gas recirculation arrangement for fuel gas preheating (scavenger). Tube centering bracket with adjustable feet attached to venturi.


Gas Nozzle

Custom gas nozzle with main gas port located inside conical air deflector with peripheral gas ports behind the deflector. Secondary air spinner welded to the gas nozzle includes flame shaping tube shroud.


Gas Mixer & Primary Air Adjustment

Modified Eclipse mixer with fuel gas entry through the back of the assembly. Eclipse needle valve replaced with custom machined sleeve designed to induce negative pressure inside the fuel chamber for fuel gas recirculation (FGR). Amount of FGR can be tuned by adjusting the position of the sleeve. Primary air shutter modified by drilling 8 holes and adding a set screw to lock the shutter position.

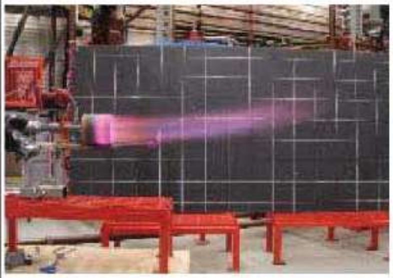
Secondary Air Adjustment

Fixed secondary air spinner welded to gas nozzle. Spinner blades angled to induce spin on the secondary air stream. External shroud tube used to contain and shape the flame. "simplified" Venturi made out of crimped tube.

FIGURE 8.38 Kenilworth – 1-1/2" (Config 101) burner characteristics.

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Kenilworth (Config. 101)
Description:	1-1/2" low pressure with flame scavenger, 1-1/2"x5" turbulator
Orifice:	#23
Date:	29-Mar-05



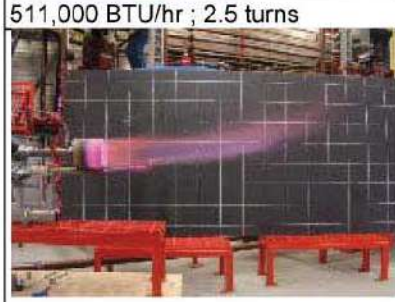
507,000 BTU/hr ; 6 turns

87,000 BTU/hr ; 6 turns

511,000 BTU/hr ; 2.5 turns

248,000 BTU/hr ; 2.5 turns

88,000 BTU/hr ; 2.5 turns



512,000 BTU/hr ; 1 turn

248,000 BTU/hr ; 1 turn

93,000 BTU/hr ; 1 turn

517,000 BTU/hr ; 0 turns

417,000 BTU/hr ; 0 turns

93,000 BTU/hr ; 0 turns

FIGURE 8.39 Kenilworth – 1-1/2" (Config 101) burner open flame tests.

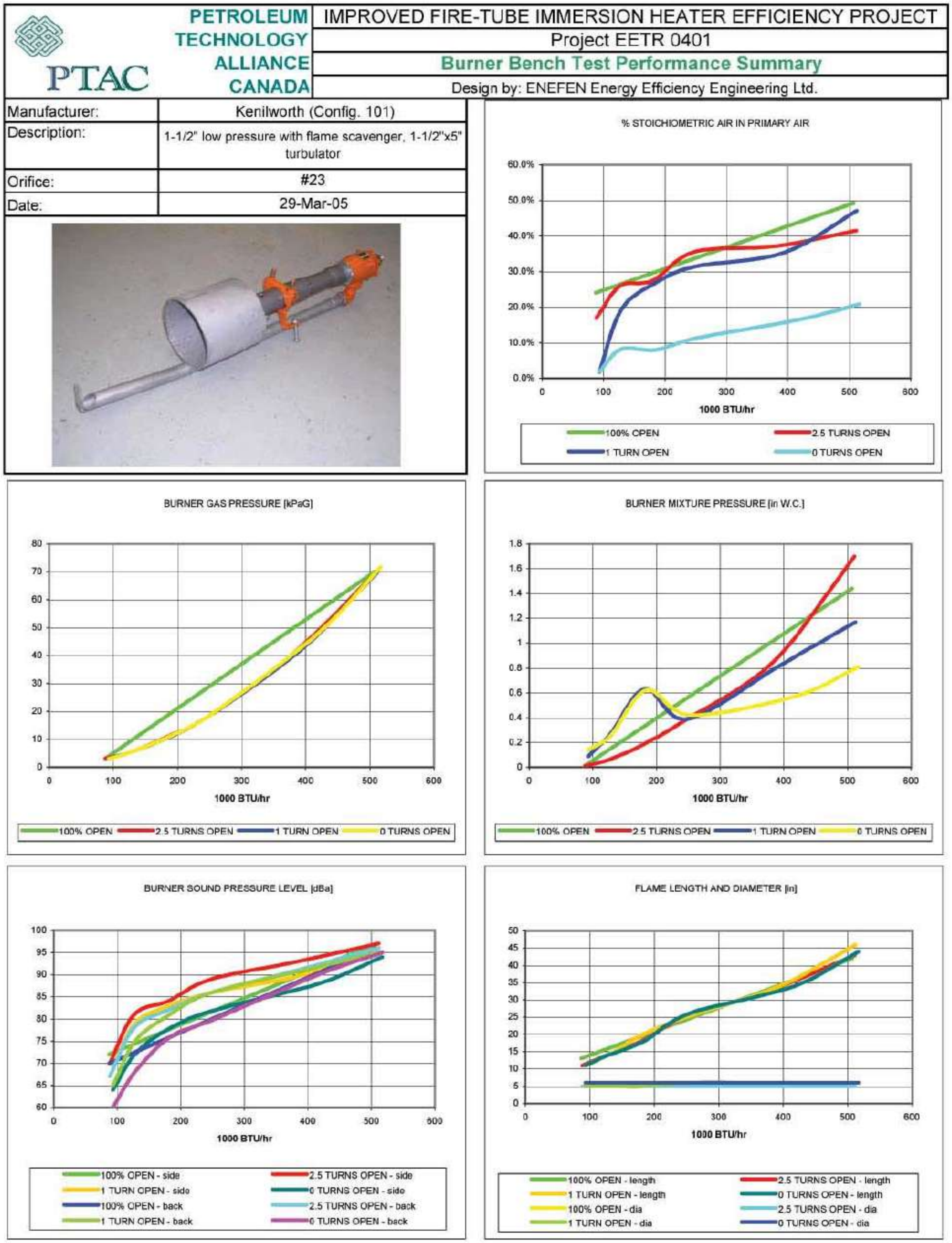


FIGURE 8.40 Kenilworth – 1-1/2" (Config 101) burner bench test performance summary.

8.13 Kenilworth 1-1/2" (Config. 102) Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.41;
- combination of gas nozzle with secondary air spinner and external burner sleeve
- good flame retention capability
- large non-plugging burner orifices
- Standard small size Eclipse mixer, compound barrel and Venturi sleeve
- Self-centering bracket

Open Flame Tests

- see Figure 8.42;
- long but relatively straight flame shaped by the external burner sleeve.
- Reddish flame colour indicates soot caused by insufficient primary combustion air, internal burner flame impingement, and/or carbon from local overheating of steel burner surfaces. High burner sleeve temperature indicated by red glow, and sleeve discoloration, may lead to premature oxidation of the sleeve.

Bench Test results

- See figure 8.43;
- Stoichiometric air in primary air at approximately 75%;
- Gas pressure at 10 PSIG not fully utilized for primary air induction;
- Burner mixture pressure measured at .45" W.C;
- Sound pressure level (back measurement) high at between 95 to 97 dBA;
- medium flame volume with high Q/V (BTU/volume) = 726,100 BTU/ft3;
- L/D (length/diameter) ratio = 7.0

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT		
	Project EETR 0401		
	Burner Characteristics		
	Design by: ENEFEN Energy Efficiency Engineering Ltd.		
Manufacturer:	Kenilworth (Config. 102)	Address:	Box 12118
Description:	1-1/2" with Eclipse Mixer, compound, sleeve, 2"x6" turbulator	City, Province, Code:	Lloydminster, AB T9V 3C4
Orifice:	#27	Telephone / Fax:	780 853 7775
Overall Length:	28"	Web Site:	www.kenilworth.ca


General Arrangement

Burner assembly features gas nozzle / secondary air spinner combination, Eclipse venturi, compound barrel, and mixer with primary air shutter. Tube centering bracket with adjustable feet attached to venturi.


Gas Nozzle

Custom gas nozzle with main gas port located inside conical air deflector with peripheral gas ports behind the deflector. Secondary air spinner welded to the gas nozzle includes flame shaping tube shroud.

Gas Mixer & Primary Air Adjustment

Eclipse mixer commonly used in the industry. Basic mixer features cast iron body with gas orifice and primary air shutter. Also supplied with the burner is a needle valve, which allows fine adjustment to the orifice opening. The compound barrel is used to enhance fuel/air mixing, and is recommended for heavier fuel gases. Side fuel gas entry.

Secondary Air Adjustment

Fixed secondary air spinner welded to gas nozzle. Spinner blades angled to induce spin on the secondary air stream. External shroud tube used to contain and shape the flame.

FIGURE 8.41 Kenilworth – 1-1/2" (Config 102) burner characteristics.

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Kenilworth (Config. 102)
Description:	1-1/2" with Eclipse Mixer, compound, sleeve, 2"x6" turbulator
Orifice:	#27
Date:	29-Mar-05

499,000 BTU/hr ; 6 turns

351,000 BTU/hr ; 6 turns

94,000 BTU/hr ; 6 turns

499,000 BTU/hr ; 2 turns

354,000 BTU/hr ; 2 turns

94,000 BTU/hr ; 2 turns

500,000 BTU/hr ; 1 turn

352,000 BTU/hr ; 1 turn

96,000 BTU/hr ; 1 turn

500,000 BTU/hr ; 0.5 turns

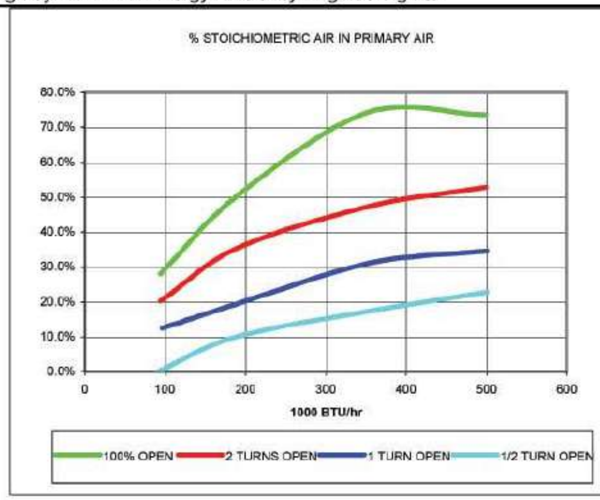
350,000 BTU/hr ; 0.5 turns

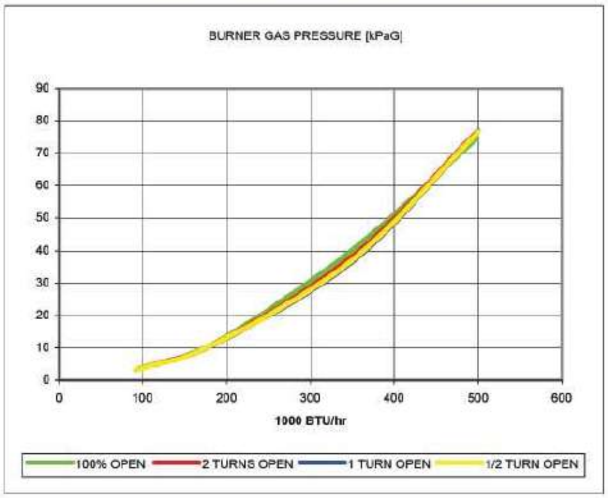
91,000 BTU/hr ; 0.5 turns

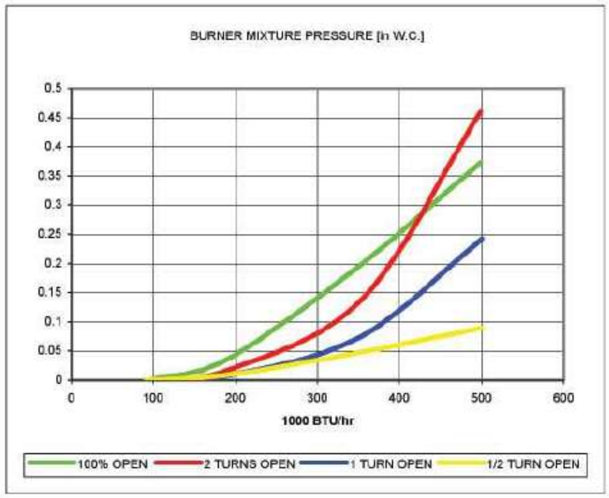
FIGURE 8.42 Kenilworth – 1-1/2" (Config 102) burner open flame tests.

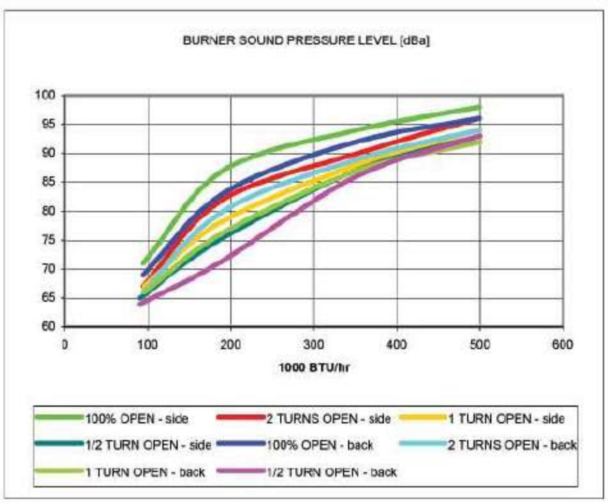
PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Bench Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Kenilworth (Config. 102)
Description:	1-1/2" with Eclipse Mixer, compound, sleeve, 2"x6" turbulator
Orifice:	#27
Date:	29-Mar-05









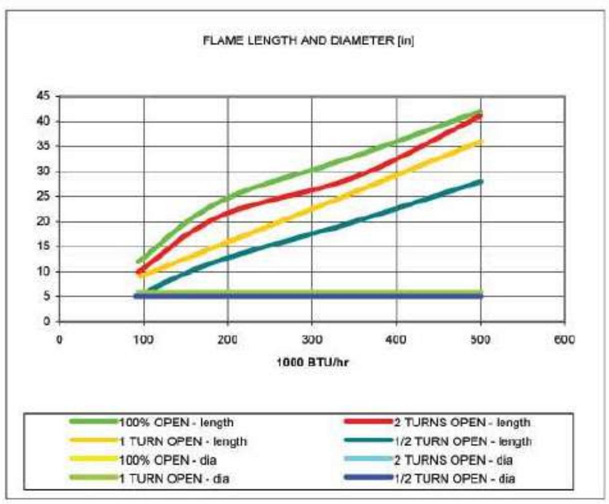


FIGURE 8.43 Kenilworth – 1-1/2" (Config 102) burner bench test performance summary.

8.14 Kenilworth 1-1/2" (Config. 103) Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.44;
- combination of gas nozzle with secondary air spinner and external burner sleeve
- good flame retention capability
- large non-plugging burner orifices
- Standard small size Eclipse mixer
- Simplified "stepped" small diameter and lower efficiency "Venturi"
- Self-centering bracket

Open Flame Tests

- see Figure 8.45;
- long but relatively straight flame shaped by the external burner sleeve.
- Reddish flame colour indicates soot caused by insufficient primary combustion air, internal burner flame impingement, and/or carbon from local overheating of steel burner surfaces. High burner sleeve temperature indicated by red glow, and sleeve discoloration, may lead to premature oxidation of the sleeve.

Bench Test results

- See figure 8.46;
- Stoichiometric air in primary air at approximately 60%;
- Gas pressure at 10 PSIG not fully utilized for primary air induction;
- Burner mixture pressure measured at 1.2" W.C;
- Sound pressure level (back measurement) high at between 95 to 100 dBA;
- low flame volume with high Q/V (BTU/volume) = 1,048,000 BTU/ft3;
- L/D (length/diameter) ratio = 8.4

PETROLEUM TECHNOLOGY ALLIANCE CANADA

PTAC

IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT

Project EETR 0401

Burner Characteristics

Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Kenilworth (Config. 103)	Address:	Box 12118
Description:	1-1/2" conventional , 1-1/2"x5" turbulator		
		City, Province, Code:	Lloydminster, AB T9V 3C4
Orifice:	#27	Telephone / Fax:	780 853 7775
Overall Length:	24"	Web Site:	www.kenilworth.ca


General Arrangement

Burner assembly features gas nozzle / secondary air spinner combination, "simplified" venturi, Eclipse mixer with primary air shutter. Tube centering bracket with adjustable feet attached to venturi.


Gas Nozzle

Custom gas nozzle with main gas port located inside conical air deflector with peripheral gas ports behind the deflector. Secondary air spinner welded to the gas nozzle includes flame shaping tube shroud.

Gas Mixer & Primary Air Adjustment

Eclipse mixer commonly used in the industry. Basic mixer features cast iron body with gas orifice and primary air shutter. Also supplied with the mixer is a needle valve, which allows fine adjustment to the orifice opening. Side fuel gas entry.

Secondary Air Adjustment

Fixed secondary air spinner welded to gas nozzle. Spinner blades angled to induce spin on the secondary air stream. External shroud tube used to contain and shape the flame. "Simplified" Venturi made out of crimped tube.

FIGURE 8.44 Kenilworth – 1-1/2" (Config 103) burner characteristics.

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Kenilworth (Config. 103)
Description:	1-1/2" conventional , 1-1/2"x5" turbulator
Orifice:	#27
Date:	29-Mar-05

500,000 BTU/hr ; 6 turns

353,000 BTU/hr ; 6 turns

92,000 BTU/hr ; 6 turns

500,000 BTU/hr ; 2 turns

348,000 BTU/hr ; 2 turns

98,000 BTU/hr ; 2 turns

500,000 BTU/hr ; 1 turn

351,000 BTU/hr ; 1 turn

93,000 BTU/hr ; 1 turn

502,000 BTU/hr ; 0 turns

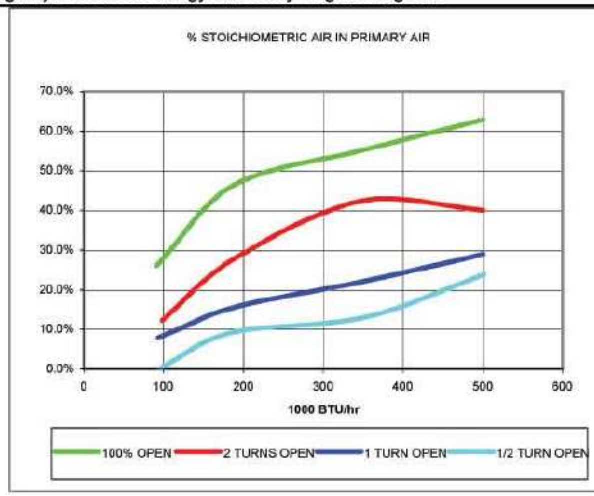
351,000 BTU/hr ; 0 turns

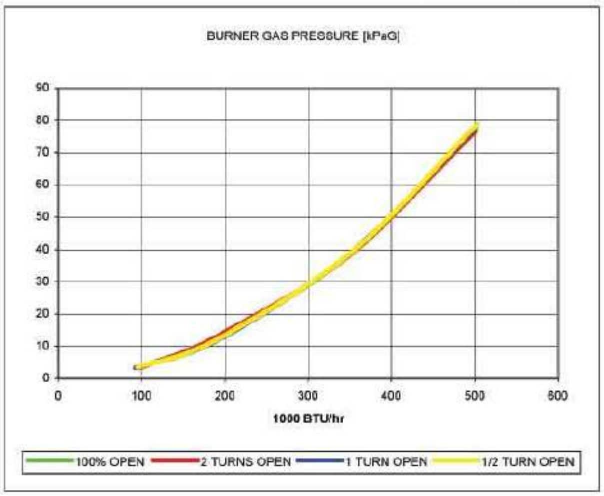
95,000 BTU/hr ; 0 turns

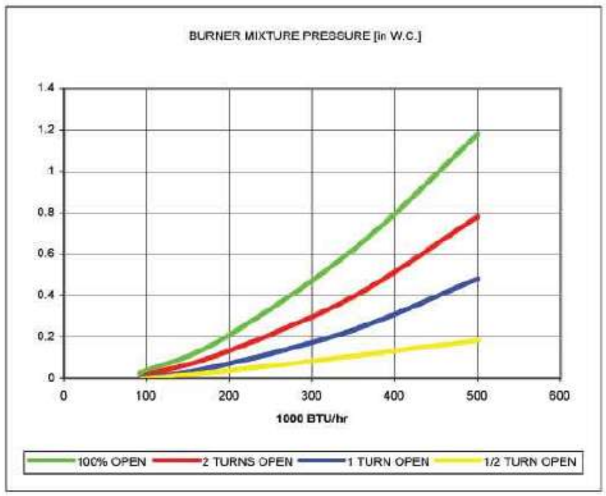
FIGURE 8.45 Kenilworth – 1-1/2" (Config 103) burner open flame tests.

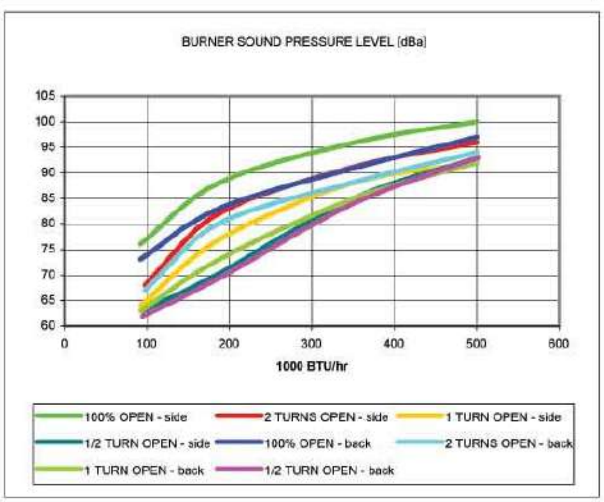
PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Bench Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Kenilworth (Config. 103)
Description:	1-1/2" conventional , 1-1/2"x5" turbulator
Orifice:	#27
Date:	29-Mar-05









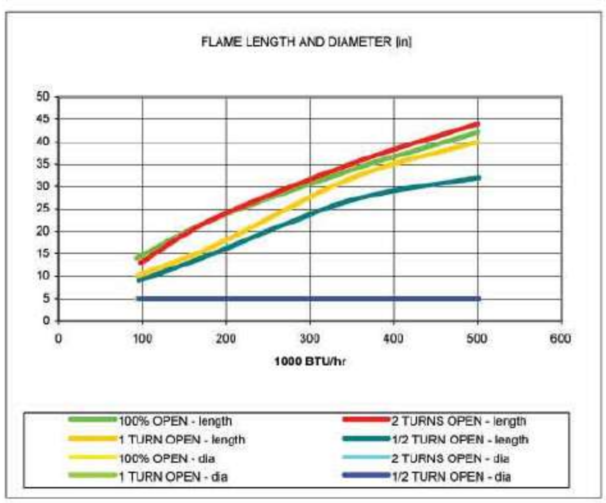


FIGURE 8.46 Kenilworth – 1-1/2" (Config 103) burner bench test performance summary.

8.15 Kenilworth 1-1/2" (Config. 104) Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.47;
- combination of gas nozzle with secondary air spinner and external burner sleeve
- good flame retention capability
- large non-plugging burner orifices
- Simplified "stepped" small diameter and lower efficiency "Venturi"
- Modified small Eclipse mixer, with low air entrance coefficient, and difficult to reach gas orifice, but redrilled internally to accommodate flue gas recirculation, compound barrel
- Secure locking mechanism of the primary air, plus adjusting plate drilled to ensure sufficient airflow.
- Unique "scavenger" flue gas recirculation arrangement designed to preheat wet fuel gas using hot products of combustion.
- Self-centering bracket

Open Flame Tests

- see Figure 8.48;
- long but relatively straight flame shaped by the external burner sleeve.
- Reddish flame colour indicates soot caused by insufficient primary combustion air, internal burner flame impingement, and/or carbon from local overheating of steel burner surfaces. High burner sleeve temperature indicated by red glow, and sleeve discoloration, may lead to premature oxidation of the sleeve.

Bench Test results

- See figure 8.49;
- Stoichiometric air in primary air low at approximately 50%;
- Gas pressure at 10 PSIG not fully utilized for primary air induction;
- Burner mixture pressure measured at 1.4" W.C;
- Sound pressure level (back measurement) high at between 95 dBA;
- small flame volume due to external flame with high Q/V (BTU/volume) = 1,062,000 BTU/ft3;
- L/D (length/diameter) ratio = 8.4
- Very similar in performance to configuration 101

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT		
	Project EETR 0401		
	Burner Characteristics		
	Design by: ENEFEN Energy Efficiency Engineering Ltd.		
Manufacturer:	Kenilworth (Config. 104)	Address:	Box 12118
Description:	1-1/2" low pressure with flame scavenger, compound mixer, 1-1/2" x 5" turbulator	City, Province, Code:	Lloydminster, AB T9V 3C4
Orifice:	#23	Telephone / Fax:	780 853 7775
Overall Length:	31"	Web Site:	www.kenilworth.ca

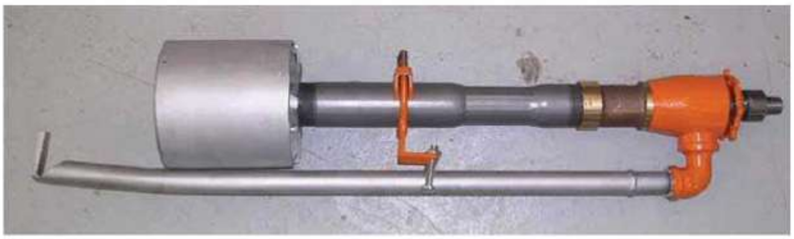
	General Arrangement Burner assembly features gas nozzle / secondary air spinner combination, "simplified" venturi, mixer with primary air shutter air flue gas recirculation arrangement for fuel gas preheating (scavenger). Tube centering bracket with adjustable feet attached to venturi.
 	Gas Nozzle Custom gas nozzle with main gas port located inside conical air deflector with peripheral gas ports behind the deflector. Secondary air spinner welded to the gas nozzle includes flame shaping tube shroud.
 	Gas Mixer & Primary Air Adjustment Modified Eclipse mixer with fuel gas entry through the back of the assembly. Eclipse needle valve replaced with custom machined sleeve designed to induce negative pressure inside the fuel chamber for fuel gas recirculation (FGR). Amount of FGR can be tuned by adjusting the position of the sleeve. Primary air shutter modified by drilling 8 holes and adding a set screw to lock the shutter position.
	Secondary Air Adjustment Fixed secondary air spinner welded to gas nozzle. Spinner blades angled to induce spin on the secondary air stream. External shroud tube used to contain and shape the flame. "simplified" Venturi made out of crimped tube.

FIGURE 8.47 Kenilworth – 1-1/2" (Config 104) burner characteristics.

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Kenilworth (Config. 104)
Description:	1-1/2" low pressure with flame scavenger, compound mixer, 1-1/2" x 5" turbulator
Orifice:	#23
Date:	29-Mar-05

507,000 BTU/hr ; 6 turns

312,000 BTU/hr ; 6 turns

87,000 BTU/hr ; 6 turns

506,000 BTU/hr ; 1 turn

312,000 BTU/hr ; 1 turn

88,000 BTU/hr ; 1 turn

506,000 BTU/hr ; 0 turns

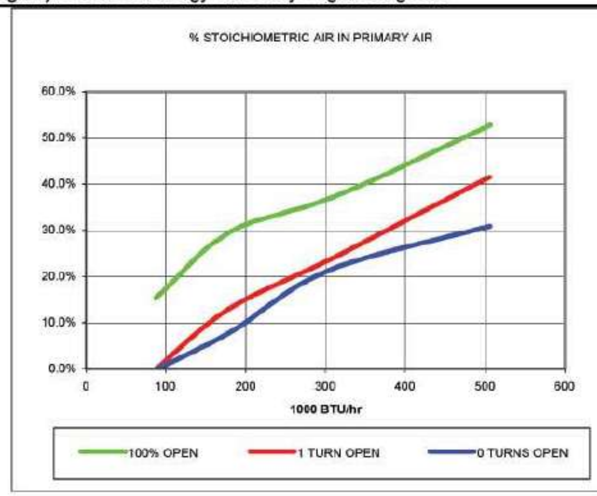
340,000 BTU/hr ; 0 turns

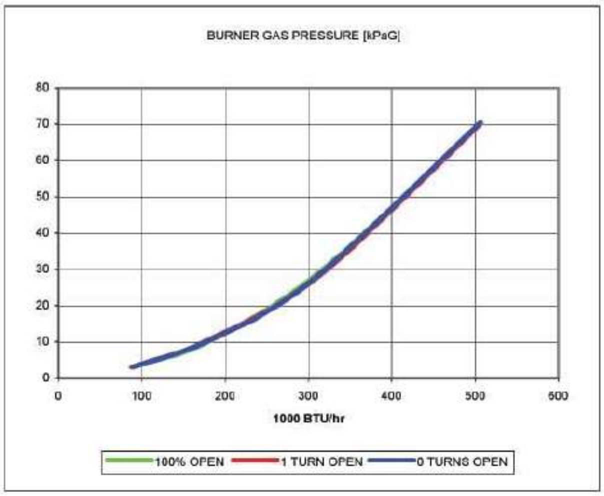
89,000 BTU/hr ; 0 turns

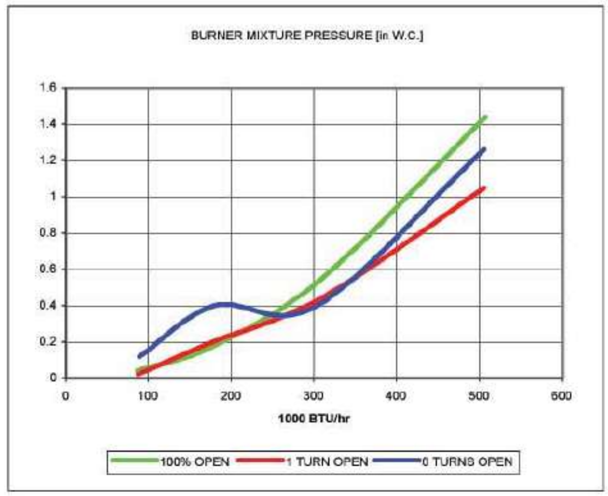
FIGURE 8.48 Kenilworth – 1-1/2" (Config 104) burner open flame tests.

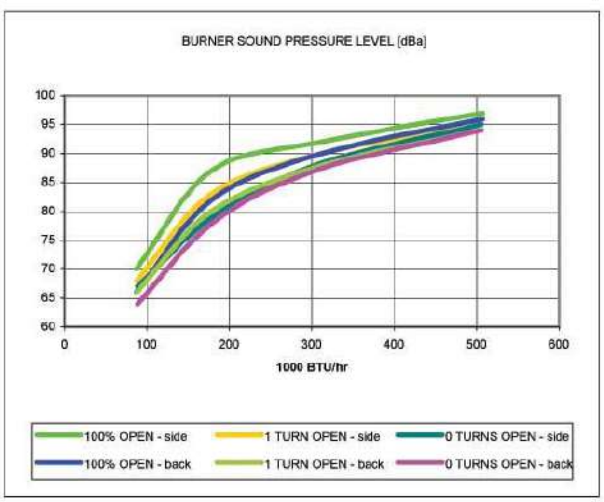
PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
		Project EETR 0401
		Burner Bench Test Performance Summary
		Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Kenilworth (Config. 104)
Description:	1-1/2" low pressure with flame scavenger, compound mixer, 1-1/2" x 5" turbulator
Orifice:	#23
Date:	29-Mar-05









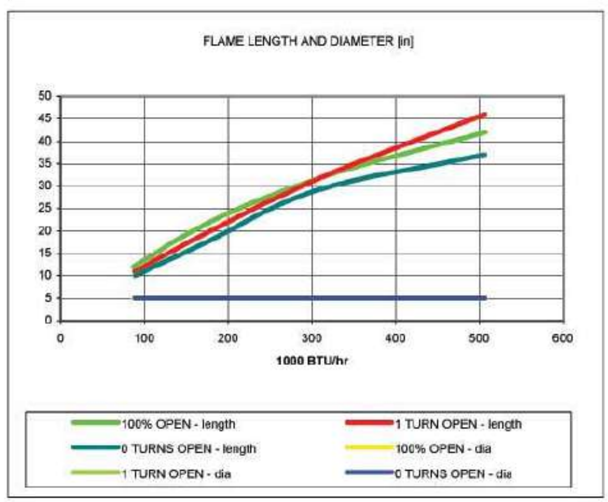


FIGURE 8.49 Kenilworth – 1-1/2" (Config 104) burner bench test performance summary.

8.16 Maxon 3" Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.50;
- un-common burner in Alberta
- Heavy duty cast gas nozzle design with good flame retention capability
- Simple assembly with integral mixer and Venturi sleeve with large bell, low entry loss air entrance.
- Easy to reach gas orifice.
- Secure locking mechanism of the primary air register.

Open Flame Tests

- see Figure 8.51;
- excellent high momentum/intensity premix burner. Good flame stability, for all firing ranges and most primary air settings.
- Top three rows of photographs illustrate between 80% and 130% stoichiometric air/fuel ratio homogeneously premixed inside the mixer; resulting in a fully aerated short and straight flame; blue, purple and white in colour; ideal for the fire tube application; will not impinge on the tube surface and will also result in the highest radiative heat transfer.

Bench Test results

- See figure 8.52;
- Stoichiometric air in primary air high at approximately 110% ideal for fire tube application;
- Gas pressure at 20 PSIG produces good air induction in this high efficiency Venturi;
- Burner mixture pressure measured at .8" W.C (? possibly in error);
- Sound pressure level (back measurement) high at 100 dBA;
- small flame volume flame with high Q/V (BTU/volume) = 2,190,000 BTU/ft3;
- L/D (length/diameter) ratio = 5.8

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT		
	Project EETR 0401		
	Burner Characteristics		
	Design by: ENEFEN Energy Efficiency Engineering Ltd.		
Manufacturer:	Maxon Large	Address:	6375 Dixie Road, Unit 3
Description:	3" Ventite	City, Province, Code:	Mississauga, ON L5T 2E1
Orifice:	1/8"	Telephone / Fax:	(905) 795-0717/(905) 795-1819
Overall Length:	21"	Web Site:	http://www.maxoncorp.com


General Arrangement

Compact burner assembly features gas nozzle venturi, mixer, and primary air shutter combination. Heavy duty cast iron components


Gas Nozzle

Heavy duty cast iron nozzle includes internal flame retention device with large main gas orifice and 8 smaller holes located around its perimeter. Available with integral pilot and flame rod mount (PilotPak).


Gas Mixer & Primary Air Adjustment

Gas mixer features a low entrance loss bell shaped inlet. Heavy duty cast iron "register" type shutter includes a locking screw. Gas Connection through the back of the mixer. Simple rear access to the orifice by unbolting the back plate of the register.

Secondary Air Adjustment

No secondary air adjustment incorporated

FIGURE 8.50 Maxon – 3” burner characteristics.

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Maxon Large
Description:	3" Ventite
Orifice:	1/8"
Date:	16-Mar-05

524,000 BTU/hr ; 100%

304,000 BTU/hr ; 100%

148,000 BTU/hr ; 100%

531,000 BTU/hr ; 50%

295,000 BTU/hr ; 50%

118,000 BTU/hr ; 50%

530,000 BTU/hr ; 28%

289,000 BTU/hr ; 28%

117,000 BTU/hr ; 28%

531,000 BTU/hr ; 10%

290,000 BTU/hr ; 10%

FIGURE 8.51 Maxon – 3" burner open flame tests.

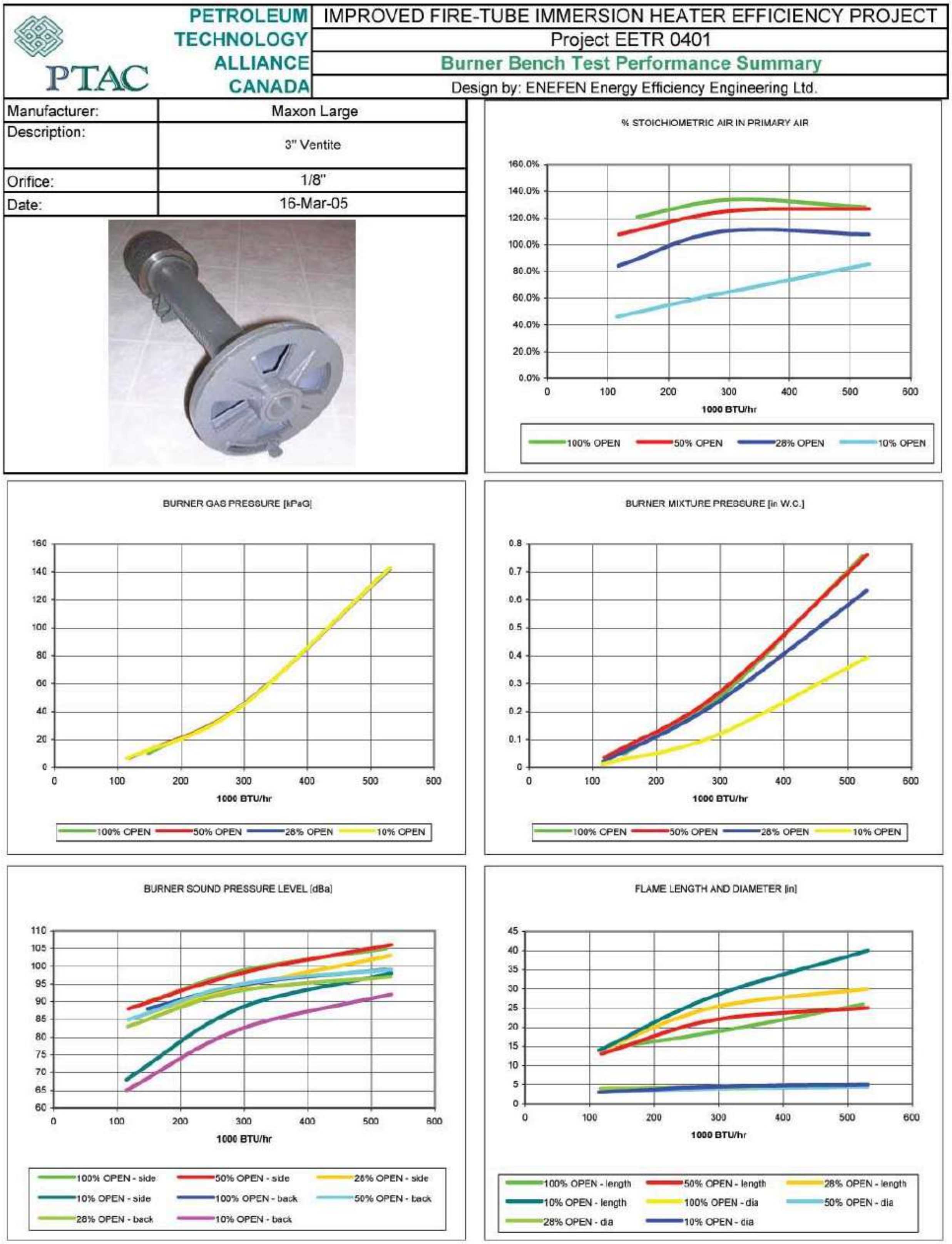


FIGURE 8.52 Maxon – 3" burner bench test performance summary.

8.17 Maxon 1-1/2" Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.53;
- un-common burner in Alberta
- Heavy duty cast gas nozzle design with good flame retention capability
- Simple assembly with integral mixer and Venturi sleeve with large bell, low entry loss air entrance.
- Easy to reach gas orifice.
- Secure locking mechanism of the primary air register.

Open Flame Tests

- see Figure 8.54;
- excellent high momentum/intensity premix burner. Good flame stability, for all firing ranges and most primary air settings.
- photographs illustrate between 65% and 70% stoichiometric air/fuel ratio; resulting in a partially aerated long and straight blue flame; for this application this burner was too small and therefore overfired and with lower primary air
- ideal for the fire tube application; will not impinge on the tube surface and will also result in the highest radiative heat transfer, if used within its lower capacity ratings.

Bench Test results

- See figure 8.55;
- Stoichiometric air in primary air high at approximately 65%;
- Gas pressure at 20 PSIG produces good air induction in this high efficiency Venturi;
- Burner mixture pressure measured at .8" W.C (? possibly in error);
- Sound pressure level (back measurement) high at 95 dBA;
- small flame volume flame with high Q/V (BTU/volume) = 2,270,000 BTU/ft3;
- L/D (length/diameter) ratio = 10.3

PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
		Project EETR 0401
		Burner Characteristics
		Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Maxon Medium	Address:	6375 Dixie Road, Unit 3
Description:	1-1/2" Ventite		
		City, Province, Code:	Mississauga, ON L5T 2E1
Orifice:	#29	Telephone / Fax:	(905) 795-0717/(905) 795-1819
Overall Length:	15"	Web Site:	http://www.maxoncorp.com

 	General Arrangement Compact burner assembly features gas nozzle venturi, mixer, and primary air shutter combination. Heavy duty cast iron components
 	Gas Nozzle Heavy duty cast iron nozzle includes internal flame retention device with large main gas orifice and 8 smaller holes located around its perimeter. Available with integral pilot and flame rod mount (PilotPak).
 	Gas Mixer & Primary Air Adjustment Gas mixer features a low entrance loss bell shaped inlet. Heavy duty cast iron "register" type shutter includes a locking screw. Gas Connection through the back of the mixer. Simple rear access to the orifice by unbolting the back plate of the register.
	Secondary Air Adjustment No secondary air adjustment incorporated

FIGURE 8.53 Maxon – 1-1/2" burner characteristics.

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Maxon Medium
Description:	1-1/2" Ventite
Orifice:	#29
Date:	16-Mar-05

455,000 BTU/hr ; 100%

289,000 BTU/hr ; 100%

145,000 BTU/hr ; 100%

435,000 BTU/hr ; 50%

286,000 BTU/hr ; 50%

106,000 BTU/hr ; 50%

393,000 BTU/hr ; 30%

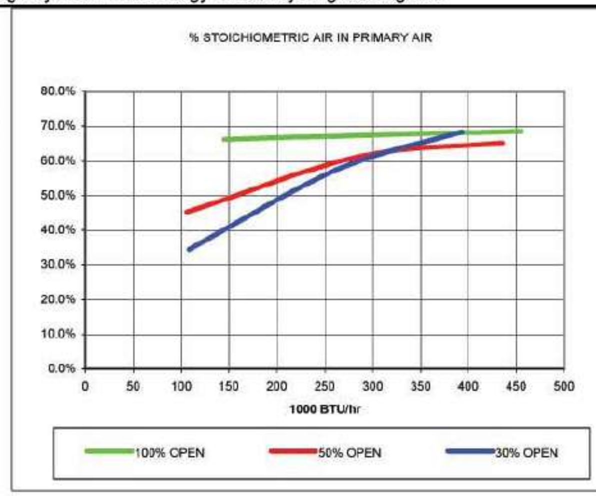
263,000 BTU/hr ; 30%

108,000 BTU/hr ; 30%

FIGURE 8.54 Maxon – 1-1/2" burner open flame tests.

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Bench Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Maxon Medium
Description:	1-1/2" Ventite
Orifice:	#29
Date:	16-Mar-05



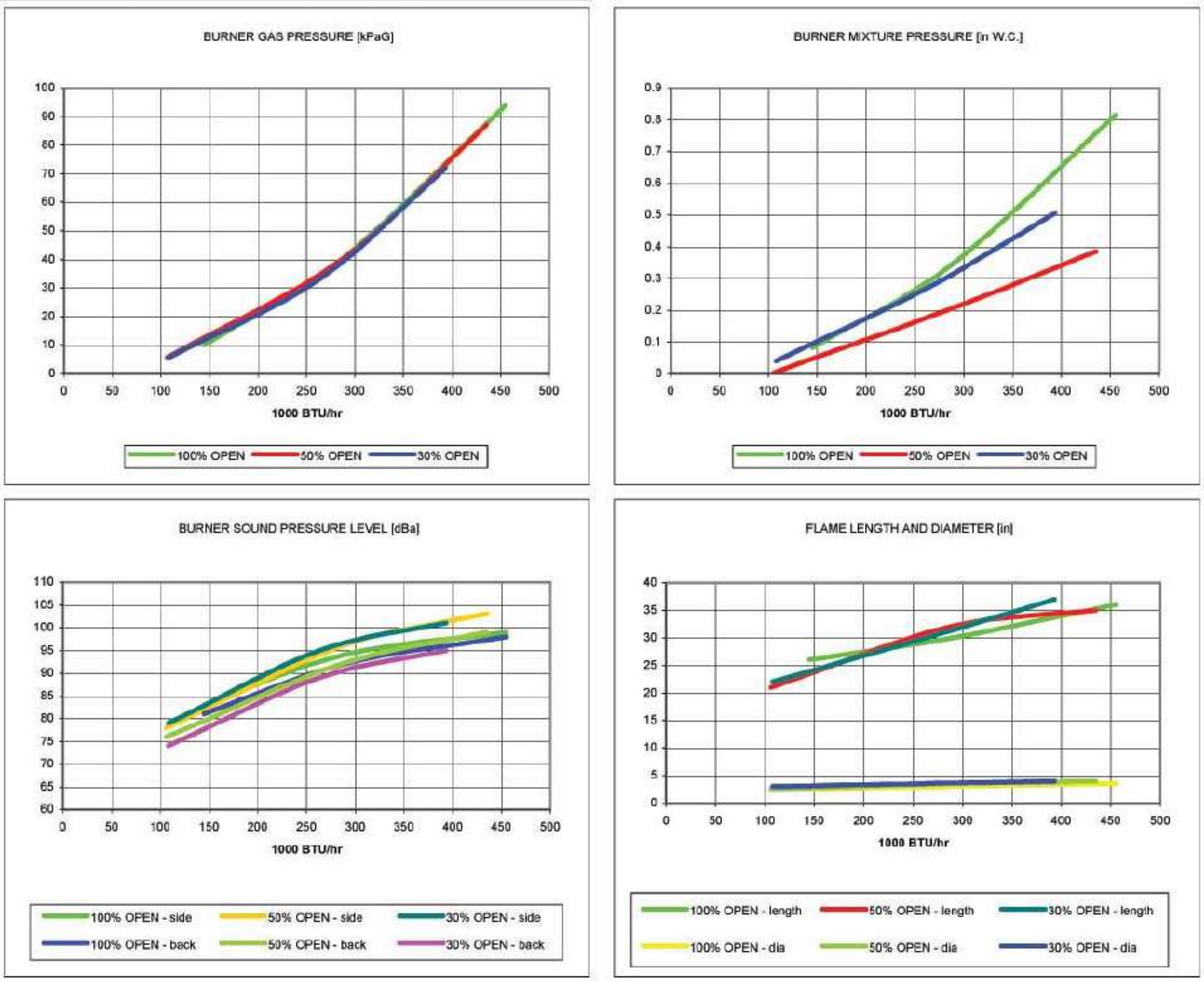


FIGURE 8.55 Maxon – 1-1/2" burner bench test performance summary.

8.18 Maxon 1" Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.56;
- un-common burner in Alberta
- Heavy duty cast gas nozzle design with good flame retention capability
- Simple assembly with integral mixer and Venturi sleeve with large bell, low entry loss air entrance.
- Easy to reach gas orifice.
- Secure locking mechanism of the primary air register.

Open Flame Tests

- see Figure 8.57;
- excellent high momentum/intensity premix burner. Good flame stability, for all firing ranges and most primary air settings.
- photographs illustrate between 60% stoichiometric air/fuel ratio resulting in an air deficient long and sharp blue flame; ideal for very small fire tube applications; will not impinge on the tube surface and will also result in the highest radiative heat transfer.

Bench Test results

- See figure 8.58;
- Stoichiometric air in primary air high at approximately 65% ideal for fire tube application;
- Gas pressure at 20 PSIG produces good air induction in this high efficiency Venturi;
- Burner mixture pressure measured at 1.3" W.C.;
- Sound pressure level (back measurement) high at 90 dBA;
- small flame volume flame with high Q/V (BTU/volume) = 2,900,000 BTU/ft3;
- L/D (length/diameter) ratio = 11

PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT Project EETR 0401 **Burner Characteristics** Design by: ENEFEN Energy Efficiency Engineering Ltd.	
Manufacturer:	Maxon Small	Address:	6375 Dixie Road, Unit 3
Description:	1" Ventite	City, Province, Code:	Mississauga, ON L5T 2E1
Orifice:	#53	Telephone / Fax:	(905) 795-0717/(905) 795-1819
Overall Length:	10"	Web Site:	http://www.maxoncorp.com


General Arrangement

Compact burner assembly features gas nozzle venturi, mixer, and primary air shutter combination. Heavy duty cast iron components


Gas Nozzle

Heavy duty cast iron nozzle includes internal flame retention device with large main gas orifice and 8 smaller holes located around its perimeter


Gas Mixer & Primary Air Adjustment

Gas mixer features a low entrance loss bell shaped inlet. Heavy duty cast iron "register" type shutter includes a locking screw. Gas Connection through the back of the mixer. Simple rear access to the orifice by unbolting the back plate of the register.

Secondary Air Adjustment

No secondary air adjustment incorporated

FIGURE 8.56 Maxon – 1" burner characteristics.

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Maxon Small
Description:	1" Ventite
Orifice:	#53
Date:	16-Mar-05

116,000 BTU/hr ; 100%

97,000 BTU/hr ; 100%

56,000 BTU/hr ; 100%

120,000 BTU/hr ; 60%

80,000 BTU/hr ; 60%

56,000 BTU/hr ; 60%

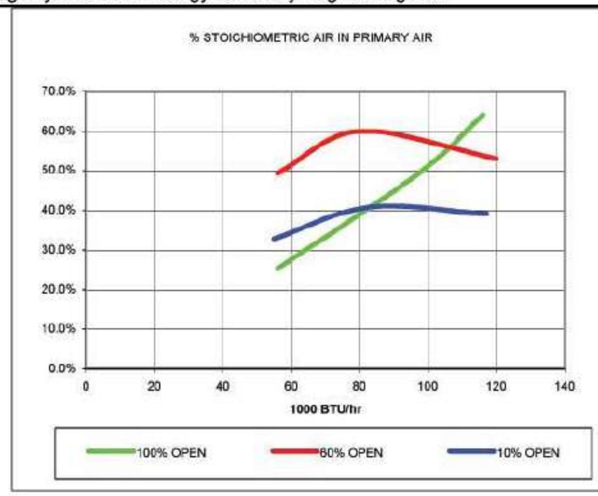
117,000 BTU/hr ; 10%

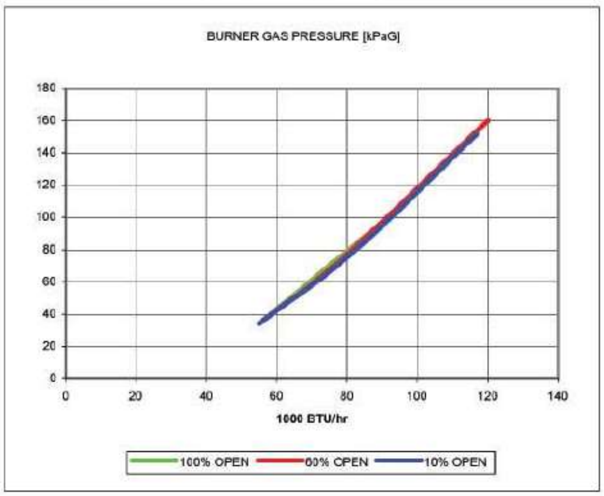
82,500 BTU/hr ; 10%

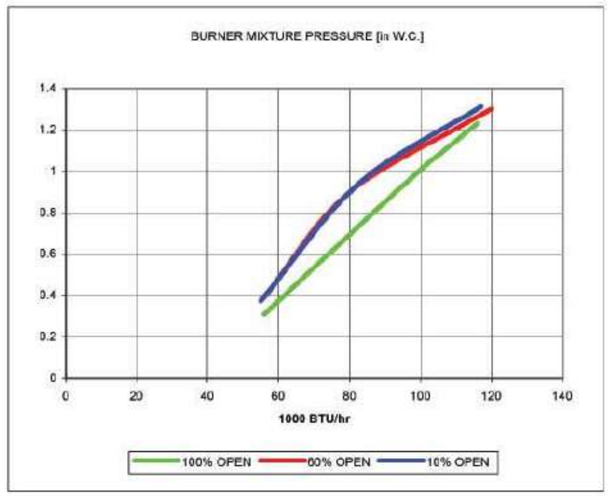
FIGURE 8.57 Maxon – 1" burner open flame tests.

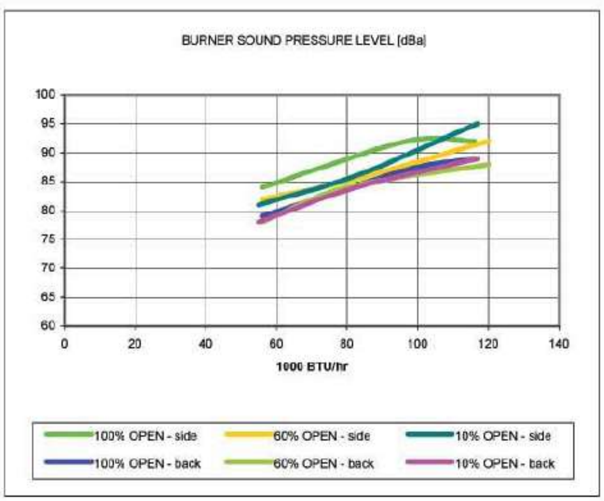
PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Bench Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Maxon Small
Description:	1" Ventite
Orifice:	#53
Date:	16-Mar-05









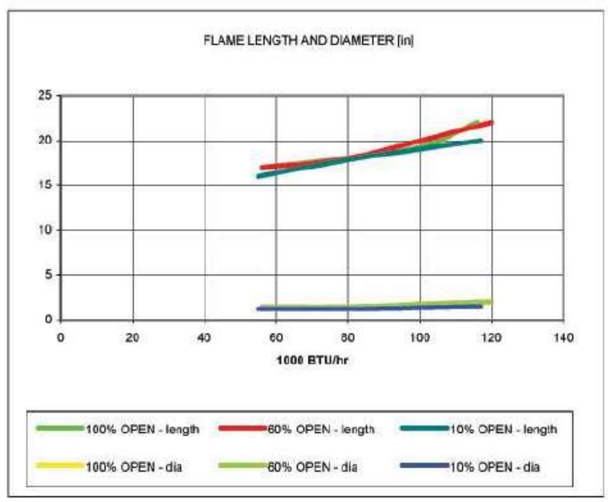


FIGURE 8.58 Maxon – 1" burner bench test performance summary.

8.19 North American 3" Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.59;
- un-common burner in Alberta
- Excellent, heavy duty cast gas nozzle design with good flame retention capability
- Simple assembly with integral mixer and Venturi sleeve with low air inlet coefficient.
- Easy to reach gas orifice.

Open Flame Tests

- see Figure 8.60;
- excellent high momentum/intensity premix burner. Good flame stability, for all firing ranges and most primary air settings.
- Top row of photographs illustrate 110% stoichiometric air/fuel ratio homogeneously premixed inside the mixer; resulting in a fully aerated short and straight flame; blue, purple and white in colour; ideal for the fire tube application; will not impinge on the tube surface and will also result in the highest radiative heat transfer.

Bench Test results

- See figure 8.61;
- Stoichiometric air in primary air high at approximately 110% ideal for fire tube application;
- Gas pressure at 20 PSIG produces good air induction in this high efficiency Venturi;
- Burner mixture pressure measured at 2" W.C (? possibly in error);
- Sound pressure level (back measurement) high at between 93 dBA;
- small flame volume flame with high Q/V (BTU/volume) = 2,216,000 BTU/ft3;
- L/D (length/diameter) ratio = 8.4

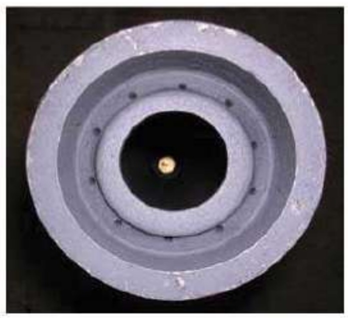
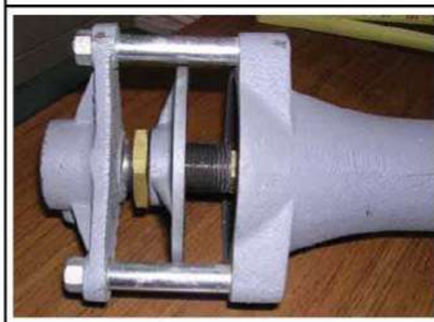
PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT		
	Project EETR 0401		
	Burner Characteristics		
	Design by: ENEFEN Energy Efficiency Engineering Ltd.		
Manufacturer:	North American	Address:	#13-1515 Highfield Cres. S.E.
Description:	3"		
		City, Province, Code:	Calgary, Alberta T2G 5M4
Orifice:	1/8"	Telephone / Fax:	403 250.1075/403 250.1076
Overall Length:	28"	Web Site:	www.namfg.com
			General Arrangement Burner assembly features gas nozzle, venturi mixer, and primary air shutter combination. Cast iron components
			Gas Nozzle Heavy duty cast iron nozzle includes internal flame retention device with large main gas orifice and 10 smaller holes located around its perimeter
			Gas Mixer & Primary Air Adjustment Gas mixer features a low entrance loss bell shaped inlet and perpendicular flow of combustion air relative to gas flow, for enhanced mixing. Heavy duty cast iron shutter includes a locking nut Gas Connection through the back of the mixer. Orifice can be replaced from rear by removing back assembly
			Secondary Air Adjustment No secondary air adjustment incorporated

FIGURE 8.59 North American – 3" burner characteristics.

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

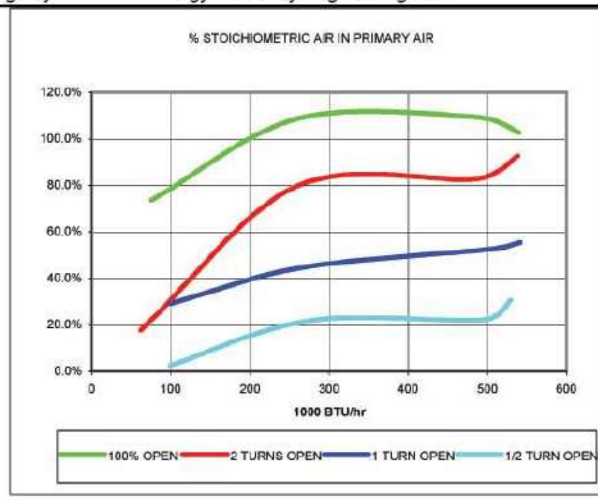
Manufacturer:	North American	
Description:	3"	
Orifice:	1/8"	
Date:	17-Mar-05	

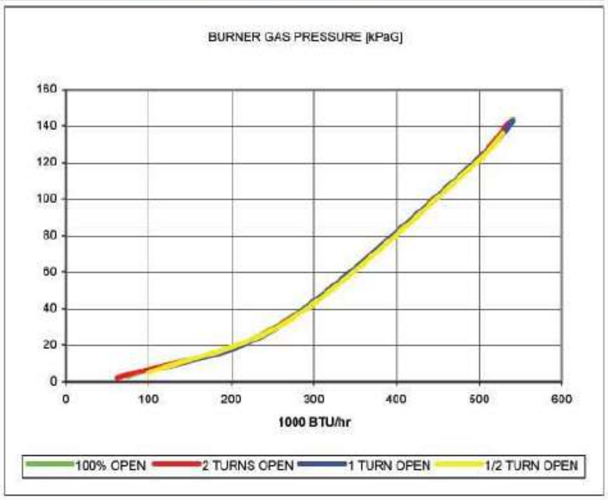
 540,000 BTU/hr ; 11 turns	 261,000 BTU/hr ; 11 turns	 75,000 BTU/hr ; 11 turns
 538,000 BTU/hr ; 2 turns	 259,000 BTU/hr ; 2 turns	 61,500 BTU/hr ; 2 turns
 506,000 BTU/hr ; 1 turns	 291,000 BTU/hr ; 3 turns	 147,000 BTU/hr ; 3 turns
 529,000 BTU/hr ; 0.5 turns	 506,000 BTU/hr ; 0.5 turns	 99,000 BTU/hr ; 0.5 turns

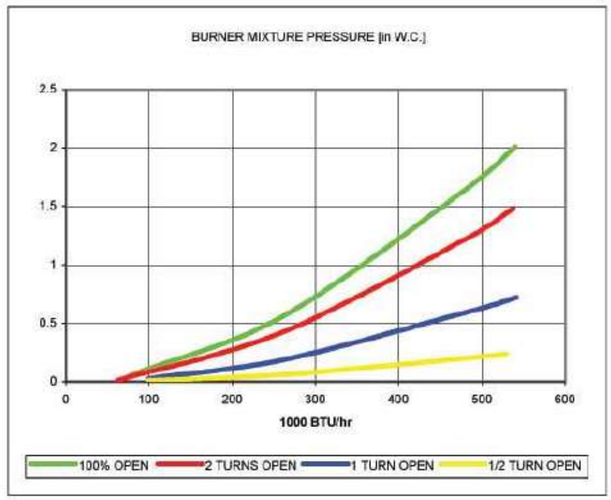
FIGURE 8.60 North American – 3” burner open flame tests.

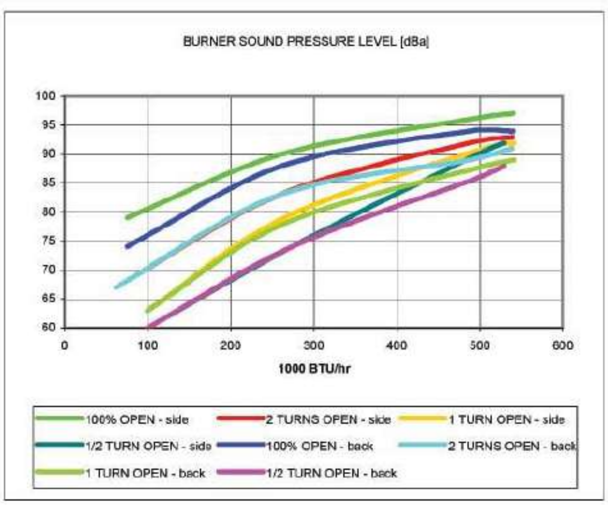
PETROLEUM TECHNOLOGY ALLIANCE CANADA (PTAC)	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Bench Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	North American
Description:	3"
Orifice:	1/8"
Date:	17-Mar-05









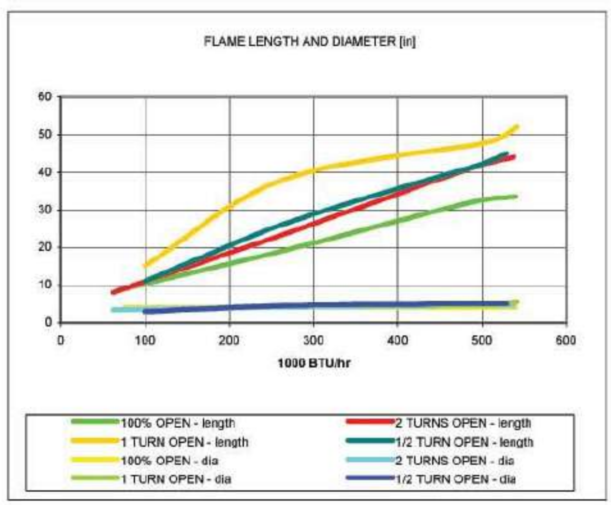


FIGURE 8.61 North American – 3" burner bench test performance summary.

8.20 Profire 1" (w/o Venturi) Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.62;
- lowest cost "bare bone" burner, often used on smaller installations.
- flame nozzle with limited spin;
- standard small Eclipse mixer
- small diameter straight pipe nipple resulting in high mixture pressure drop and therefore limited air induction capability.

Open Flame Tests

- see Figure 8.63;
- stable, well anchored flame
- straight log and narrow blue flame due to low primary air, but suitable for smaller tubes
- Small perimeter gas ports produce individual "flower" like flames with angular trajectory;
- Tube soot deposits and hot spots due to impingement possible.

Bench Test results

- See figure 8.64;
- Stoichiometric air in primary air at less than 42%, qualifies this burner as low primary air burner;
- Gas pressure at 20 PSIG not used effectively for primary air induction and fuel air mixing due to small mixer and straight connecting nipple;
- Burner mixture pressure – 2" W.C.;
- sound pressure level high (back measurement) at 90 dBA;
- Low flame volume with high Q/V (BTU/volume) = 3,029,000 BTU/ft3;
- Acceptable L/D (length/diameter) ratio = 13.7.

PTAC

PETROLEUM TECHNOLOGY ALLIANCE CANADA

IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT

Project EETR 0401

Burner Characteristics

Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Profire	Address:	Box 3313
Description:	1" with BS&B Nozzle, 1" Nipple		Bay 11, 55 Alberta Avenue
		City, Province, Code:	Spruce Grove, Alberta, T7X 3A6
Orifice:	1/8"	Telephone / Fax:	780-960-5278/780-960-5078
Overall Length:	22"	Web Site:	http://profirecombustion.com


General Arrangement

Eclipse burner mixer and extension pipe nipple with alternate gas nozzle.

Gas Nozzle

"Bell" type gas nozzle with large centre port and 16 angled side ports in two sizes. Cast iron construction.



Gas Mixer & Primary Air Adjustment

Eclipse mixer commonly used in the industry. Basic mixer features cast iron body with gas orifice and primary air shutter. Needle valve removed and replaced with a plug, to avoid burner misadjustment. Side fuel gas entry.

Secondary Air Adjustment

No secondary air adjustment incorporated

FIGURE 8.62 ProFire –1" burner without Venturi characteristics.

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Profire	
Description:	1" with BS&B Nozzle, 1" Nipple	
Orifice:	1/8"	
Date:	17-Mar-05	

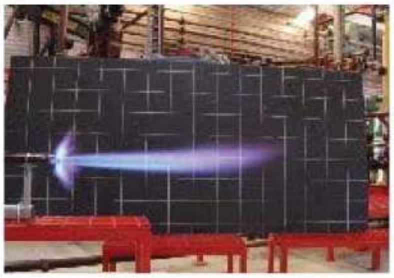
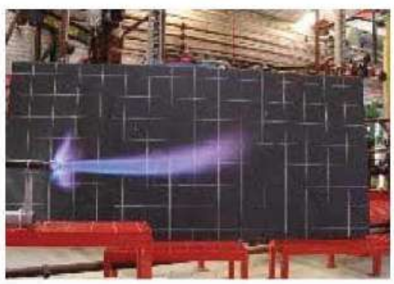
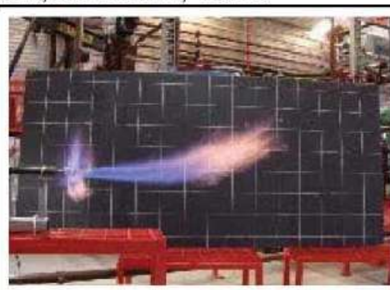
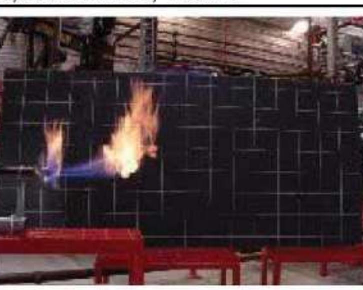
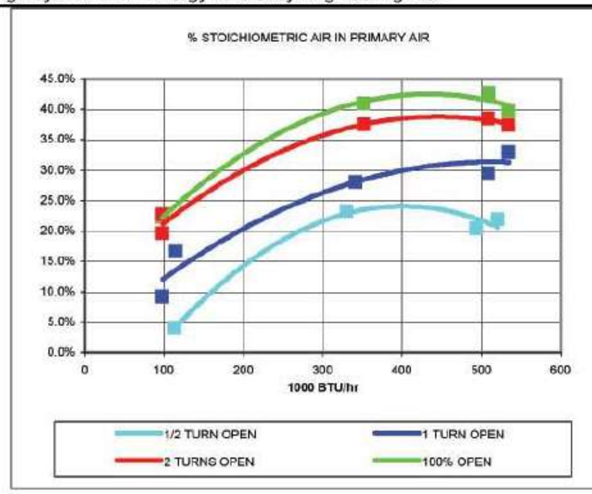
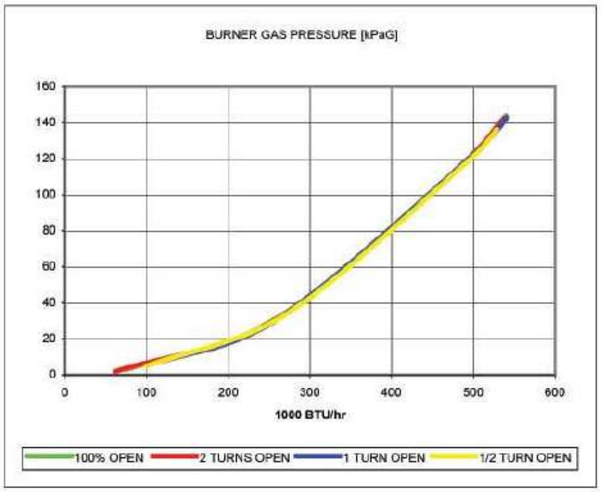
 509,000 BTU/hr ; 16.5 turns	 351,000 BTU/hr ; 16.5 turns	 98,000 BTU/hr ;16.5 turns
 535,000 BTU/hr ; 2 turns	 291,000 BTU/hr ; 3 turns	 98,000 BTU/hr ; 2 turns
 535,000 BTU/hr ; 1 turns	 342,000 BTU/hr ; 1 turns	 98,000 BTU/hr ; 1 turns
 521,000 BTU/hr ; 0.5 turns	 330,000 BTU/hr ; 0.5 turns	 114,000 BTU/hr ; 0.5 turns

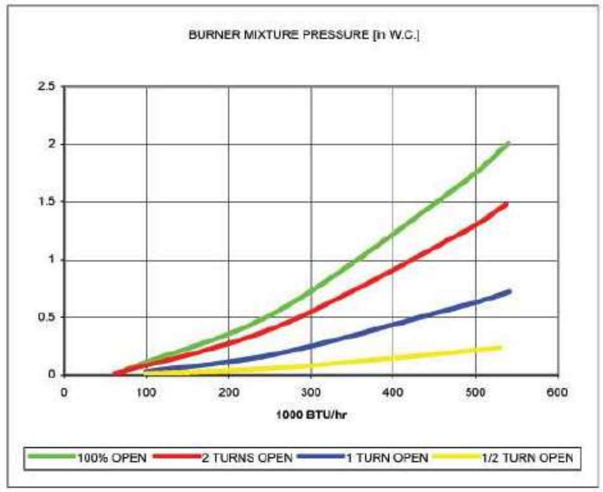
FIGURE 8.63 ProFire –1” burner without Venturi open flame tests.

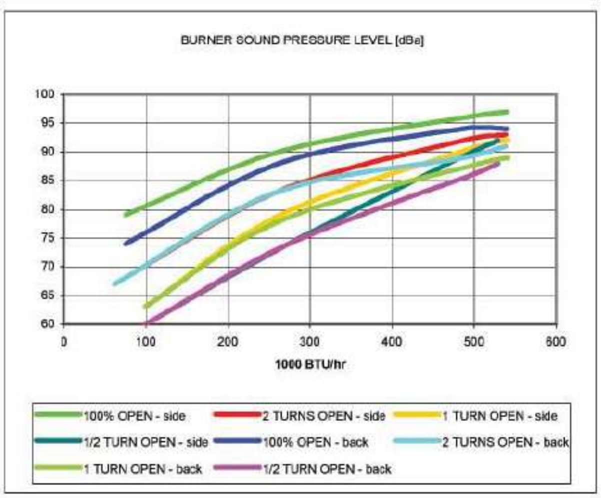
PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Bench Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Profire
Description:	1" with BS&B Nozzle, 1" Nipple
Orifice:	1/8"
Date:	17-Mar-05









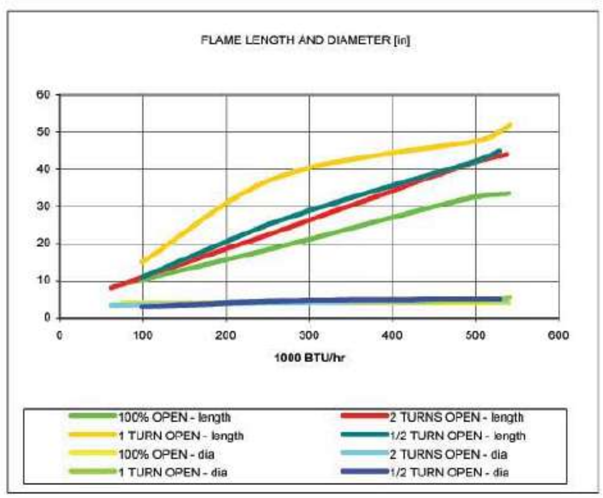


FIGURE 8.64 ProFire –1” burner without Venturi bench test performance summary.

8.21 Profire 1” (with Venturi) Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.65;
- low cost burner, often used on smaller installations.
- flame nozzle with limited spin;
- standard small Eclipse mixer and Venturi sleeve
- small diameter components resulting in high mixture pressure drop and therefore limited air induction capability.

Open Flame Tests

- see Figure 8.66;
- stable, well anchored flame
- Venturi adds 10% stoichiometric air to the mixture as compared to a burner with only a pipe nipple
- straight log and narrow blue flame due to low primary air, but suitable for smaller tubes
- Small perimeter gas ports produce individual “flower” like flames with angular trajectory;
- Tube soot deposits and hot spots due to impingement possible.

Bench Test results

- See figure 8.67;
- Stoichiometric air in primary air at less than 55%, qualifies this burner as medium primary air burner;
- Gas pressure at 20 PSIG not used effectively for primary air induction and fuel air mixing due to small mixer and Venturi, although mixture pressure higher than without Venturi;
- Burner mixture pressure – 3” W.C.;
- sound pressure level high (back measurement) at 95 dBA;
- Low flame volume with high Q/V (BTU/volume) = 3,370,000 BTU/ft3;
- Acceptable L/D (length/diameter) ratio = 12.3.

PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT	
		Project EETR 0401	
		Burner Characteristics	
		Design by: ENEFEN Energy Efficiency Engineering Ltd.	
Manufacturer:	Profire	Address:	Box 3313
Description:	1" with BS&B Nozzle, 1" x 1" Venturi		Bay 11, 55 Alberta Avenue
		City, Province, Code:	Spruce Grove, Alberta, T7X 3A6
Orifice:	1/8"	Telephone / Fax:	780-960-5278/780-960-5078
Overall Length:	22"	Web Site:	http://profirecombustion.com

 	General Arrangement Eclipse burner components (mixer, Venturi), and extension pipe nipple with alternate gas nozzle.
	Gas Nozzle "Bell" type gas nozzle with large centre port and 16 angled side ports in two sizes. Cast iro construction.
  	Gas Mixer & Primary Air Adjustment Eclipse mixer commonly used in the industry. Basic mixer features cast iron body with gas orifice and primary air shutter. Needle valve removed and replaced with a plug, to avoid burner misadjustment. Side fuel gas entry.
	Secondary Air Adjustment No secondary air adjustment incorporated

FIGURE 8.65 ProFire –1" burner with Venturi characteristics.

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Profire
Description:	1" with BS&B Nozzle, 1" x 1" Venturi
Orifice:	1/8"
Date:	17-Mar-05

529,000 BTU/hr ; 16.5 turns

358,000 BTU/hr ; 16.5 turns

139,000 BTU/hr ; 16.5 turns

537,000 BTU/hr ; 1.5 turns

359,000 BTU/hr ; 1.5 turns

123,000 BTU/hr ; 1.5 turns

537,000 BTU/hr ; 0.5 turns

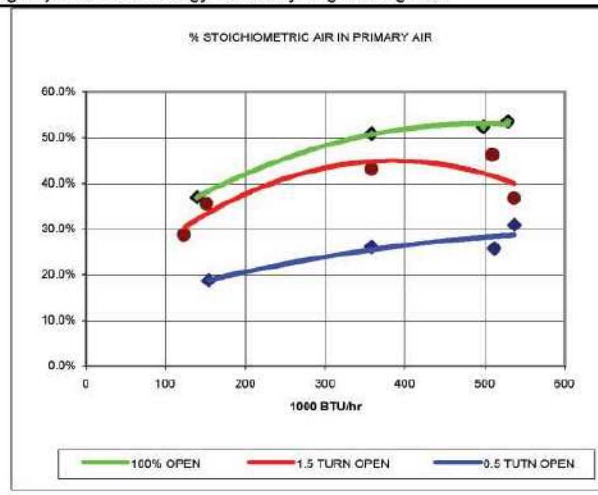
358,000 BTU/hr ; 0.5 turns

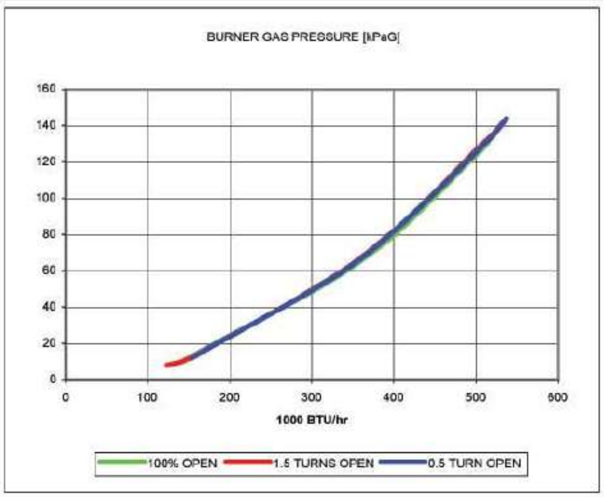
154,000 BTU/hr ; 0.5 turns

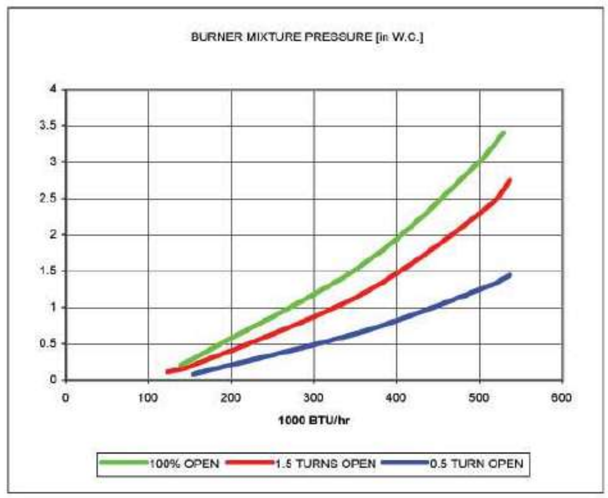
FIGURE 8.66 ProFire –1" burner with Venturi open flame tests.

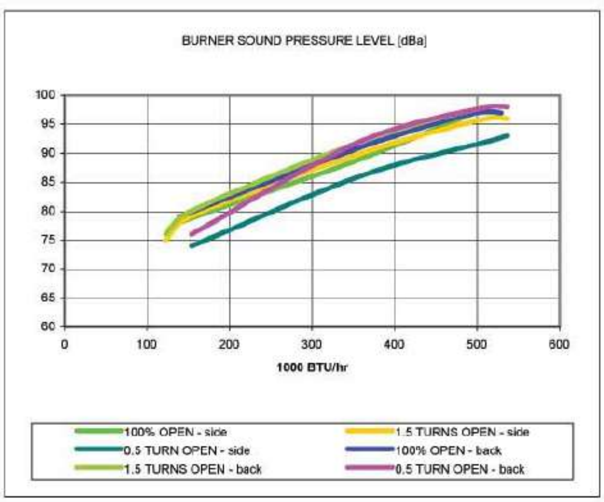
PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Bench Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Profire
Description:	1" with BS&B Nozzle, 1" x 1" Venturi
Orifice:	1/8"
Date:	17-Mar-05









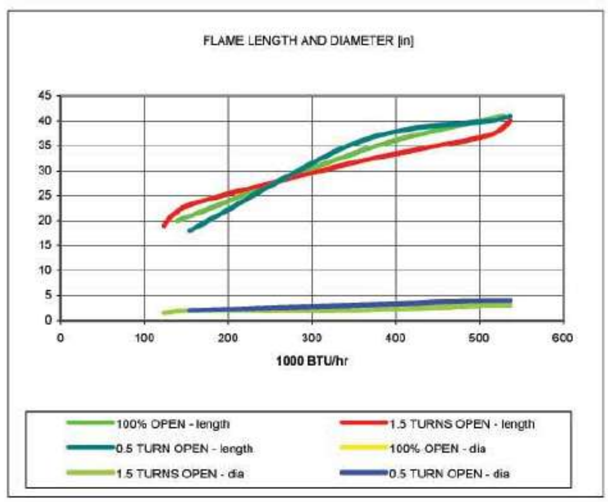


FIGURE 8.67 ProFire –1" burner with Venturi bench test performance summary.

8.22 Pyronics 2-1/2" Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.68;
- uncommon burner in Alberta
- Heavy duty cast gas nozzle design with good flame retention capability
- Simple assembly with integral mixer and Venturi sleeve.

Open Flame Tests

- see Figure 8.69;
- excellent high momentum/intensity premix burner. Good flame stability, for all firing ranges and most primary air settings.
- photographs illustrate between 75% and 105% stoichiometric air/fuel ratio homogeneously premixed inside the mixer; resulting in a fully aerated short and straight flame; blue and white in colour; ideal for the fire tube application; will not impinge on the tube surface and will also result in the highest radiative heat transfer.

Bench Test results

- See figure 8.70;
- Stoichiometric air in primary air high at approximately 105%;
- Gas pressure at 20 PSIG produces good air induction in this high efficiency Venturi;
- Burner mixture pressure measured at 1.4" W.C (? possibly in error);
- Sound pressure level (back measurement) high at 93 dBA;
- small flame volume with high Q/V (BTU/volume) = 4,501,000 BTU/ft3;
- L/D (length/diameter) ratio = 9.7

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT Project EETR 0401 **Burner Characteristics** Design by: ENEFEN Energy Efficiency Engineering Ltd.		
Manufacturer:	Pyronics (Large)	Address:	17700 Miles Ave
Description:	2-1/2", 2000T, 600,000 BTU/hr @ 25 psig		
		City, Province, Code:	Cleveland, OH 44128
Orifice:	#31	Telephone / Fax:	(216) 662-8800/ (216) 663-8954
Overall Length:	27"	Web Site:	http://pyronics.com

General Arrangement

Burner assembly features gas nozzle, extension nipple and coupling, venturi, mixer, and primary air shutter. Cast iron components

Gas Nozzle

Heavy duty cast iron nozzle includes internal flame retention device with large main gas orifice and 8 smaller holes located around its perimeter

Gas Mixer & Primary Air Adjustment

Gas mixer features a streamlined air inlet, and perpendicular flow of combustion air relative to gas flow, for enhanced mixing. Heavy duty cast iron shutter with locking nut. Gas Connection through the back or side of the mixer. Orifice can be replaced from the back by removing rear assembly (2 set screws)

Secondary Air Adjustment

Cast iron burner mount incorporates a "register" type secondary air flow adjustment, and pilot and flame rod mounting ports. Assembly is bolted externally to the firetube flange.

FIGURE 8.68 Pyronics –2-1/2" burner characteristics.

PETROLEUM TECHNOLOGY ALLIANCE CANADA (PTAC)	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Pyronics (Large)	
Description:	2-1/2", 2000T, 600,000 BTU/hr @ 25 psig	
Orifice:	#31	
Date:	19-Mar-05	

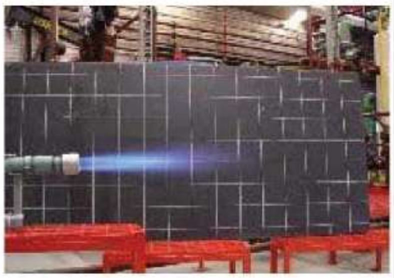
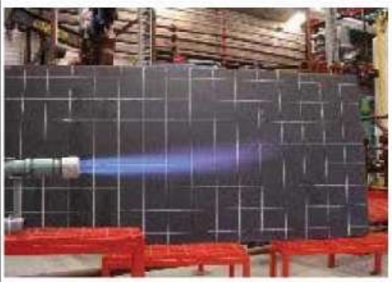
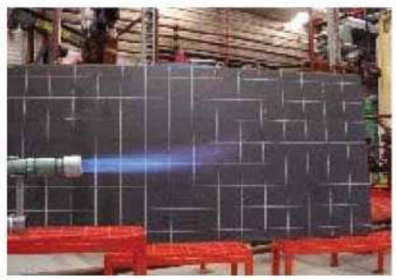
 534,000 BTU/hr ; 5 turns	 334,000 BTU/hr ; 5 turns	 94,000 BTU/hr ; 5 turns
 534,000 BTU/hr ; 2 turns	 334,000 BTU/hr ; 2 turns	 90,000 BTU/hr ; 2 turns
 534,000 BTU/hr ; 1 turn	 300,000 BTU/hr ; 1 turn	 90,000 BTU/hr ; 1 turn

FIGURE 8.69 Pyronics –2-1/2" burner open flame tests.

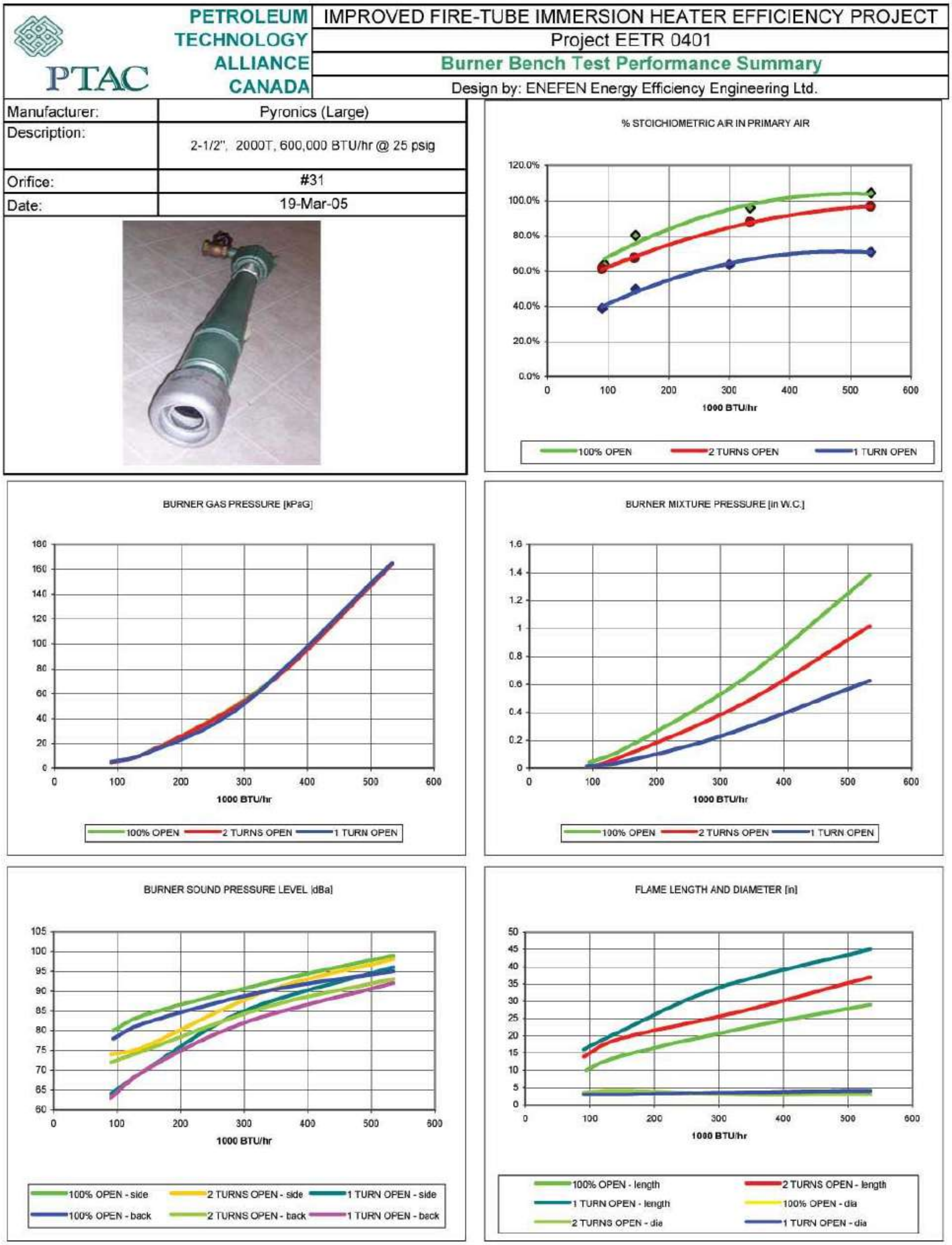


FIGURE 8.70 Pyronics –2-1/2" burner bench test performance summary.

8.23 Pyronics 1-1/2" Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.71;
- uncommon burner in Alberta
- Heavy duty cast gas nozzle design with good flame retention capability
- Simple assembly with integral mixer and Venturi sleeve.

Open Flame Tests

- see Figure 8.72;
- excellent high momentum/intensity premix burner. Good flame stability, for all firing ranges and most primary air settings. Too small for this application
- photographs illustrate 75% stoichiometric air/fuel ratio resulting in an air deficient long, narrow and straight flame; blue in colour; ideal for small fire tube application; will not impinge on the tube surface.

Bench Test results

- See figure 8.73;
- Stoichiometric air in primary air high at approximately 75%; Burner overfired.
- Gas pressure at 20 PSIG produces good air induction in this high efficiency Venturi;
- Burner mixture pressure measured at 1.6" W.C;
- Sound pressure level (back measurement) high at 90 dBA;
- small flame volume with high Q/V (BTU/volume) = 3,661,000 BTU/ft3;
- L/D (length/diameter) ratio = 12.

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT		
	Project EETR 0401		
	Burner Characteristics		
	Design by: ENEFEN Energy Efficiency Engineering Ltd.		
Manufacturer:	Pyronics (Small)	Address:	17700 Miles Ave
Description:	1-1/2", 1200T, 300,000 BTU/hr @ 25PSIG		
		City, Province, Code:	Cleveland, OH 44128
Orifice:	#44	Telephone / Fax:	(216) 662-8800/ (216) 663-8954
Overall Length:	22"	Web Site:	http://pyronics.com

	General Arrangement Burner assembly features gas nozzle, extension nipple and coupling, venturi, mixer, and primary air shutter. Cast iron components
 	Gas Nozzle Heavy duty cast iron nozzle includes internal flame retention device with large main gas orifice and 8 smaller holes located around its perimeter
	Gas Mixer & Primary Air Adjustment Gas mixer features a streamlined air inlet, and perpendicular flow of combustion air relative to gas flow, for enhanced mixing. Heavy duty cast iron shutter with locking nut. Gas Connection through the back or side of the mixer. Orifice can be replaced from the back by removing rear assembly (2 set screws)
	Secondary Air Adjustment Cast iron burner mount incorporates a "register" type secondary air flow adjustment, and pilot and flame rod mounting ports. Assembly is bolted externally to the firetube flange.

FIGURE 8.71 Pyronics –1-1/2" burner characteristics.

PETROLEUM TECHNOLOGY ALLIANCE CANADA (PTAC)	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Pyronics (Small)
Description:	1-1/2", 1200T, 300,000 BTU/hr @ 25PSIG
Orifice:	#44
Date:	19-Mar-05

312,000 BTU/hr ; 5 turns

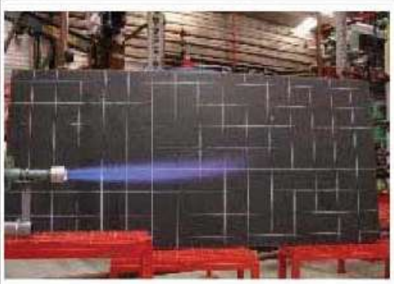
144,000 BTU/hr ; 5 turns

71,000 BTU/hr ;5 turns

312,000 BTU/hr ; 2 turns

145,000 BTU/hr ; 2 turns

67,000 BTU/hr ; 2 turns



311,000 BTU/hr ; 1 turn

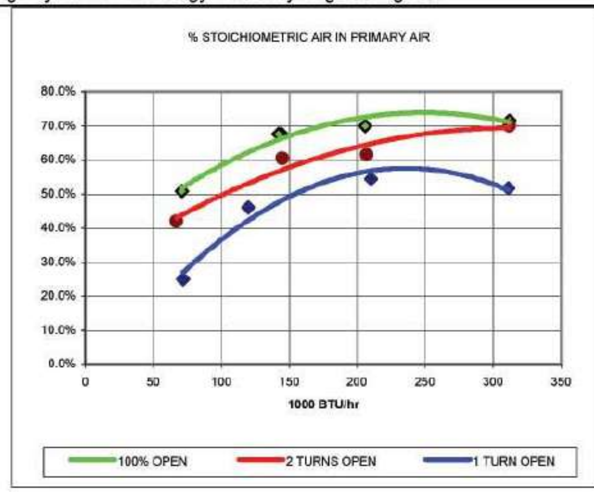
120,000 BTU/hr ; 1 turn

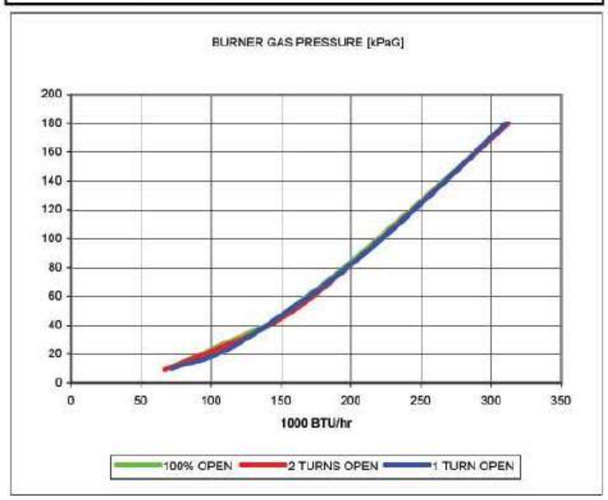
72,000 BTU/hr ; 1 turn

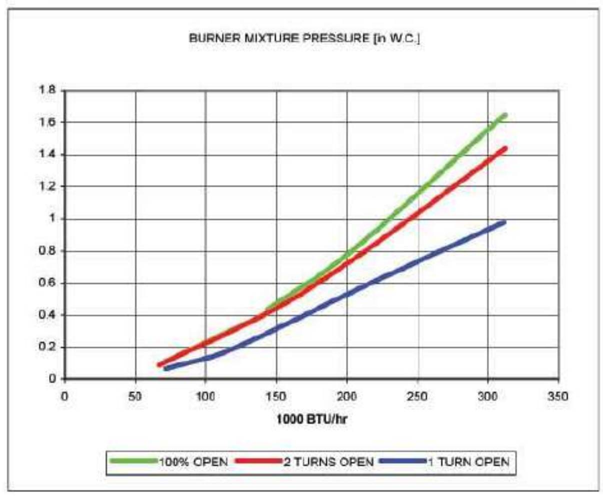
FIGURE 8.72 Pyronics –1-1/2" burner open flame tests.

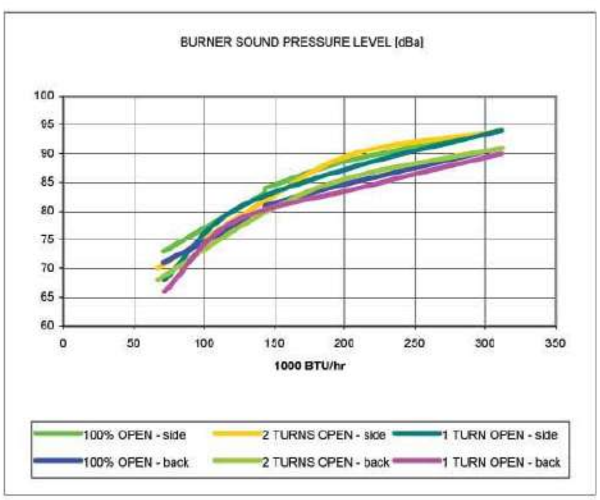
PTAC — PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Bench Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Pyronics (Small)
Description:	1-1/2", 1200T, 300,000 BTU/hr @ 25PSIG
Orifice:	#44
Date:	19-Mar-05









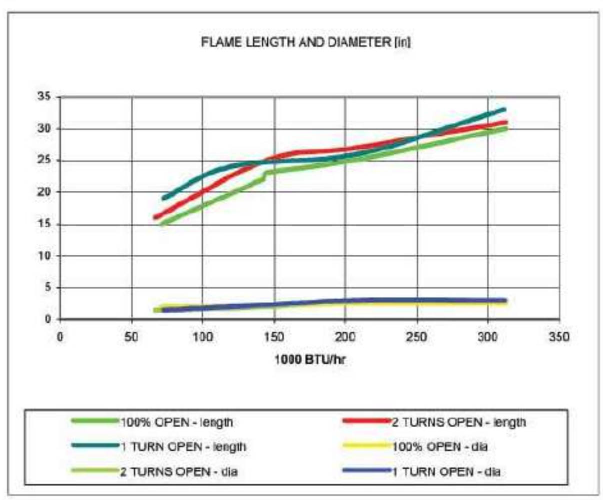


FIGURE 8.73 Pyronics –1-1/2" burner bench test performance summary.

8.24 Pyronics 2” (Self-Adjusting) Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.74;
- uncommon burner in Alberta
- Heavy duty cast gas nozzle design with good flame retention capability
- Pneumatically self-adjusting orifice plate inside the burner nozzle
- Simple assembly with integral mixer and Venturi sleeve.

Open Flame Tests

- see Figure 8.75;
- medium intensity burner; too much radial momentum in gas causing too wide flame which combined with buoyancy may cause flame impingement and high CO.
- photographs illustrate very wide and buoyant flames not suitable for fire tube application..

Bench Test results

- See figure 8.76;
- Stoichiometric air in primary air low at approximately 35%;
- Gas pressure at 10 PSIG does not produce good aeration;
- Burner mixture pressure measured at .1” W.C;
- Sound pressure level (back measurement) high at 85 dBA;
- large flame volume with low Q/V (BTU/volume) = 692,700 BTU/ft3;
- L/D (length/diameter) ratio = 2.5

PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT Project EETR 0401 **Burner Characteristics** Design by: ENEFEN Energy Efficiency Engineering Ltd.	
Manufacturer:	Pyronics (Large Auto)	Address:	17700 Miles Ave
Description:	2" 16HLT-MA, 600,000 BTU/hr @ 5 PSIG	City, Province, Code:	Cleveland, OH 44128
Orifice:	#8	Telephone / Fax:	(216) 662-8800/ (216) 663-8954
Overall Length:	20"	Web Site:	http://pyronics.com

General Arrangement

Burner assembly features self-adjusting gas nozzle with pneumatic actuator, Venturi, mixer, and primary air shutter. Cast iron components

Gas Nozzle

Heavy duty cast iron nozzle includes internal flame retention device with large main gas port and 8 smaller holes located around its perimeter. High temperature stainless disk which blocks partially the main port is attached to a control rod attached to the pneumatic actuator. As the gas pressure to the burner increases, the actuator moves the disk forward increasing the main port opening.

Gas Mixer & Primary Air Adjustment

Gas mixer features a streamlined air inlet, and perpendicular flow of combustion air relative to gas flow, for enhanced mixing. Heavy duty cast iron shutter with locking nut. Gas Connection through the side of the mixer. Orifice can be replaced from the back by removing rear assembly (2 set screws)

Secondary Air Adjustment

Cast iron burner mount incorporates a "register" type secondary air flow adjustment, and pilot and flame rod mounting ports. Assembly is bolted externally to the firetube flange.

FIGURE 8.74 Pyronics –2" self-adjusting burner characteristics.

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Pyronics (Large Auto)
Description:	2" 16HLT-MA, 600,000 BTU/hr @ 5 PSIG
Orifice:	#8
Date:	19-Mar-05

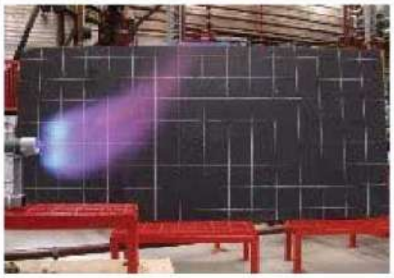
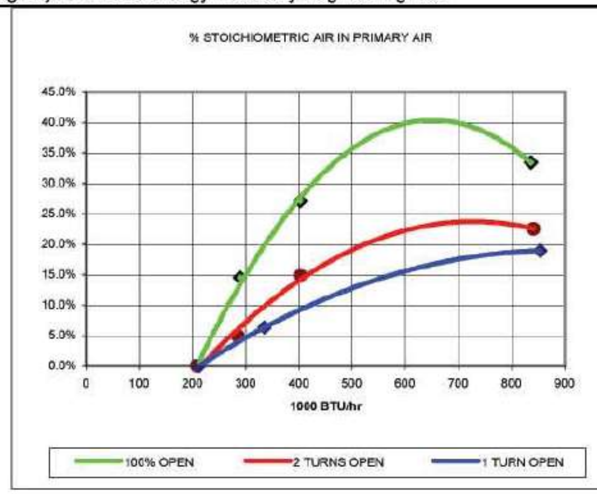
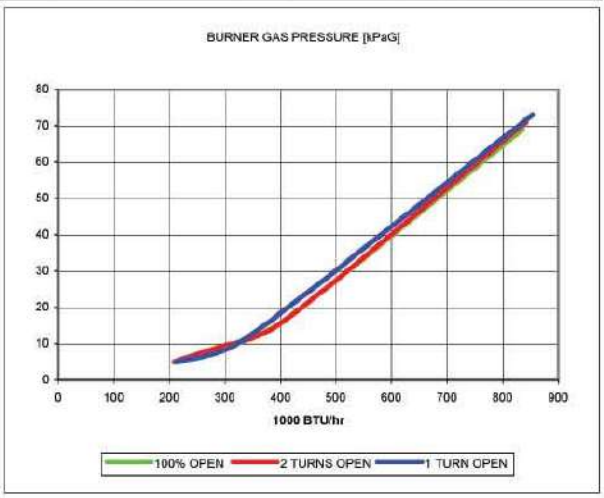
 836,000 BTU/hr ; 3.5 turns	 403,000 BTU/hr ; 3.5 turns	 212,000 BTU/hr ; 3.5 turns
 842,000 BTU/hr ; 2 turns	 404,000 BTU/hr ; 2 turns	 209,000 BTU/hr ; 2 turns
 854,000 BTU/hr ; 1 turn	 336,000 BTU/hr ; 1 turn	 212,000 BTU/hr ; 1 turn

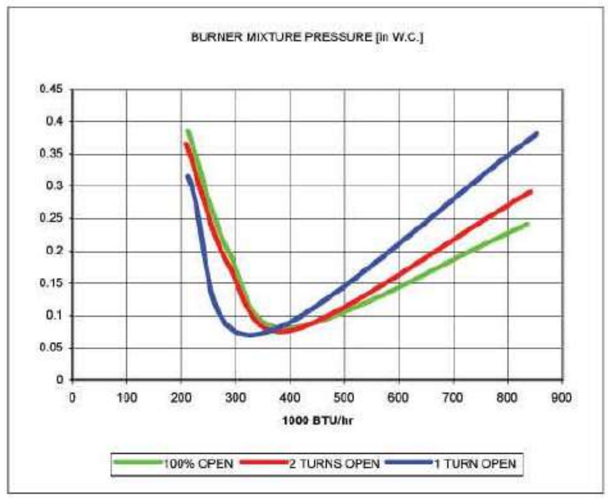
FIGURE 8.75 Pyronics –2" self-adjusting burner open flame tests.

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Bench Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Pyronics (Large Auto)
Description:	2" 16HLT-MA, 600,000 BTU/hr @ 5 PSIG
Orifice:	#8
Date:	19-Mar-05







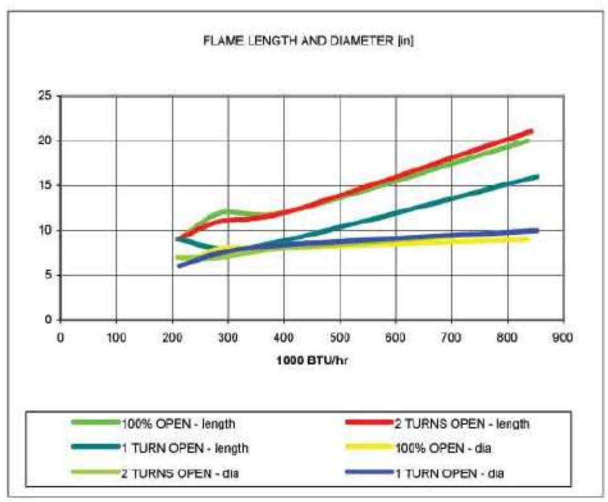


FIGURE 8.76 Pyronics –2” self-adjusting burner bench test performance summary.

8.25 Pyronics 1-1/2" (Self-Adjusting) Burner Bench Tests

Following is the summary of the bench testing performed on this burner:

Review of Mechanical Design:

- see Figure 8.77;
- uncommon burner in Alberta
- Heavy duty cast gas nozzle design with good flame retention capability
- Pneumatically self-adjusting orifice plate inside the burner nozzle
- Simple assembly with integral mixer and Venturi sleeve.

Open Flame Tests

- see Figure 8.78;
- medium intensity burner; too much radial momentum in gas causing too wide flame which combined with buoyancy may cause flame impingement and high CO.
- photographs illustrate very wide and buoyant flames not suitable for fire tube application..

Bench Test results

- See figure 8.79;
- Stoichiometric air in primary air low at approximately 100%;
- Gas pressure at 10 PSIG does produce good aeration;
- Burner mixture pressure measured at .45" W.C;
- Sound pressure level (back measurement) high at 93 dBA;
- small flame volume with high Q/V (BTU/volume) = 2,035,900 BTU/ft3;
- L/D (length/diameter) ratio = 3

PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT Project EETR 0401 **Burner Characteristics** Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Pyronics (Small Auto)	Address:	17700 Miles Ave
Description:	1-1/2" 12HLT-MA, 300,000 BTU/hr @ 5 PSIG		
		City, Province, Code:	Cleveland, OH 44128
Orifice:	#29	Telephone / Fax:	(216) 662-8800/ (216) 663-8954
Overall Length:	20"	Web Site:	http://pyronics.com

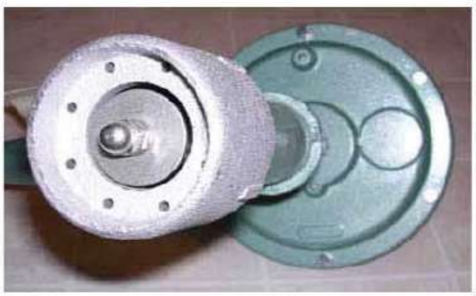
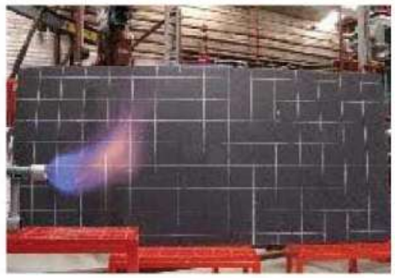
	General Arrangement Burner assembly features self-adjusting gas nozzle with pneumatic actuator, Venturi, mixer, and primary air shutter. Cast iron components
 	Gas Nozzle Heavy duty cast iron nozzle includes internal flame retention device with large main gas port and 8 smaller holes located around its perimeter. High temperature stainless disk which blocks partially the main port is attached to a control rod attached to the pneumatic actuator. As the gas pressure to the burner increases, the actuator moves the disk forward increasing the main port opening.
	Gas Mixer & Primary Air Adjustment Gas mixer features a streamlined air inlet, and perpendicular flow of combustion air relative to gas flow, for enhanced mixing. Gas Connectio through the side of the mixer. Orifice can be replaced from the back by removing rear assembly (1 set screw)
	Secondary Air Adjustment Cast iron burner mount incorporates a "register" type secondary air flow adjustment, and pilot and flame rod mounting ports. Assembly is bolted externally to the firetube flange.

FIGURE 8.77 Pyronics – 1-1/2” self-adjusting burner characteristics.

PETROLEUM TECHNOLOGY ALLIANCE CANADA (PTAC)	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Pyronics (Small Auto)
Description:	1-1/2" 12HLT-MA, 300,000 BTU/hr @ 5 PSIG
Orifice:	#29
Date:	19-Mar-05

695,000 BTU/hr ; 3.5 turns



347,000 BTU/hr ; 3.5 turns

73,000 BTU/hr ; 3.5 turns

695,000 BTU/hr ; 1 turn

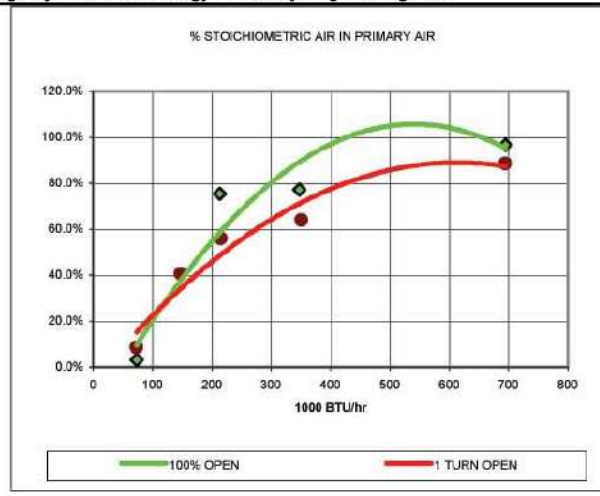
351,000 BTU/hr ; 1 turn

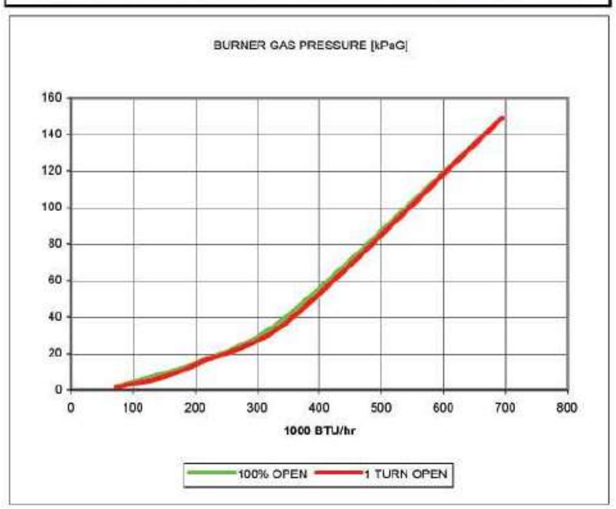
73,000 BTU/hr ; 1 turn

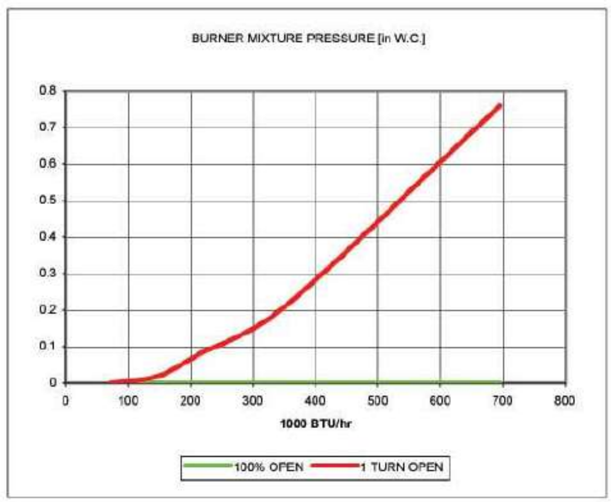
FIGURE 8.78 Pyronics – 1-1/2" self-adjusting burner open flame tests.

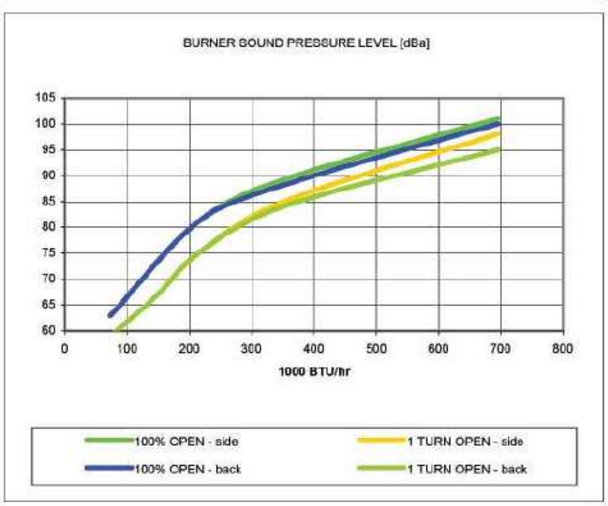
PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Bench Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Pyronics (Small Auto)
Description:	1-1/2" 12HLT-MA, 300,000 BTU/hr @ 5 PSIG
Orifice:	#29
Date:	19-Mar-05









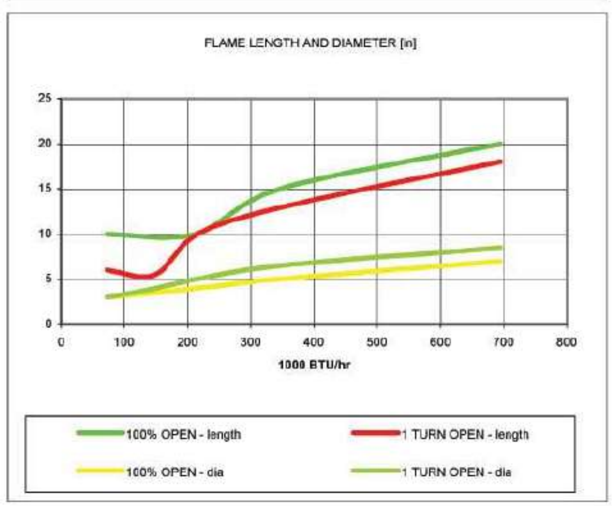


FIGURE 8.79 Pyronics – 1-1/2" self-adjusting burner bench test performance summary.

8.26 Comparison of All Burners – Bench Tests

The results of bench testing presented in this report, represent only a selected group of burners and their sizes, as supplied by their respective manufacturers for evaluation in a specific configuration of our test unit. As we previously demonstrated in our test report, various sizes of the same burner make and model may produce different results. Consequently, it is the match between the burner selection and the fire tube configuration, which is of greater importance to the heater efficiency than any specific burner make or model. In other words, even the seemingly “best” burner can be misapplied to a specific fire-tube application, thus creating both poor efficiency and reliability problems.

Figure 8.80 illustrates the comparison of the following flame parameters for all bench tested burners: fuel Input Q in BTU/hr HHV; flame length L in inches; flame diameter D in inches; flame volume in ft3, flame intensity Q/V in BTU/hr/ft3; and flame momentum L/D [dimensionless].

FLAME PARAMETERS	Q	L	D	V	Q/V	L/D
CALCULATION	BTU/hr	in	in	ft3	BTU/hr/ft3	-
ACL 1"	501,000	42	10	1.909	262,447	4.2
A-Fire 1"	507,000	36	4	0.262	1,936,597	9.0
Bekaert 3"x12" (A)	500,000	12	29	4.587	109,005	0.4
Bekaert 3"x12" (B)	495,000	12	30	4.909	100,841	0.4
Bekaert 3"x12" (C)	494,000	12	25	3.409	144,917	0.5
Bekaert 3"x18" (D)	500,000	18	30	7.363	67,906	0.6
Bekaert 3"x18" (E)	496,000	18	29	6.880	72,089	0.6
Bekaert 3"x18" (F)	497,000	18	25	5.113	97,198	0.7
Bekaert 4"x24" (G)	477,000	24	24	6.283	75,917	1.0
Eclipse 1-1/2"	496,000	24	3	0.098	5,052,215	8.0
Hauck 2"	366,000	30	4	0.218	1,677,620	7.5
Kenilworth 1-1/2" (101)	507,000	42	5	0.477	1,062,362	8.4
Kenilworth 1-1/2" (102)	499,000	42	6	0.687	726,110	7.0
Kenilworth 1-1/2" (103)	500,000	42	5	0.477	1,047,694	8.4
Kenilworth 1-1/2" (104)	507,000	42.0	5.0	0.477	1,062,362	8.4
Maxon 1"	116,000	22.0	2.0	0.040	2,900,208	11.0
Maxon 1-1/2"	455,000	36.0	3.5	0.200	2,270,004	10.3
Maxon 3"	524,000	26.0	4.5	0.239	2,189,711	5.8
North American 3"	540,000	33.5	4.0	0.244	2,216,577	8.4
Profire (w/o Venturi) 1"	508,000	41.0	3.0	0.168	3,028,944	13.7
Profire (with Venturi) 1"	510,000	37.0	3.0	0.151	3,369,611	12.3
Pyronics 1-1/2"	312,000	30.0	2.5	0.085	3,661,063	12.0
Pyronics 2-1/2"	534,000	29.0	3.0	0.119	4,501,473	9.7
Pyronics 1-1/2" Auto	347,000	15.0	5.0	0.170	2,035,879	3.0
Pyronics 2" Auto	403,000	20.0	8.0	0.582	692,706	2.5

FIGURE 8.80 Burner Flame Parameters Comparison

In order to better illustrate methods of evaluating burner performance, a number o comparison charts also were prepared. These charts are presented below.

Figures 8.81, 8.82, and 8.83 provide side-by-side comparison of photographs of flames from all burners at maximum fire. Burners with short, intense flames with full aeration can be easily identified by their white and blue color and short and sharp shape. Similarly flames lacking air can be identified though their long blue flames sometimes turning reddish or orange. Also flames, which are not suitable for fire tube application can be identified through their amorphous, uncontrollable and buoyant shape.

Figure 8.84 illustrates side-by-side comparison of the % stoichiometric air in the primary air for tested burners. Burners with minimum 100% stoichiometric air at maximum fire are recommended. In addition, the curve should be as flat as possible for lower firing rates.

Figure 8.85 illustrates the burner pressure. Burners with fuel pressure of 20 psig (approx. 140 kPaG) offer the best performance due to maximized primary air induction and the highest turndown. Burner pressures above 25 psig should be avoided due to burner noise problems. Burner pressure lower than 20 psig, results in the reduced air induction, and limited turndown.

Figure 8.86 illustrates the burner mixture pressure. Although an exact correlation is difficult to establish, generally larger diameter burners, with higher air induction, had lower mixture pressures upstream of the gas nozzle than the small diameter, mostly raw gas burners. The larger burners also had proportionally larger openings in the gas nozzle than the smaller burners. There were a number of large burners, which did not show any reliable and steady air/fuel mixture pressure readings.

Figure 8.87 illustrates the flame lengths of all burners at various firing rates. At the maximum firing rate of 500,000 BTU/hr, burners with high aeration had shorter flames between 25” and 33”. Burners with lower aeration had on average 36% longer flames at 36” to 43”.

Figure 8.88 illustrates the flame diameters of all burners at various firing rates. To match the 8” fire tube diameter of the test unit, acceptable flame diameters were between 2” to 6”, with an average 4” diameter providing the best compromise between the maximum radiant heat absorption and the lowest probability of flame impingement on the tube surface. Long and large diameter flames are the most likely to impinge on the tube due to flame buoyancy.

Figures 8.89, 8.90 illustrate the sound pressure measurements recorded during the open air firing at a one-meter horizontal distance on the side and in the back of the burner. The radiant metal mesh burners emitted the lowest sound pressure levels between 83 and 88 dBA. The large burners with high primary air induction emitted the highest sound pressure levels at between 94 and 99 dBA. Side measurements were higher than the back measurements.

The key to matching burner performance with tube performance is in its flame characteristics, some of which were previously discussed in this report.

In general, following are the guidelines related to flames for fire tube applications:

a) Flame “envelope” should match the tube diameter so that it is neither too large, nor too small. Flame, which is too large causes flame impingement, tube wall oxidation and high CO. Flame, which is too small is ineffective in radiant heat transfer.

b) Short flames are preferred over longer flames. Long flames are a symptom of air deficiency in the fuel/air mixture and are subject to buoyancy and impingement on the tube wall also leading to tube oxidation and high CO. Despite popular belief, long, orange flames do not increase the radiant heat transfer,

c) High aeration flames recommended, preferably 110% stoichiometric at maximum fire with flat aeration curve at turndown

d) Short, narrow, straight, high intensity flames recommended as opposed to long, wide, buoyant and “lazy” flames.

e) White/clear to blue flames recommended as opposed to reddish or orange flames

f) Flame momentum L/D between 5 and 10 recommended

g) Flame intensity Q/V from 600,000 BTU/hr/ft3 and up recommended

Based on the above guidelines, the burners which are not recommended for the fire tube application due to their flame characteristics are: Bekaert metal mesh burners, and Pyronics self-adjusting burners.

All of the remaining burners submitted for our evaluation provided acceptable performance and could be used for fire tube application providing they are sized properly to provide acceptable fuel/air mixture aeration, flame shape, and the turndown.

To address this requirement we created the following list of nominal burner sizes (including matching mixers and Venturi sleeves) and their recommended maximum fuel input capacities (expressed in BTU/hr HHV), which will provide desired burner performance, all in accordance to the above listed recommendations: ½" – 24,000; ¾" - 52,000; 1" – 96,000; 1-¼" – 148,000; 1-½ - 212,000; 2" – 380,000; 3" – 848,000; 4" – 1,500,000; 5" – 2,400,000; 6" – 3,400,000; 8" – 6,000,000.

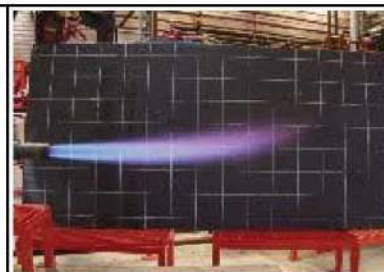
A detailed list showing maximum and minimum firing rates, as well as, gas orifice sizes is included in the final recommendations of this study in the Figure 15.2.

8.26.1 Comparison of All Burners - Flame Tests

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.
Manufacturer:	ALL BURNERS
Description:	
Orifice:	-
Date:	-


ACL 501,000 BTU/hr


A-Fire 507,000 BTU/hr

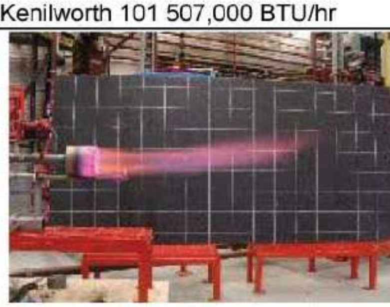

Eclipse 497,000 BTU/hr


Hauck 365,000 BTU/hr


Kenilworth 101 507,000 BTU/hr


Kenilworth 102 499,000 BTU/hr


Kenilworth 103 500,000 BTU/hr


Kenilworth 104 507,000 BTU/hr


Maxon Small 116,000 BTU/hr


Maxon Medium 455,000 BTU/hr


Maxon Large 524,000 BTU/hr


North American 540,000 BTU/hr

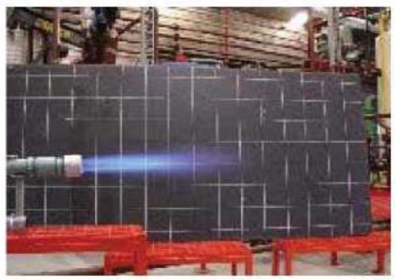
FIGURE 8.81 Burner Bench Test Performance Comparison – Burner Flames A

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.
Manufacturer:	ALL BURNERS
Description:	
Orifice:	-
Date:	-

Profire Venturi 537,000 BTU/hr

Profire Pipe 535,000 BTU/hr

Pyronics Small 312,000 BTU/hr



Pyronics Large 534,000 BTU/hr

Pyronics Sm Auto 695,000 BTU/hr

Pyronics Lg Auto 836,000 BTU/hr

FIGURE 8.82 Burner Bench Test Performance Comparison – Burner Flames B

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner Open Flame Tests
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	ALL BURNERS
Description:	Radiant Burners
Orifice:	-
Date:	-

Bekaert Short A 497,000 BTU/hr

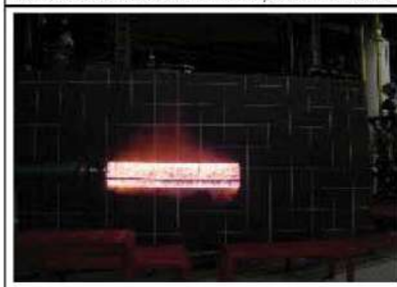
Bekaert Short B 496,000 BTU/hr

Bekaert Short C 498,000 BTU/hr

Bekaert Medium D 500,000 BTU/hr

Bekaert Medium E 498,000 BTU/hr

Bekaert Medium F 498,000 BTU/hr



Bekaert Long G 478,000 BTU/hr

FIGURE 8.83 Burner Bench Test Performance Comparison – Bekaert Radiant Burners Flames

8.26.2 Comparison of All Burners - % Stoichiometric Air in Primary Air Tests

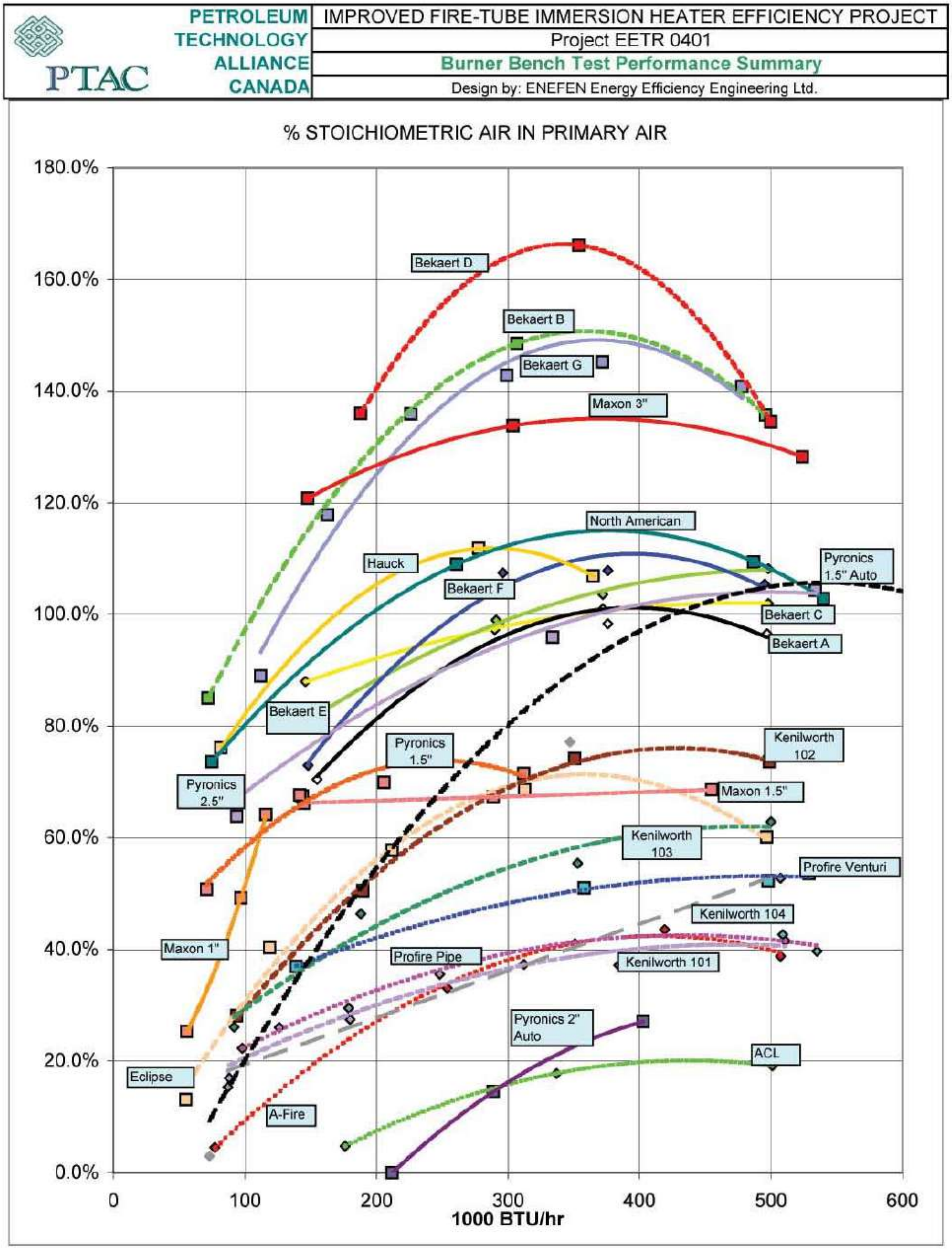


FIGURE 8.84 Burner Bench Test Performance Comparison – % Stoichiometric Air in Primary Air

8.26.3 Comparison of All Burners - Burner Gas Pressure

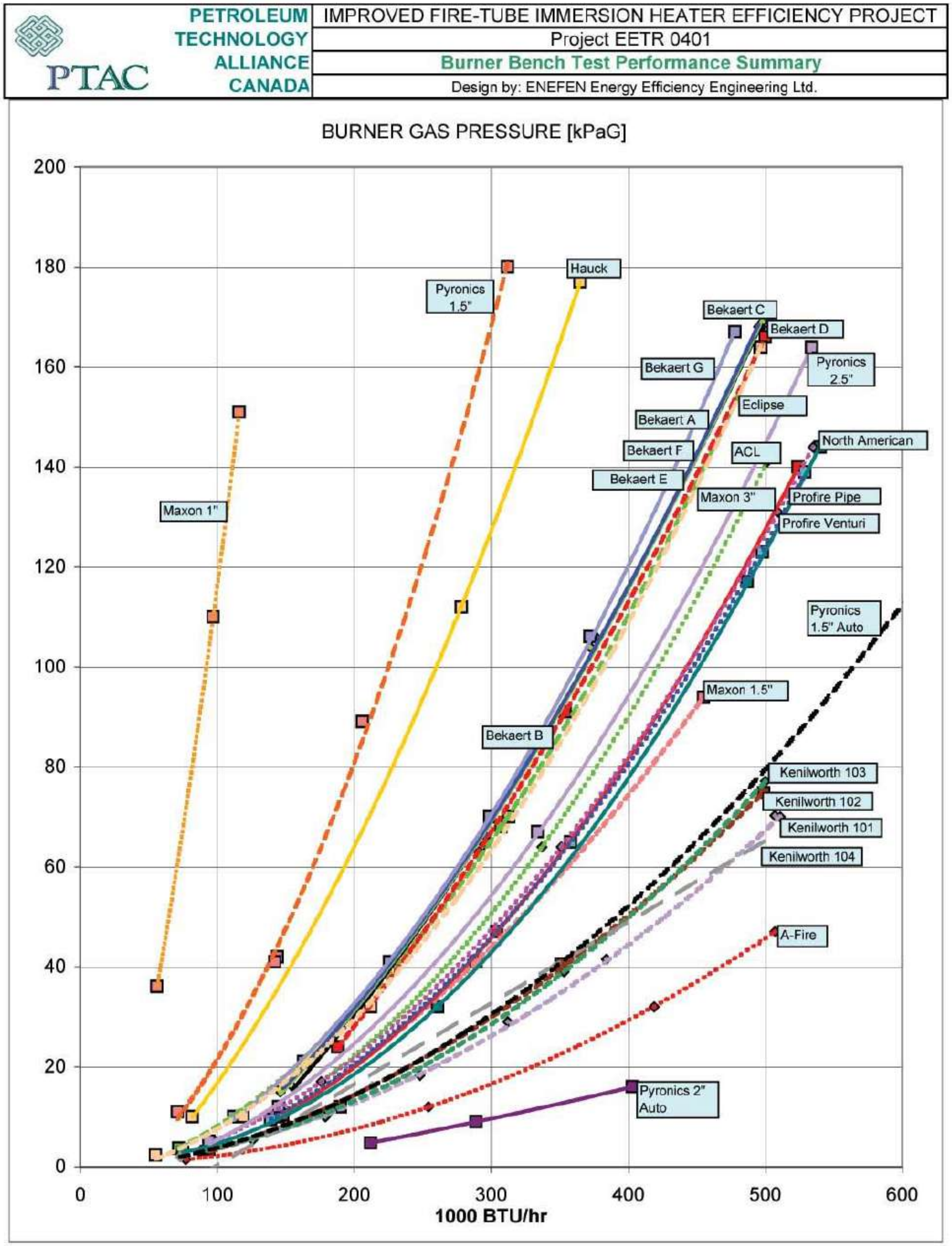


FIGURE 8.85 Burner Bench Test Performance Comparison – Burner Gas Pressure

8.26.4 Comparison of All Burners - Burner Mixture Pressure

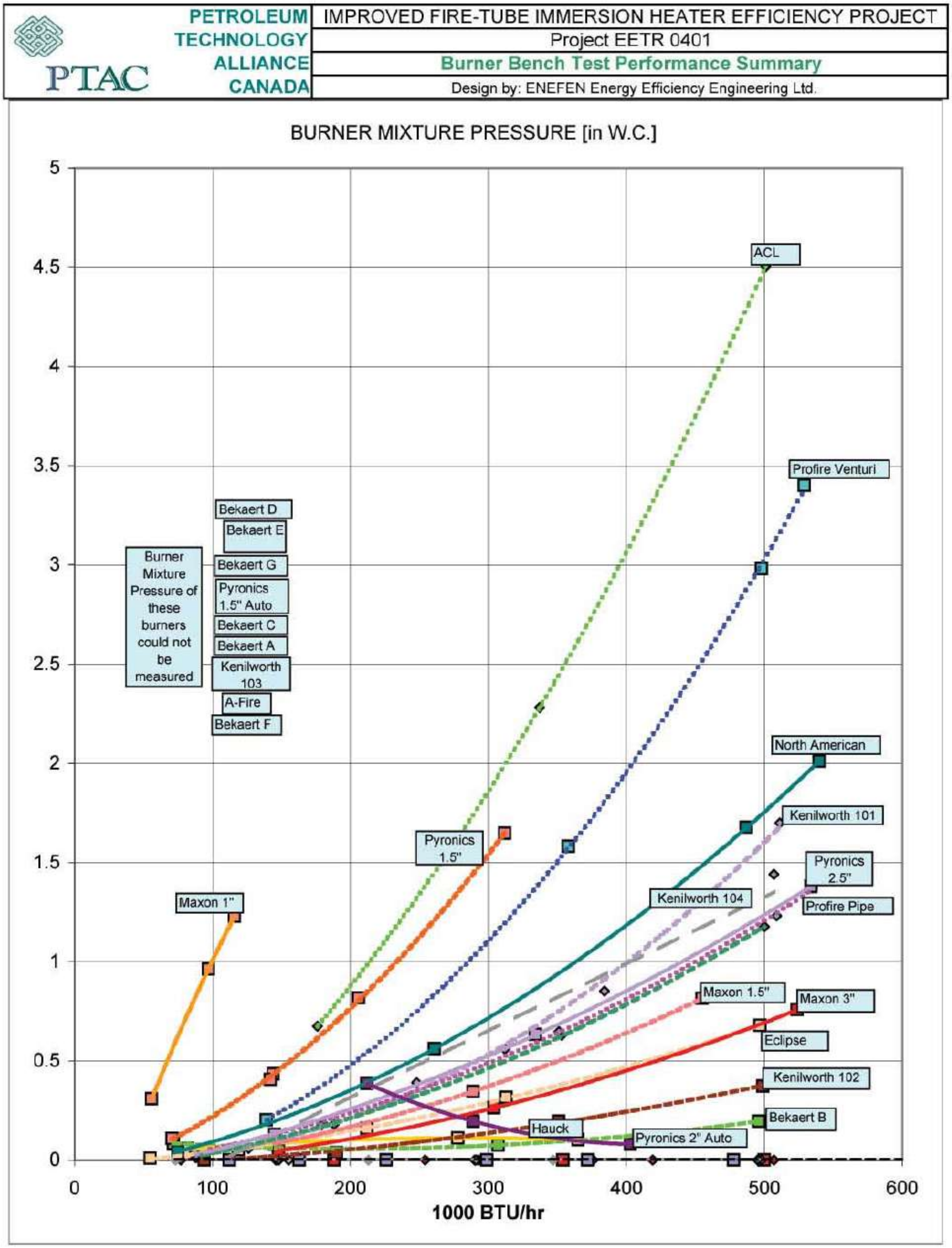


FIGURE 8.86 Burner Bench Test Performance Comparison – Burner Mixture Pressure

8.26.5 Comparison of All Burners – Flame Length

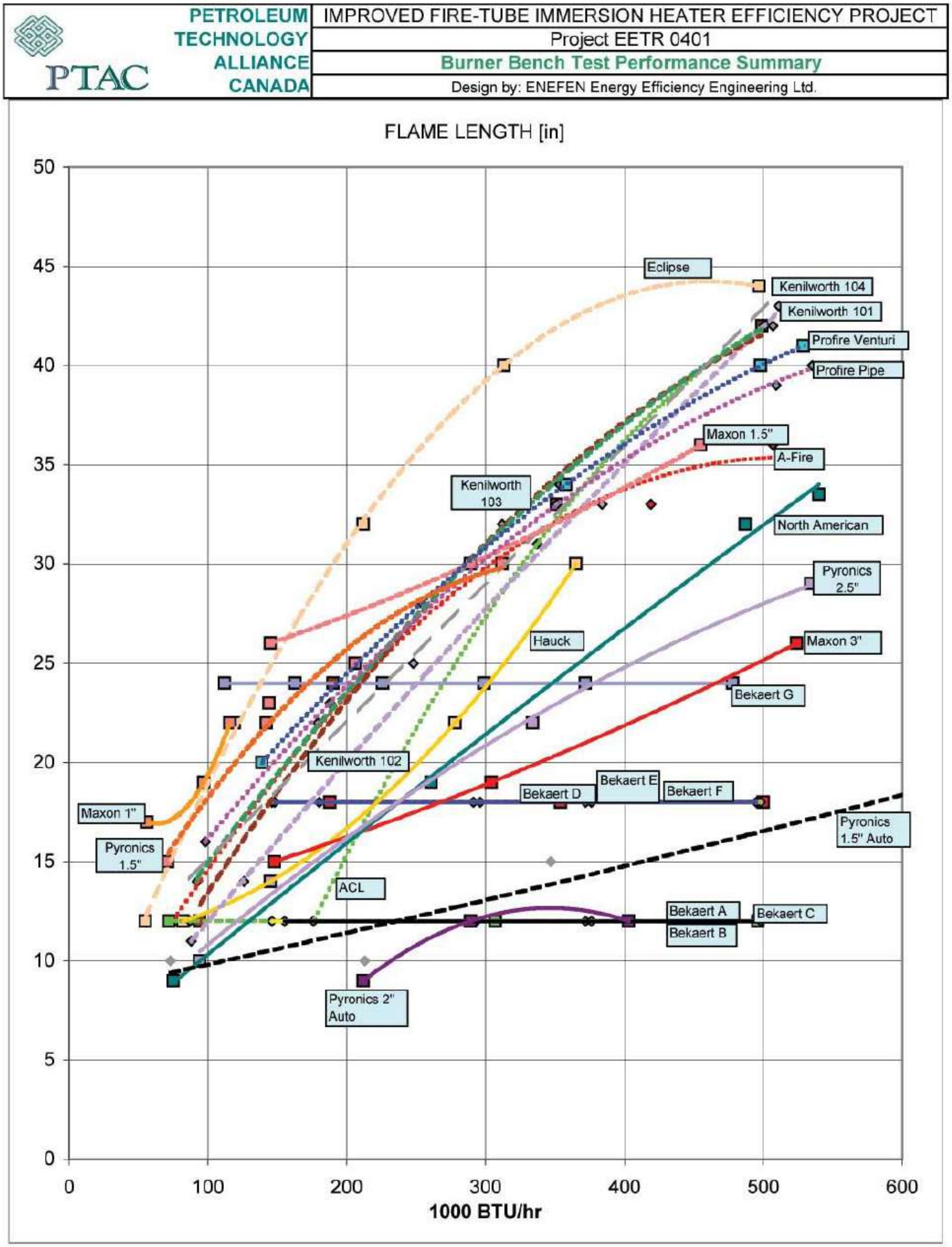


FIGURE 8.87 Burner Bench Test Performance Comparison – Flame Length

8.26.6 Comparison of All Burners – Flame Diameter

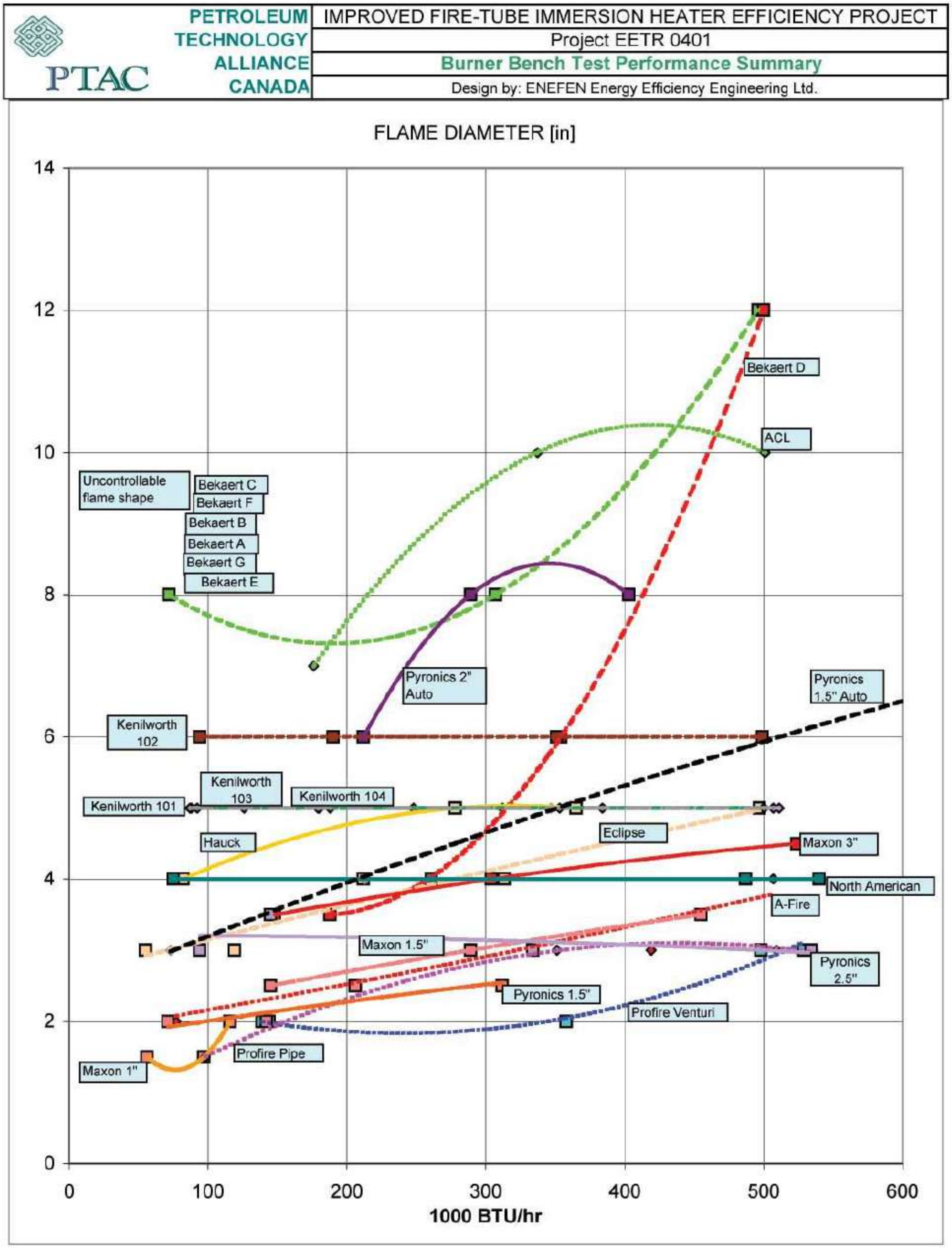


FIGURE 8.88 Burner Bench Test Performance Comparison – Flame Diameter

8.26.7 Comparison of All Burners – Sound Pressure Level (1m to side)

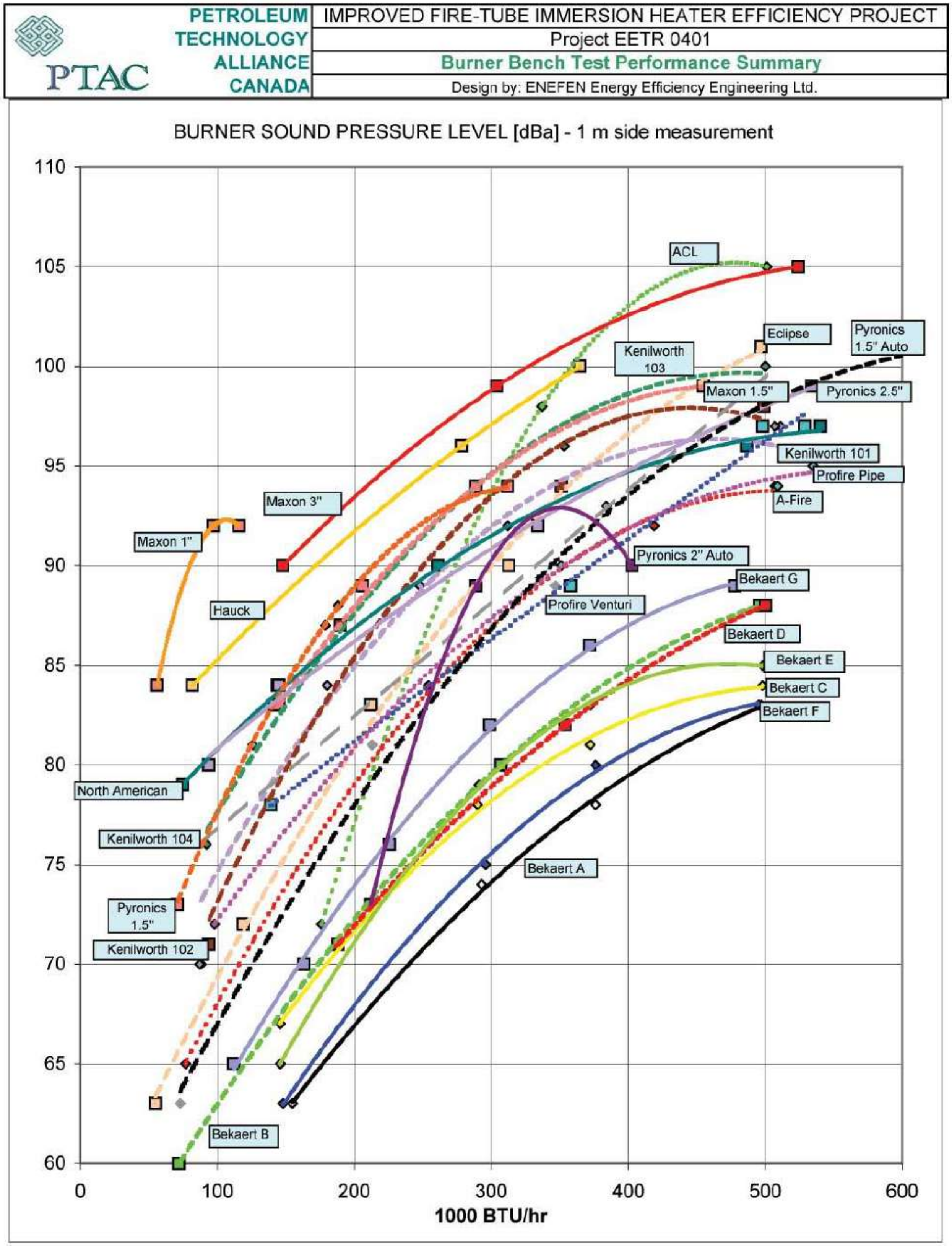


FIGURE 8.89 Burner Bench Test Performance Comparison – Burner Sound Pressure Levels (1m to side)

8.26.8 Comparison of All Burners – Sound Pressure Level (1m back)

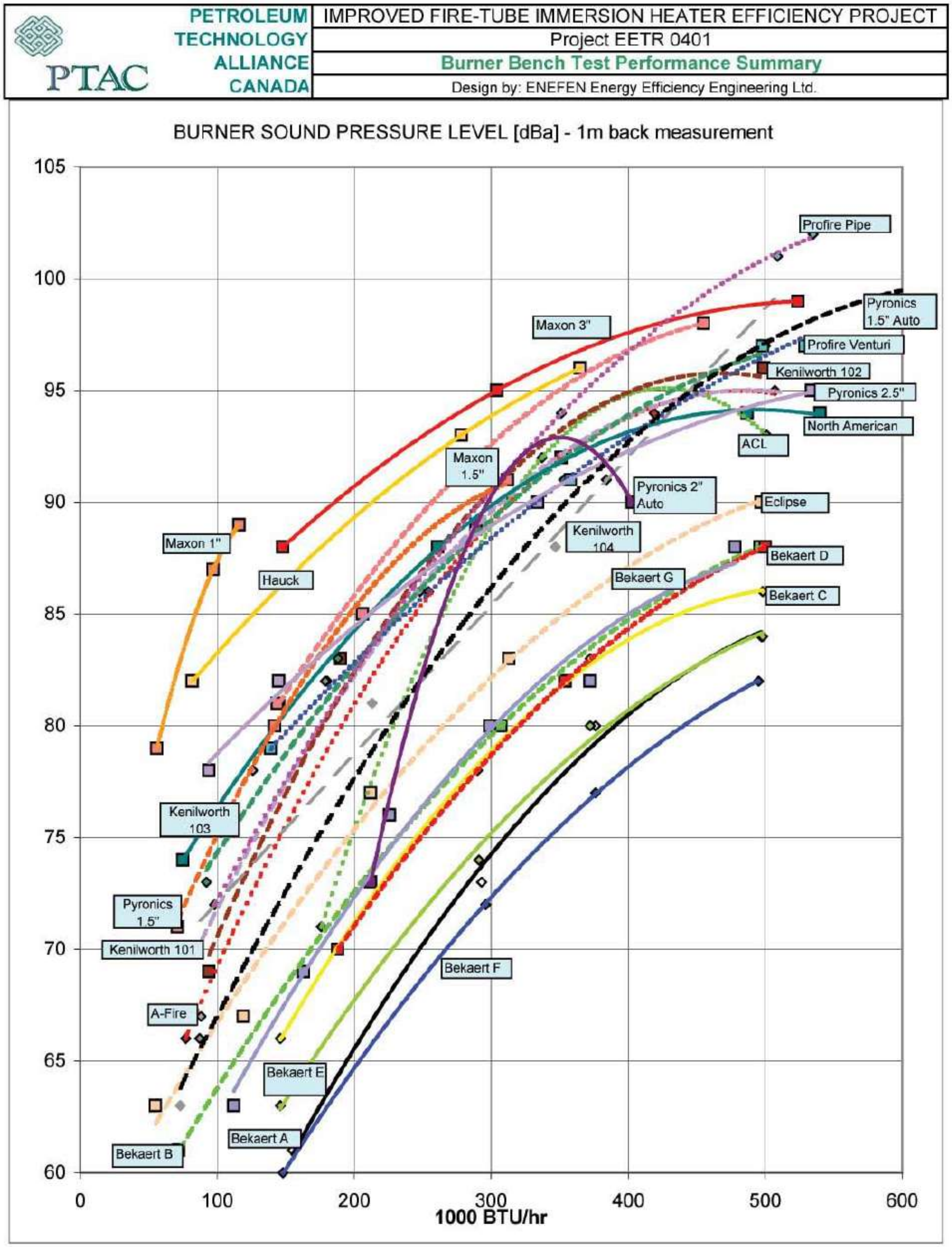


FIGURE 8.90 Burner Bench Test Performance Comparison – Burner Sound Pressure Levels (1m behind)

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9 BURNER HEATER TESTS

This chapter contains performance data from burner firing tests in the test unit, configured to a 2-pass operation with water bath. This configuration was chosen to provide closest resemblance to actual field installations common in the industry.

Not all burner configurations presented in the previous chapter were tested. Nineteen (19) out of twenty five (25) configurations were chosen as representative. Each one of these 19 burner configurations was mounted on the universal mounting bracket, and positioned, at the centre of the fire tube entrance so that the burner flame would not affect the fire-tube portion external to the heater, and therefore, not cooled by the bath liquid (Figure 9.1).

FIGURE 9.1 Burner Mounted for Testing in the Test Unit

Each burner was started, and the firing rate was increased to the nominal fuel flow of 500 CFH, corresponding to 500,000 BTU/hr HHV fuel input. Then the primary combustion air was set to provide the maximum possible flame aeration without loosing the burner stability. And finally, the secondary airflow was adjusted by partially blocking the fire-tube entrance area around the burner (Figure 9.2), until the stack oxygen reading of approximately 2.5% was measured.

FIGURE 9.2 Secondary Air Partially Blocked and the Fire Tube Entrance

A Similar combustion setup, optimized at the maximum firing rate, was the starting point for each of the burner tests. Almost all of the 19 burners tested, offered an acceptable performance at this setting with the exception of the radiant metal fibre burners and the self-adjusting burners.

The radiant metal fibre burners did not provide sufficient forward flame velocity to induce the secondary airflow. This was especially evident during the burner startup with very limited natural draft, and, with the substantial flame external to the burner mesh. This external flame traveled both in the forward direction into the tube but also backwards towards the fire-tube inlet where normally a flame arrester would be located. Even after the stack draft was fully developed, the firing rate of the radiant burners had to be limited to about 50% in order to stop the flame travel in the backwards direction. Consequently, due to the flame shape characteristics and the lack of the flame forward momentum the radiant burners as supplied for this test had to be considered unsuitable.

We also experienced some flame stability problems with the self-adjusting burners, which we attributed to their wide flame pattern. Consequently, although these burners are designed to provide a wide turndown range, in a fire-tube application such turndown could not be achieved.

To better illustrate the flame behavior inside a fire tube, we have taken the photographs of the comparable maximum flame sizes from bench testing, and cropped them to an approximate dimension of an 8" fire tube, "as if" the flame was photographed through a fire-tube made of glass. Although the secondary airflow induced by the natural draft, as well as, by the "air pump" effect of the burner itself, may in part alter these flame shapes, it is our observation, that flame shape inside and outside of the fire-tube is similar. Figure 9.3 illustrates the comparison between "sharp and dynamic" flame shapes, where Figure 9.4 illustrates "wide and static" flame shapes.

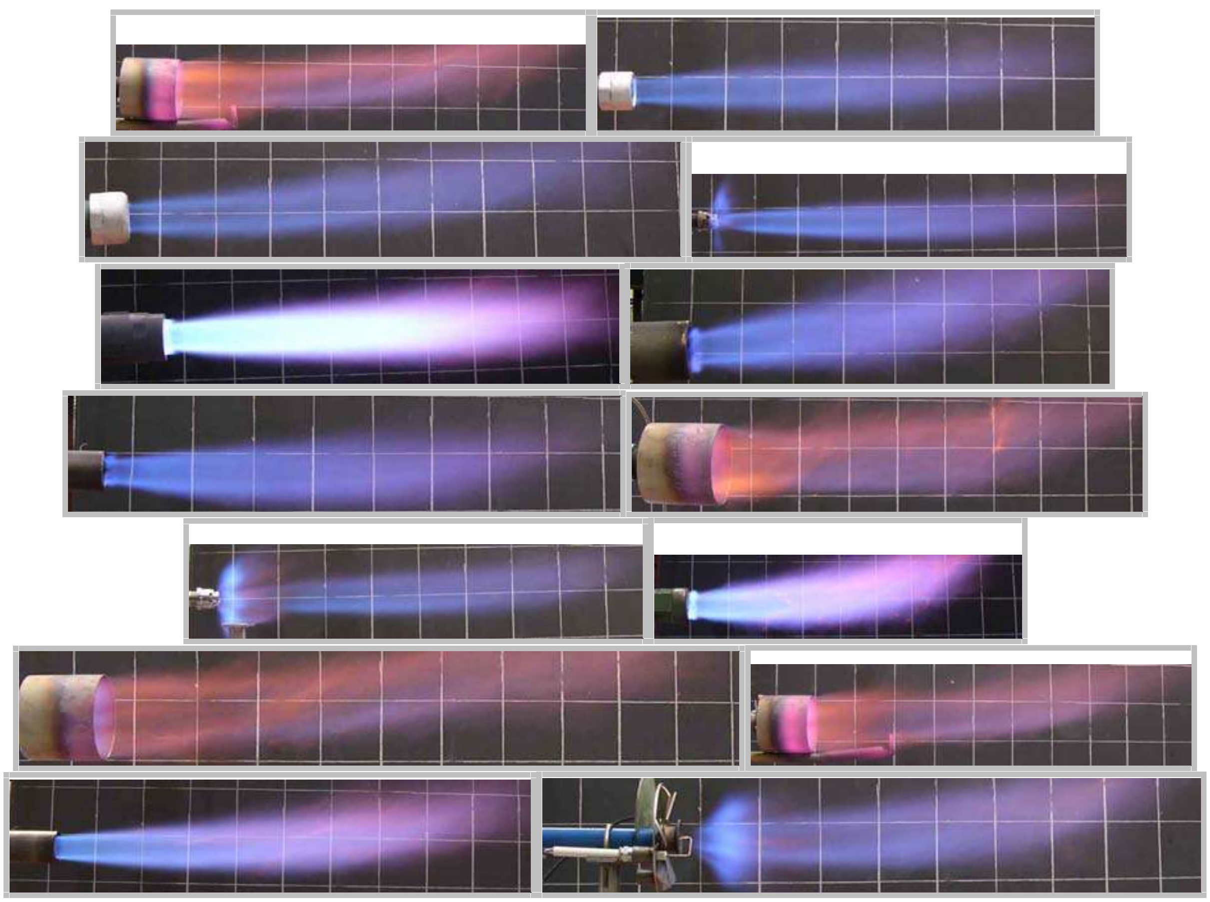


FIGURE 9.3 "Sharp and Dynamic" Flame Shapes inside a Fire Tube

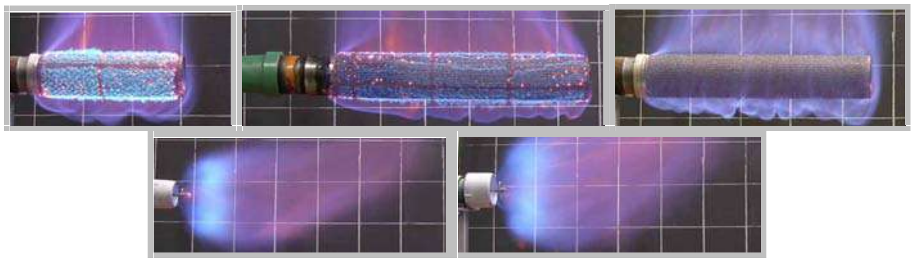


FIGURE 9.4 "Wide and Static " Flame Shapes inside a Fire Tube

It is worth noting that none of the above photographs shows a long, lazy and "smoking" flame, which can be found from time to time in the field installations, and which should be altogether avoided.

Looking at the above photographs, we can visualize how "sharp and dynamic" flames better promote flame and products of combustion flow through the fire tube, than the "wide and static" flames. This is especially important in fire-tube applications with frequent ON/OFF cycling, where the natural draft has to be re-established every time the burner is fired, since it naturally diminishes during the burner OFF period.

The photographs also demonstrate potential tube impingement and overheating problems due to flame buoyancy. Mounting burner slightly below tube centerline, and inclining it downwards can help to minimize the tube impingement, as long as the flame remains "sharp and dynamic" throughout its turndown range. It is not uncommon that at high turndown even sharp flames loose their shape and become "lazy and static", consequently impinging on the fire-tube surface immediately above the burner nozzle. This common characteristic of natural draft Venturi style burners puts a practical limit on the ability to modulate their fuel input, which must be carefully assessed during heater and controls design, as well as, during burner setup up. Figure 9.5 illustrates a sharp, high intensity flame, which does not impinge on the fire-tube. A row of glowing points along the tube bottom represents the tube temperature thermocouples installed on a 12" spacing in the test unit.

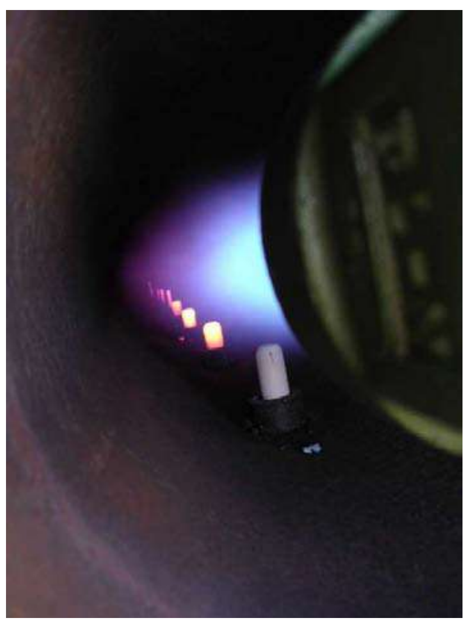


FIGURE 9.5 "Sharp and Dynamic" Non-Impinging Flame inside the Test Unit's Fire-Tube

In addition to the burner flame shaping capability at various fuel inputs, fire-tube performance also is influenced by the secondary airflow. As discussed previously, burners, which have higher percentage of stoichiometric air induced through the primary air inlet, require less secondary air. Ideally, their fuel/air mixture delivered from the mixer to the burner nozzle should be homogeneous, and should have enough oxygen (including 10% excess), to provide complete combustion regardless of the natural draft condition.

Conversely, burners, which do not induce high percentage of stoichiometric air through the mixer (raw gas burners), rely heavily on the natural draft providing air necessary for combustion, and on some means of mixing this air with the fuel inside the fire-tube. Modulation of fuel input to such burners is problematic, since only the fuel flow changes, while the secondary airflow is maintained due to a presence of the relatively constant natural draft. This results in high excess air combustion and low heater efficiency.

The objective of an energy efficient heater design is therefore, to provide a combustion and controls solution, which allows the burner to modulate while maintaining a constant low air/fuel ratio with 10% excess air.

The currently used heater designs including burners, fire-tubes and controls do not address the above objective. Although most of the burners can be set, as proven in this study, to provide a relatively efficient combustion at one specific firing rate, finding such rate in a field application is practically impossible due to changing process demand or ambient conditions. Consequently, the firing rate has to be set higher than the highest possible energy demand, thus causing heater to cycle ON/OFF. Not only is this inefficient due to the heater overfiring during most of the ON times, but also inefficient due to heater loosing energy to natural draft during the OFF times.

At the same time, a conventional method of fuel modulation using a fuel control valve, is a step in the wrong direction, since the perceived efficiency gain due to modulation is counteracted by the efficiency loss due to high excess air.

Individual burner testing in a 2-pass configuration of the test unit was aimed at researching this efficiency dilemma. To achieve this goal, burner performance was optimized at the maximum firing of 500,000 BTU/hr and then the firing rate was gradually reduced to 100,000 BTU/hr (without readjusting the burner). These tests simulated a conventional modulating control valve application.

The following heater performance parameters were recorded:

a) Gross thermal efficiency;

b) Stack oxygen;

c) Stack temperature;

d) Stack CO

e) Stack NOx;

f) Burner Sound pressure level;

g) Fire-tube and stack temperature profiles

The following pages contain graphs illustrating these parameters for each tested burner, and are followed by comparison graphs of all burners.

As explained previously, the generalization of this data should be done with caution, as the performance of each burner is dictated by its “match” to a specific fire-tube configuration. For different tube sizes, each burner may perform better or worse. Also, any burner from any manufacturer may be misapplied and create flame instability, impingement problems, or low efficiency.

9.1 ACL 1" Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.6;
- colder fire-tube "entry zone": first 3 to 4 feet of the fire-tube
- temperature peak: 1730 deg F at 5.5 feet
- partial tube flow: at less than 150,000 BTU/hr; approx above 3:1 turndown.

Burner Performance Graphs:

- see Figure 9.7;
- maximum fire: 500,000 BTU/hr; minimum fire: 100,000 BTU/hr; 5:1 turndown
- gross thermal efficiency: 72% HHV at maximum fire, 58% HHV at minimum fire
- stack oxygen: 2.5% at maximum fire; 16.8% at minimum fire – show high reliance on secondary air flow
- stack temperature: 500 deg C at maximum fire; 260 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 102 dBA at maximum fire; 61 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 10 and 45 ppm
- stack CO: between 50 ppm and 87 ppm

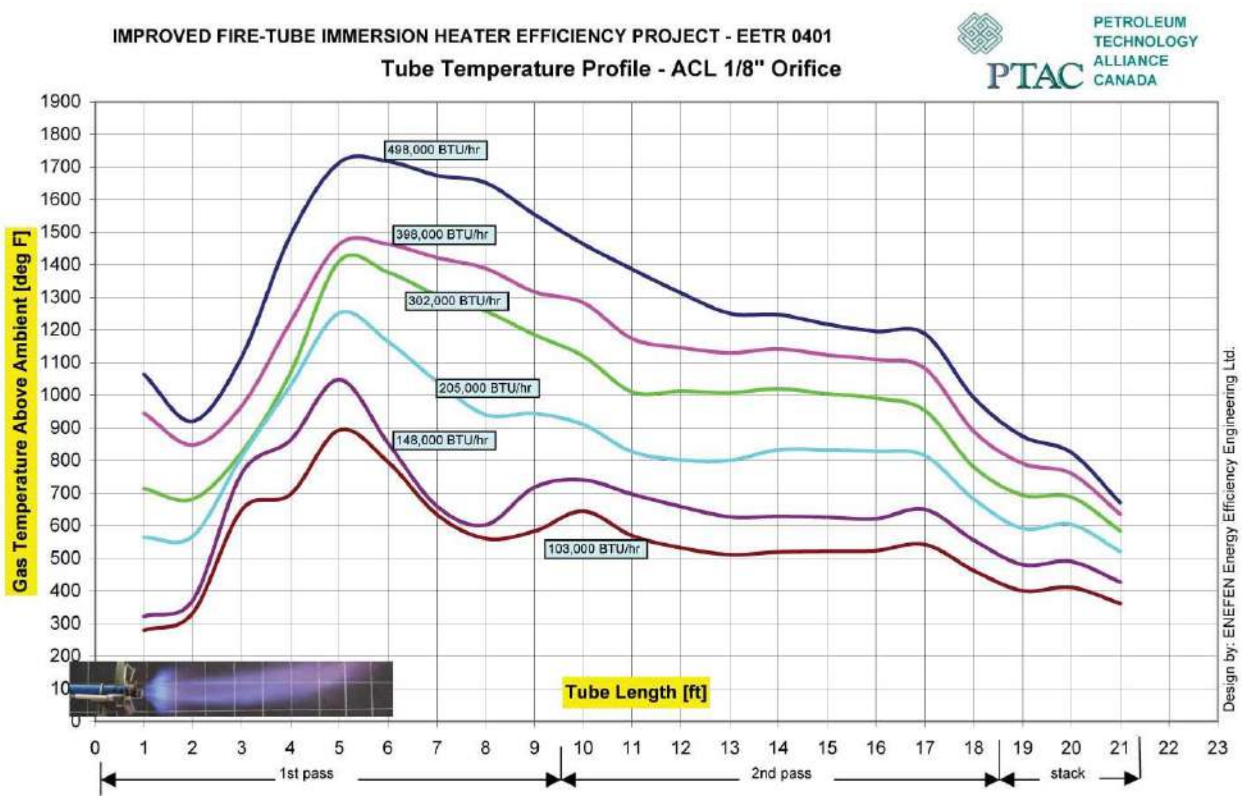
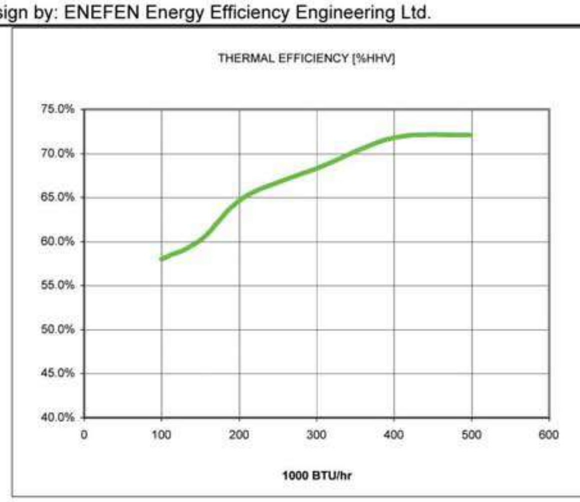
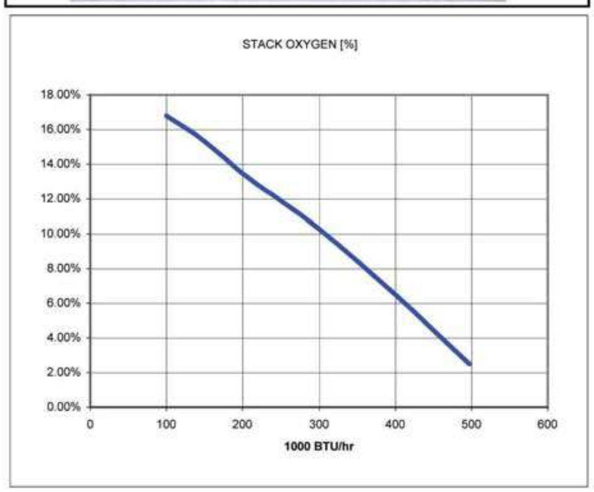


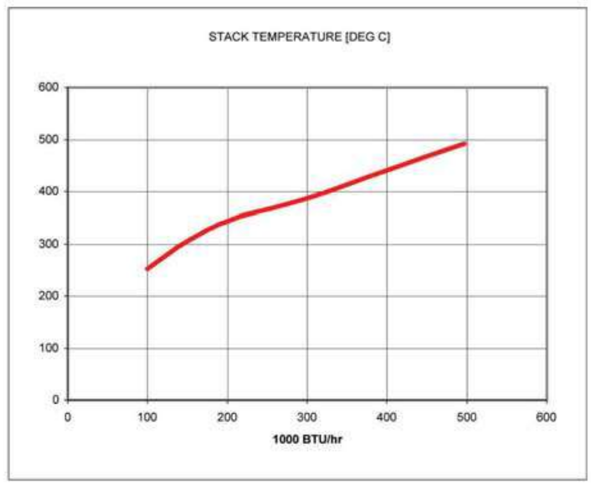
FIGURE 9.6 Tube Temperature Profiles with 1" ACL Burner

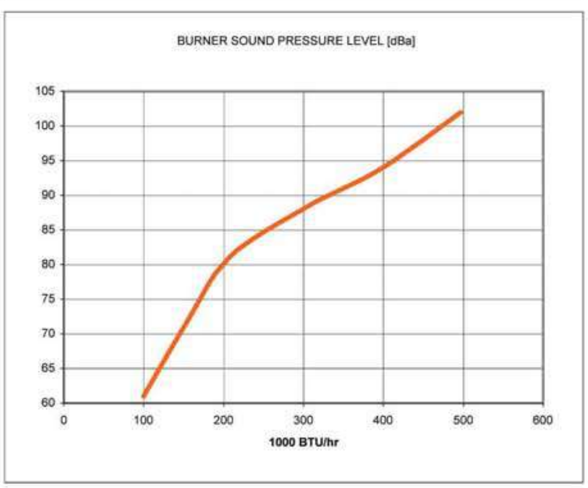
PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner 2-Pass Heater Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	ACL MANUFACTURING
Description:	1" ACL Burner
Orifice:	1/8"
Date:	23-Mar-05









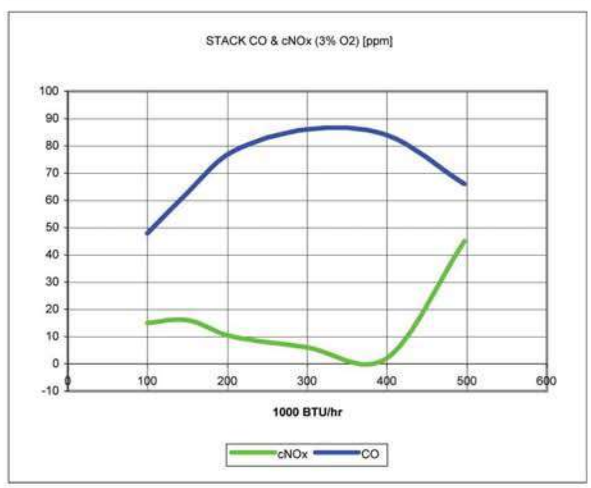


FIGURE 9.7 1" ACL Burner Performance in the Fire Tube

9.2 A-Fire 1" Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.8;
- colder fire-tube "entry zone": first 3 to 4 feet of the fire-tube
- temperature peak: 1930 deg F at 5. feet
- partial tube flow: at less than 120,000 BTU/hr; approx above 4:1 turndown.

Burner Performance Graphs:

- see Figure 9.9;
- maximum fire: 500,000 BTU/hr; minimum fire: 100,000 BTU/hr; 5:1 turndown
- gross thermal efficiency: 72% HHV at maximum fire, 55% HHV at minimum fire
- stack oxygen: 2.6% at maximum fire; 16.5% at minimum fire – show high reliance on secondary air flow
- stack temperature: 520 deg C at maximum fire; 280 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 95 dBA at maximum fire; 67 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 10 and 80 ppm
- stack CO: between 0 ppm and 165 ppm

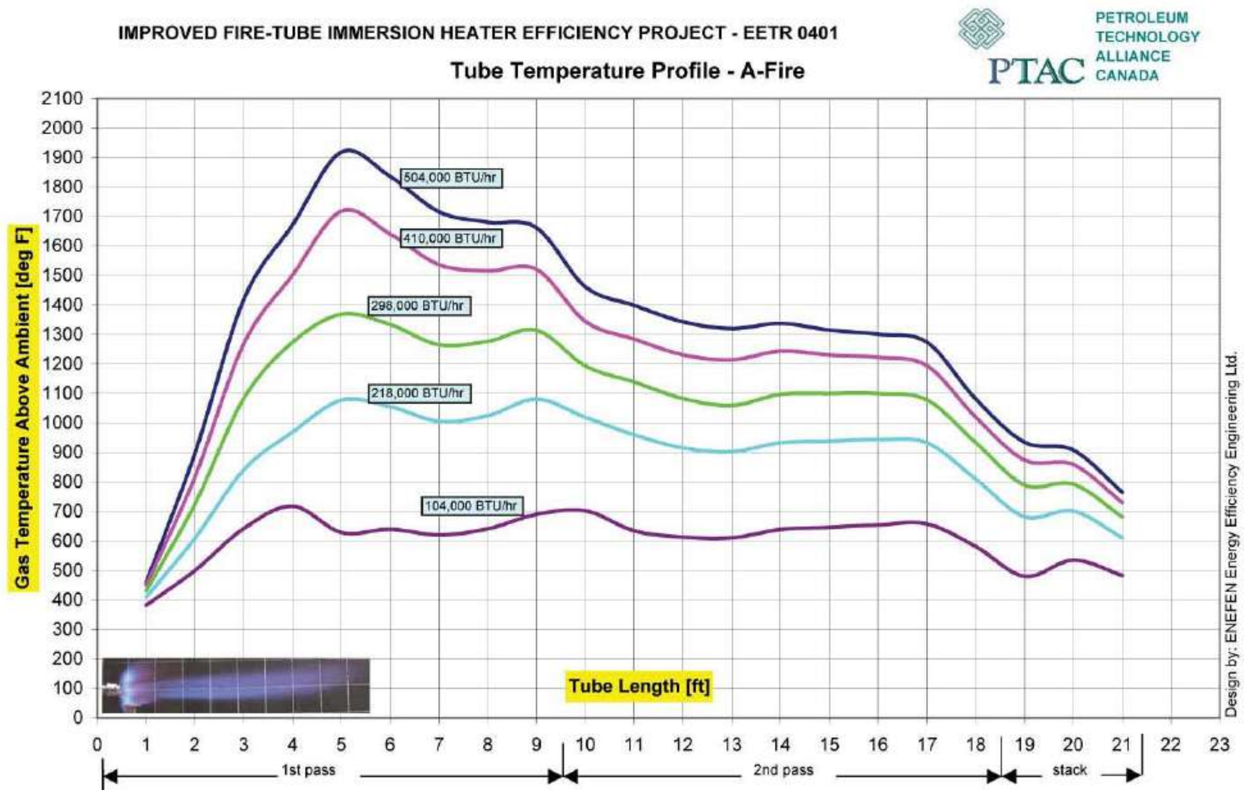
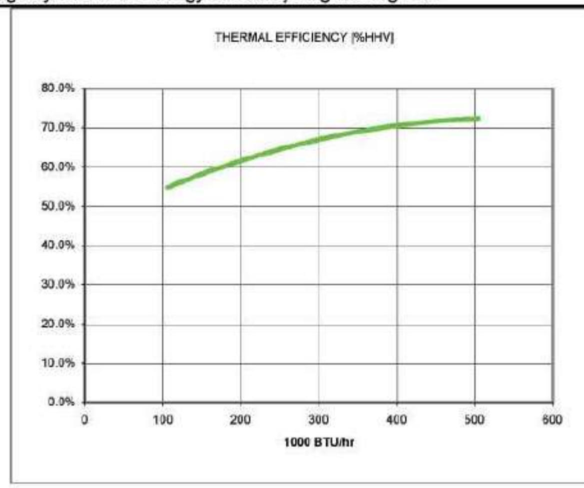
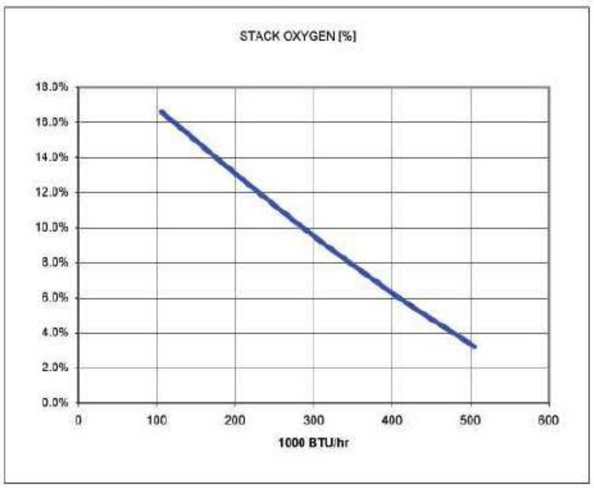


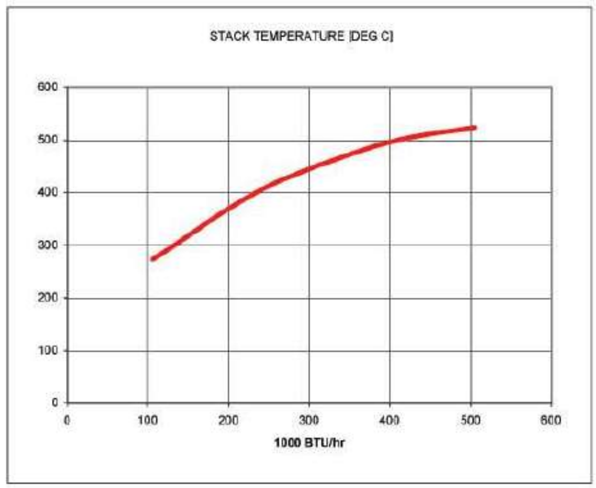
FIGURE 9.8 Tube Temperature Profiles with 1" A-Fire Burner

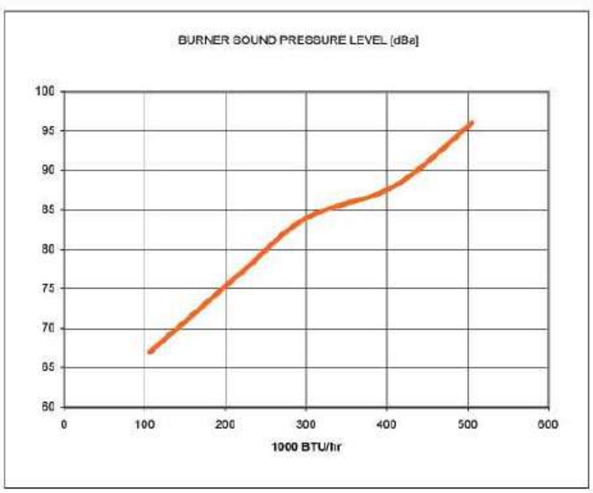
PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
PTAC	Project EETR 0401
	Burner 2-Pass Heater Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	A-Fire
Description:	1" A-Fire Burner
Orifice:	11/64"
Date:	23-Mar-05









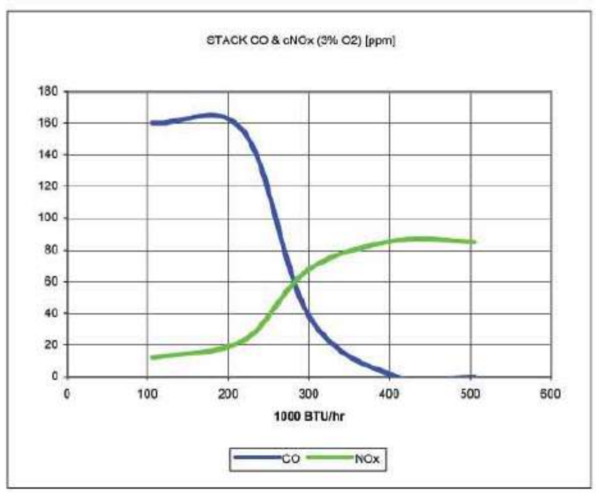


FIGURE 9.9 1" A-Fire Burner Performance in the Fire Tube

9.3 Bekaert 3”x12” (Config. A) Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.10;
- direct flame impingement and overheating around the burner nozzle
- temperature peak: 3000 deg F at 1 foot
- limited temperature gain above 300,000 BTU/hr, due to flame flowing backwards.

Burner Performance Graphs:

- see Figure 9.11;
- maximum fire: 300,000 BTU/hr; minimum fire: 100,000 BTU/hr; 3:1 turndown – flame flowing backwards (into flame arrester) when firing rate in excess of 250,000 BTU/hr
- gross thermal efficiency: 65% HHV at maximum fire, 52% HHV at minimum fire (low due to high excess air)
- stack oxygen: 10% at maximum fire; 17% at minimum fire – needs high excess air to operate
- stack temperature: 400 deg C at maximum fire; 220 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 81 dBA at maximum fire; 61 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 12 and 65 ppm
- stack CO: between 5 ppm and 58 ppm

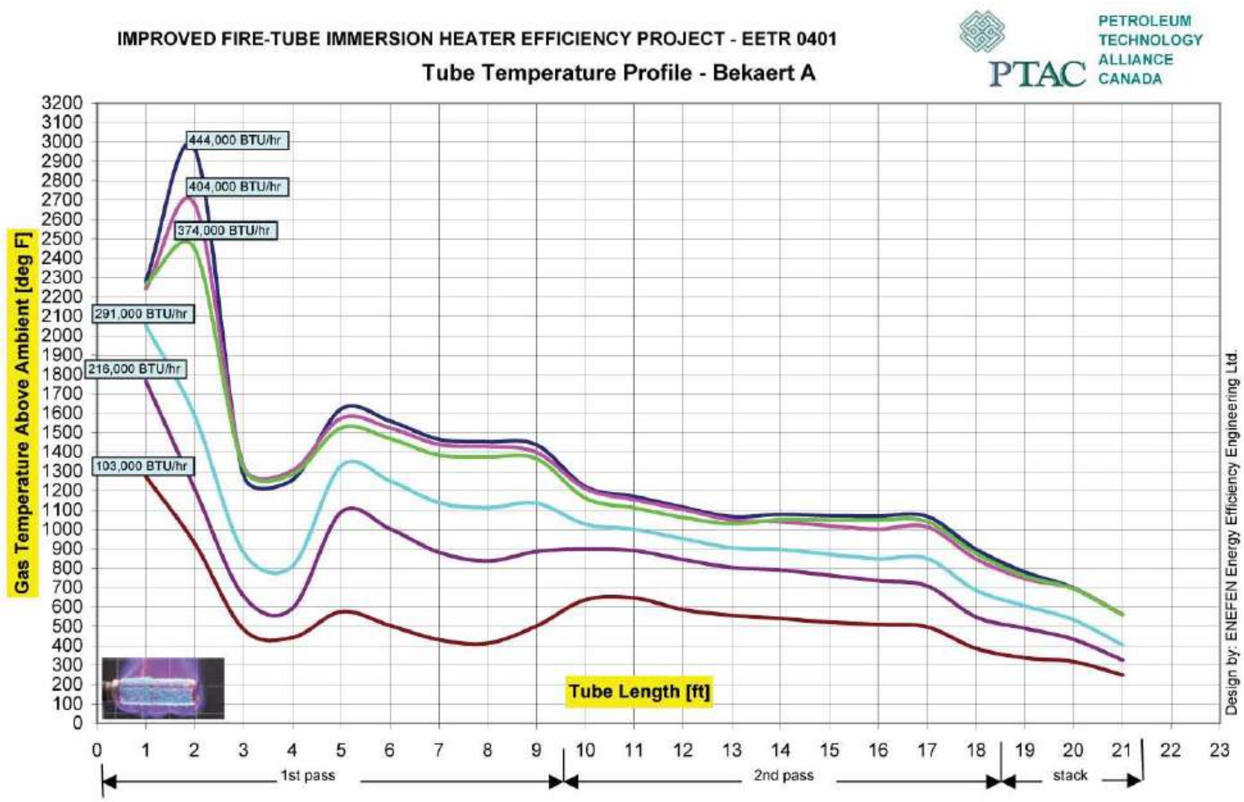
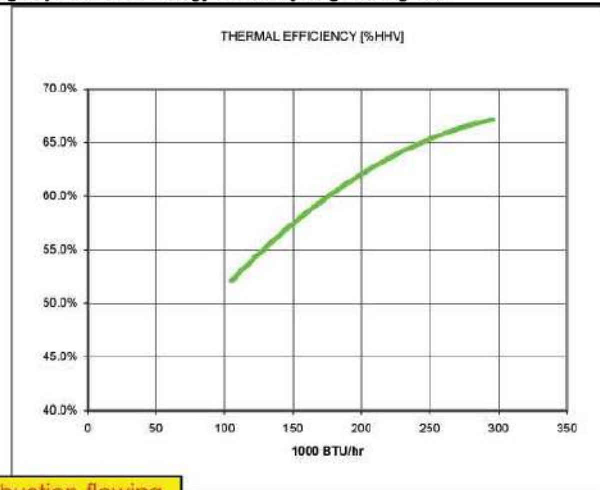


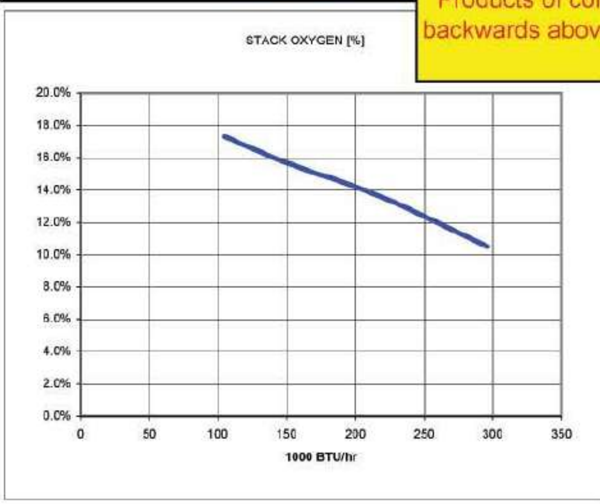
FIGURE 9.10 Tube Temperature Profiles with 3”x12” Bekaert Burner (Config. A)

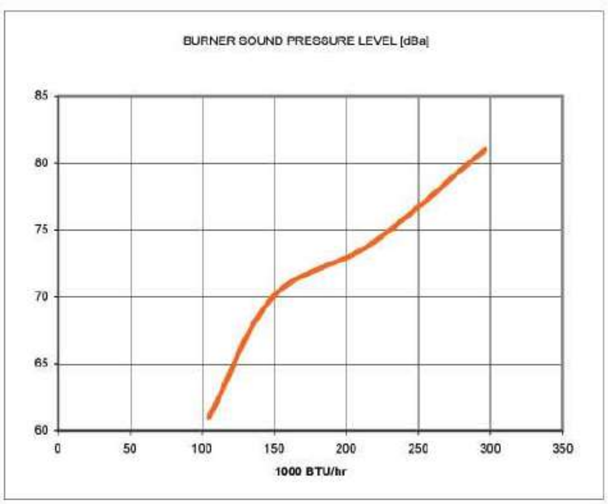
PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
		Project EETR 0401
		Burner 2-Pass Heater Test Performance Summary
		Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Bekaert (Config Short A)
Description:	3"dia x12" mesh burner with 2-1/2" Eclipse Mixer, No Compund Barel, 2-1/2" Nipple
Orifice:	1/8"
Date:	24-Mar-05



Products of combustion flowing backwards above 250,000 BTU/hr





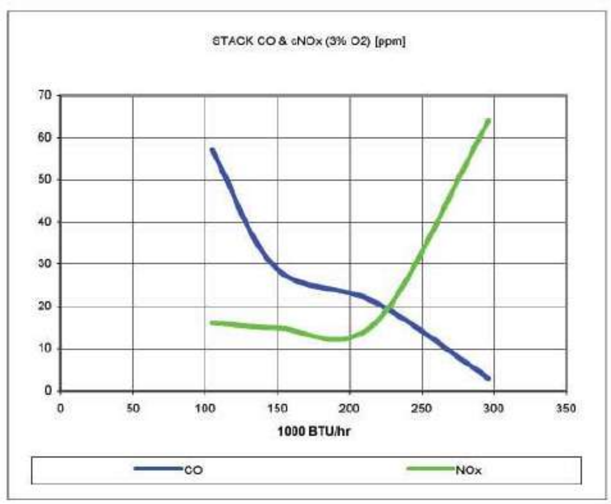


FIGURE 9.11 3”x12” Bekaert Burner (Config. A) Performance in the Fire Tube

9.4 Bekaert 3”x18” (Config. F) Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.12;
- direct flame impingement and overheating around the burner nozzle
- temperature peak: 2000 deg F at 1 feet
- limited temperature gain above 300,000 BTU/hr, due to flame flowing backwards.

Burner Performance Graphs:

- see Figure 9.13;
- maximum fire: 300,000 BTU/hr; minimum fire: 100,000 BTU/hr; 3:1 turndown – flame flowing backwards (into flame arrester) when firing rate in excess of 250,000 BTU/hr
- gross thermal efficiency: 67% HHV at maximum fire, 55% HHV at minimum fire
- stack oxygen: 11% at maximum fire; 18% at minimum fire – shows high reliance on secondary air flow
- stack temperature: 370 deg C at maximum fire; 180 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 80 dBA at maximum fire; 67 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 10 and 55 ppm
- stack CO: between 5 ppm and 70 ppm

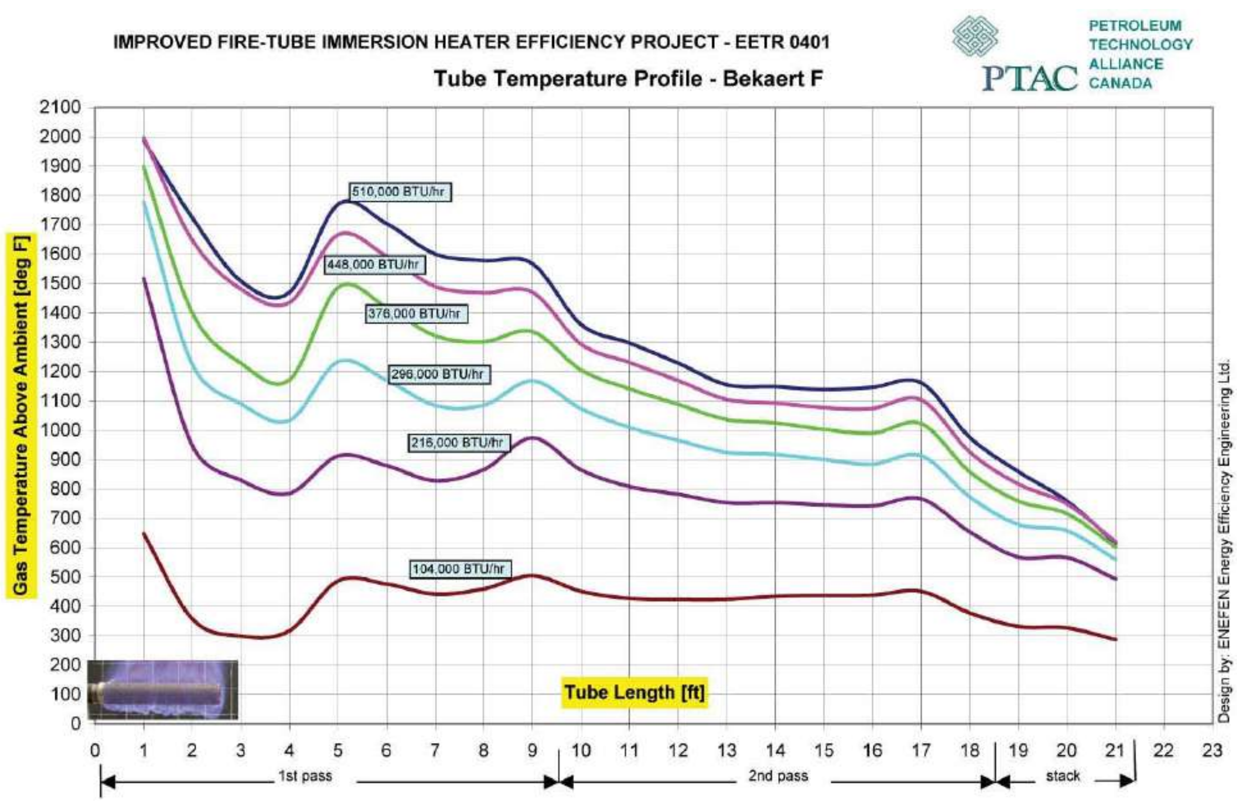
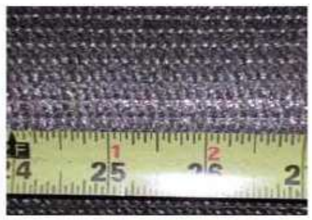
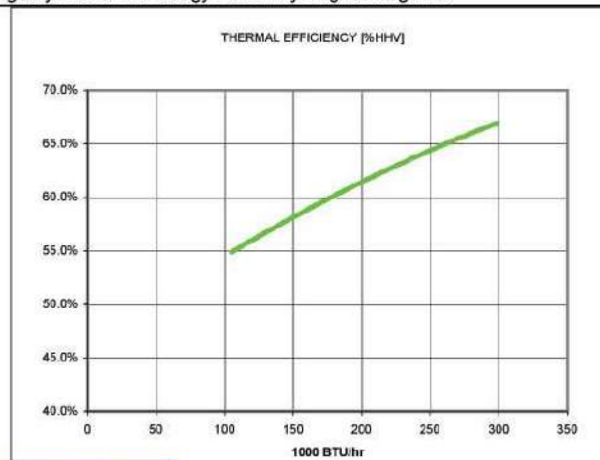


FIGURE 9.12 Tube Temperature Profiles with 3”x18” Bekaert Burner (Config. F)

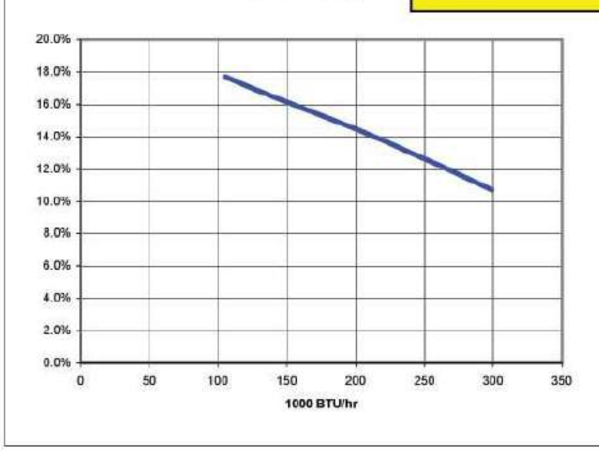
PETROLEUM TECHNOLOGY ALLIANCE CANADA (PTAC)	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner 2-Pass Heater Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

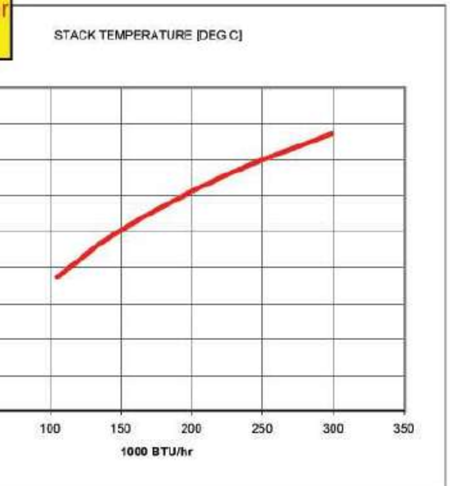
Manufacturer:	Bekaert (Config Medium F)
Description:	3"dia x18" mesh burner with 2-1/2" Eclipse Mixer, No Compound Barel, 2-1/2" Nipple
Orifice:	1/8"
Date:	19-Mar-05

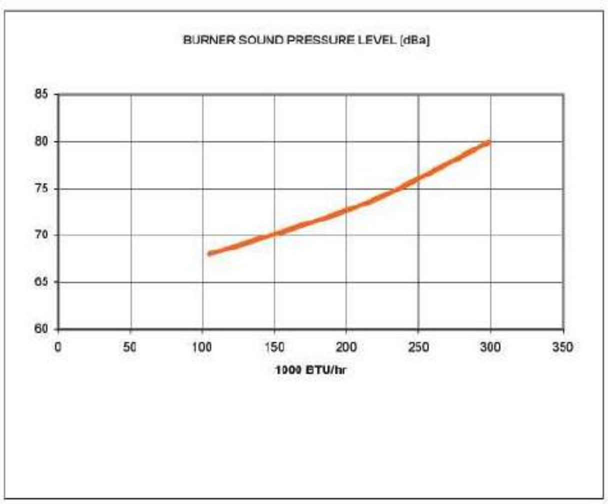




Products of combustion flowing backwards above 250,000 BTU/hr







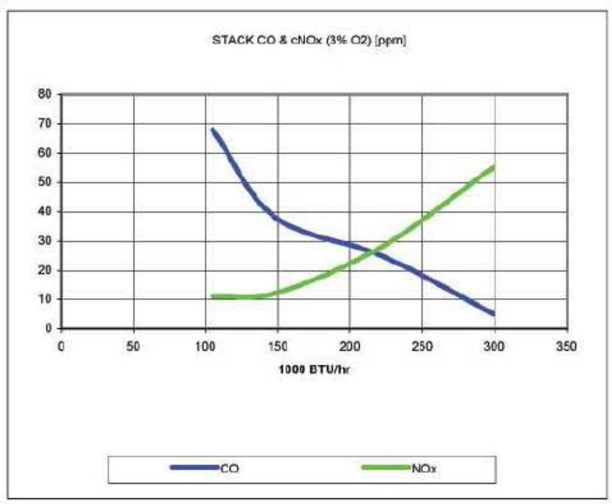


FIGURE 9.13 3”x18” Bekaert Burner (Config. F) Performance in the Fire Tube

9.5 Bekaert 4”x24” (Config. G) Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.14;
- direct flame impingement and overheating around the burner nozzle
- temperature peak: 2100 deg F at 2 feet
- limited temperature gain above 300,000 BTU/hr, due to flame flowing backwards.

Burner Performance Graphs:

- see Figure 9.15;
- maximum fire: 300,000 BTU/hr; minimum fire: 100,000 BTU/hr; 3:1 turndown – flame flowing backwards (into flame arrester) when firing rate in excess of 250,000 BTU/hr
- gross thermal efficiency: 73% HHV at maximum fire, 63% HHV at minimum fire
- stack oxygen: 9.5% at maximum fire; 17.2% at minimum fire – show high reliance on secondary air flow
- stack temperature: 300 deg C at maximum fire; 170 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 82 dBA at maximum fire; 67 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 10 and 35 ppm
- stack CO: between 10 ppm and 50 ppm

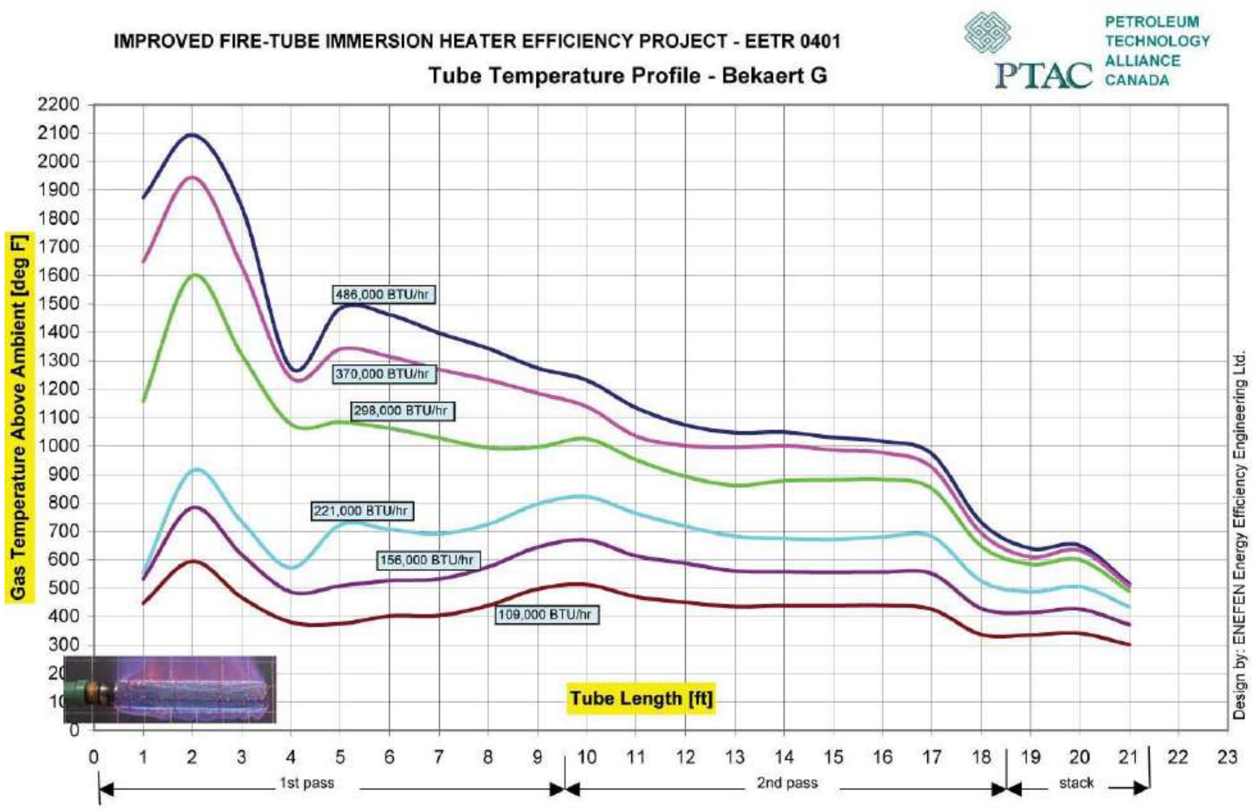
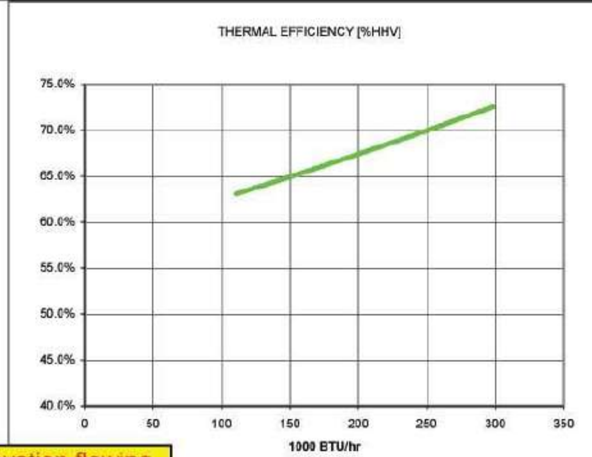


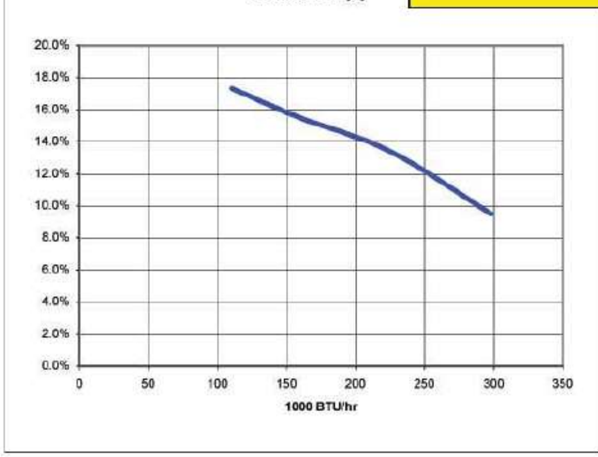
FIGURE 9.14 Tube Temperature Profiles with 4”x24” Bekaert Burner

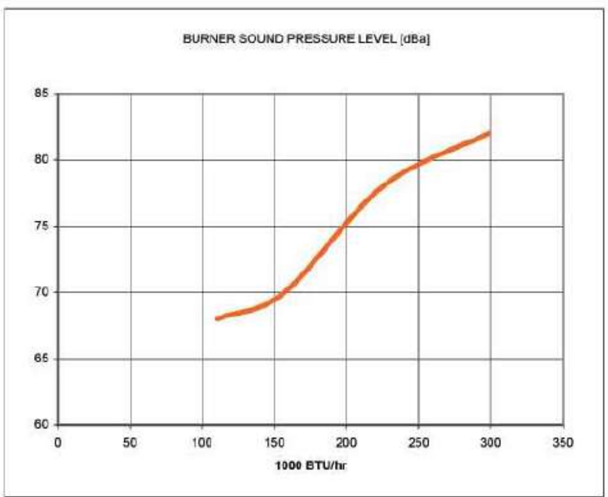
PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner 2-Pass Heater Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Bekaert (Config Long G)
Description:	4"dia x24" mesh burner with 2-1/2" Eclipse Mixer, With 2-1/2" Compound Barel, 2-1/2" x 3" Venturi
Orifice:	1/8"
Date:	30-Mar-05



Products of combustion flowing backwards above 250,000 BTU/hr





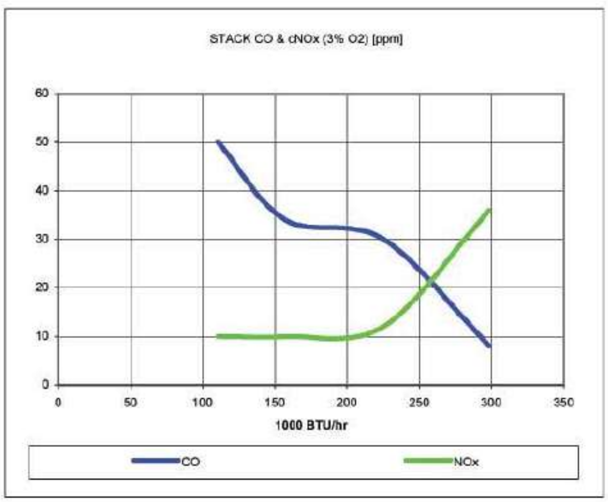


FIGURE 9.15 4”x24” Bekaert Burner (Config. G) Performance in the Fire Tube

9.6 Eclipse 1-1/2" Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.16;
- colder fire-tube "entry zone": first 3 to 4 feet of the fire-tube
- temperature peak: 160 deg F at 5 feet
- partial tube flow: at less than 220,000 BTU/hr; approx above 2.5:1 turndown.

Burner Performance Graphs:

- see Figure 9.17;
- maximum fire: 500,000 BTU/hr; minimum fire: 100,000 BTU/hr; 5:1 turndown
- gross thermal efficiency: 72% HHV at maximum fire, 60% HHV at minimum fire
- stack oxygen: 4% at maximum fire; 16% at minimum fire
- stack temperature: 520 deg C at maximum fire; 220 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 96 dBA at maximum fire; 67 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 60 and 75 ppm
- stack CO: between 5 ppm and 10 ppm

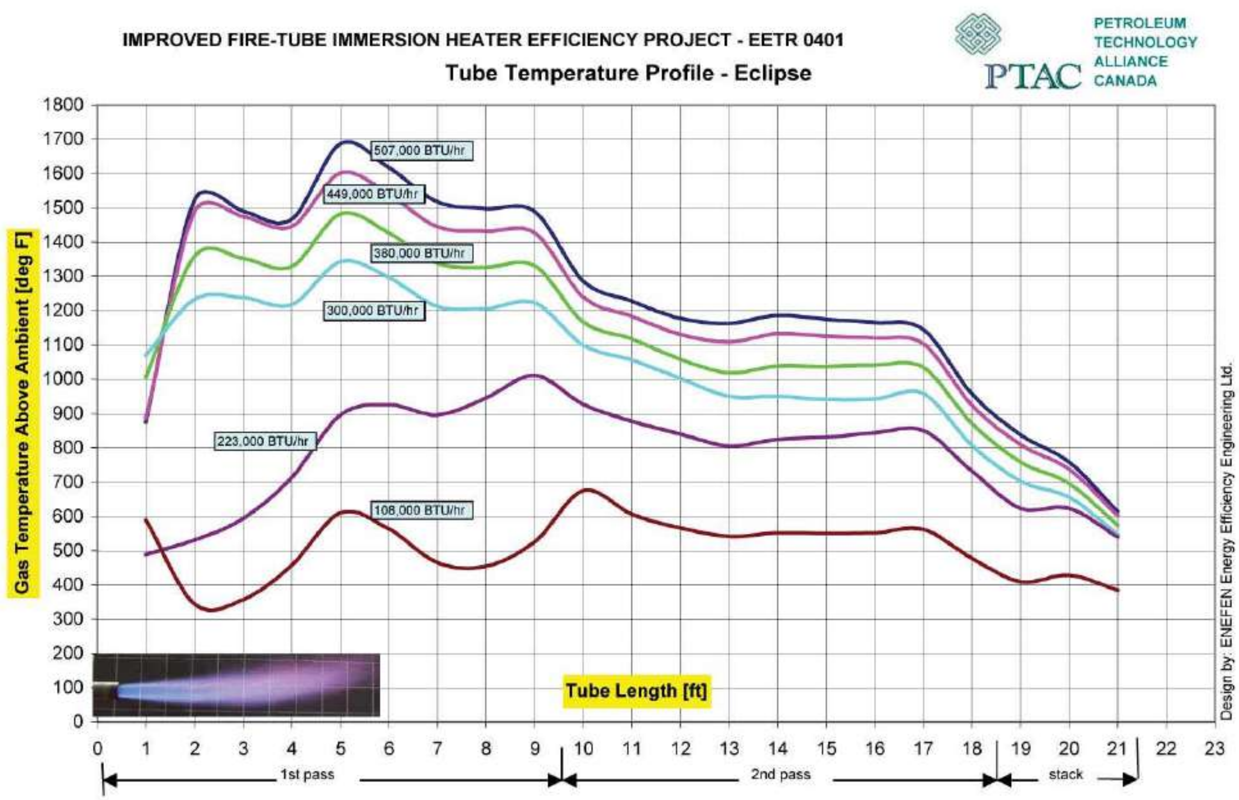


FIGURE 9.16 Tube Temperature Profiles with 1-1/2" Eclipse Burner

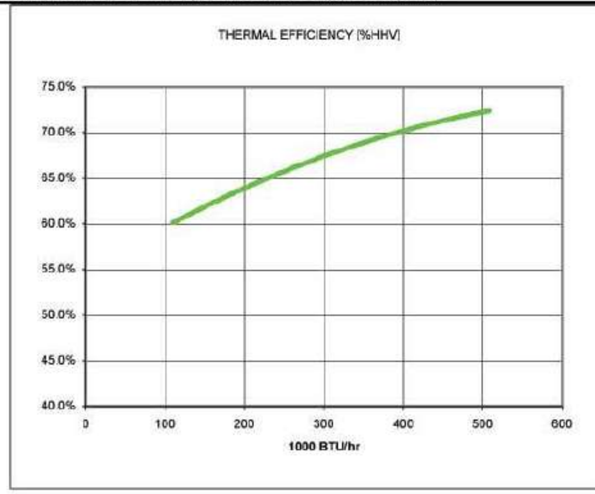
PTAC — PETROLEUM TECHNOLOGY ALLIANCE CANADA

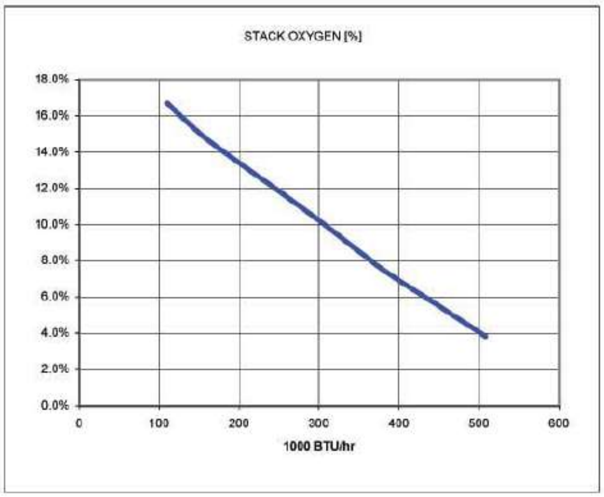
Project EETR 0401

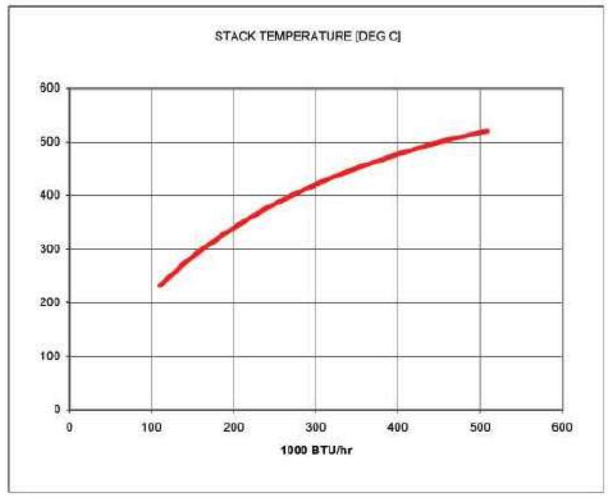
Burner 2-Pass Heater Test Performance Summary

Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Eclipse
Description:	1-1/2" Eclipse Mixer, With 1-1/2" Compound Barel, 1-1/2" x 2-1/2" Venturi, 2-1/2" Nozzle
Orifice:	1/8"
Date:	14-Mar-05







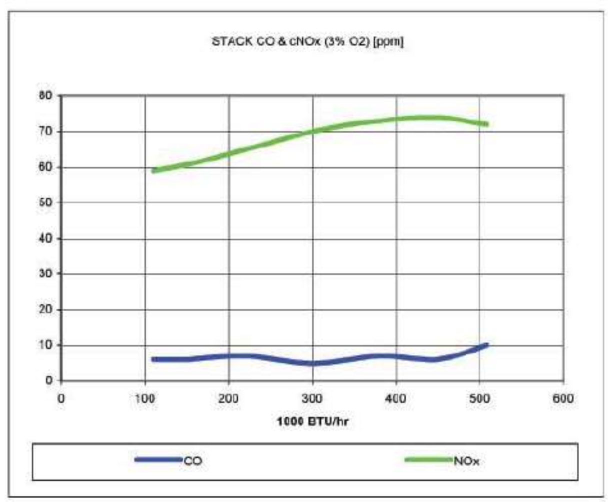


FIGURE 9.17 1-1/2" Eclipse Burner Performance in the Fire Tube

9.7 Hauck 2" Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.18;
- colder fire-tube "entry zone": first 2 feet of the fire-tube (good entry performance)
- temperature peak: 1680 deg F at 5 feet
- partial tube flow: at less than 200,000 BTU/hr; approx above 2.5:1 turndown.

Burner Performance Graphs:

- see Figure 9.19;
- maximum fire: 500,000 BTU/hr; minimum fire: 100,000 BTU/hr; 5:1 turndown
- gross thermal efficiency: 74-76% HHV at maximum fire, 66% HHV at minimum fire
- stack oxygen: 3% at maximum fire; 14% at minimum fire
- stack temperature: 500 deg C at maximum fire; 270 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 93 dBA at maximum fire; 74 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 75 and 88 ppm
- stack CO: between 0 ppm and 5 ppm

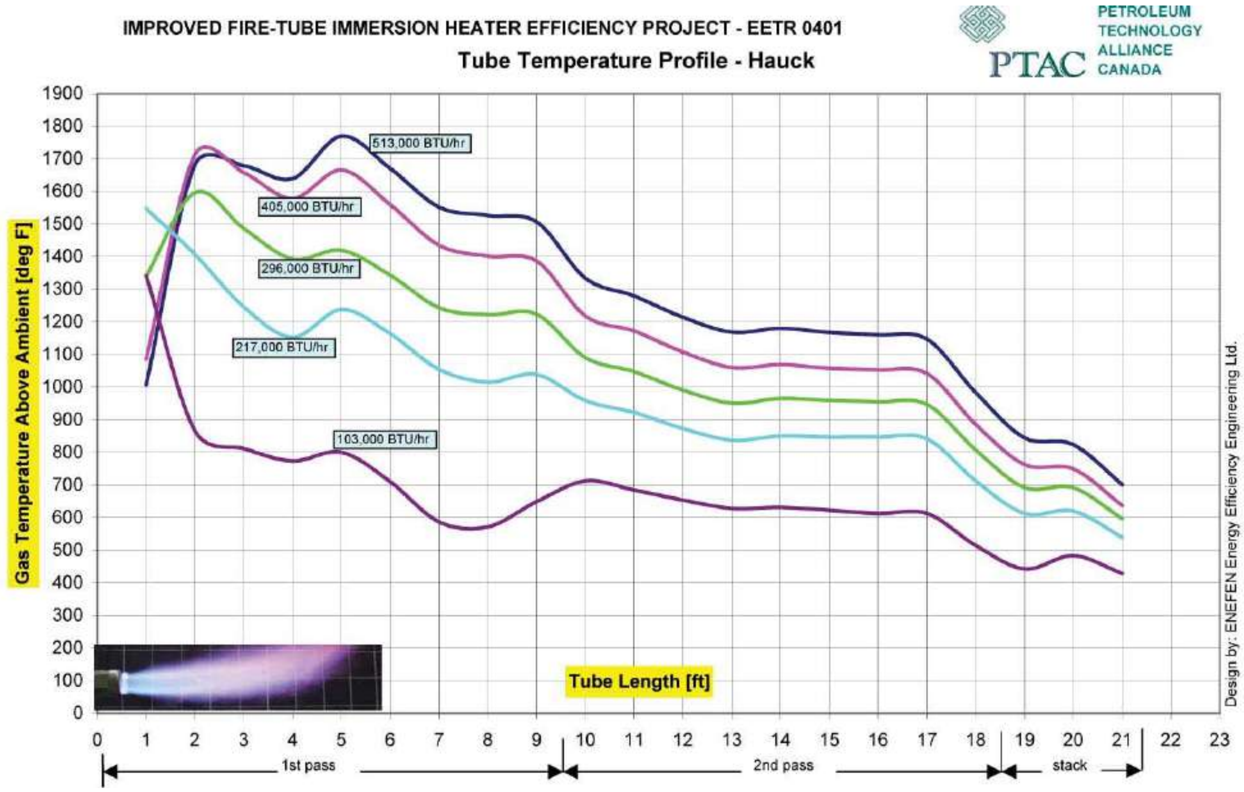
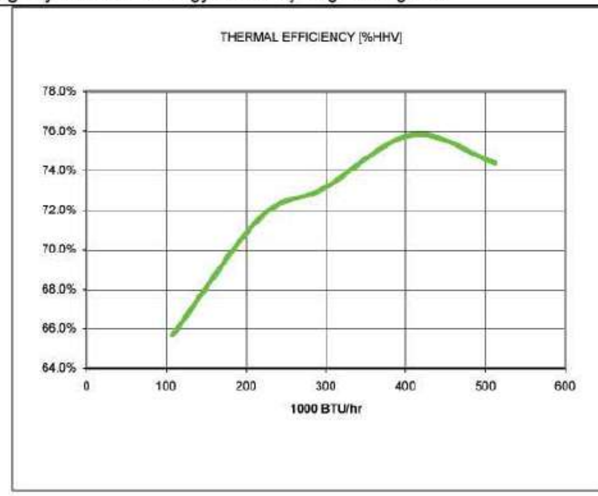
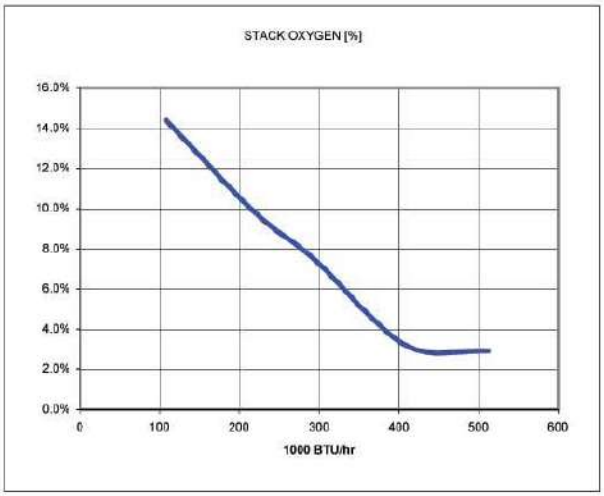


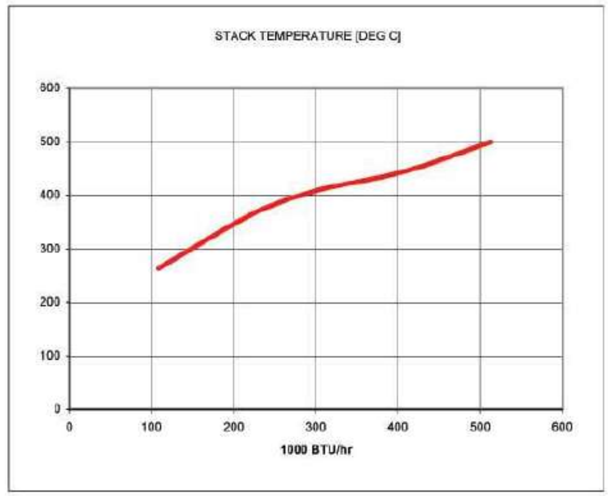
FIGURE 9.18 Tube Temperature Profiles with 2" Hauck Burner

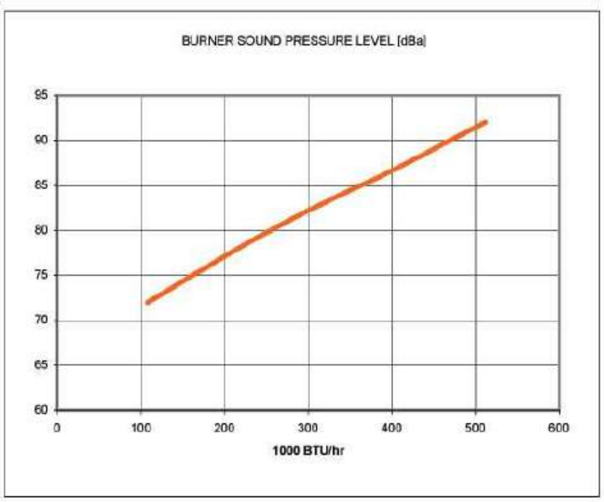
PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
		Project EETR 0401
		Burner 2-Pass Heater Test Performance Summary
		Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Hauck Manufacturing
Description:	2" Venturi with RAF nozzle
Orifice:	3/32"
Date:	23-Mar-05









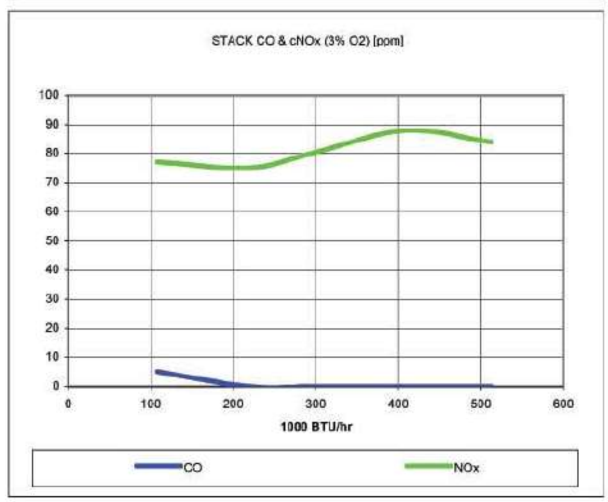


FIGURE 9.19 2" Hauck Burner Performance in the Fire Tube

9.8 Kenilworth 1-1/2” (Config. 101) Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.20;
- colder fire-tube “entry zone”: none – good entry performance
- temperature peak: 1950 deg F at 2 and 5 feet
- partial tube flow: at less than 200,000 BTU/hr; approx above 2.5:1 turndown.

Burner Performance Graphs:

- see Figure 9.21;
- maximum fire: 500,000 BTU/hr; minimum fire: 100,000 BTU/hr; 5:1 turndown
- gross thermal efficiency: 73% HHV at maximum fire, 55% HHV at minimum fire
- stack oxygen: 3.5% at maximum fire; 17% at minimum fire
- stack temperature: 500 deg C at maximum fire; 220 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 96 dBA at maximum fire; 75 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 48 and 68 ppm
- stack CO: between 0 ppm and 23 ppm

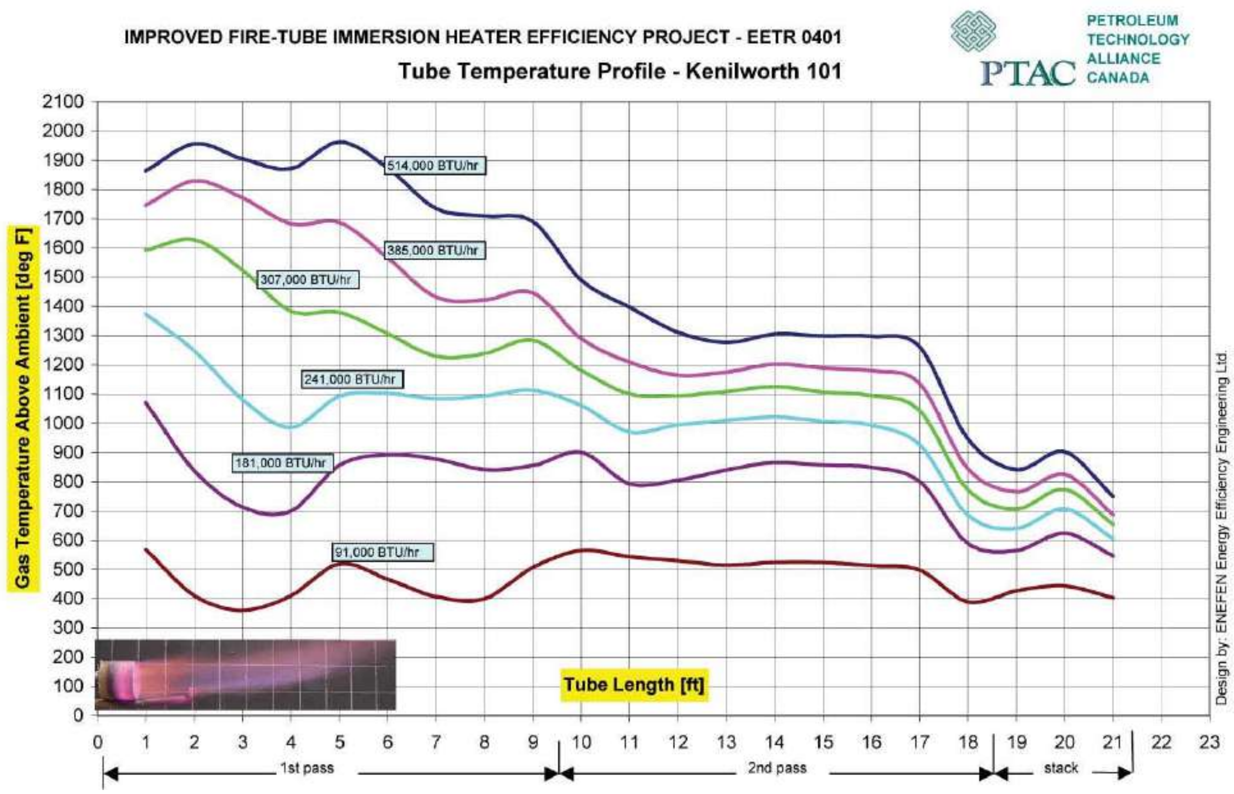
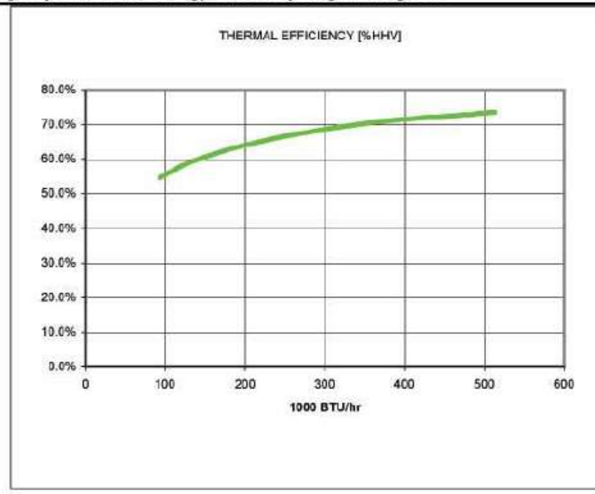
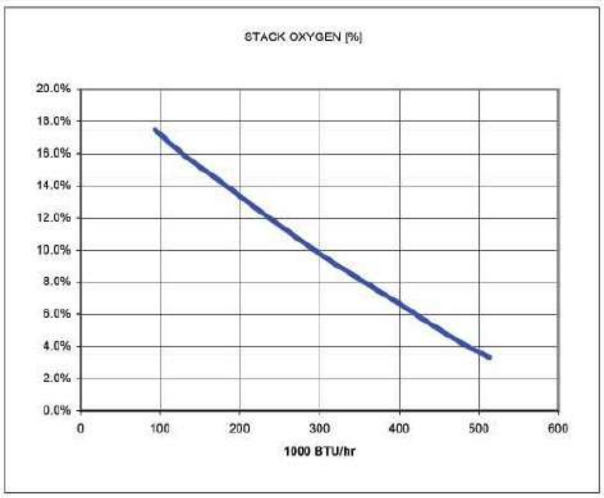


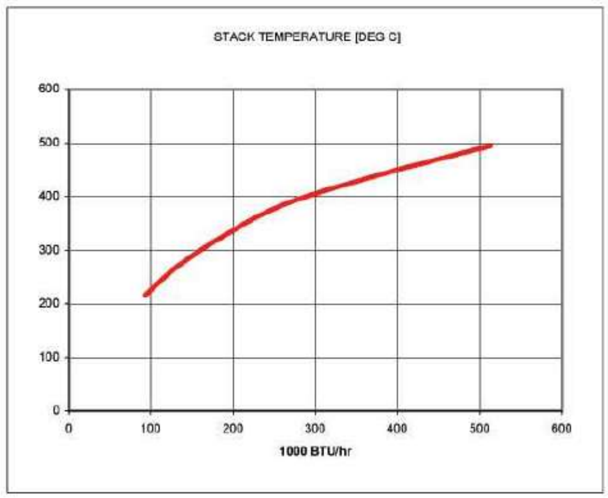
FIGURE 9.20 Tube Temperature Profiles with 1-1/2” Kenilworth Burner (Config. 101)

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner 2-Pass Heater Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Kenilworth (Config. 101)
Description:	1-1/2" low pressure with flame scavenger, 1-1/2"x5" turbulator
Orifice:	#23
Date:	29-Mar-05







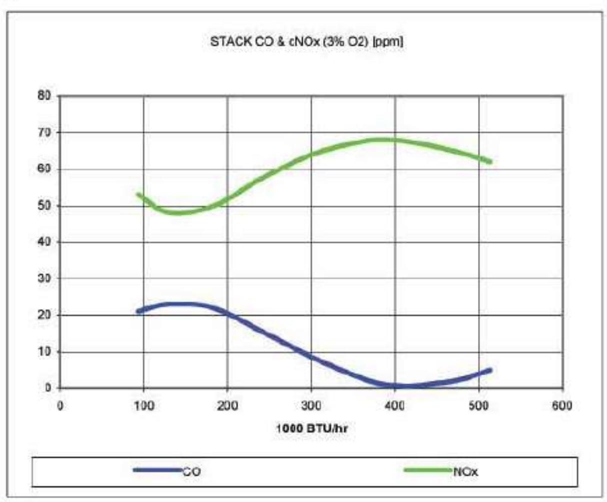


FIGURE 9.21 1-1/2" Kenilworth Burner (Config.101) Performance in the Fire Tube

9.9 Kenilworth 1-1/2" (Config. 102) Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.22;
- colder fire-tube "entry zone": none – good entry performance
- temperature peak: 1800 deg F at 5 feet
- partial tube flow: at less than 180,000 BTU/hr; approx above 2.7:1 turndown.

Burner Performance Graphs:

- see Figure 9.23;
- maximum fire: 500,000 BTU/hr; minimum fire: 100,000 BTU/hr; 5:1 turndown
- gross thermal efficiency: 74% HHV at maximum fire, 56% HHV at minimum fire
- stack oxygen: 2.5% at maximum fire; 17.2% at minimum fire
- stack temperature: 505 deg C at maximum fire; 220 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 98 dBA at maximum fire; 72 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 48 and 72 ppm
- stack CO: between 0 ppm and 20 ppm

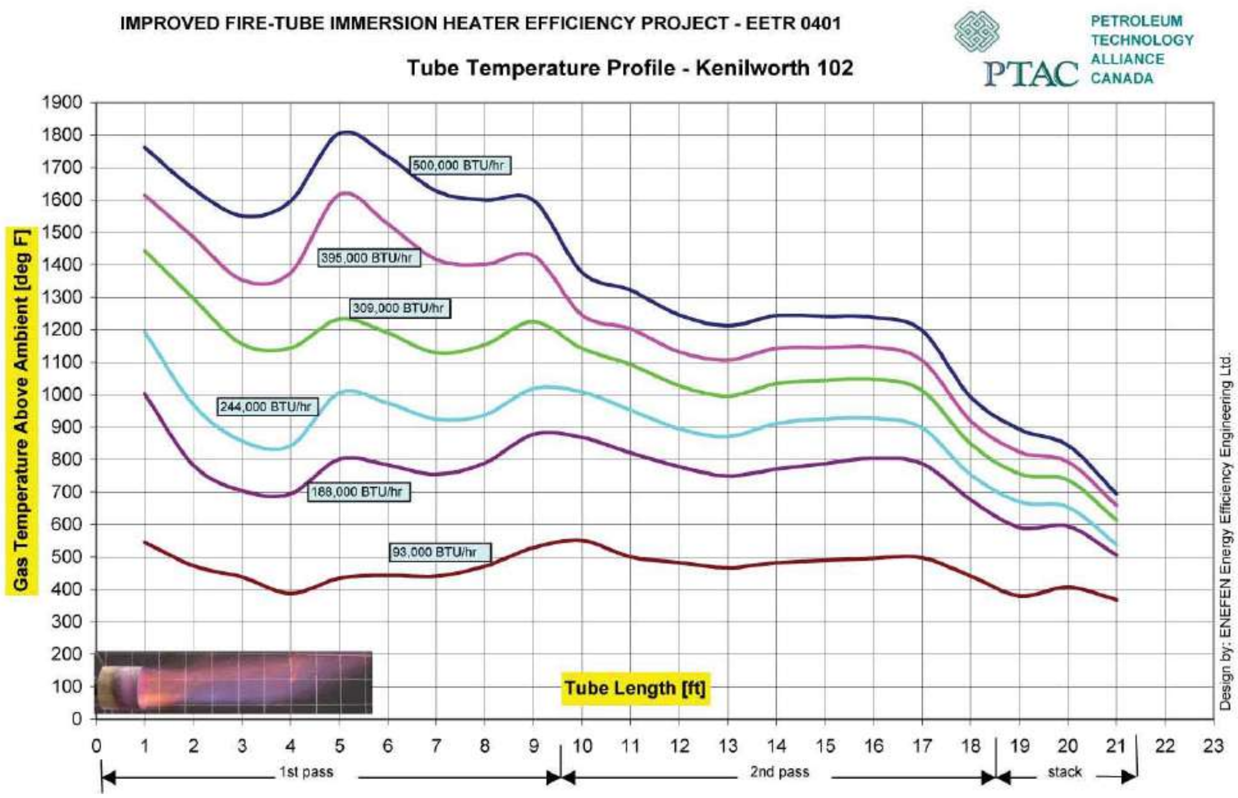
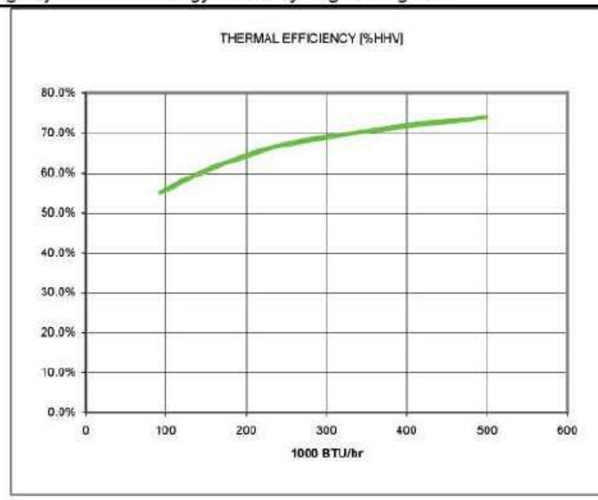
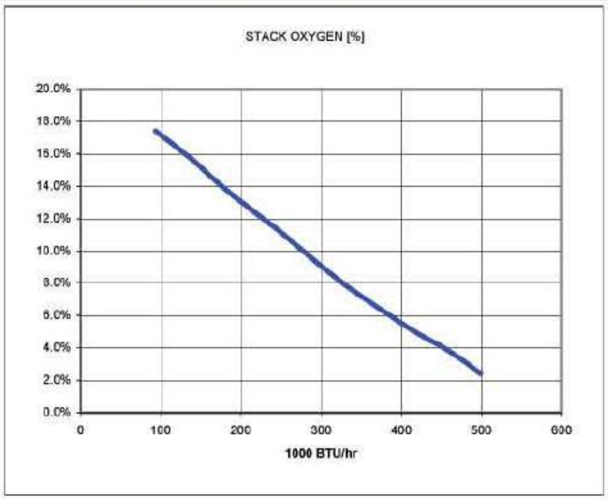


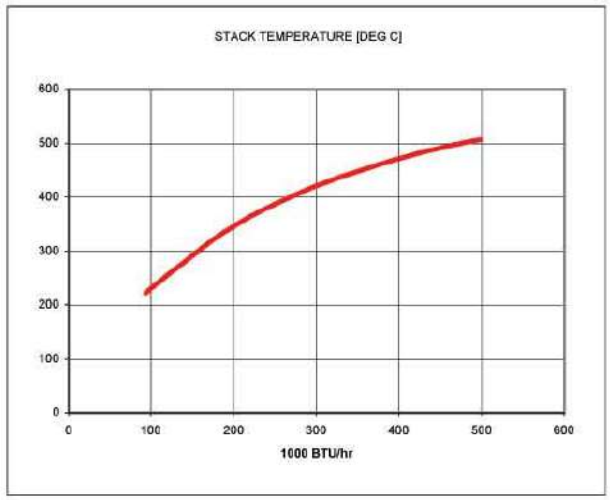
FIGURE 9.22 Tube Temperature Profiles with 1-1/2" Kenilworth Burner (Config. 102)

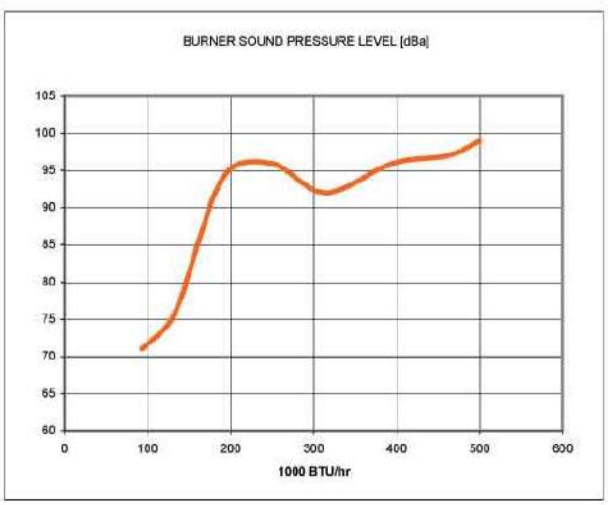
PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner 2-Pass Heater Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Kenilworth (Config. 102)
Description:	1-1/2" with Eclipse Mixer, compound, sleeve, 2"x6" turbulator
Orifice:	#27
Date:	29-Mar-05









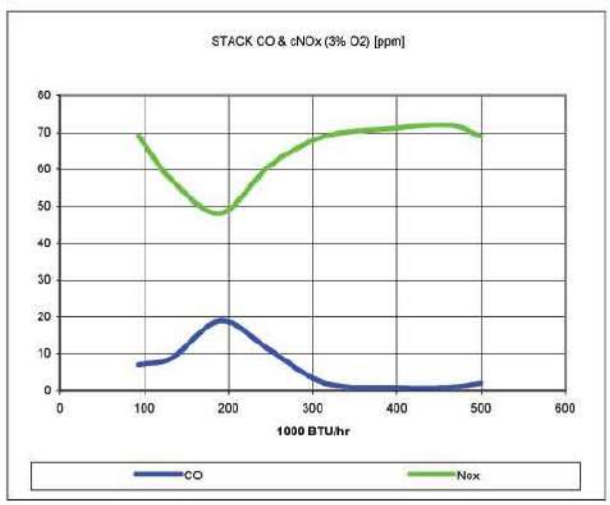


FIGURE 9.23 1-1/2" Kenilworth Burner (Config.102) Performance in the Fire Tube

9.10 Kenilworth 1-1/2" (Config. 103) Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.24;
- colder fire-tube "entry zone": none – 3 to 4 feet
- temperature peak: 1780 deg F at 5 feet
- partial tube flow: at less than 190,000 BTU/hr; approx above 2.6:1 turndown.

Burner Performance Graphs:

- see Figure 9.25;
- maximum fire: 500,000 BTU/hr; minimum fire: 100,000 BTU/hr; 5:1 turndown
- gross thermal efficiency: 75% HHV at maximum fire, 57% HHV at minimum fire
- stack oxygen: 2% at maximum fire; 16.8% at minimum fire
- stack temperature: 500 deg C at maximum fire; 220 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 97 dBA at maximum fire; 76 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 32 and 80 ppm
- stack CO: between 0 ppm and 45 ppm

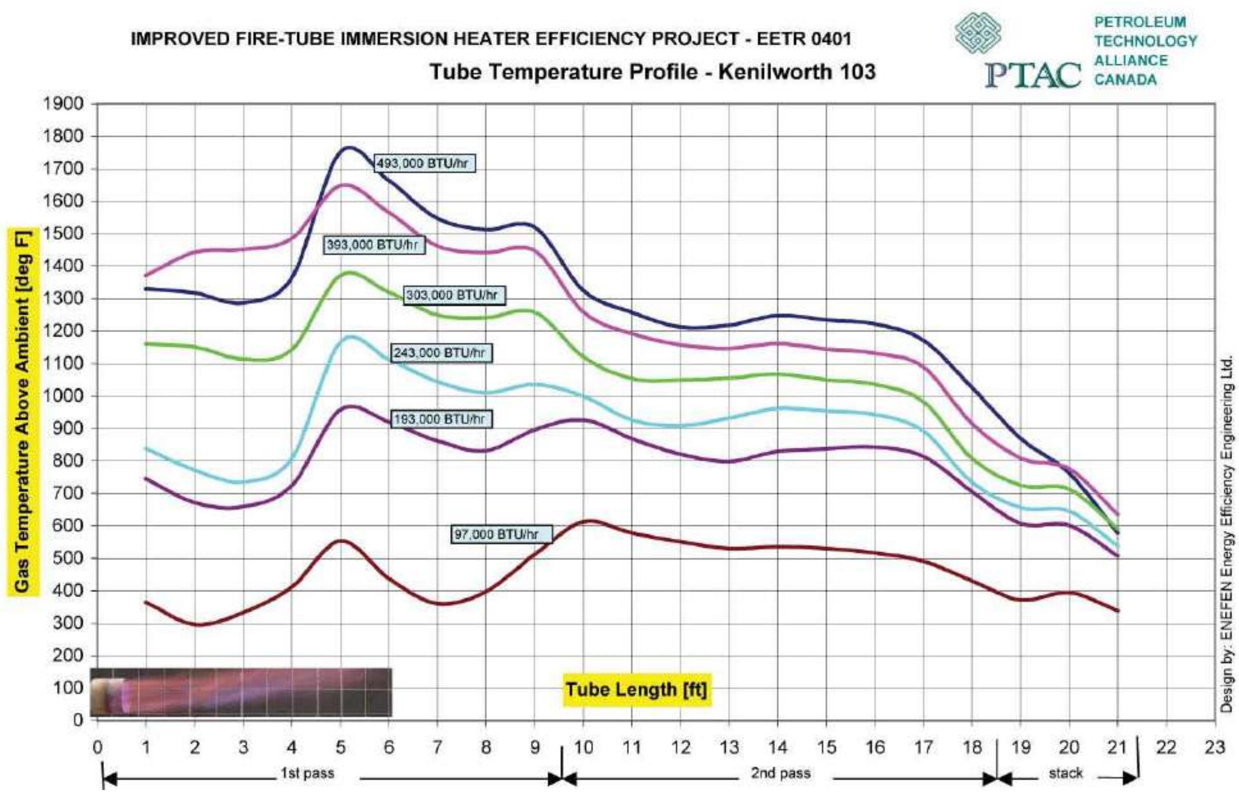
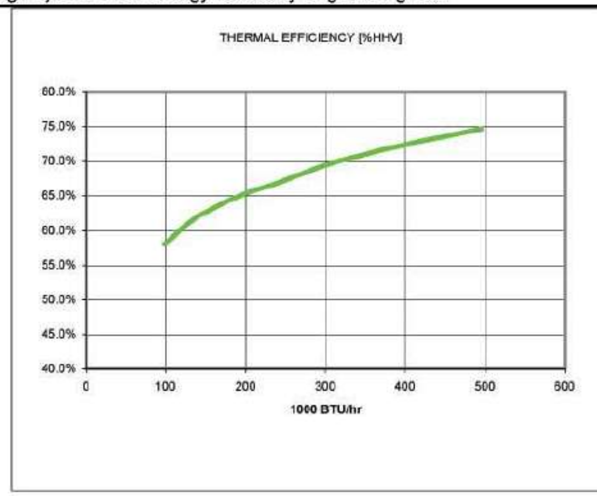
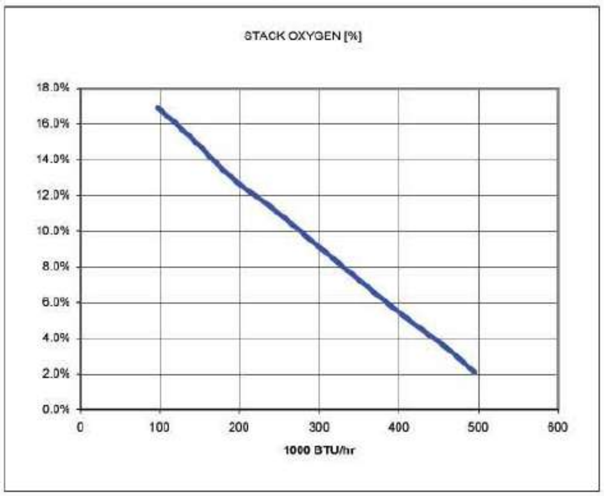


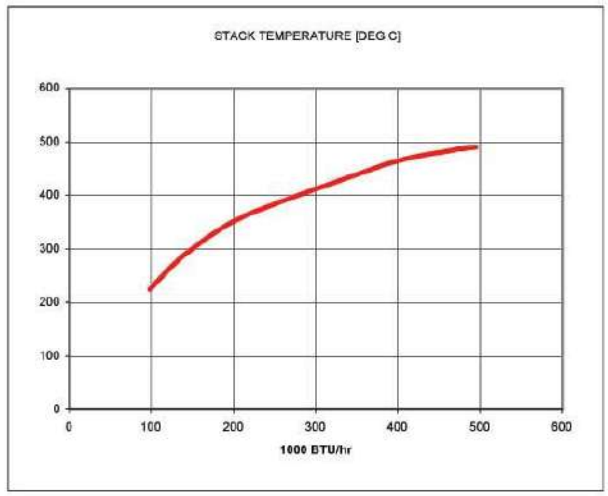
FIGURE 9.24 Tube Temperature Profiles with 1-1/2" Kenilworth Burner (Config. 103)

PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
		Project EETR 0401
		Burner 2-Pass Heater Test Performance Summary
		Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Kenilworth (Config. 103)
Description:	1-1/2" conventional , 1-1/2"x5" turbulator
Orifice:	#27
Date:	29-Mar-05







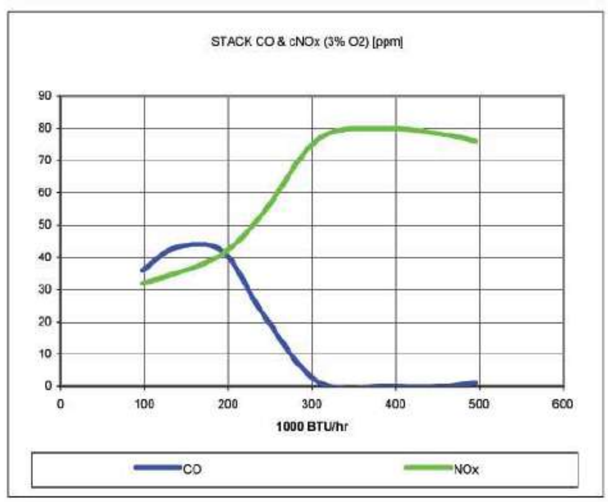


FIGURE 9.25 1-1/2" Kenilworth Burner (Config.103) Performance in the Fire Tube

9.11 Kenilworth 1-1/2" (Config. 104) Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.26;
- colder fire-tube "entry zone": none – good entry performance
- temperature peak: 2000 deg F at 1-5 feet
- partial tube flow: at less than 250,000 BTU/hr; approx above 2:1 turndown.

Burner Performance Graphs:

- see Figure 9.27;
- maximum fire: 500,000 BTU/hr; minimum fire: 100,000 BTU/hr; 5:1 turndown
- gross thermal efficiency: 73% HHV at maximum fire, 55% HHV at minimum fire
- stack oxygen: 3.5% at maximum fire; 17% at minimum fire
- stack temperature: 500 deg C at maximum fire; 220 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 97 dBA at maximum fire; 77 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 48 and 72 ppm
- stack CO: between 0 ppm and 16 ppm

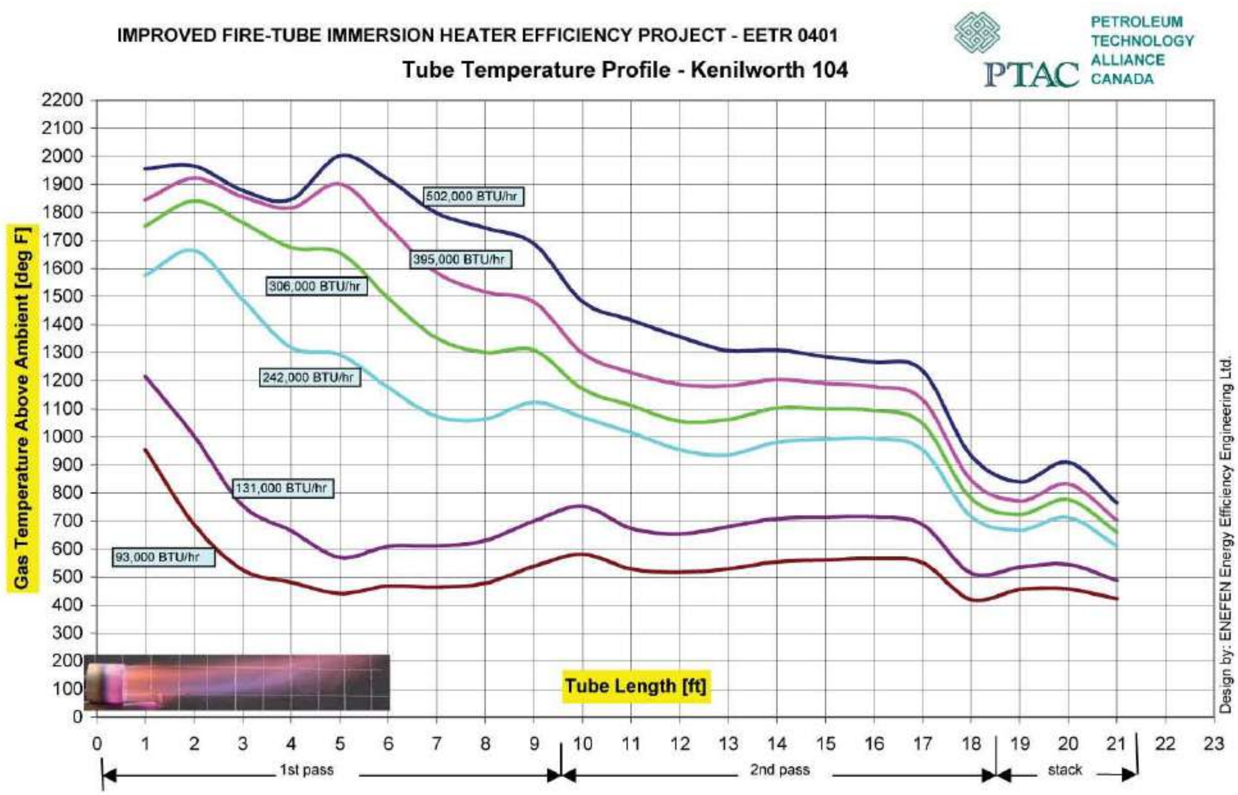
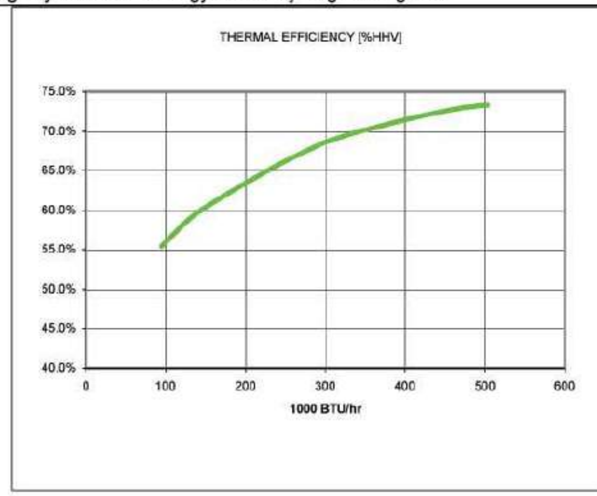
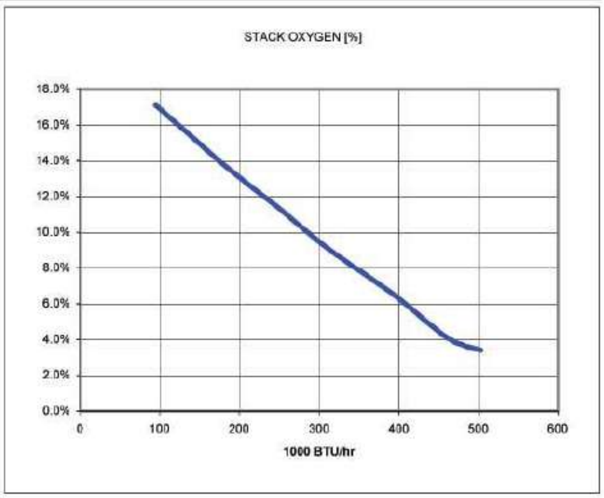


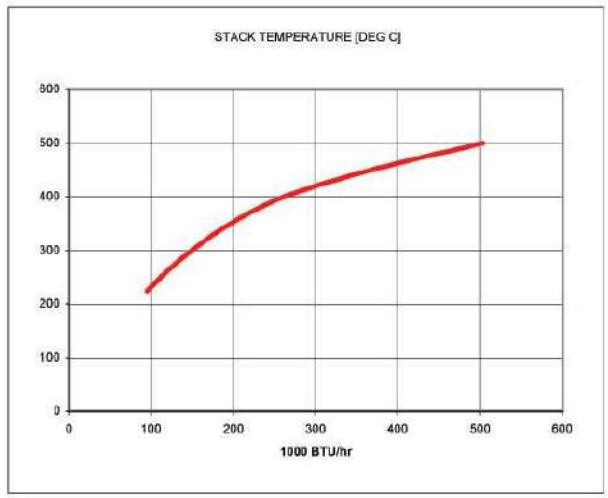
FIGURE 9.26 Tube Temperature Profiles with 1-1/2" Kenilworth Burner (Config. 104)

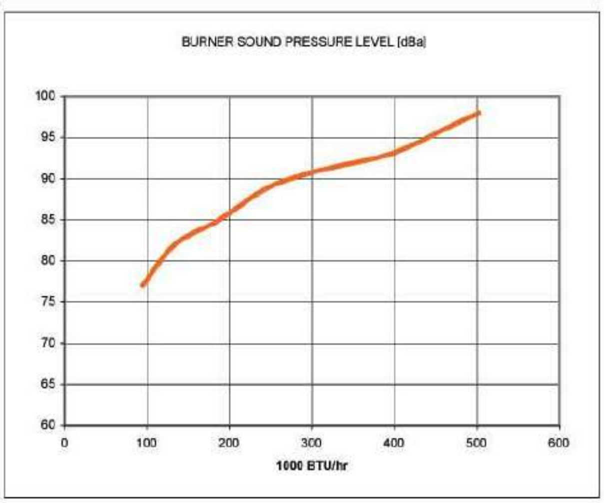
PETROLEUM TECHNOLOGY ALLIANCE CANADA (PTAC)	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner 2-Pass Heater Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Kenilworth (Config. 104)
Description:	1-1/2" low pressure with flame scavenger, compound mixer, 1-1/2" x 5" turbulator
Orifice:	#23
Date:	29-Mar-05









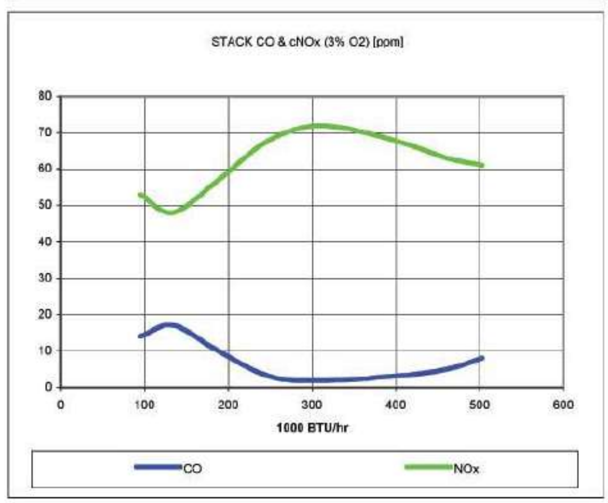


FIGURE 9.27 1-1/2" Kenilworth Burner (Config.104) Performance in the Fire Tube

9.12 Maxon 1-1/2" Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.28;
- colder fire-tube "entry zone": first 2 feet of the fire-tube
- temperature peak: 1900 deg F at 2 feet
- partial tube flow: at less than 150,000 BTU/hr; approx above 3:1 turndown.

Burner Performance Graphs:

- see Figure 9.29;
- maximum fire: 500,000 BTU/hr; minimum fire: 100,000 BTU/hr; 5:1 turndown
- gross thermal efficiency: 73.5% HHV at maximum fire, 63% HHV at minimum fire
- stack oxygen: 3.2% at maximum fire; 15% at minimum fire
- stack temperature: 500 deg C at maximum fire; 250 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 92 dBA at maximum fire; 65 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 70 and 90 ppm
- stack CO: between 0 ppm and 5 ppm

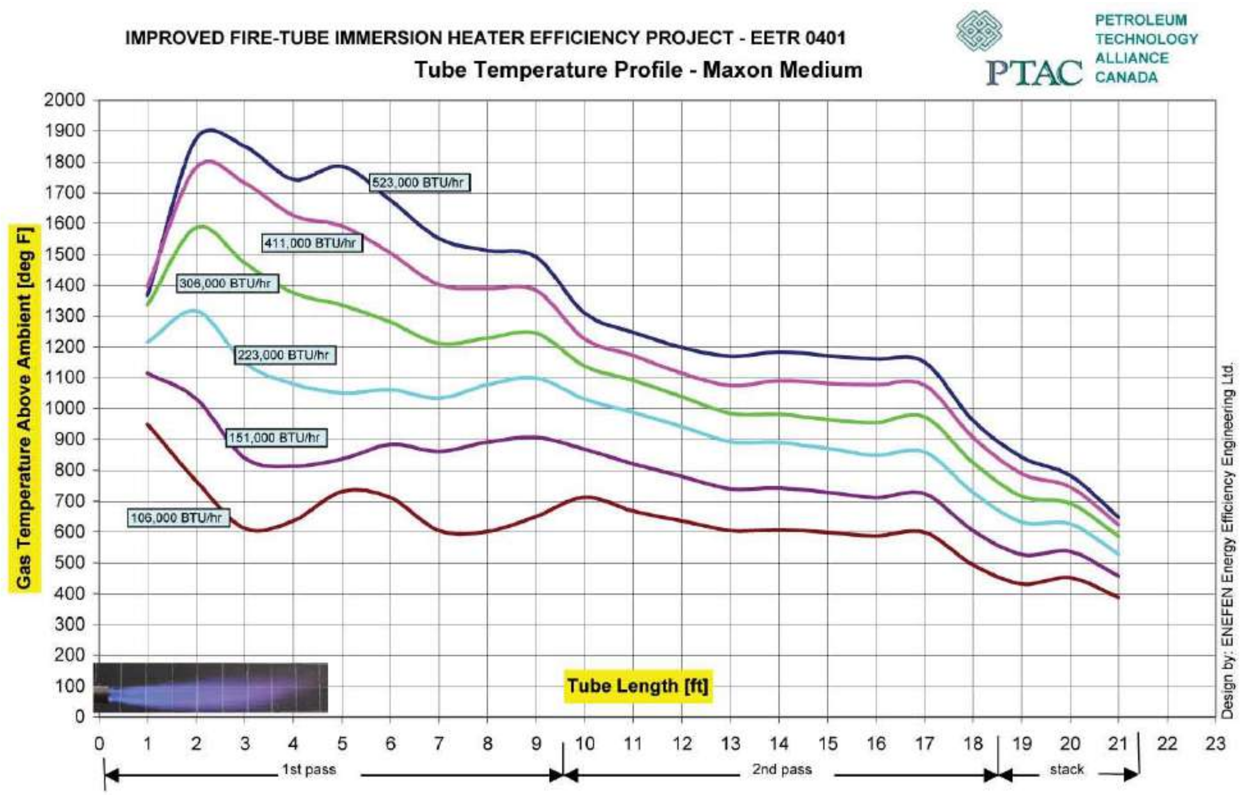
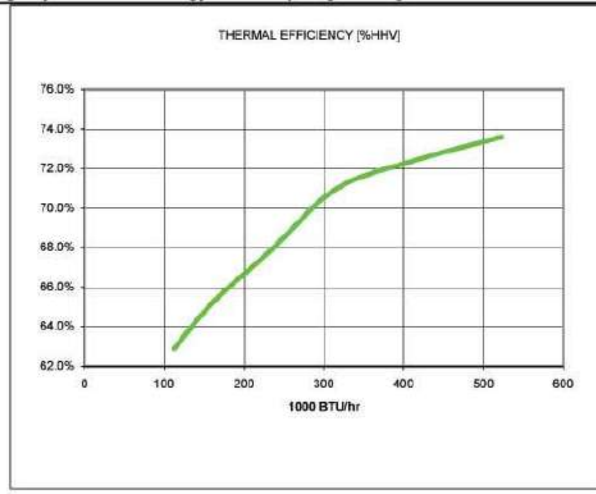
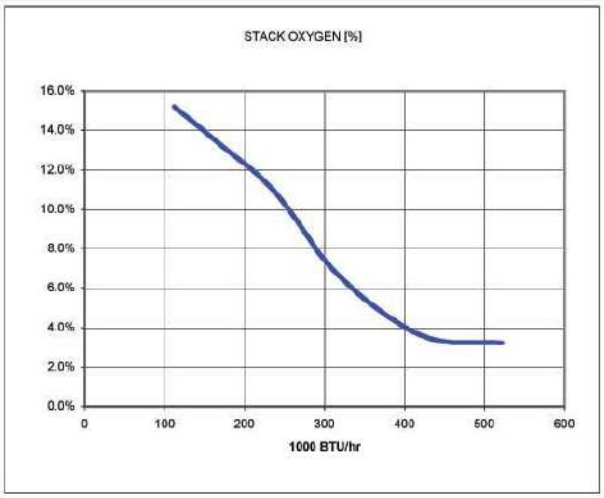


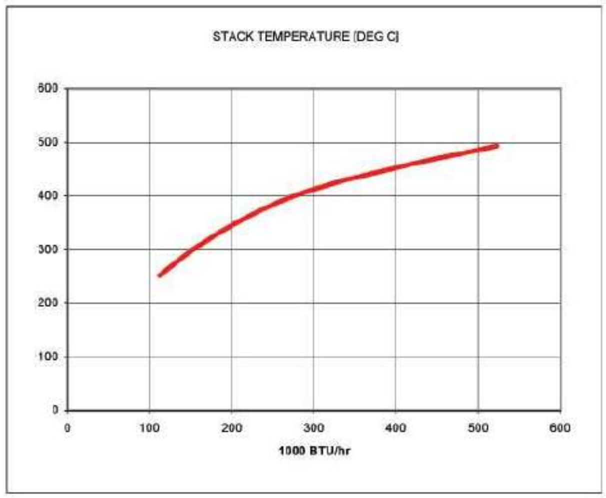
FIGURE 9.28 Tube Temperature Profiles with 1-1/2" Maxon Burner

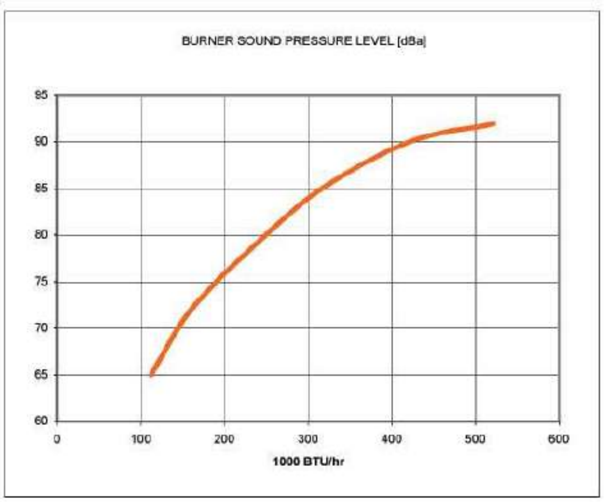
PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
		Project EETR 0401
		Burner 2-Pass Heater Test Performance Summary
		Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Maxon Medium
Description:	1-1/2" Ventite
Orifice:	1/8"
Date:	23-Mar-05









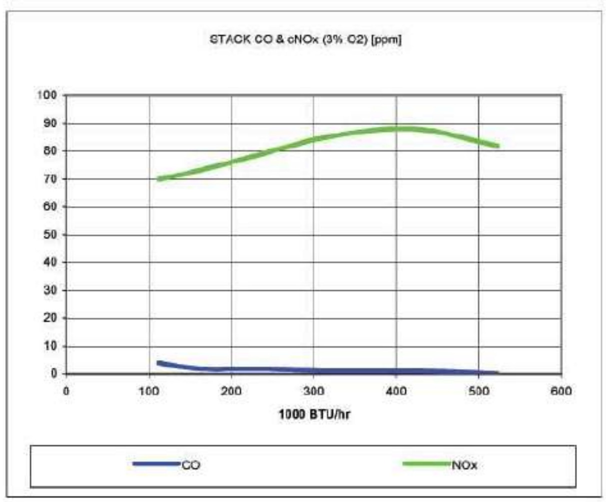


FIGURE 9.29 1-1/2" Maxon Burner Performance in the Fire Tube

9.13 Maxon 3" Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.30;
- colder fire-tube "entry zone": none – good entry performance
- temperature peak: 2000 deg F at 1 foot
- partial tube flow: at less than 150,000 BTU/hr; approx above 3:1 turndown.

Burner Performance Graphs:

- see Figure 9.31;
- maximum fire: 500,000 BTU/hr; minimum fire: 100,000 BTU/hr; 5:1 turndown
- gross thermal efficiency: 76% HHV at maximum fire, 62% HHV at minimum fire
- stack oxygen: 2.8% at maximum fire; 18% at minimum fire
- stack temperature: 470 deg C at maximum fire; 175 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 88 dBA at maximum fire; 60 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 50 and 95 ppm
- stack CO: between 0 ppm and 10 ppm

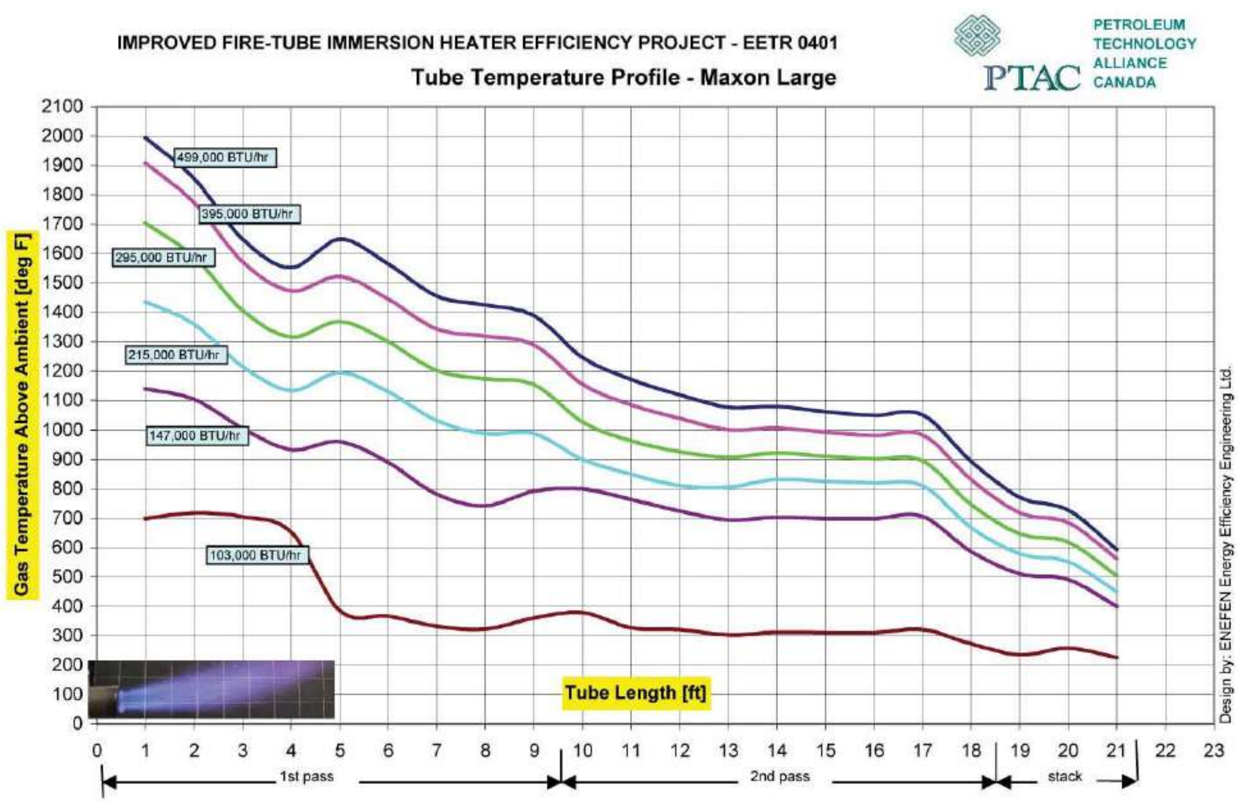
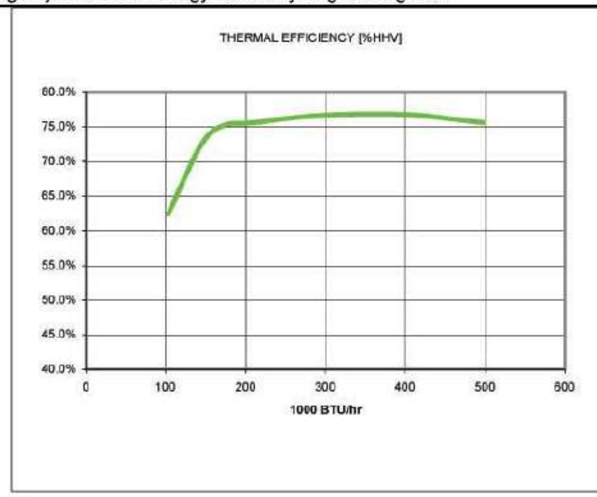
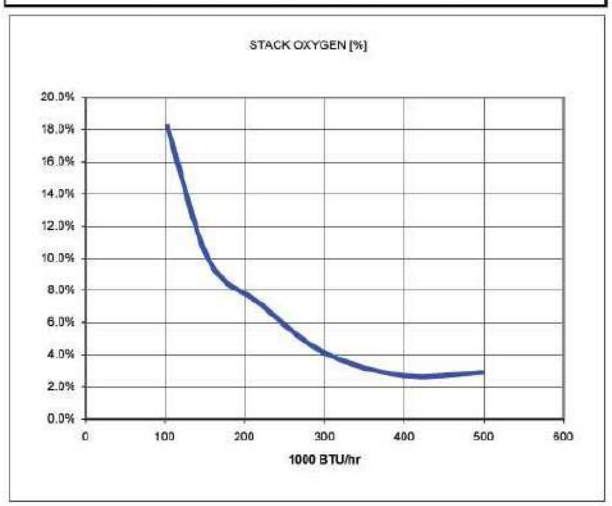


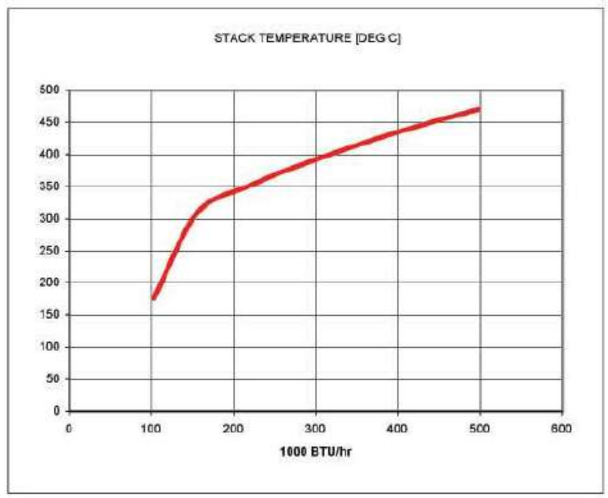
FIGURE 9.30 Tube Temperature Profiles with 3" Maxon Burner

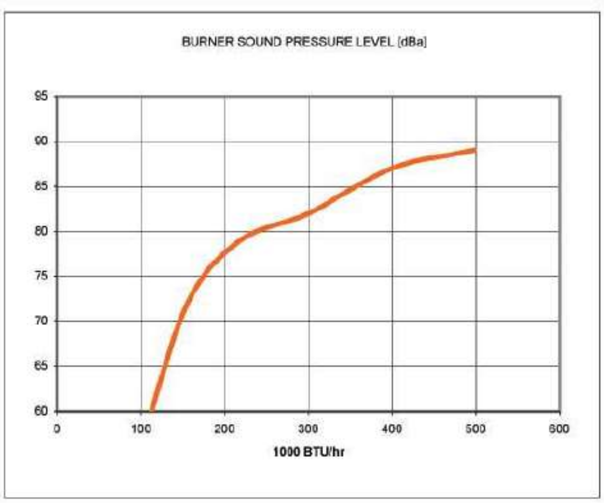
PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
		Project EETR 0401
		Burner 2-Pass Heater Test Performance Summary
		Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Maxon Large
Description:	3" Ventite
Orifice:	1/8"
Date:	22-Mar-05









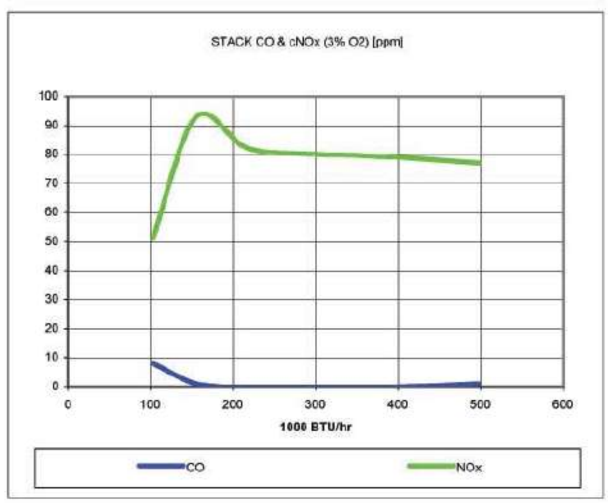


FIGURE 9.31 3" Maxon Burner Performance in the Fire Tube

9.14 North American 3" Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.32;
- colder fire-tube "entry zone": first 2 feet of the fire-tube
- temperature peak: 1600 deg F at 2 feet
- partial tube flow: at less than 210,000 BTU/hr; approx above 2.5:1 turndown.

Burner Performance Graphs:

- see Figure 9.33;
- maximum fire: 500,000 BTU/hr; minimum fire: 150,000 BTU/hr; 3.5:1 turndown
- gross thermal efficiency: 74.5% HHV at maximum fire, 71.5% HHV at minimum fire
- stack oxygen: 3.2% at maximum fire; 11.8% at minimum fire
- stack temperature: 475 deg C at maximum fire; 290 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 90 dBA at maximum fire; 68 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 50 and 92 ppm
- stack CO: between 0 ppm and 3 ppm

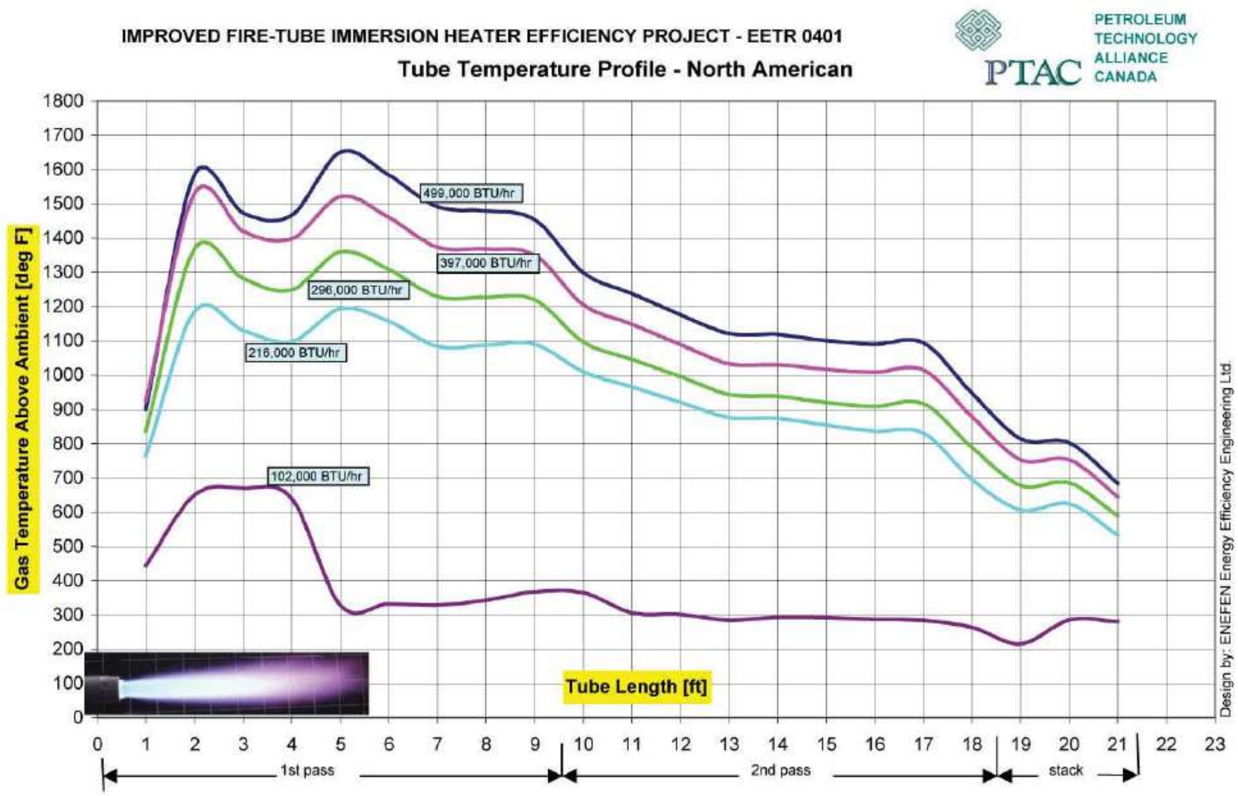
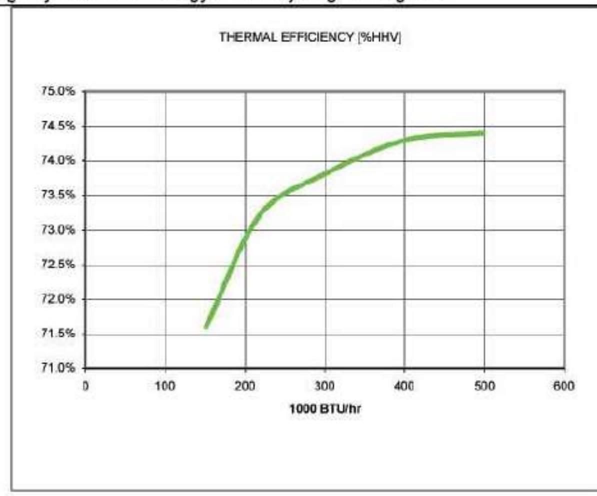
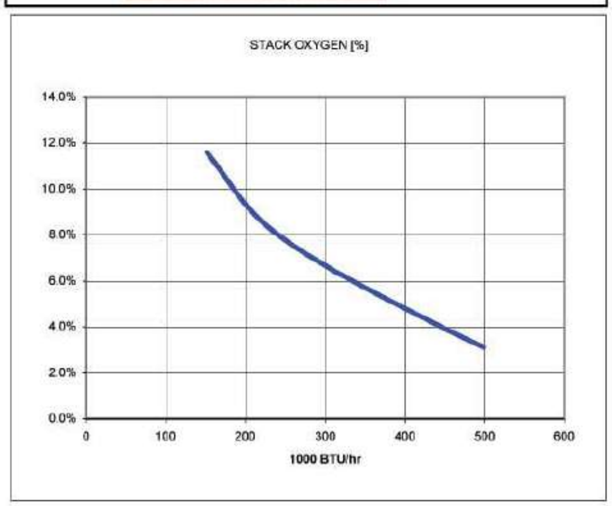


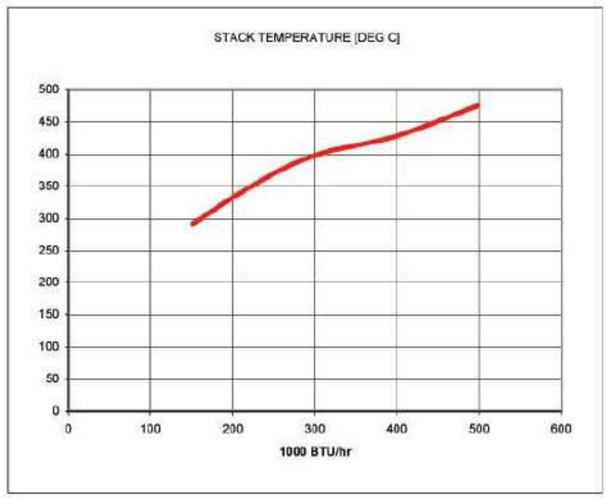
FIGURE 9.32 Tube Temperature Profiles with 3" North American Burner

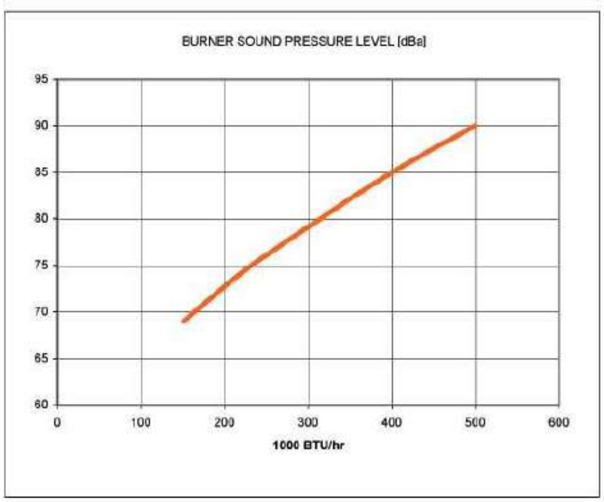
PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
		Project EETR 0401
		Burner 2-Pass Heater Test Performance Summary
		Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	North American
Description:	3"
Orifice:	1/8"
Date:	23-Mar-05









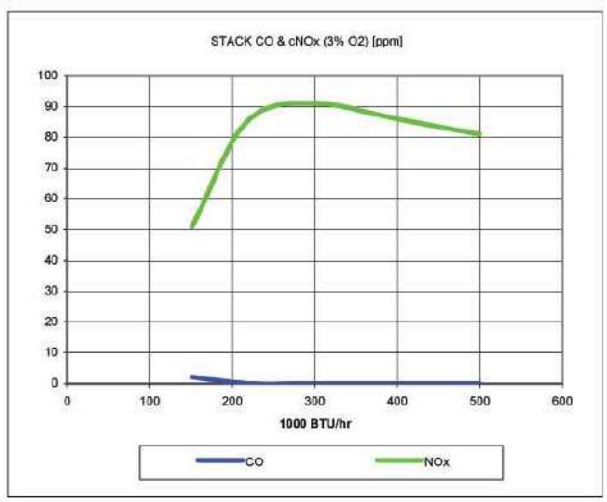


FIGURE 9.33 3" North American Burner Performance in the Fire Tube

9.15 Profire 1” (with Venturi) Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.34;
- colder fire-tube “entry zone”: first 4 feet of the fire-tube
- temperature peak: 1730 deg F at 5 feet
- partial tube flow: at less than 210,000 BTU/hr; approx above 2.5:1 turndown.

Burner Performance Graphs:

- see Figure 9.35;
- maximum fire: 500,000 BTU/hr; minimum fire: 100,000 BTU/hr; 5:1 turndown
- gross thermal efficiency: 74% HHV at maximum fire, 61% HHV at minimum fire
- stack oxygen: 3.2% at maximum fire; 16.5% at minimum fire
- stack temperature: 505 deg C at maximum fire; 250 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 97 dBA at maximum fire; 67 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 25 and 78 ppm
- stack CO: between 0 ppm and 50 ppm

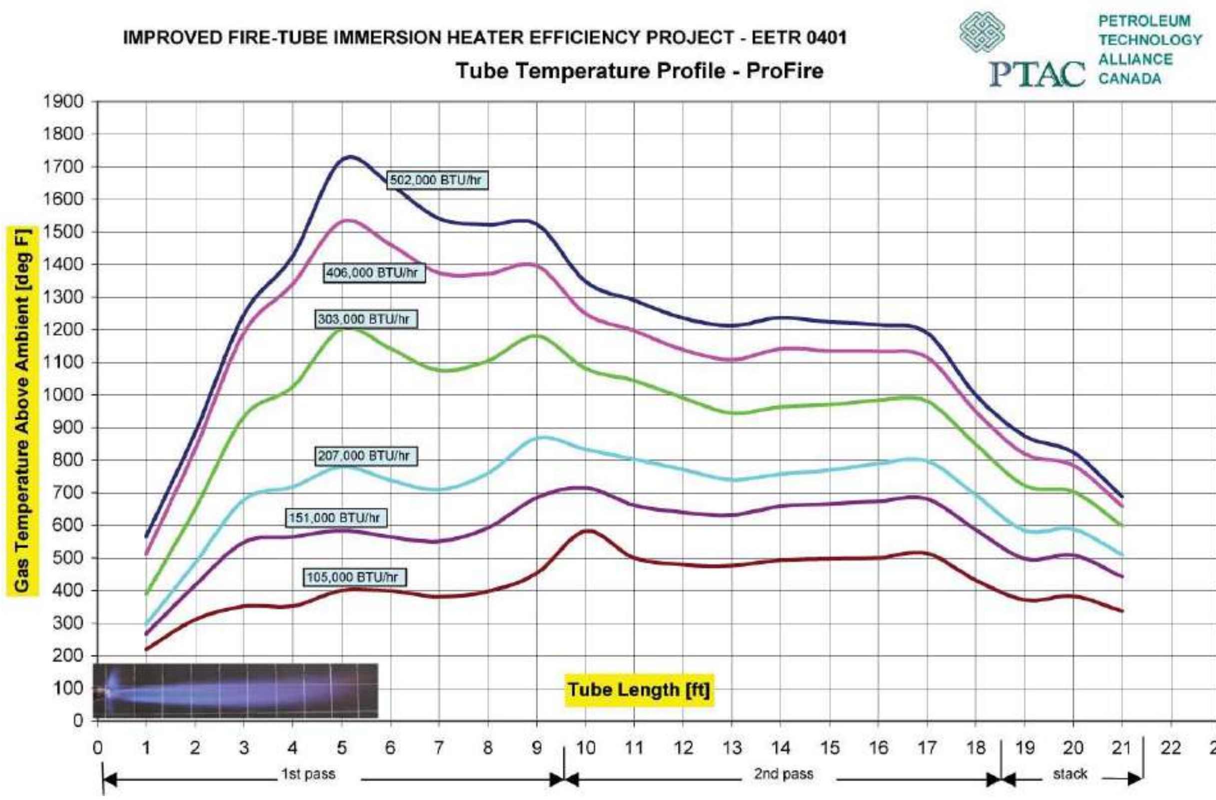
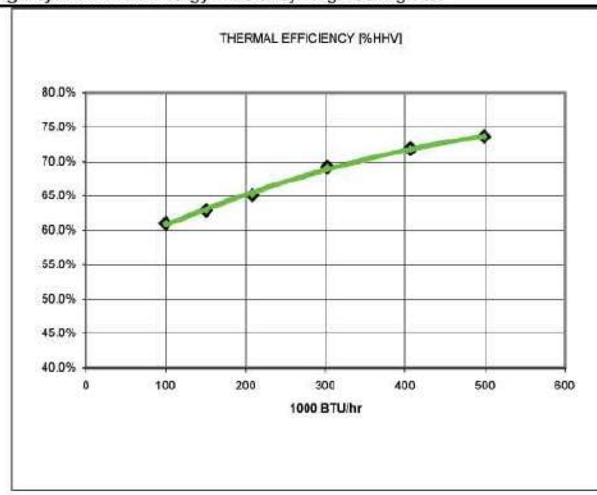
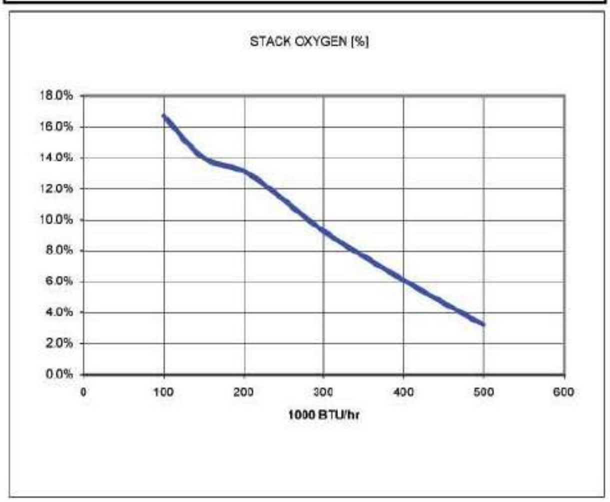


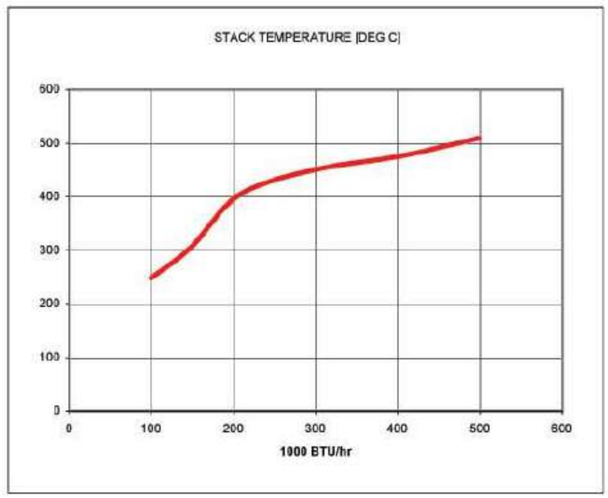
FIGURE 9.34 Tube Temperature Profiles with 1” ProFire Burner

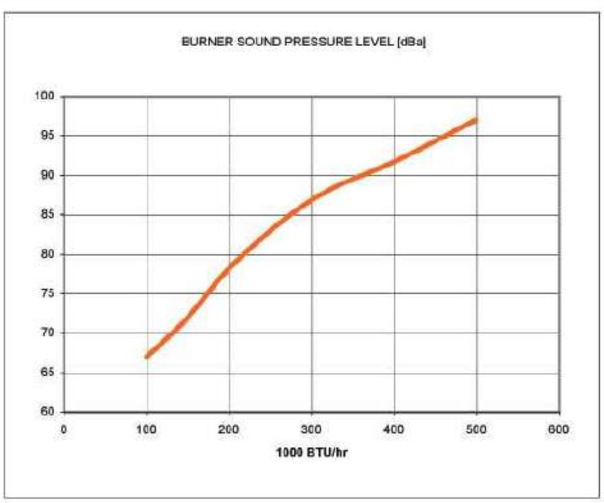
PETROLEUM TECHNOLOGY ALLIANCE CANADA (PTAC)	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner 2-Pass Heater Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Profire
Description:	1" with BS&B Nozzle, 1" x 1" Venturi
Orifice:	1/8"
Date:	23-Mar-05









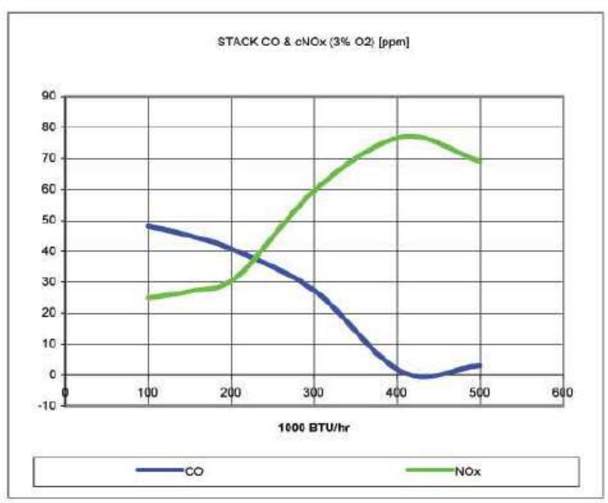


FIGURE 9.35 1" ProFire Burner Performance in the Fire Tube

9.16 Pyronics 1-1/2" Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.36;
- colder fire-tube "entry zone": first 5 feet of the fire-tube
- temperature peak: 1300 deg F at 5 feet
- partial tube flow: at less than 130,000 BTU/hr; approx above 2:1 turndown.

Burner Performance Graphs:

- see Figure 9.37;
- maximum fire: 250,000 BTU/hr; minimum fire: 100,000 BTU/hr; 2.5:1 turndown (NOTE: LOW INPUT!!!)
- gross thermal efficiency: 73.5% HHV at maximum fire, 76% HHV at minimum fire
- stack oxygen: 3.2% at maximum fire; 12.2% at minimum fire
- stack temperature: 305 deg C at maximum fire; 190 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 80 dBA at maximum fire; 60 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 20 and 78 ppm
- stack CO: between 0 ppm and 37 ppm

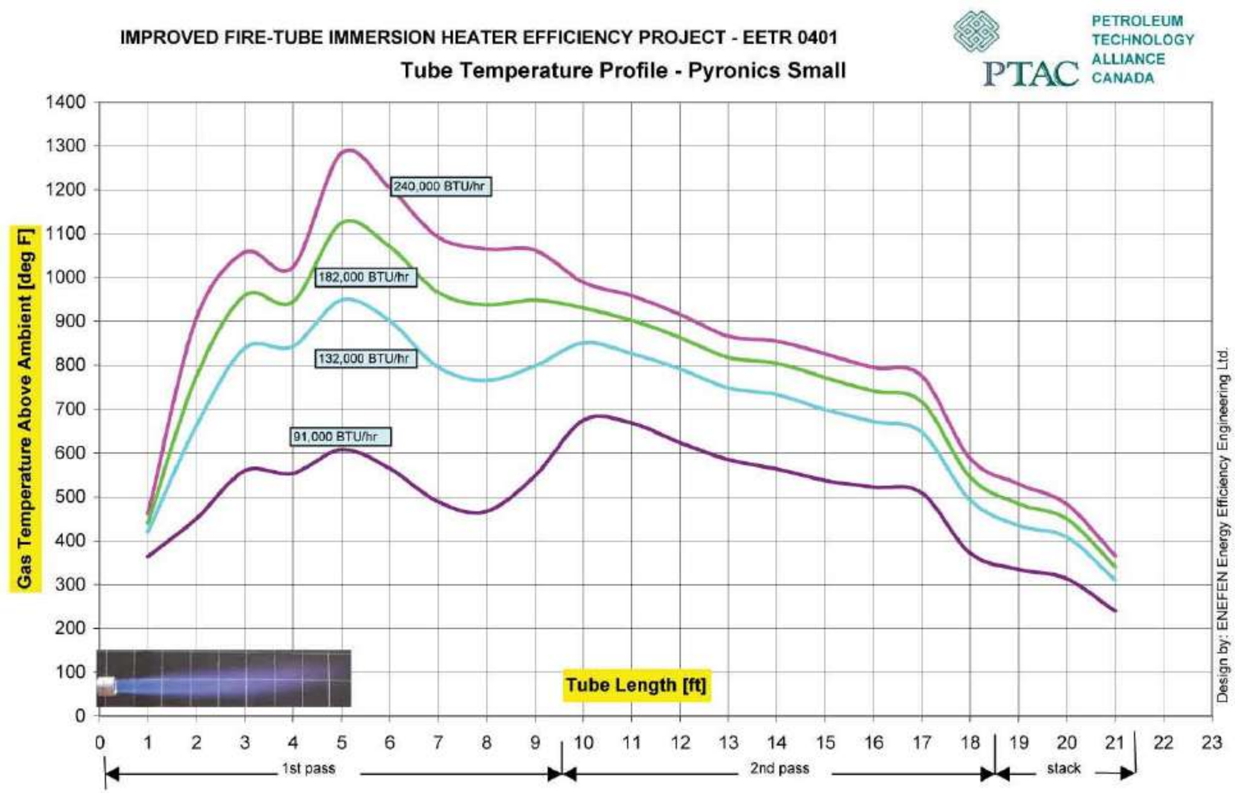
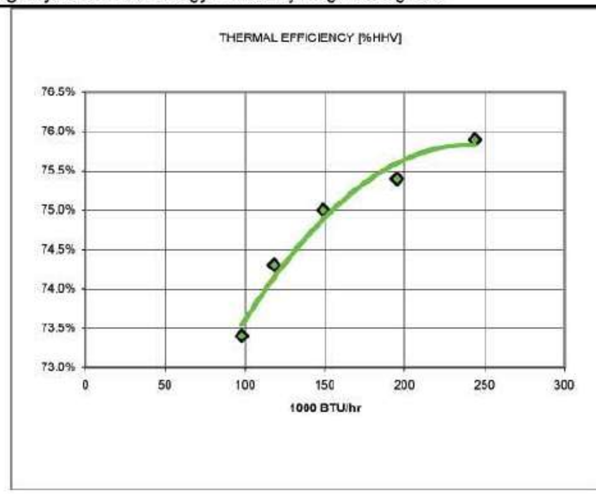
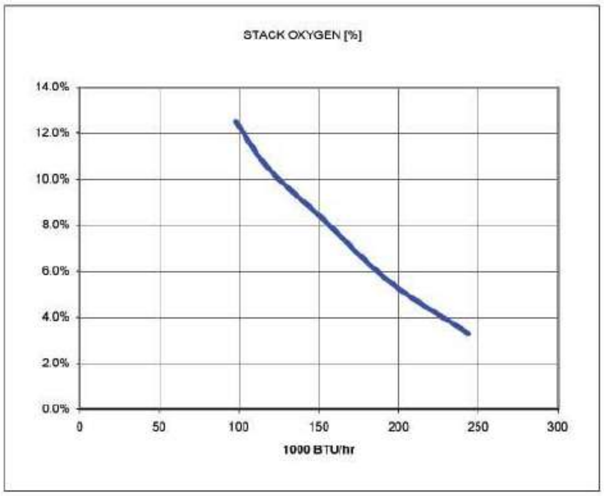


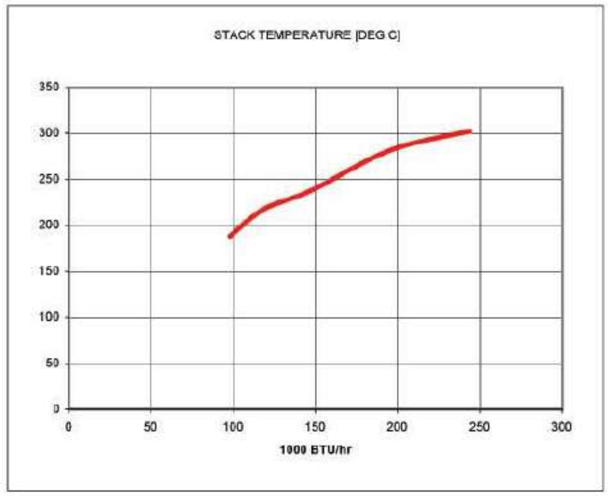
FIGURE 9.36 Tube Temperature Profiles with 1-1/2" Pyronics Burner

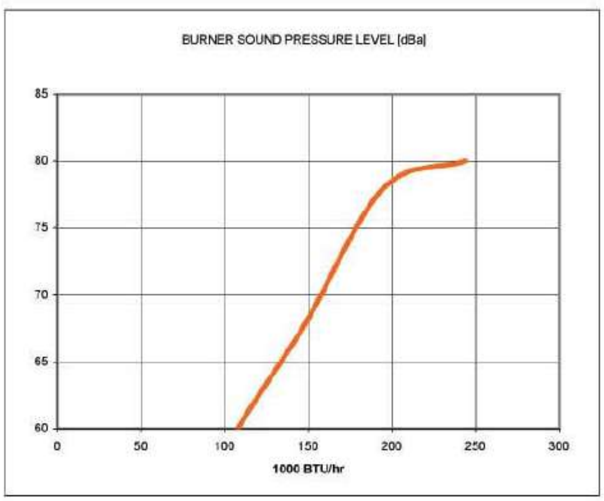
PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner 2-Pass Heater Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Pyronics (Small)
Description:	1-1/2", 1200T, 300,000 BTU/hr @ 25PSIG
Orifice:	#44
Date:	24-Mar-05









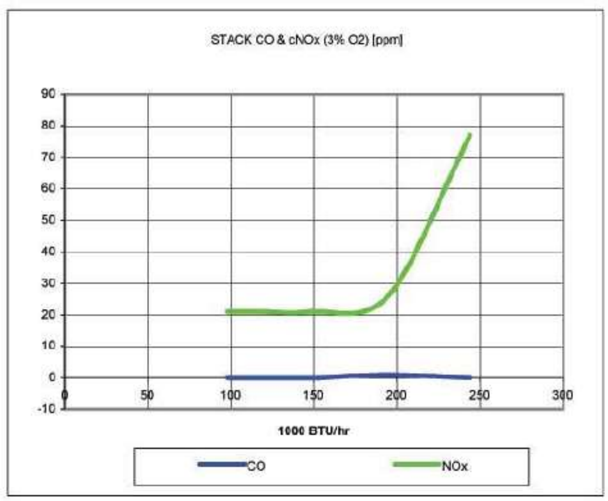


FIGURE 9.37 1-1/2" Pyronics Burner Performance in the Fire Tube

9.17 Pyronics 2-1/2" Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.38;
- colder fire-tube "entry zone": none; good entry performance
- temperature peak: 1900 deg F at 1 ft
- partial tube flow: at less than 200,000 BTU/hr; approx above 2.5:1 turndown.

Burner Performance Graphs:

- see Figure 9.39;
- maximum fire: 500,000 BTU/hr; minimum fire: 100,000 BTU/hr; 5:1 turndown
- gross thermal efficiency: 75.2% HHV at maximum fire, 69.5% HHV at minimum fire
- stack oxygen: 2.5% at maximum fire; 13.8% at minimum fire
- stack temperature: 430 deg C at maximum fire; 230 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 97 dBA at maximum fire; 69 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 75 and 105 ppm
- stack CO: between 0 ppm and 3 ppm

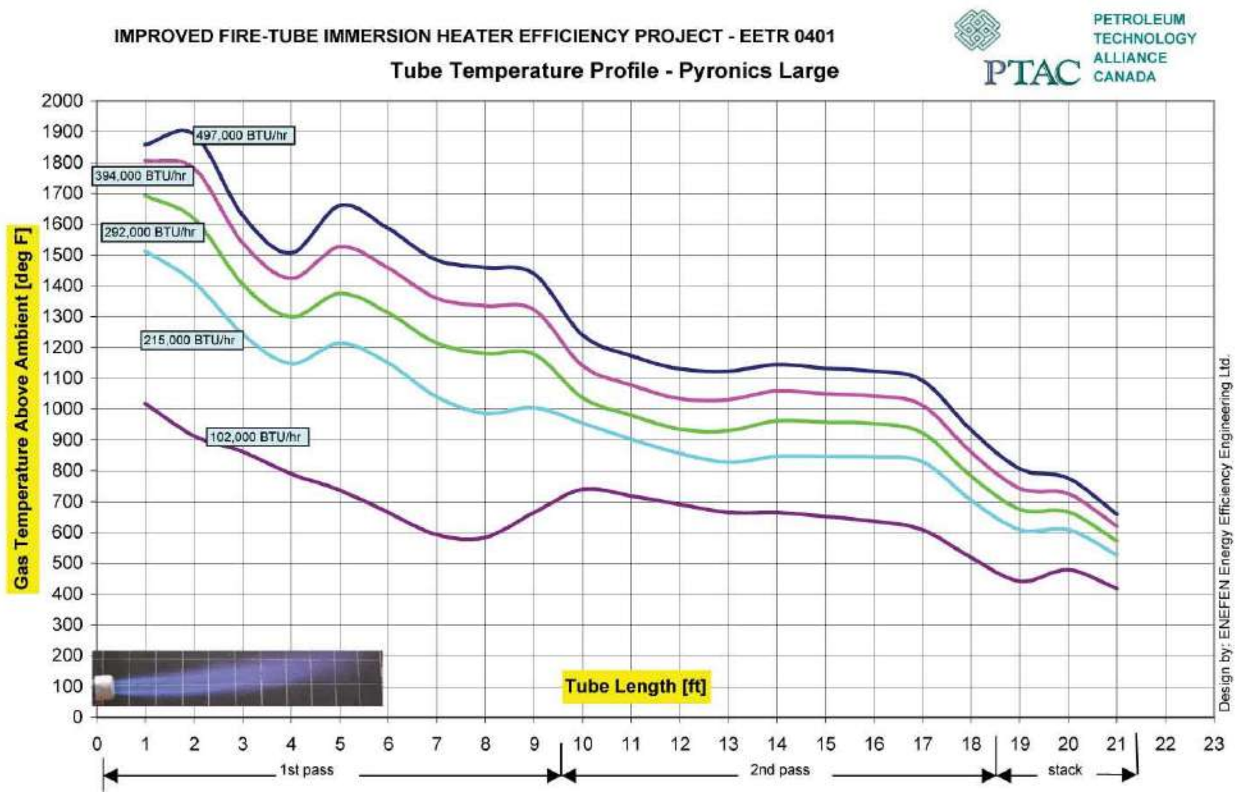
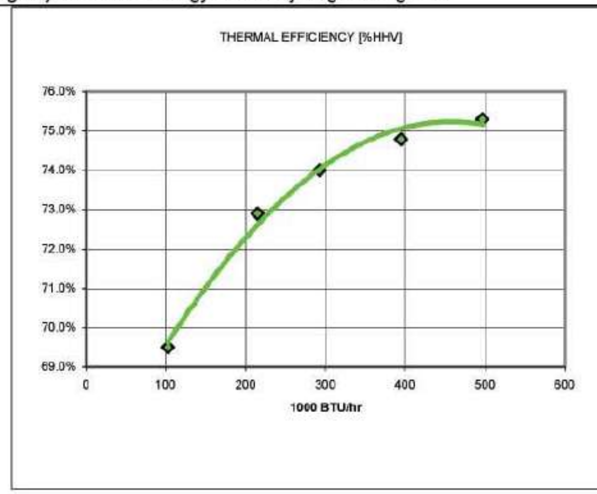
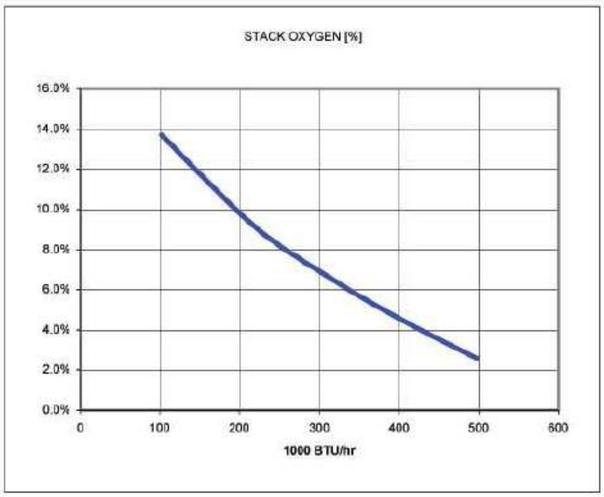


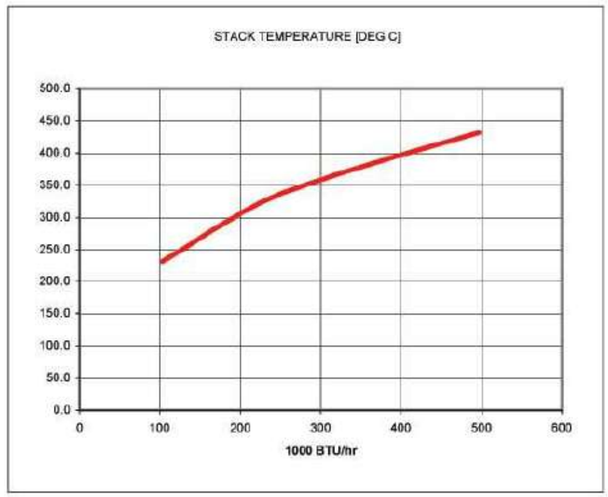
FIGURE 9.38 Tube Temperature Profiles with 2-1/2" Pyronics Burner

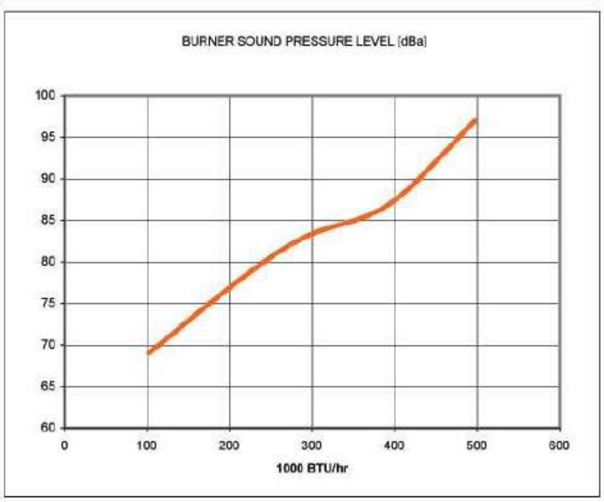
PTAC	PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
		Project EETR 0401
		Burner 2-Pass Heater Test Performance Summary
		Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Pyronics (Large)
Description:	2-1/2", 2000T, 600,000 BTU/hr @ 25 psig
Orifice:	1/8"
Date:	24-Mar-05









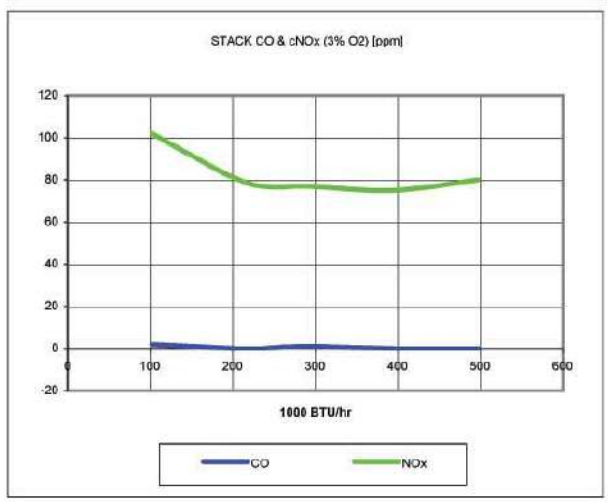


FIGURE 9.39 2-1/2" Pyronics Burner Performance in the Fire Tube

9.18 Pyronics 1-1/2" (Self-Adjusting) Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.40;
- colder fire-tube "entry zone": first 3 feet of the fire-tube
- temperature peak: 1900 deg F at 1ft – direct flame impingement!!!!
- partial tube flow: at less than 190,000 BTU/hr; approx above 2.6:1 turndown.

Burner Performance Graphs:

- see Figure 9.41;
- maximum fire: 500,000 BTU/hr; minimum fire: 100,000 BTU/hr; 5:1 turndown
- gross thermal efficiency: 74% HHV at maximum fire, 58% HHV at minimum fire
- stack oxygen: 4% at maximum fire; 17% at minimum fire
- stack temperature: 500 deg C at maximum fire; 220 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 88 dBA at maximum fire; 64 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 20 and 60 ppm
- stack CO: between 5 ppm and 85 ppm

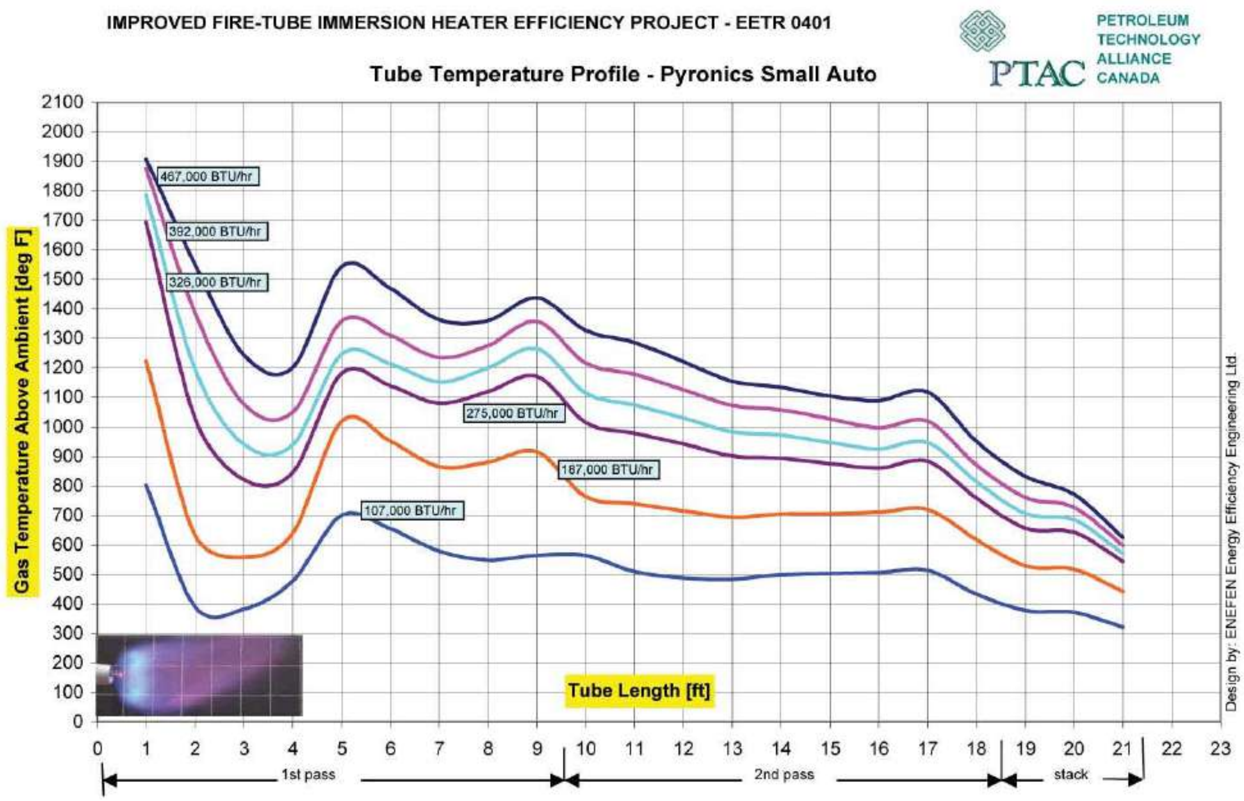
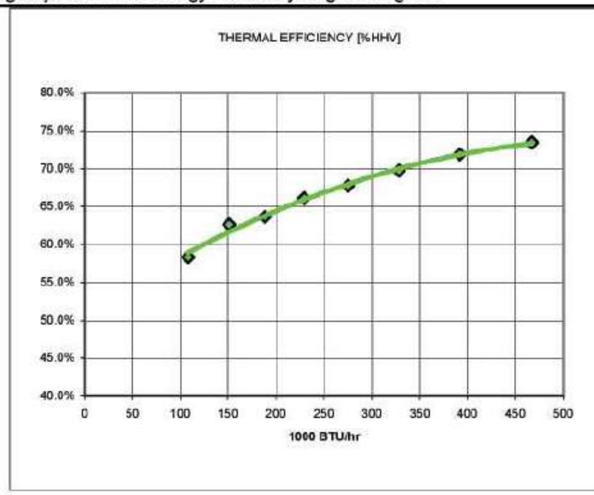
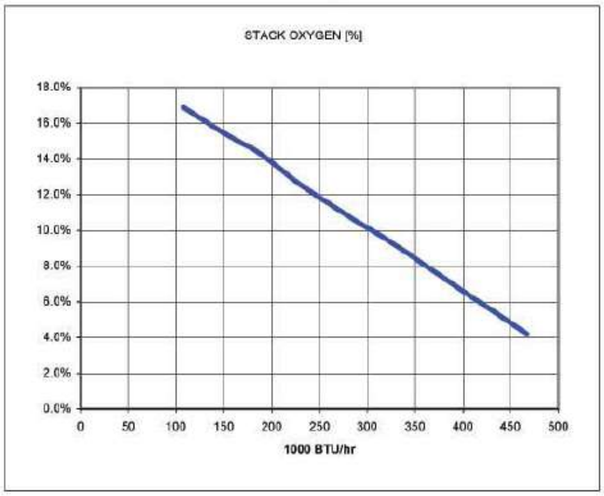


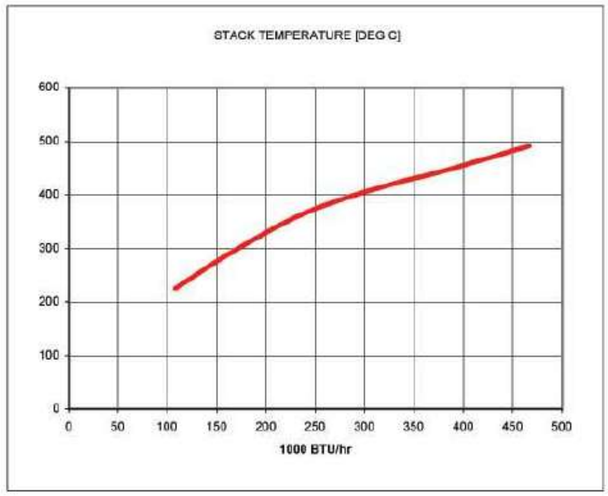
FIGURE 9.40 Tube Temperature Profiles with 1-1/2" Pyronics Self-Adjusting Burner

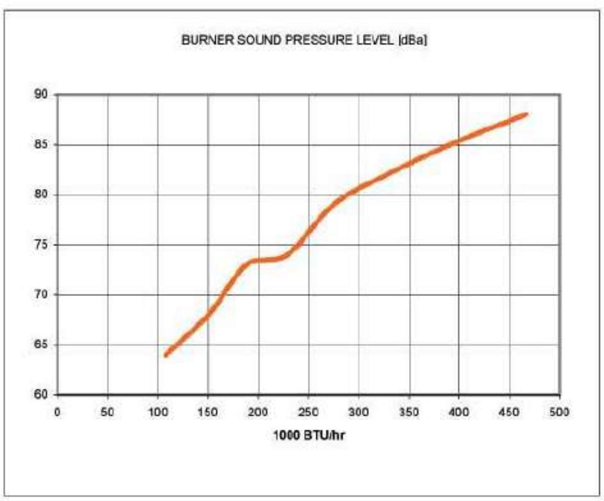
PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner 2-Pass Heater Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Pyronics (Small Auto)
Description:	1-1/2" 12HLT-MA, 300,000 BTU/hr @ 5 PSIG
Orifice:	#29
Date:	23-Mar-05









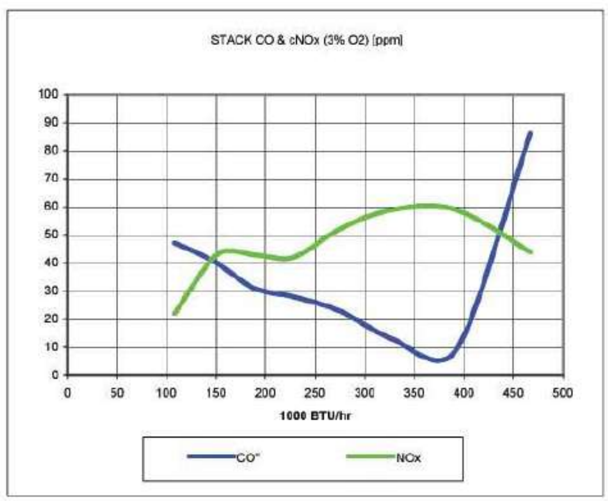


FIGURE 9.41 1-1/2" Pyronics Self-Adjusting Burner Performance in the Fire Tube

9.19 Pyronics 2" (Self-Adjusting) Burner Heater Tests

Following is the summary of this burner testing in the 2-pass fire-tube configuration of the test unit.

Fire-Tube Temperature Profiles

- see Figure 9.42;
- colder fire-tube "entry zone": none – direct impingement due to a wide flame
- temperature peak: 1600 deg F at 1 ft
- partial tube flow: not recorded.

Burner Performance Graphs:

- see Figure 9.43;
- maximum fire: 500,000 BTU/hr; minimum fire: 100,000 BTU/hr; 5:1 turndown
- gross thermal efficiency: 58% HHV at maximum fire, 72% HHV at minimum fire
- stack oxygen: 5.5% at maximum fire; 16% at minimum fire
- stack temperature: 480 deg C at maximum fire; 260 deg C at minimum fire
- burner sound pressure level (without flame arrestor): 84 dBA at maximum fire; 70 dBA at minimum fire
- stack NOx corrected to 3% excess O_2: between 0 and 70 ppm
- stack CO: between 20 ppm and 370 ppm (high CO producer)

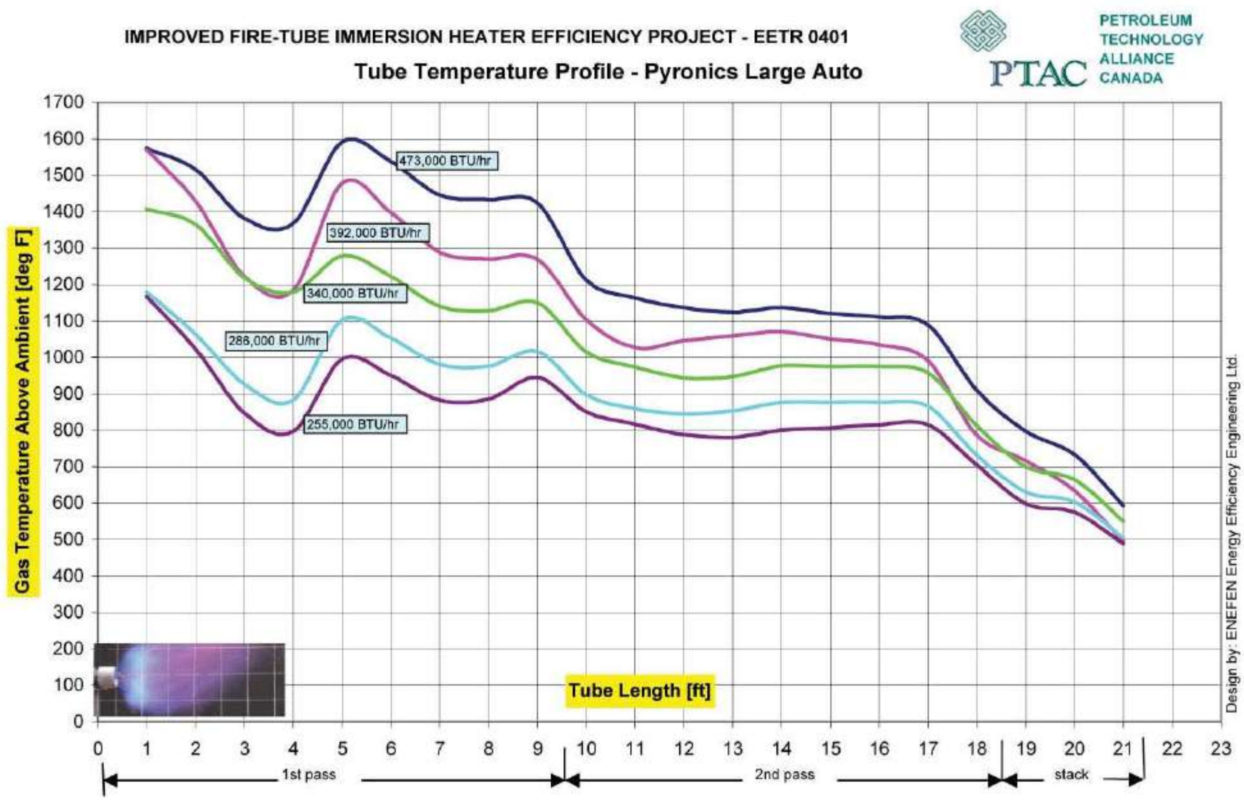
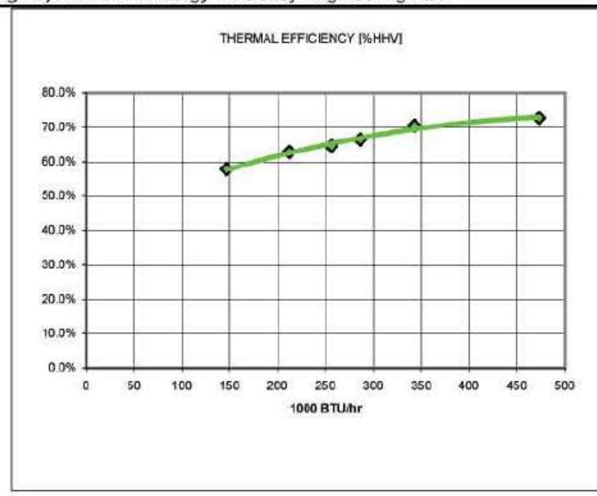
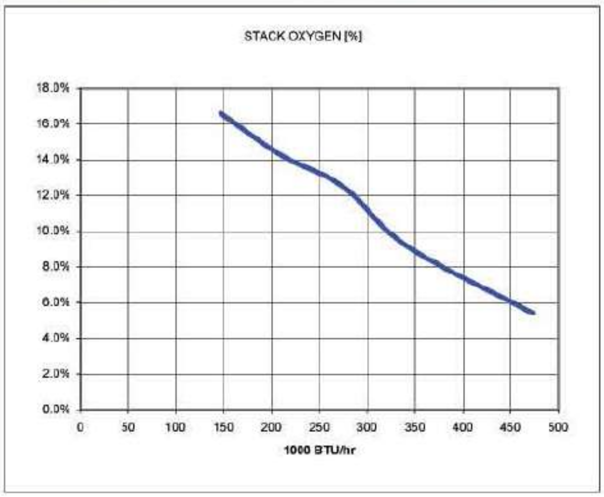


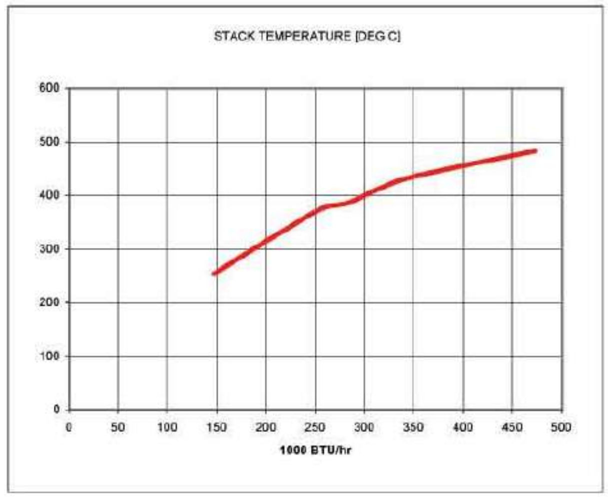
FIGURE 9.42 Tube Temperature Profiles with 2" Pyronics Self-Adjusting Burner

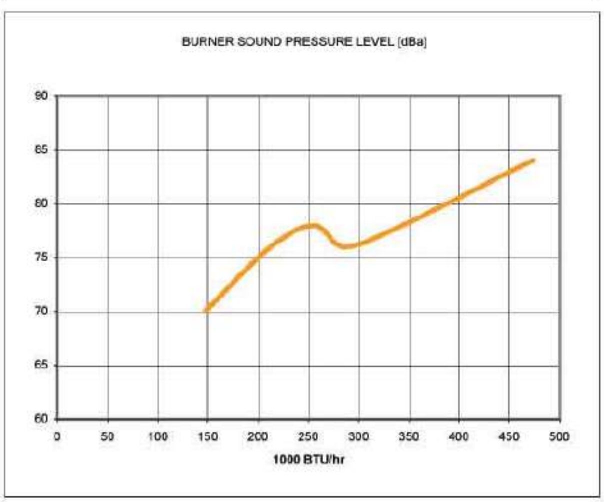
PETROLEUM TECHNOLOGY ALLIANCE CANADA (PTAC)	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner 2-Pass Heater Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

Manufacturer:	Pyronics (Large Auto)
Description:	2" 16HLT-MA, 600,000 BTU/hr @ 5 PSIG
Orifice:	#8
Date:	19-Mar-05









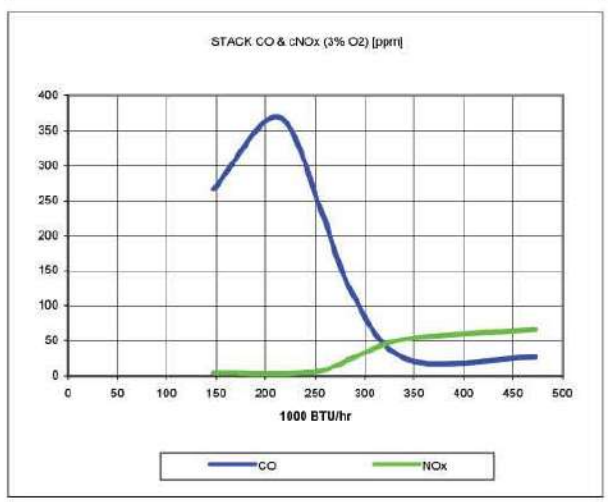


FIGURE 9.43 2" Pyronics Self-Adjusting Burner Performance in the Fire Tube

9.20 Comparison of all Burners – Heater Tests

The following pages contain comparative performance graphs of all burners.

Figure 9.44 illustrates stack bottom temperatures at various firing rates. Disregarding the radiant metal fibre burners, the maximum fire temperatures vary between 460 and 520 deg C with only one burner at 430 deg C. The minimum fire temperatures vary between 220 and 260 deg. These stack bottom temperatures for all burners follow a similar profile and the differences can be explained due to variations in excess air. In general, burner type does not have a significant influence on the stack bottom temperature.

Figure 9.45 illustrates excess oxygen in the stack. As explained previously, all burners were set to approximately 2.5% excess oxygen at maximum firing rate of 500,000 BTU/hr. The actual recorded values at that rate were between 2% and 4%. A distinct difference can be observed between the burners with low, versus with high aeration through the mixer. When turned down, the burners with low aeration follow a straight excess oxygen line between 3% O_2 at 500,000 BTU/hr and 17% O_2 at 100,000 BTU/hr. Burners with higher aeration follow a curve, which limits the increase of excess O_2 in the initial stages of turndown so that at 50% of the firing rate it is only between 5% and 8%. The ability of burners with higher aeration to better maintain the excess air between 100% and 50% firing rate can be utilized to obtain higher heater efficiencies.

Figure 9.46 illustrates the gross thermal efficiency of the test unit recorded during tests with various burners. With all burners set to similar maximum fire operating conditions the efficiency was between 72% and 76%. For the burners with low aeration the efficiency decreased at low fire to between 57% and 62%. For the burners with high aeration, this efficiency decrease occurred slower to between 66% and 74%. Although all burners are set to similar efficiencies at maximum fire, on average, there is approximately 10% difference in efficiency of both types of burners at low fire. Also, if the turndown was limited to 2:1, the burners with high aeration would maintain the efficiency within our 72% to 82% target range.

Figure 9.47 illustrates a comparison of stack CO for various burners. With the exception of two burners, which had slightly elevated but still acceptable CO levels, all other burners were able to maintain CO levels below 50ppm, through the entire turndown range. Consequently, we conclude that the high CO cases found occasionally in the field installations are not inherent to any specific burner design but are the result of burner misadjustment, blocked air flow, and poor maintenance.

Figure 9.48 illustrates a comparison of stack NOx corrected to 3% O2 in the stack, for various burners. Although low fire NOx values are difficult to interpret due to varying levels of excess air, all burners produced at high fire between 60 to 90 ppm of NOx, which is not unusual for this type of combustion equipment.

Figure 9.49 illustrates a comparison of sound pressure levels from various burners. These levels were measured at 1 meter distance behind the burner nozzle, and without a flame arrester installed. At high fire all burners had a sound level in excess of 85 dBA. Burners with low aeration (mostly raw gas) operated at higher sound pressure levels between 95 and 102 dBA. Burners with high aeration thorough primary port operated at lower sound pressure levels between 87 and 94 dBA.

Figure 9.50 illustrates a comparison of fire tube temperature profiles with various burners firing at 500,000 BTU/hr. Three black lines are shown as the minimum, average and maximum temperature profiles. Following are our observations from this analysis:

a) In the first few feet of the fire-tube length, the minimum and maximum profile curves are far apart due to the way, the combustion air is introduced into the burner, and due to how the flame is formed. For burners with low aeration cold air is shielding the tube entrance from flame radiation and the tube is cold. For burners with high aeration, the tube entrance does not see the inflow of cold air, which enters mostly through the primary inlet. Consequently, for those burners the heat transfer starts working sooner and more of the tube surface area is utilized. Finally, some burners, cause very high entrance temperatures due to flame impingement close to the tube entrance, and in some cases, due to reverse flow of the products of combustion. The first thermocouple readings range from 400 to over 2100 deg F. We give to this area of the fire-tube characterized by low temperatures, a name of the

COLD ENTRY ZONE. Depending on the burner type, size, mounting arrangement and firing rate this entry zone can extend a few feet into the fire-tube, thus rendering this portion of the heat transfer surface ineffective.

b) The cold entry zone of the fire-tube turns into a FLAME ZONE, in which the fuel and air mixing and the combustion process continues and the temperature increases

c) After combustion is complete at approximately five feet of tube length (specific for the tested tube size and maximum firing rate of 500,000 BTU/hr), the temperature profile curves converge forming a HOT SPOT with temperatures between 1500 and 2000 deg F. This is the area of the fire-tube most prone to overheating, external coking with deteriorated bath liquid, and to tube failure. Although the location of the hot spot is more a function of the heat input, than the specific burner design, the actual temperature value is dictated by the flame shape

d) For the remainder of the first pass, the temperature profiles inside the tube remain parallel until they reach the return elbow, which promotes turbulence and gas mixing. Exiting the elbow, temperature profiles are between 1250 and 1500 deg F, representing a relatively small 250 deg F difference. This tube temperature profile convergence due to turbulence is indicative of the flow stratification in the first pass, rather than of a superior or inferior thermal performance of any specific burner.

e) Temperature profiles converge even further in the fire-tube exit elbow to the stack. Here the temperature ranges from 850 to 1000 deg F only a 150 deg F difference, which corresponds to approximately 4% difference in thermal efficiency. This difference can be explained through slightly different fire-tube entry conditions and accuracy and variability of measurement.

f) A generalized conclusion from this analysis is, that based on a fixed identical burner setup (fuel input and excess O_2 in the stack) the type of burner has only a small effect on the stack bottom temperature and overall efficiency of heat transfer in the tube. The small difference (up to 4% measured) can be found in the length of cold entry zone, magnitude of the hot spot, possibility of flame impingement, and in the stratification of the products of combustion in the tube.

g) Although the burner type may not make a significant difference on the momentary heat transfer in the tube, it may impact its long term performance through coking, fouling, increased corrosion, temperature stress metal cracking, all leading to shortened fire tube life.

Figure 9.51 illustrates the above fire-tube temperature profiles for each burner as a comparison between average fire-tube temperature, peak temperature, and stack bottom temperature. Following are the ranges of these temperatures:

a) peak temperature from 1591 to 2093 deg F;

b) average temperature ranged from 1292 to 1577 deg F, and;

c) stack bottom temperature from 797 to 941 deg F.

Figure 9.52 illustrates a summary of heater emissions and efficiencies with various burners with 500,000 BTU/hr firing.

Following are the recorded ranges

a) Stack O_2: 0.8% to 5.4%.(target burner setpoint was between 2.0% and 3.5% with some burners allowing lower and some requiring higher oxygen rates in order to maintain CO below 100 ppm target);

b) Stack CO: 0 to 72 ppm (below the maximum target of 100 ppm);

c) Stack NOx (corrected to 3% O_2): 48 to 95 ppm (relatively high NOx levels, but typical to this type of combustion equipment);

d) Stack CO2: 8.2% to 11.2% (function of the excess air);

e) Excess Air: 4.1% to 35.1% (ideal target excess air 10% to 20%)

f) Gross thermal efficiency: 72.5% to 75.7% (within target efficiency range of 72% to 82%)

9.20.1 Comparison of all Burners – Stack Bottom Temperature

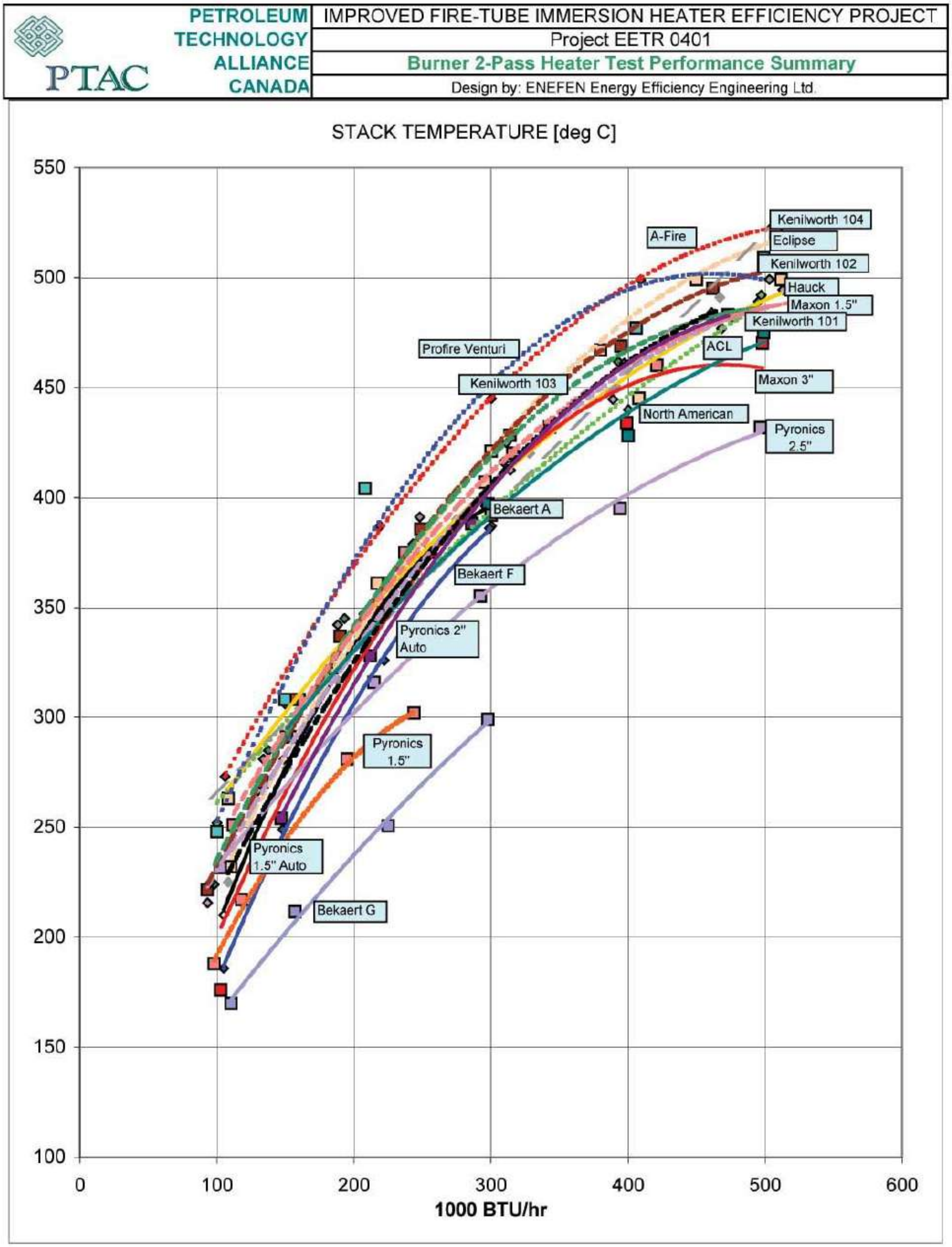


FIGURE 9.44 Burner Performance Comparison – Stack Bottom Temperatures

9.20.2 Comparison of all Burners – Stack O_2

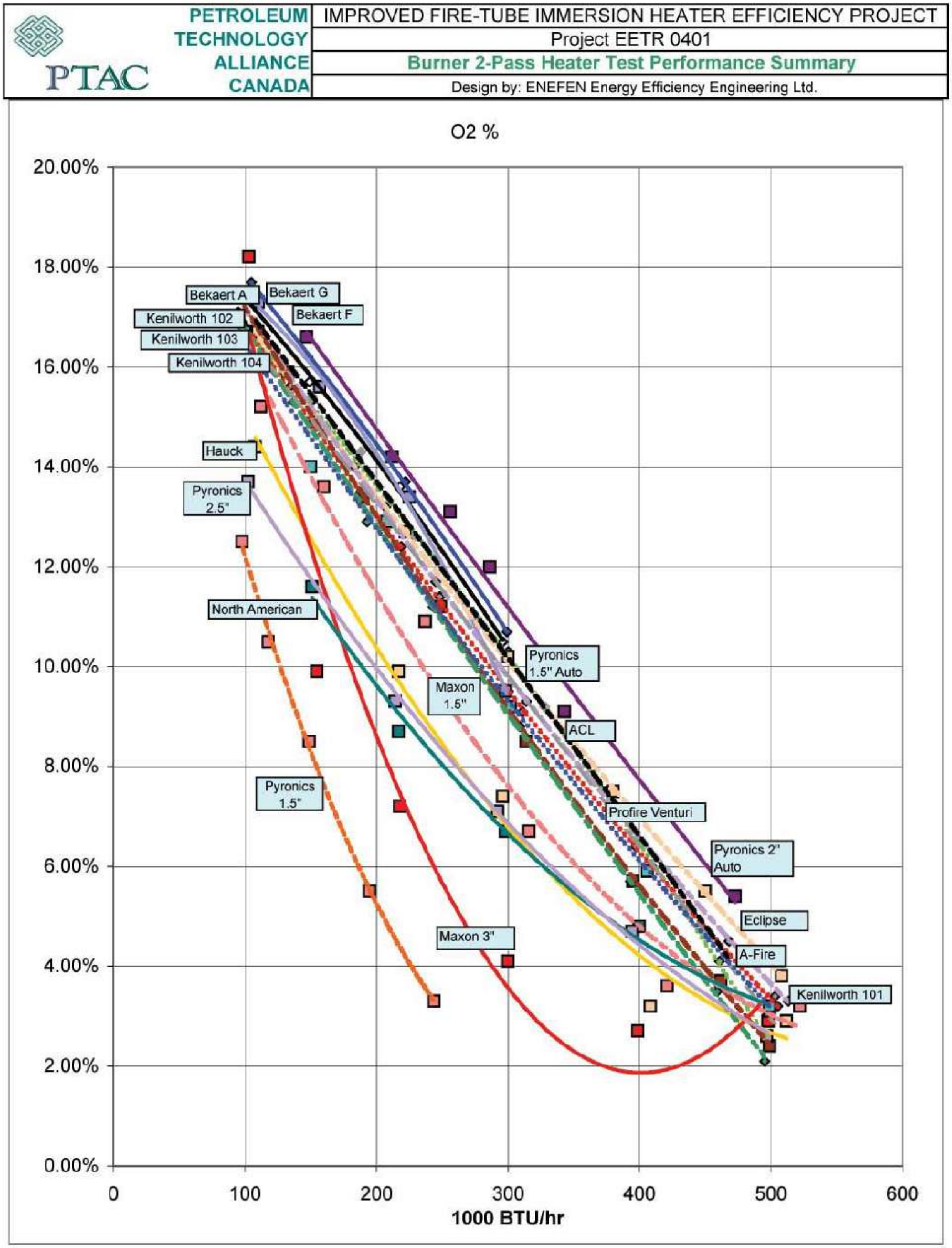


FIGURE 9.45 Burner Performance Comparison – Stack Excess O_2

9.20.3 Comparison of all Burners – Gross Efficiency HHV

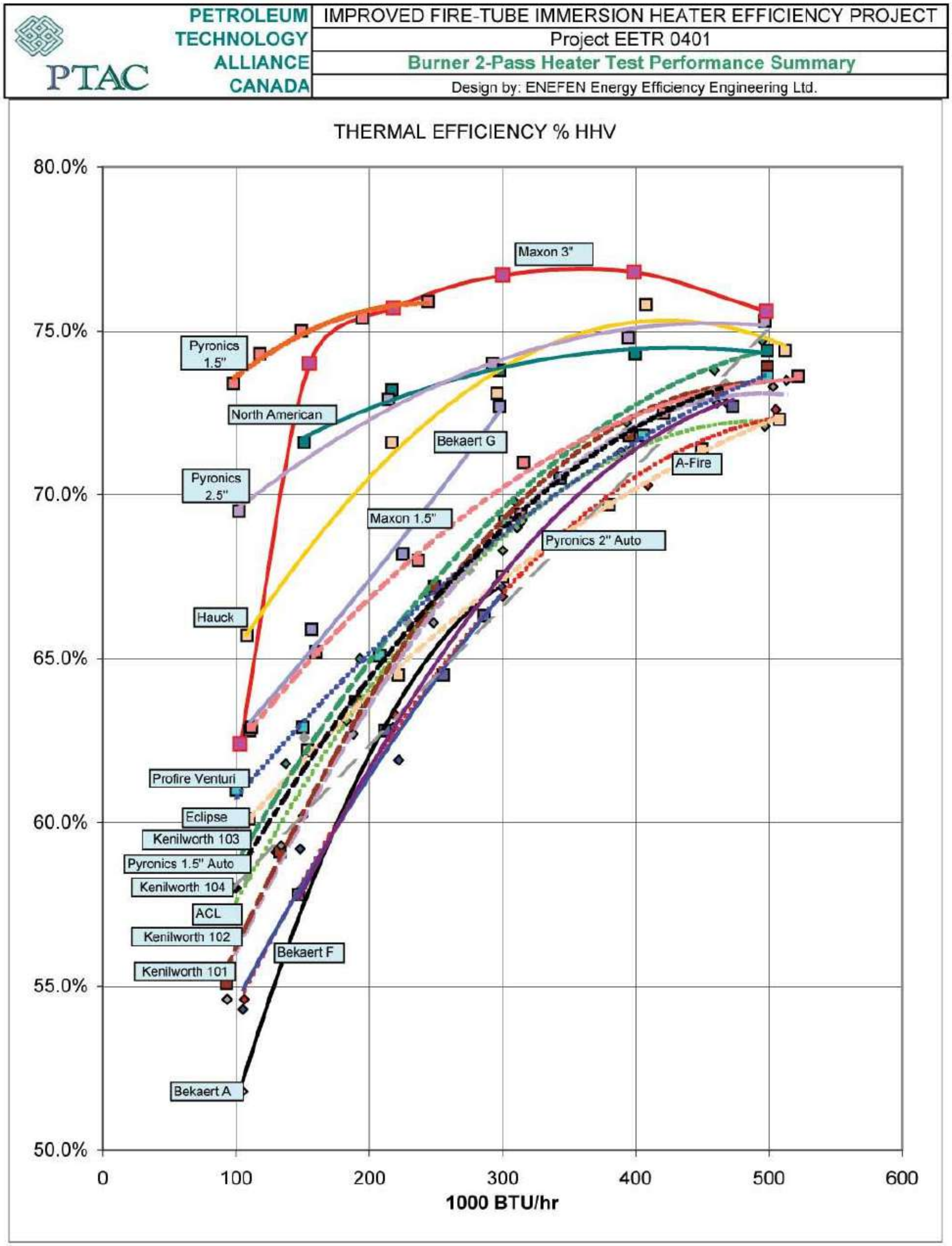


FIGURE 9.46 Burner Performance Comparison – Thermal Efficiency %HHV

9.20.4 Comparison of all Burners – CO

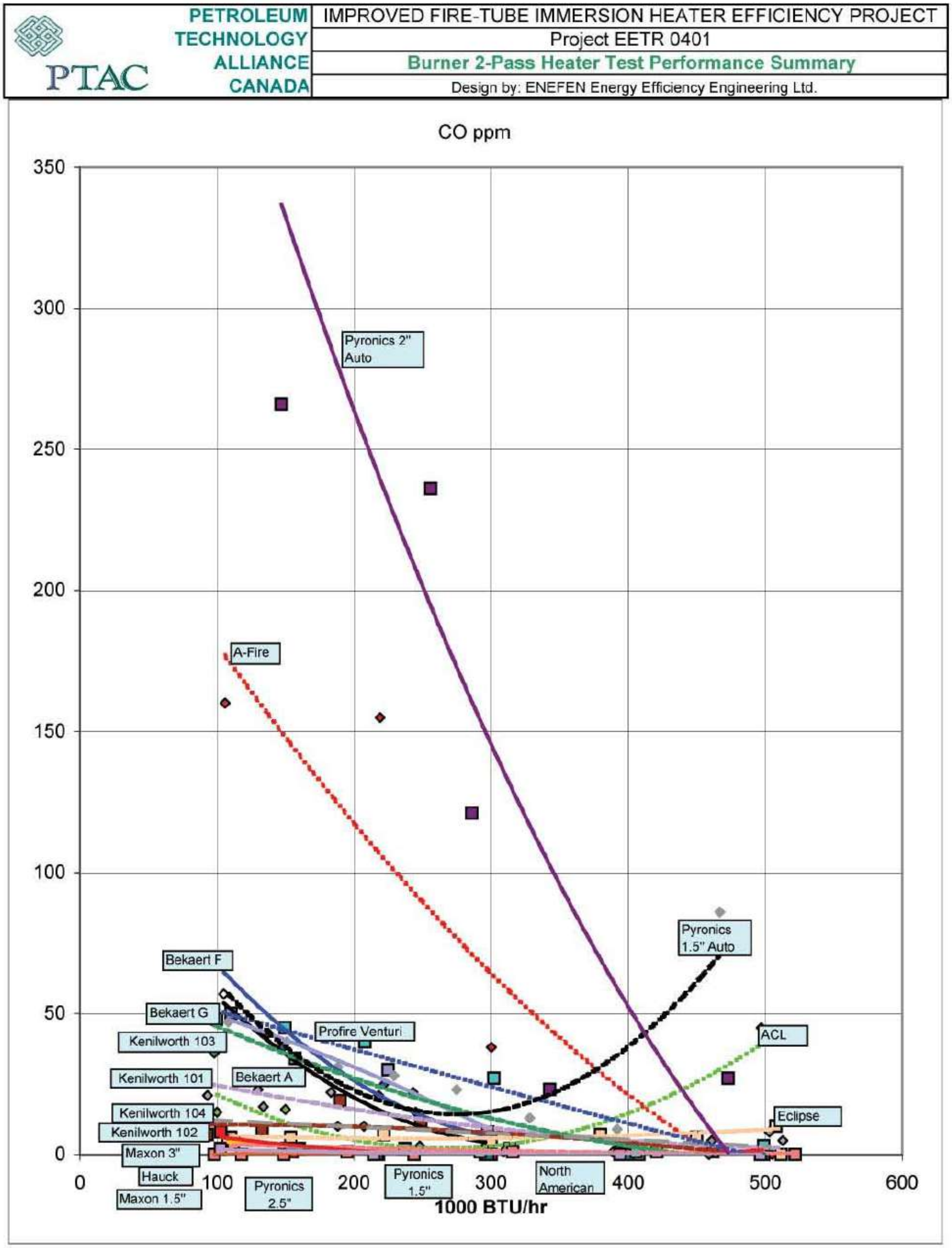


FIGURE 9.47 Burner Performance Comparison – Stack CO

9.20.5 Comparison of all Burners – cNOx (3% O_2)

PETROLEUM TECHNOLOGY ALLIANCE CANADA	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner 2-Pass Heater Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

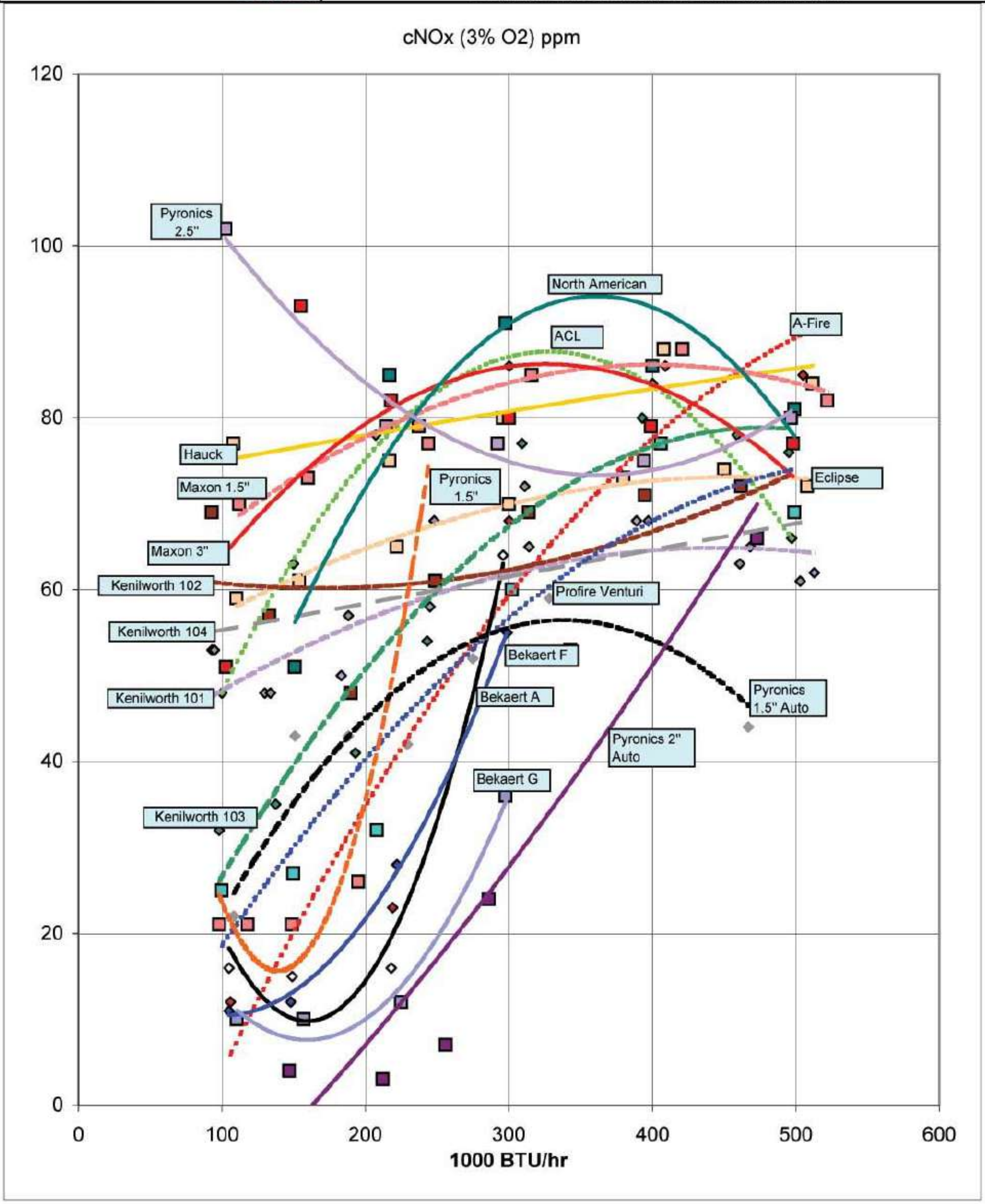


FIGURE 9.48 Burner Performance Comparison – Stack NO_x (corrected to 3% O_2)

9.20.6 <u>Comparison of all Burners – Sound Pressure Level (1m back)</u>

PETROLEUM TECHNOLOGY ALLIANCE CANADA (PTAC)	IMPROVED FIRE-TUBE IMMERSION HEATER EFFICIENCY PROJECT
	Project EETR 0401
	Burner 2-Pass Heater Test Performance Summary
	Design by: ENEFEN Energy Efficiency Engineering Ltd.

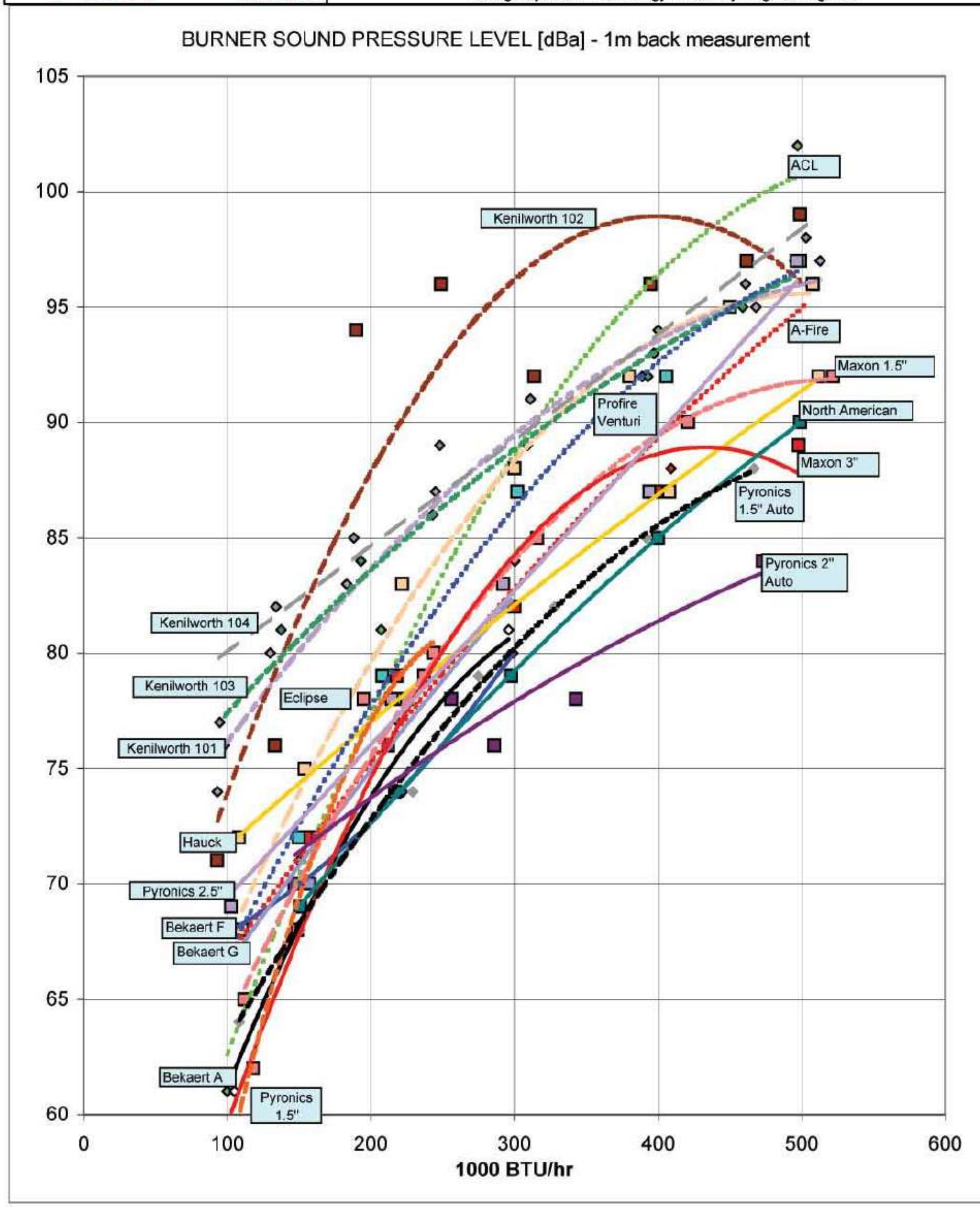


FIGURE 9.49 Burner Performance Comparison – Burner Sound Pressure Levels (1m to back)

9.20.7 Comparison of all Burners – Fire Tube Temperature Profiles

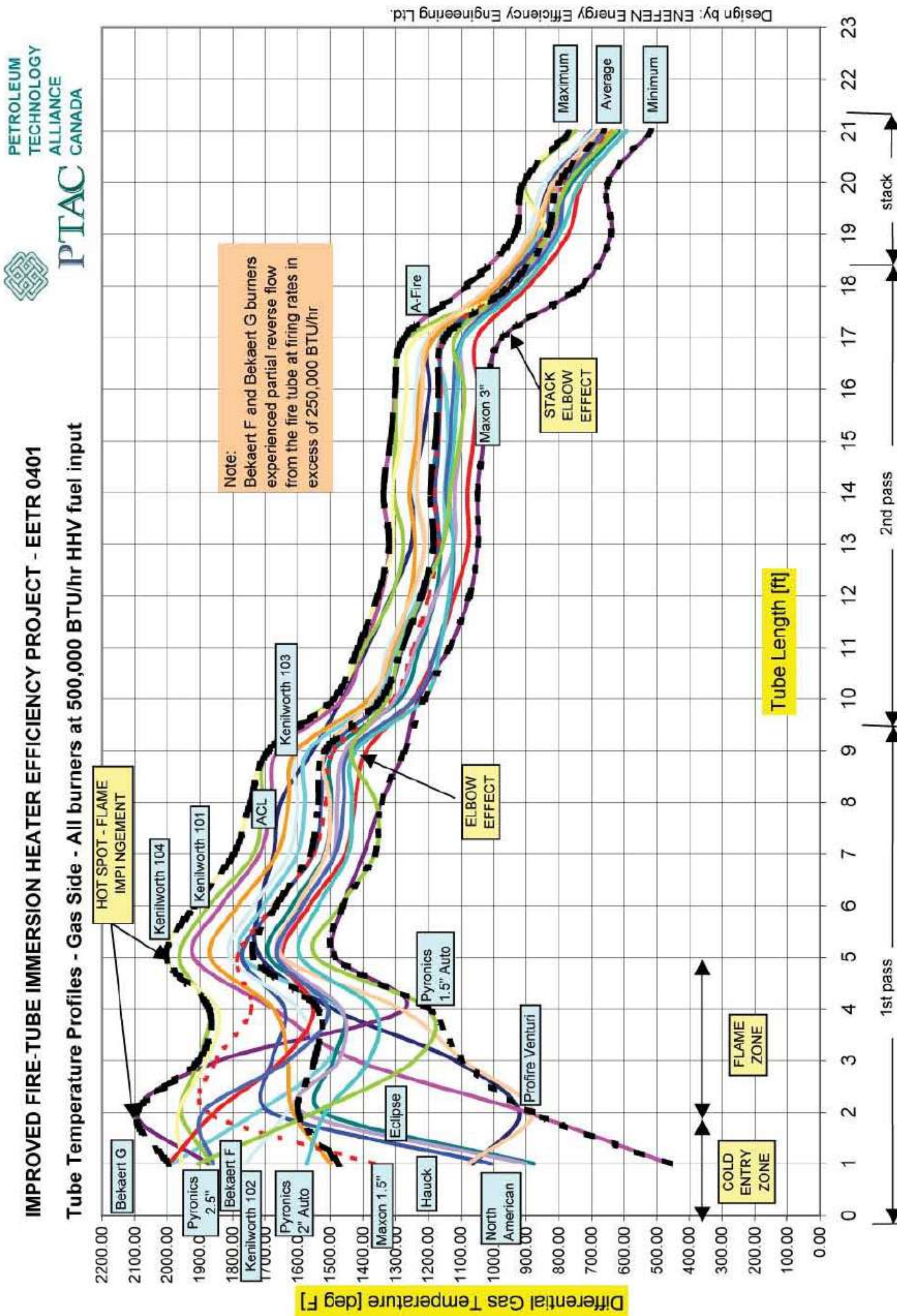


FIGURE 9.50 Burner Performance Comparison – Fire Tube Temperature Profiles

9.20.8 Comparison of all Burners – Fire-Tube Peak, Average, Stack Bottom Temperatures

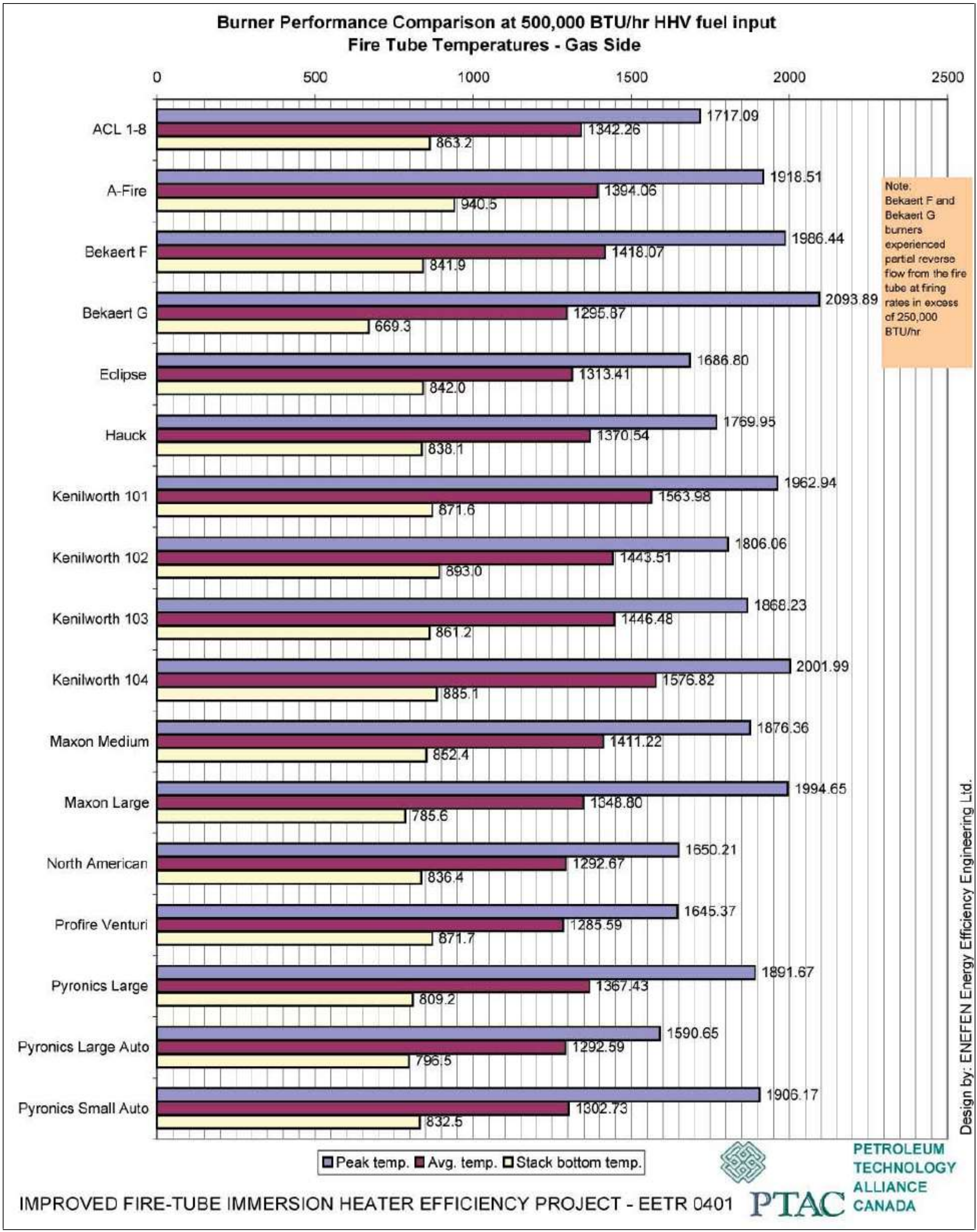


FIGURE 9.51 Burner Performance Comparison – Fire Tube Peak, Average, Stack Bottom Temperatures

9.20.9 Comparison of all Burners – Emissions and Efficiencies

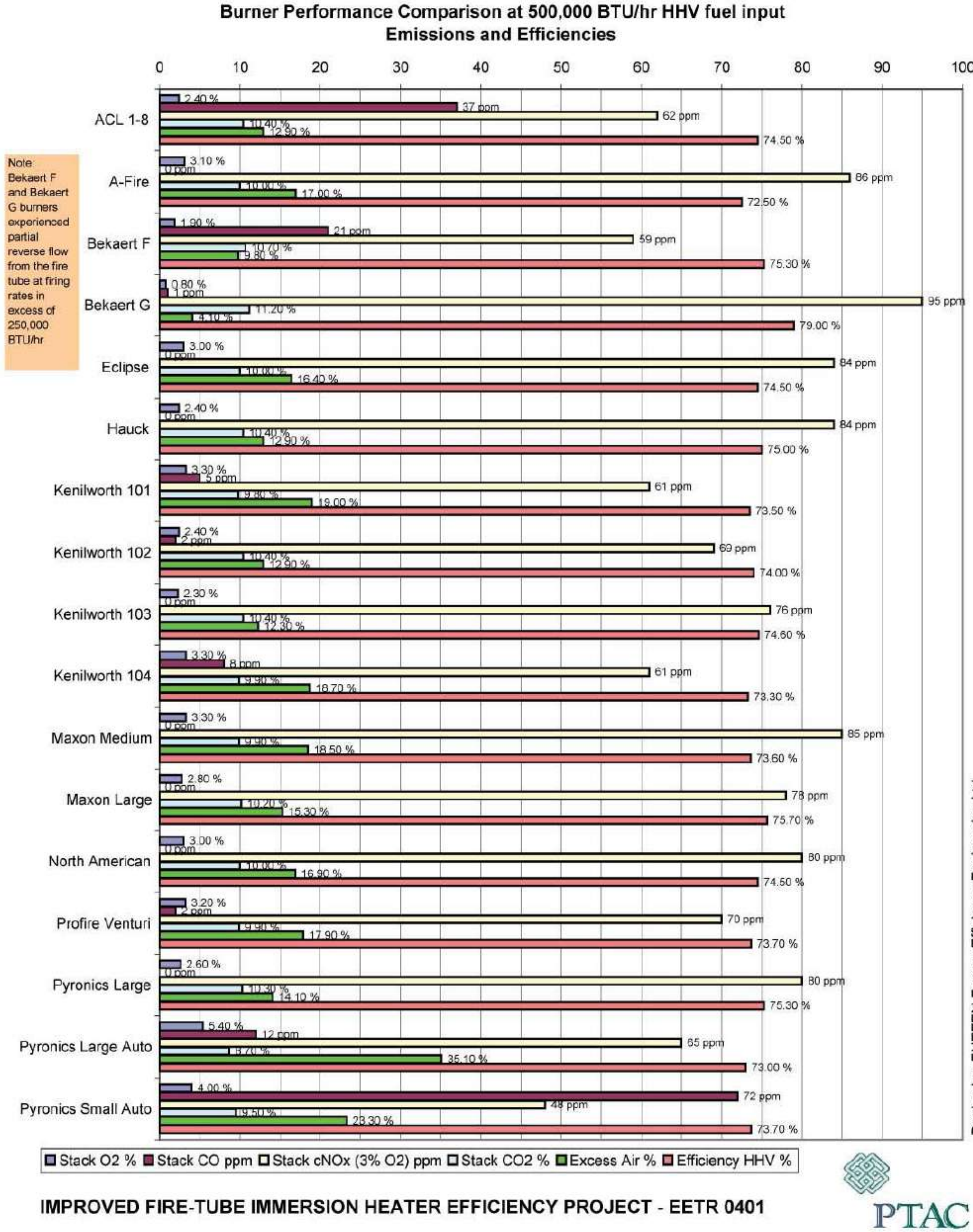


FIGURE 9.52 Burner Performance Comparison – Emissions and Efficiencies

10 2-, 3-, AND 4-PASS TUBE TESTS WITH WATER, GLYCOL AND OIL

This chapter contains data from comparative firing of the test unit with water, 50% EG (ethylene glycol) and oil, in 2-, 3-, and 4-pass configuration. All tests were conducted in similar conditions with the same burner randomly selected from the group of burners capable of higher primary aeration rates.

Figure 10.2 illustrates a comparison between fire-tube temperature profiles on the gas side, when firing with 500,000 BTU/hr at 2.5% O_2 in the stack, into a 2-, 3- , and 4-pass configuration of the test unit with water on the bath side. Figure 10.3 illustrates the results of similar tests with 50% EG, and Figure 10.4 with oil (Specific Gravity SG=0.88, Specific Heat cp=0.4365).

Table below (Figure 10.1) provides the summary of these tests.

		Hot Spot	1-st Elbow	2-nd Elbow	3-rd Elbow	4-th Elbow	2 pass stack top	3 pass stack top	4 pass stack top
2-3-4 Pass with water	Temp deg F	1567	1170	764	554	367	595	440	275
	Decrease deg F	-	397	406	210	187	169	114	92
	Decrease %	-	33.1	33.8	17.5	15.6	-	-	-
2-3-4 Pass with 50% EG	Temp deg F	1557	1196	753	529	372	590	390	279
	Decrease deg F	-	361	443	224	157	163	139	93
	Decrease %	-	30.5	37.4	18.9	13.2	-	-	-
2-3-4 Pass with oil	Temp deg F	1576	1183	729	554	367	595	440	275
	Decrease deg F	-	393	454	175	187	134	114	92
	Decrease %	-	32.5	37.6	14.5	15.5	-	-	-

FIGURE 10.1 Summary of Multipass Fire-Tube Tests with Various Liquids.

The following conclusion were drawn from these test results:

g) Fire-tube temperature profiles for 2, 3 and 4 pass fire-tube configurations follow closely the same curve, so that each additional pass curve is simply an extension of the previous pass curve.

h) Return elbows create distinct steps in the curve due to the turbulence and mixing of the gases. These steps can be attributed more to gas temperature averaging through mixing, than to the increase in heat transfer due to increased turbulence.

i) The fire tube performance with various liquids is very similar. The “hot-spot” temperature is approximately 1567 deg F, and stack bottom temperature 370 deg F (4 pass configuration).

j) Intermediate temperatures indicate that the gas temperature drops to approximately 1180 deg F at the end of the first tube pass. This can be translated from efficiency charts to approximately 58% of the heat transfer achieved in the first pass.

k) The radiant heat transfer continues in the second tube pass until the gas temperature decreases to 1000 deg F. With outlet temperature of about 750 deg F, the second pass contributes an additional 13% of heat transfer.

l) The third pass with 545 deg F exit temperature, provides 6% of overall heat transfer and the fourth pass with 370 exit temperature deg F, 4% of heat transfer.

m) Although the above examples of heat transfer rates in individual fire-tube passes may point to “diminishing returns” if the form of thermal efficiency gains from increasing the tube length, the above results are based on a well-tuned burner running at steady load with 2.5% O_2 in the stack. Therefore, the results and should not be taken as an absolute guideline for evaluating the feasibility of heater design with extended tube-length and a proper thermal design and assessment should be conducted for each application. If software program is used apply under Calibration constants: Convective Coefficient Modifier = 1.3 and Radiation Coefficient Modifier = 2.0.

10.1 Performance of 2-, 3-, 4-Pass Fire-Tube in Water

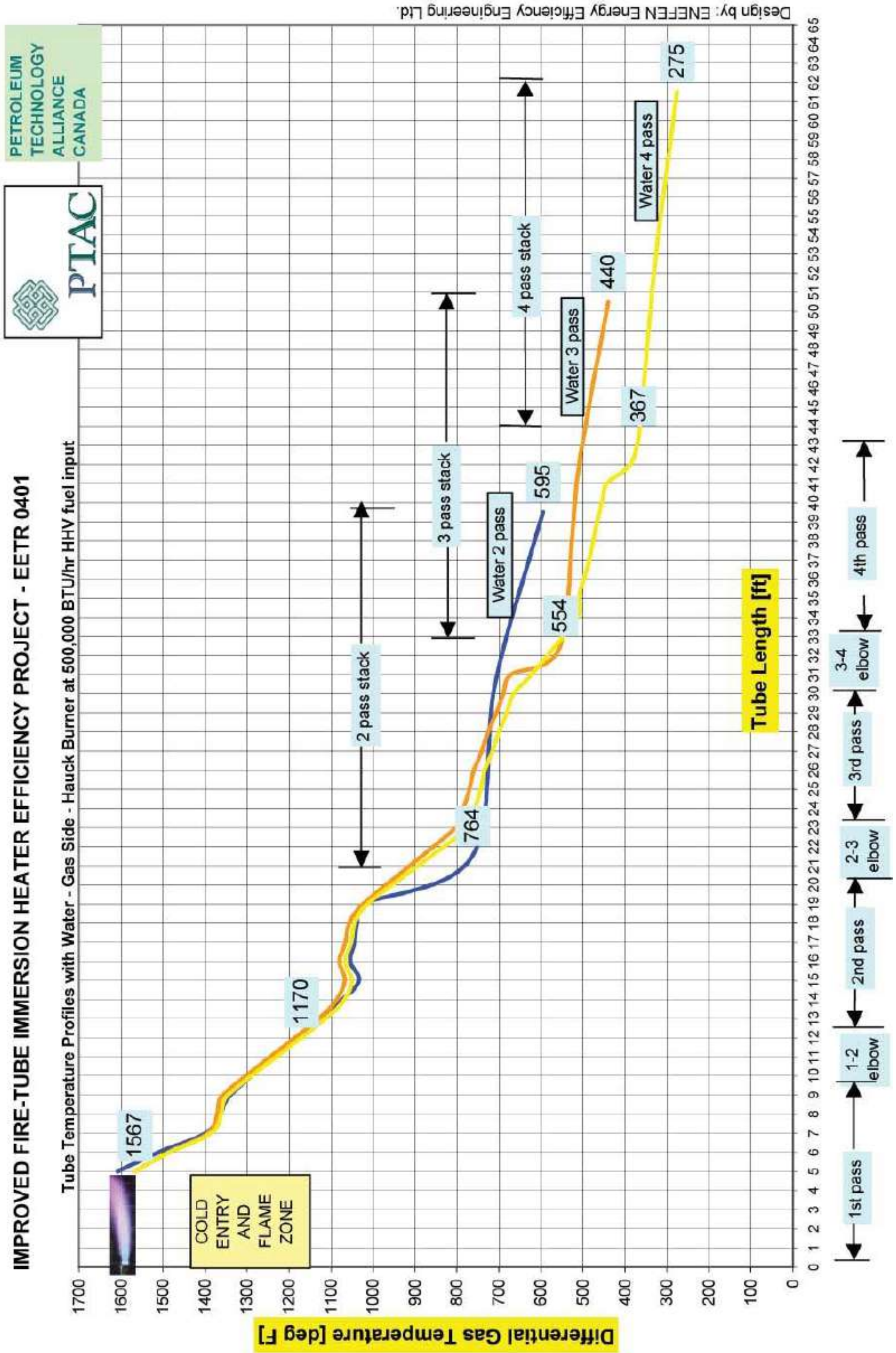


FIGURE 10.2 Performance of 2-; 3-; and 4-Pass Fire Tube in Water Bath

10.2 Performance of 2-, 3-, 4-Pass Fire-Tube in 50/50 EG

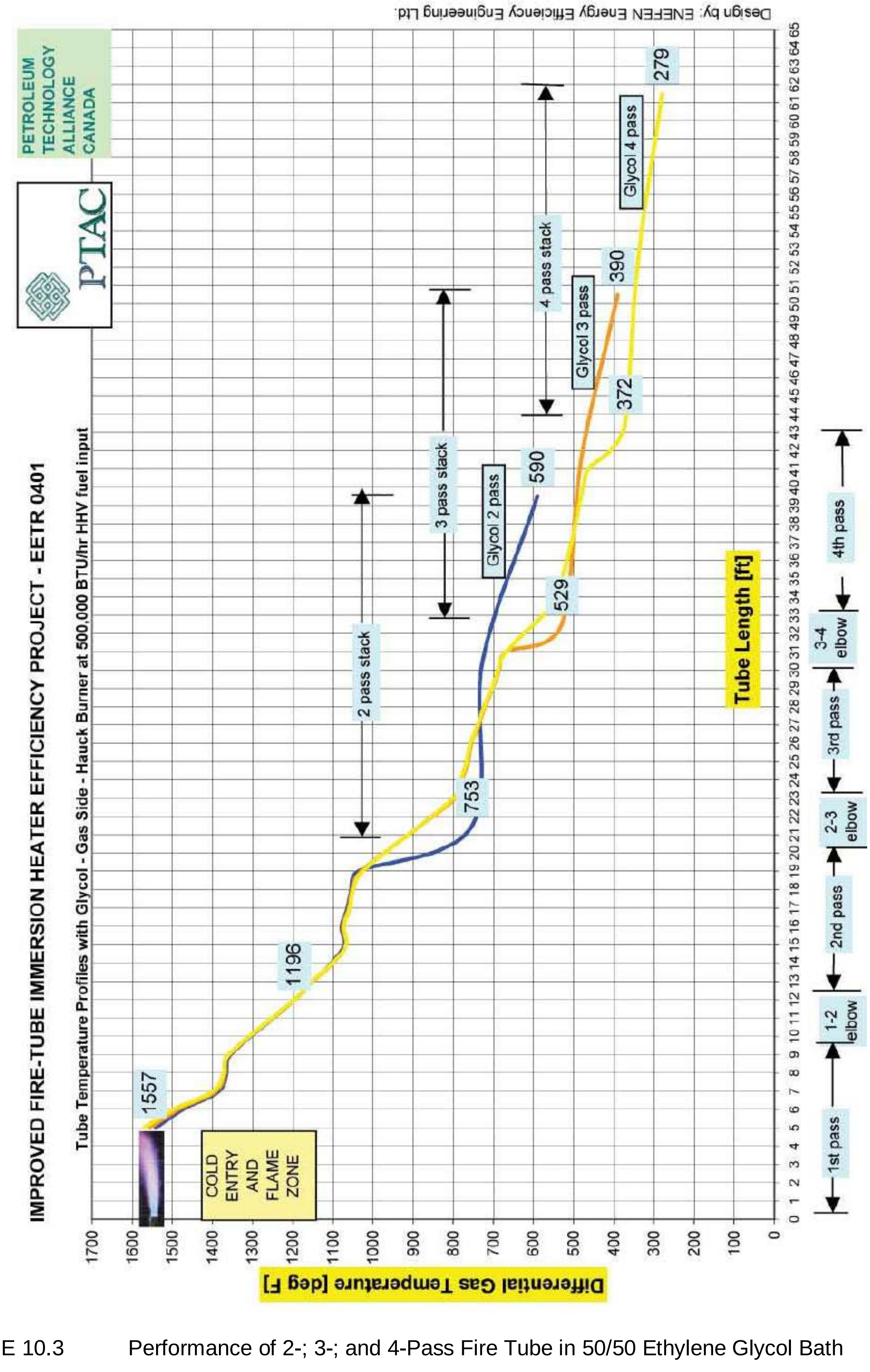


FIGURE 10.3 Performance of 2-; 3-; and 4-Pass Fire Tube in 50/50 Ethylene Glycol Bath

10.3 Performance of 2-, 3-, 4-Pass Fire-Tube in Oil

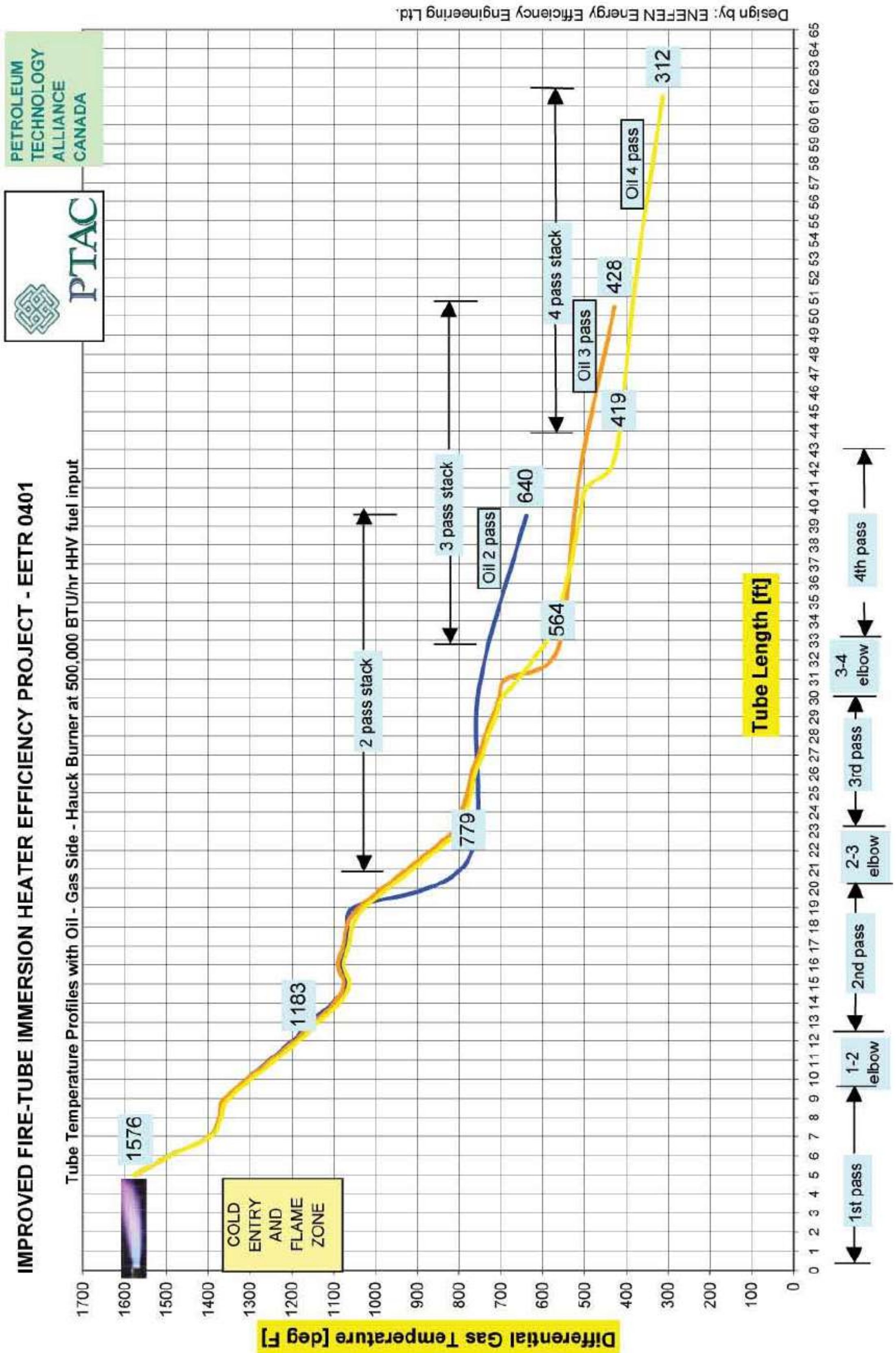


FIGURE 10.4 Performance of 2-; 3-; and 4-Pass Fire Tube in Oil Bath

The next group of graphs illustrates side-by-side the results of test unit firing with water, 50%EG and oil bath. The results were corrected for ambient temperature variations and bath liquid temperature variations. The objective of this analysis is to research the influence of the type of liquid bath on the heat transfer performance.

Figure 10.6 illustrates fire-tube temperature profile curves for a 2 pass heater with water, 50EG, and oil

Figure 10.7 illustrates similar curves for 3-pass, and Figure 10.8 for 4-pass heater configuration.

Table below (Figure 10.5) provides the summary of these tests.

		Hot Spot	1-st Elbow	2-nd Elbow	3-rd Elbow	4-th Elbow	2 pass stack top	3 pass stack top	4 pass stack top
2 Pass with water / 50EG / oil	Temp deg F	1575	1193	765	-	-	608	-	-
	Decrease deg F	-	382	428	-	-	157	-	-
	Decrease %	-	47.2	52.8	-	-	-	-	-
3 Pass with water / 50EG / oil	Temp deg F	1566	1191	803	549	-	-	419	-
	Decrease deg F	-	375	388	254	-	-	130	-
	Decrease %	-	36.9	38.2	25.0	-	-	-	-
4 Pass with water / 50EG / oil	Temp deg F	1572	1183	791	534	386	-	-	289
	Decrease deg F	-	389	392	257	148	-	-	97
	Decrease %	-	32.8	33.1	21.7	12.5	-	-	-

FIGURE 10.5 Summary of Test Results of Fire-Tube Performance with Various Liquids.

The following conclusion were drawn from these test results:

a) After correcting the test results for ambient temperature variations and bath liquid temperature variations, the tube temperature profiles are within 50 deg F tolerance for all three liquids tested. Since there does not seem to be any consistency in which bath liquid provides better or worse test results, the above tolerance is attributed to the accuracy of measurement.

b) Return elbows in the fire-tube influence the temperature profiles by increasing the mixing of the products of combustion. Average temperature values and their polynomial trends are also shown.

c) The average temperature values are similar to the individual tests previously presented. The "hot-spot" temperature is at 1570 deg F, first elbow temperature at 1190 deg F, 2-nd elbow temperature at 786 deg F, 3-rd elbow temperature at 541 deg F, and, stack elbow at 386 deg F.

d) The temperature loss in the stack averages to 128 deg F.

10.4 Performance of 2-Pass Fire-Tube in Water / 50/50EG / Oil

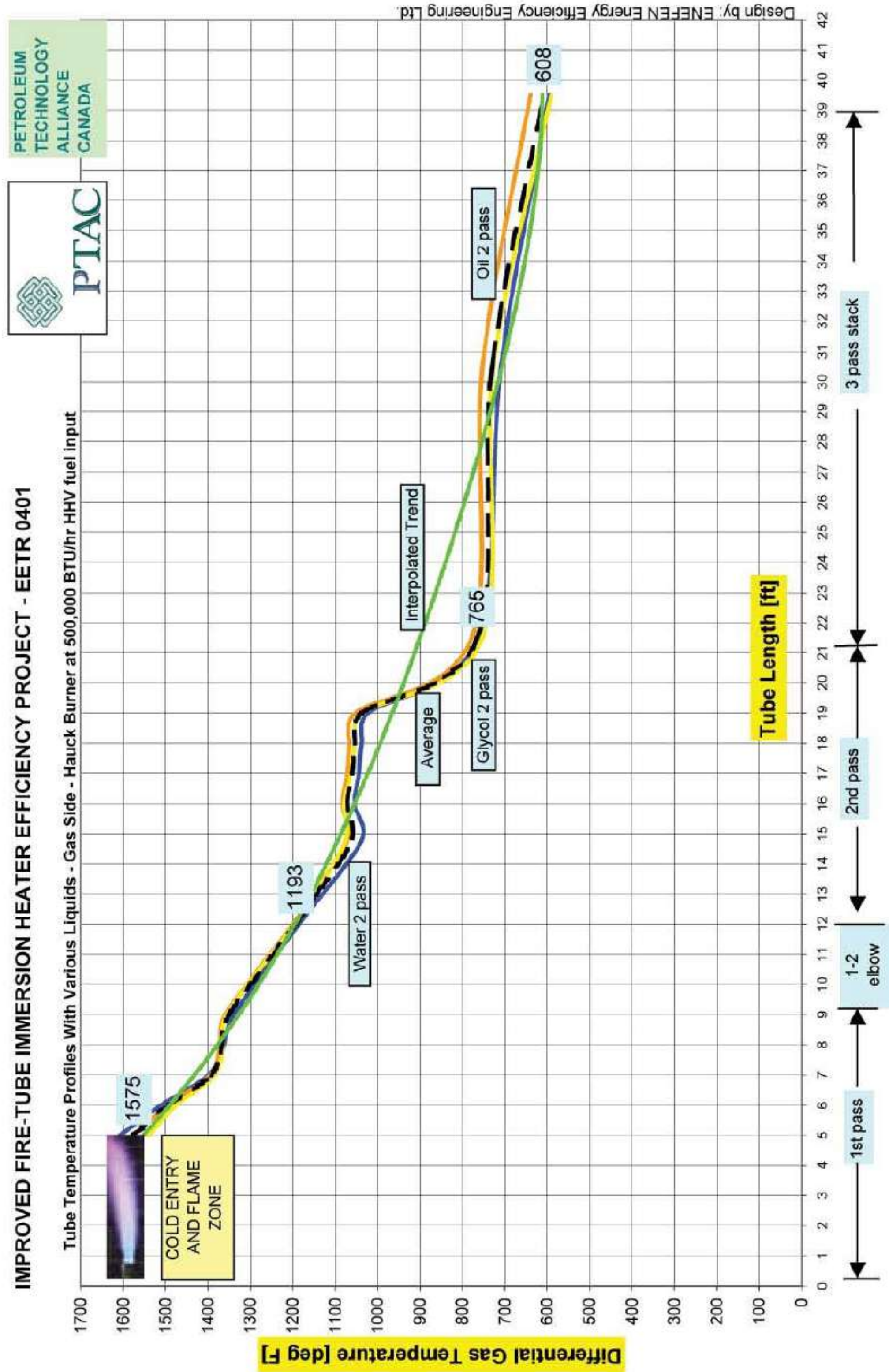


FIGURE 10.6 Comparison of 2-Pass Fire Tube Performance in Water; 50/50 EG and Oil Bath

10.5 Performance of 3-Pass Fire-Tube in Water / 50/50EG / Oil

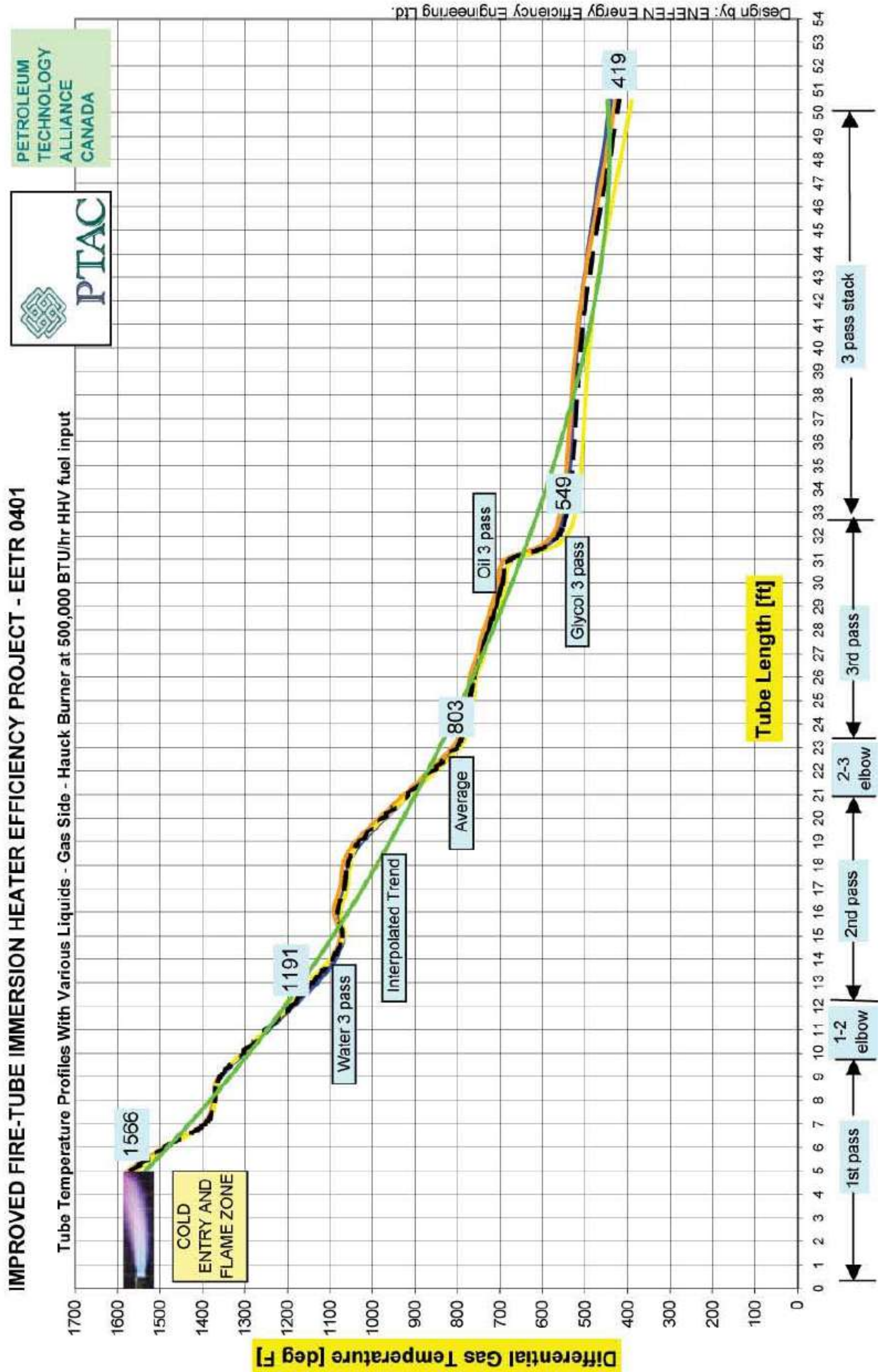


FIGURE 10.7 Comparison of 3-Pass Fire Tube Performance in Water; 50/50 EG and Oil Bath

10.6 Performance of 4-Pass Fire-Tube in Water / 50/50EG / Oil

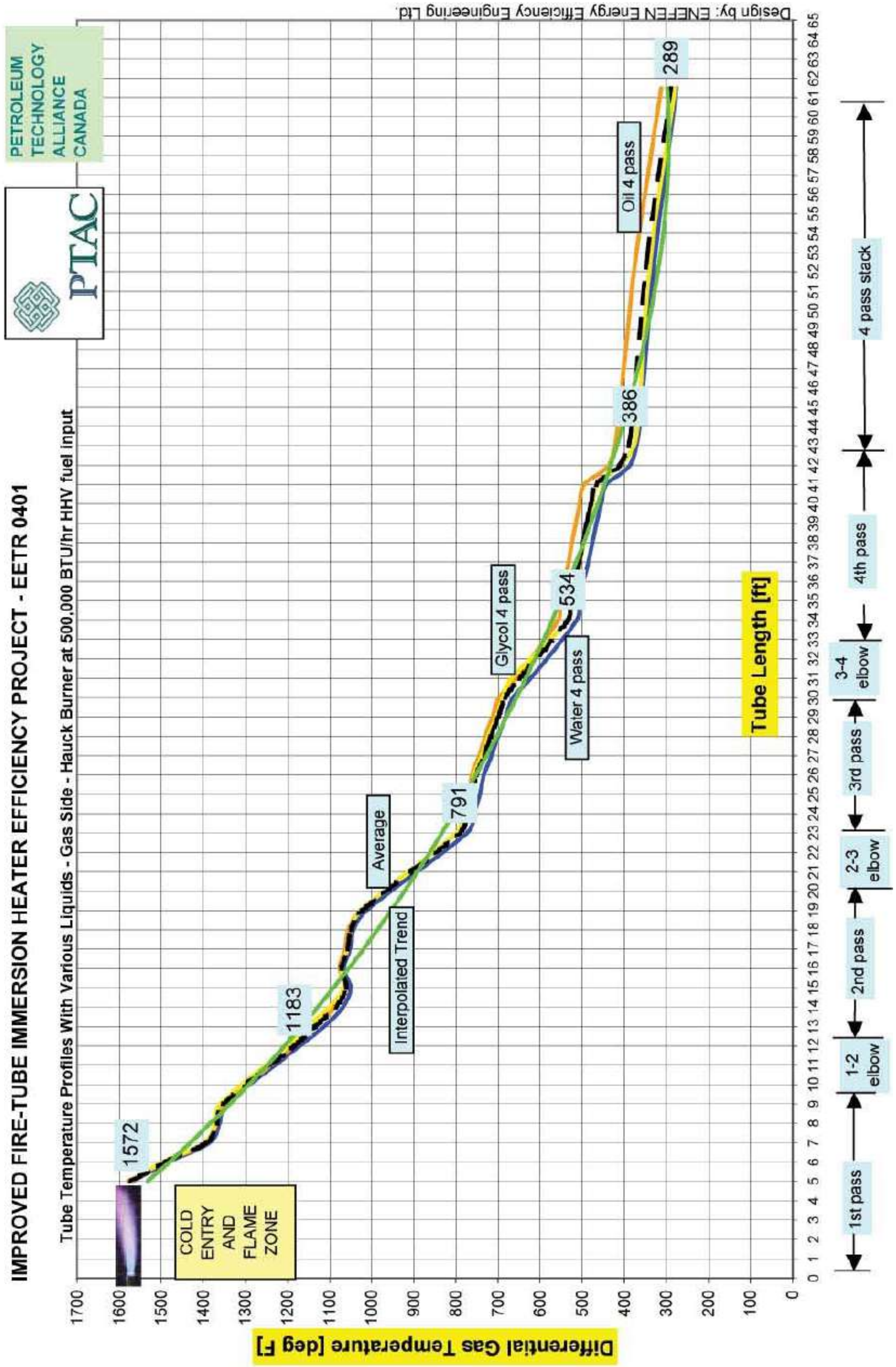


FIGURE 10.8 Comparison of 4-Pass Fire Tube Performance in Water; 50/50 EG and Oil Bath

10.7 Surface Heat Flux Rates of 2-, 3-, 4-Pass Fire-Tube in Water / 50/50EG / Oil

Based on the above temperature profiles, heat flux rates were calculated in between individual measurement points in the fire tube. This was achieved by calculating heat transfer to the tube between each pair of thermocouples then dividing by the tube surface area between these thermocouples (typically on 12" spacing). The resulting heat flux rates are illustrated in the Figure 10.9.

The following conclusion were drawn from this heat flux analysis:

a) All fire-tube configurations and, bath liquids result in similar temperature profiles in the tube, therefore also result in similar heat flux profiles;

b) heat flux rate in the flame zone area was calculated at 24,000 BTU/hr/ft2;

c) heat flux rate is influenced by the fire-tube's return elbows which create gas turbulence and mixing;

d) heat flux rate diminishes with the decrease in the temperature of the products of combustion. In the remaining portion of the fire-tube it fluctuates between 1000 and 4000 BTU/hr/sqft.;

e) An average heat flux rate in the 2 pass heater configuration was calculated at 9936 BTU/hr/sqft and resulted in 71% thermal efficiency;

f) An average heat flux rate in the 3 pass heater configuration was calculated at 7013 BTU/hr/sqft and resulted in 77% thermal efficiency; and

g) An average heat flux rate in the 4 pass heater configuration was calculated at 5599 BTU/hr/sqft and resulted in 81% thermal efficiency.

The above measured average heat flux rates are consistent with the fire-tube rating software developed in this project. The temperature profile curves were compared with the results of the program computation, and used to verify its validity. If software program is used, apply under Calibration constants: Convective Coefficient Modifier = 1.3 and Radiation Coefficient Modifier = 2.0.

The next chapter uses this calibrated fire-tube rating software program to predict heat flux rate for various fire-tube configurations.

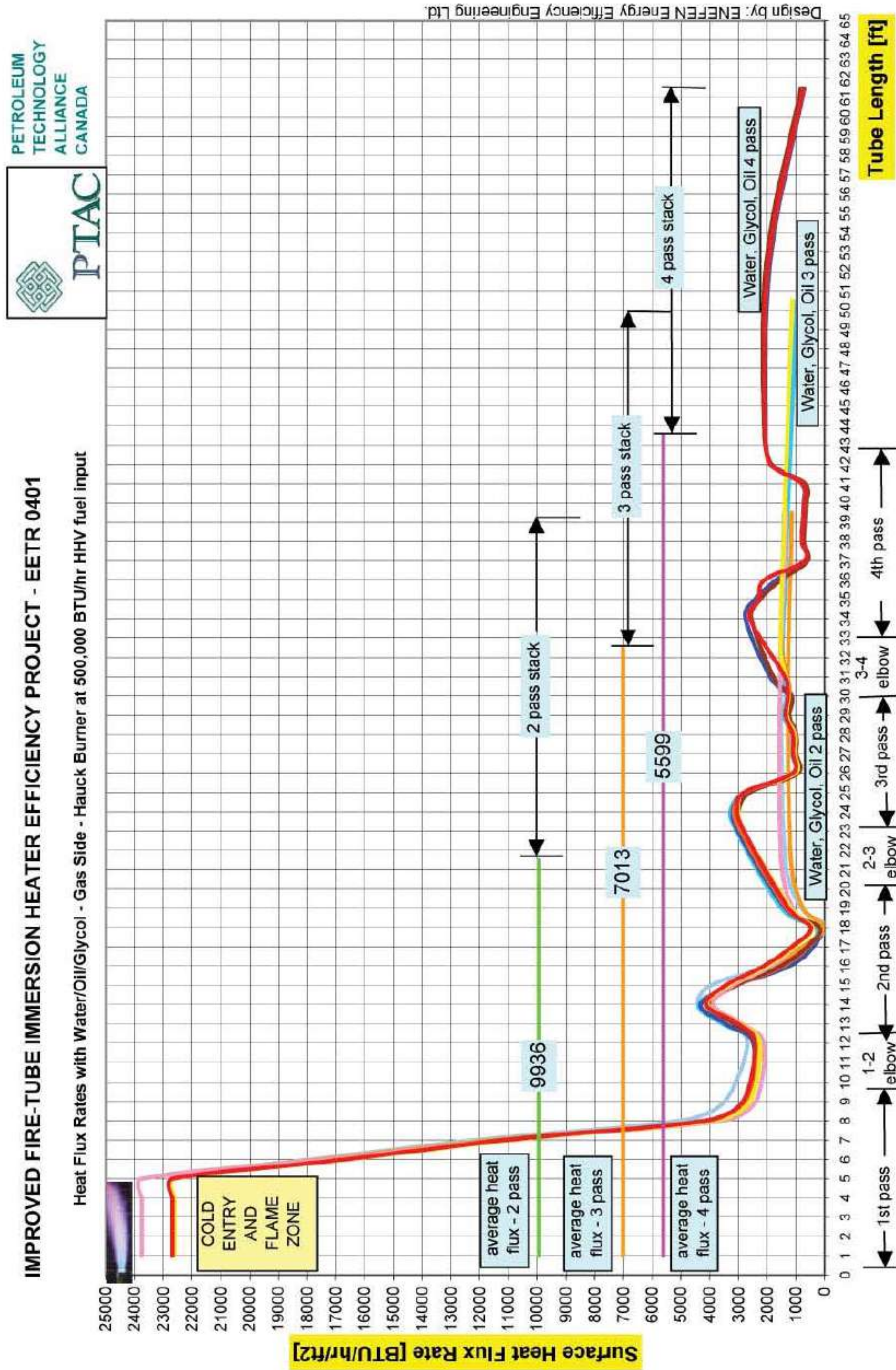


FIGURE 10.9 Surface Heat Flux Rates of 2-; 3-; and 4-Pass Fire Tube in Water; 50/50 EG; and Oil Bath

10.8 Turbulator Thermal Performance Tests

In addition to the previously described group of tests designed to research the fire-tube performance in 2-, 3-, and 4-pass configuration with water, 50EG, and oil, this part of the project included also a performance test of turbulators.

Two types of turbulators were provided: by Kenilworth (Figure 10.10) and by Profire (Figure 10.11).

FIGURE 10.10 Kenilworth Turbulator

FIGURE 10.11 Profire Turbulator

The test unit was operated in 4-pass configuration with water on the bath liquid side. The following procedure was used to conduct this test::

a) Heater was started in a 4 pass configuration (without turbulators), with a constant water flow, 500,000 BTU/hr firing rate and 2.5% O_2 in the stack. Heater temperatures were allowed to stabilize so that the difference between outlet and inlet water temperature became constant indicating that there is more heat being stored inside the heater bath. At an average water temperature of 46.7 deg F (54.5+38.9/2) and the stack temperature was 397.4 deg F, the gas to water approach temperature was 397.4-46.7=350.7 deg F

b) Profire turbulator was installed, burner readjusted to 2.5% O_2, and heater operated until similar conditions were reached. At an average water temperature of 53.3 deg F (61.6+45/2) and the stack temperature was 388.7 deg F, the gas to water approach temperature was 388.7-53.3=335.4 deg F

c) Kenilworth turbulator was installed, burner readjusted to 2.5% O_2, and heater operated again until similar conditions were reached. At an average water temperature of 58.7 deg F (66.2+51.2/2) and the stack temperature was 387 deg F, the gas to water approach temperature was 387-58.7=328.3 deg F

Figure 10.12 illustrates the results of these tests.

Based on the recorded data, the installation of the Profire turbulator lowered the stack temperature by 15.3 deg F (350.7-335.4), which can be translated to 0.38 % thermal efficiency gain.

Similarly, the installation of the Kenilworth turbulator lowered the stack temperature by 22.4 deg F (350.7-328.3), a 0.56 % thermal efficiency gain.

These results led us to a conclusion that the thermal efficiency gains due to the installation of static turbulators inside a fire-tube heater with a natural draft burner are negligible.

In addition, turbulators create pressure drop, which impacts the natural draft and the performance of the burner.

On the other hand, the application of turbulators may be of value with forced draft systems, where significant static pressure is available. In these systems turbulators should be designed to maximize the scrubbing action of the tube internal surfaces in order to lower the boundary layer heat transfer coefficient.

TURBULATOR THERMAL PERFORMANCE TESTS

Date 31-Mar-05
Passes 4
Medium Water
Flow 0.08 m3/min

Time	Fuel Gas SCFH	Inlet 1 deg F	Outlet 2 deg F	Stack deg F	Delta T Out - In	DT Incremental Trend
13:59	516.0	37.6	51.4	397.0	13.8	
14:10	513.9	37.5	53.5	397.0	16.0	2.17
14:15	512.3	38.1	54.1	396.8	15.9	-0.01
14:20	512.5	38.9	54.5	397.4	15.7	-0.29
Profire turbulator installed						
15:10	513.6	42.6	56.5	386.5	13.9	-1.72
15:20	514.7	42.6	59.1	387.8	16.5	2.53
15:25	513.5	43.0	60.0	389.0	17.0	0.49
15:30	513.2	43.6	60.4	387.7	16.9	-0.07
15:35	511.7	44.5	61.2	388.9	16.7	-0.18
15:40	511.7	45.0	61.6	388.7	16.6	-0.10
Kenilworth turbulator installed						
16:05	508.1	48.3	54.4	379.7	6.1	-10.49
16:10	510.3	48.6	58.4	388.5	9.8	3.71
16:15	510.5	48.7	61.0	390.6	12.3	2.48
16:20	513.0	48.8	62.5	392.7	13.7	1.37
16:25	512.2	48.9	63.4	392.8	14.5	0.82
16:30	511.4	49.2	64.0	391.1	14.8	0.34
16:35	512.5	49.5	64.5	390.1	15.1	0.22
16:40	512.3	50.0	65.1	388.6	15.1	0.05
16:45	513.5	50.7	65.7	387.6	15.0	-0.15
16:50	512.8	51.2	66.2	387.0	15.0	0.08

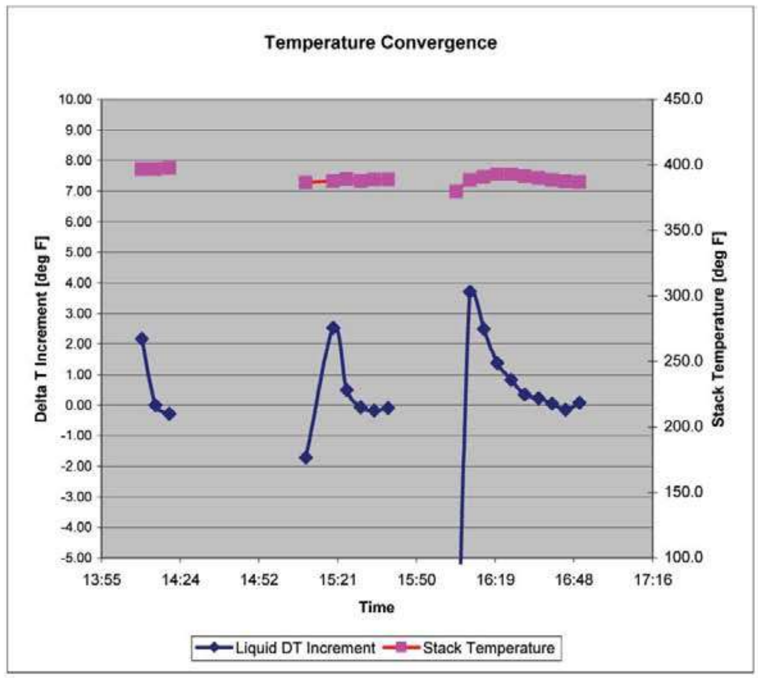


FIGURE 10.9 Turbulator Test Results

11 FIRE-TUBE RATING CHARTS

This chapter contains fire tube rating charts, which were developed based on the test results and calibrated COEN fire-tube rating program. The charts are based on the following operating conditions typical to a line heater operation:

a) Fuel: natural gas as methane at 1000 BTU/cuft HHV

b) Excess stack oxygen: 2.5% - equivalent to 12.8% excess air

c) Stack height: 20 ft minimum for 2 pass tubes, 30 ft minimum for 4 pass tubes.

d) Ambient temperature: 30 deg C

e) Bath Temperature: 80 deg C

f) Elevation: 3000 ft A.S.L (914 meters)

For operating conditions significantly different from the above values, efficiency corrections from charts presented in sections 4.6 through 4.21 could be used, or the design could be customized using the fire-tube rating software.

The intent of these rating charts is to provide an easy to use tool for evaluating thermal designs of various sizes of fire tubes. These tube sizes have been selected to represent a wide crossection of actual fire-tubes found in the industry in the following diameters: 4”; 6”; 8”; 10”; 12”; 14”; 16”; 18”; 20”; 22”; 22”; 24”; 26”; 30”; and, 36”. In addition, the following U-tube lengths were used for comparison (not for all tube diameters if not practical): 5’; 10’; 15’; 20’; 25’; 30’. Note that the expression: “U-tube length” refers to physical “immersed”, “straight-line” length of the assembly and not the total length of the tube within this assembly. Thus a 2-pass x 20’ U-tube has approximately 40’ of pipe length in it, where a 4-pass x 15’ U-tube has approximately 60’ of pipe length in it.

Intermediate tube diameters or lengths can be interpolated between the above “nominal” sizes, however, designs using changing tube diameter should be evaluated using fire-tube rating software program. If software program is used apply under Calibration constants: Convective Coefficient Modifier = 1.3 and Radiation Coefficient Modifier = 2.0.

All of the charts presented in this chapter were created with the consideration of the available draft. For 2-pass natural draft fire-tubes this draft was based on a minimum stack height of 20 ft, and for 4-pass natural draft fire-tubes on a minimum stack height of 30 ft. Hence, the maximum firing rate for each curve represents a point, where the friction loss through the fire-tube and stack will exceed the available draft.

Beyond the above firing rate limit, dictated by the available natural draft, is the area of forced draft systems, in which the products of combustion have to be pushed through the fire-tube by mechanical means such as a combustion air blower.

The computation methods used in our research and in the software program provide a “seamless” approach to both the natural draft, and the forced draft fire-tube designs. The heat transfer calculation is still valid when the friction loss exceeds the natural draft, except, a blower must supply the “missing” draft. This calculation can continue up to the point when the theoretical flame diameter becomes equal or larger than the fire-tube diameter. The 4-pass forced draft fire-tube rating charts presented in this chapter were created based on this method.

In order to simplify tube description in the charts we used the following fire tube configuration coding system:

8-2-10 fire-tube means: **8” diameter – 2 pass – 10’ immersed U-tube length**

The rating charts are organized in the following three basic sets:

a) Charts for 2-pass fire tubes; 4” to 36” diameter, using a **natural draft** burner;

b) Charts for 4-pass fire tubes; 4” to 36” diameter, using a **natural draft** burner; and,

c) Charts for 4-pass fire tubes; 4” to 18” diameter, using a **forced draft** burner.

Within each one of these three groups there are the following three sub-sets of charts:

a) Process Duty Fire Tube Rating – illustrating the gross thermal efficiency of the heater equipped with a given configuration of a fire-tube, based on the **net heat transfer** to the liquid bath; This rating is equivalent to a current industry practice of rating heaters by their process heat transfer duty. Thus a heater rated at 1 MM BTU/hr will actually transfer 1 MM BTU/hr from the gas side of the fire-tube to the bath liquid. To calculate the burner input simply divide the rated value by the gross efficiency from the chart. Thus a 1.0 MM BTU/hr heater with 75%HHV efficiency will use: 1.0 / 0.75= 1.33 MM BTU/hr (HHV) of natural gas. Lower efficiency target of 72% is shown on each chart as a red horizontal line. High efficiency target of 82% is shown as a green horizontal line.

b) Burner Input Fire Tube Rating – illustrating the gross thermal efficiency of the heater equipped with a given configuration of a fire-tube, based on the **gross heat input** from the burner; This rating is currently used for the design of burners and fuel trains and their regulatory requirements, where the purpose and thermal efficiency of the heater is secondary to how much fuel is being burned. Thus a heater rated at 1 MM BTU/hr burner input will transfer less than 1 MM BTU/hr from the gas side of the fire-tube to the bath liquid because of its efficiency. To calculate the heat transfer, simply multiply the burner input by the gross efficiency from the chart. Thus a 1.0 MM BTU/hr burner input with 75%HHV efficiency will produce: 1.0 * 0.75= 0.75 MM BTU/hr heat transfer to the bath liquid. Lower efficiency target of 72% is shown on each chart as a red horizontal line. High efficiency target of 82% is shown as a green horizontal line.

c) Surface Heat Flux Charts – illustrate the gross thermal efficiency of each fire-tube as a function of the surface heat flux rate. For example using Figure 11.15, an 18-2-20 fire-tube configuration fired with 10,000 BTU/hr/ft2 average heat flux rate will operate at 70.5 (%HHV) gross thermal efficiency. The chart includes two horizontal lines: a green high 82% target efficiency line, and a red low 72% target efficiency line. There are also a number of vertical reference lines. An orange line marks the standard industry design heat flux value of 10,000 BTU/hr/ft2. The blue lines are located to point to the areas where all the curves either drop below the 72% efficiency, exceed the 72% efficiency, or exceed the 82% efficiency. In Figure 11.15, those values would be respectively: 11,800; 6,100; and, 2,200 BTU/hr/ft2

In order to find an appropriate chart the following procedure could be used:

a) Decide if 2 pass natural draft, 4 pass natural draft, or 4 pass forced draft should be used.

b) Chose chart type: process duty, burner input, or surface heat flux rate.

c) Find desired range of tube diameters (for example: 14” to 18”). Note that for convenience the largest tube diameter from smaller range chart is always shown as the smallest diameter on the next chart, hence an 18” tube curve can be found on either 14” to 18” chart or 18” to 22” chart.

d) Find curve representing desired fire-tube configuration, for example: 18-2-20.

e) Compare to other fire-tube configurations with equivalent thermal performance.

f) Apply efficiency corrections as per sections 4.6 through 4.21 or confirm thermal performance using fire-tube rating software program. If software program is used apply under Calibration constants: Convective Coefficient Modifier = 1.3 and Radiation Coefficient Modifier = 2.0.

11.1 Process Duty Charts for 2 Pass Fire Tube with Natural Draft

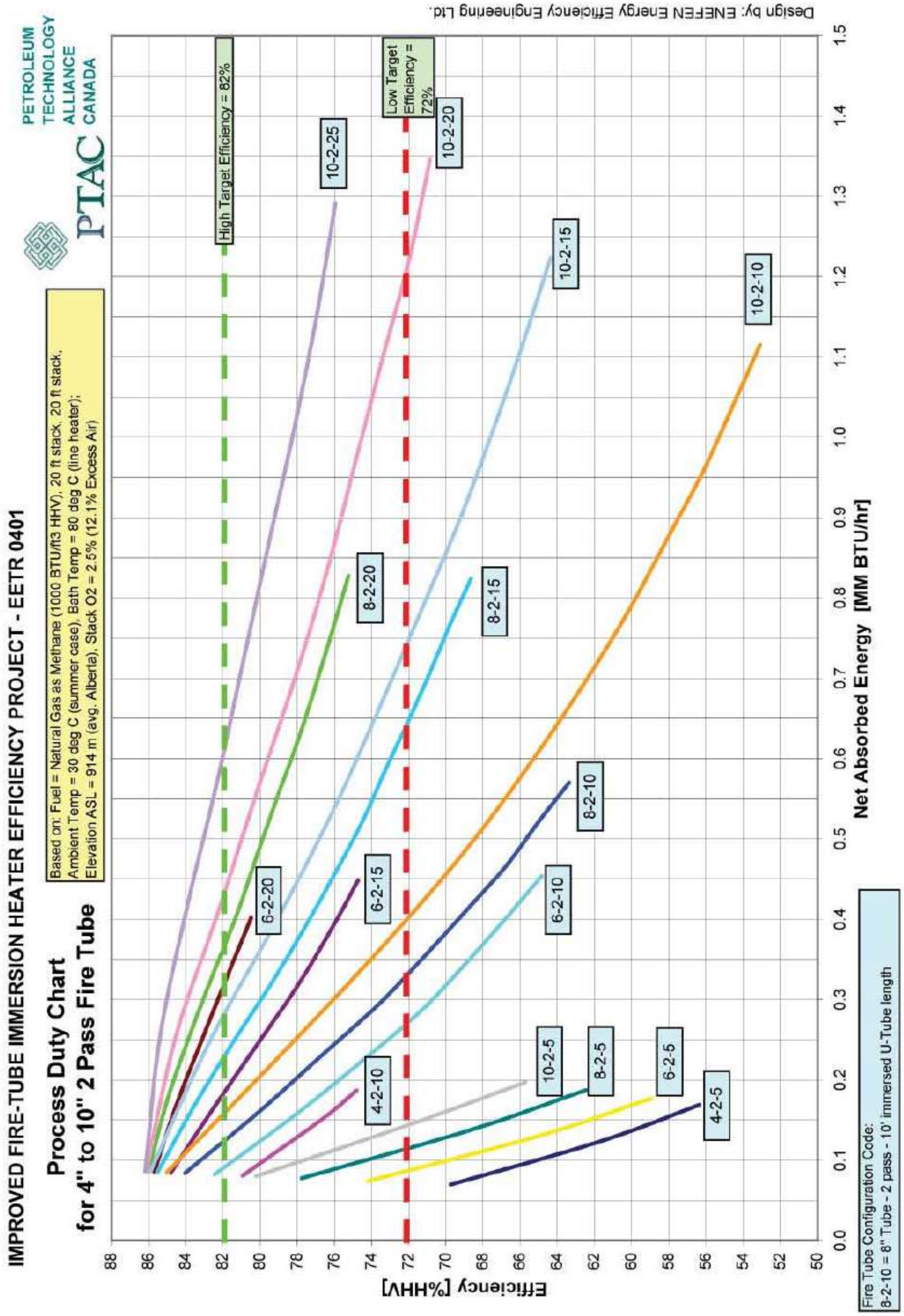


FIGURE 11.1 Process Duty Chart for 2 Pass 4" to 10" Fire Tube with Natural Draft

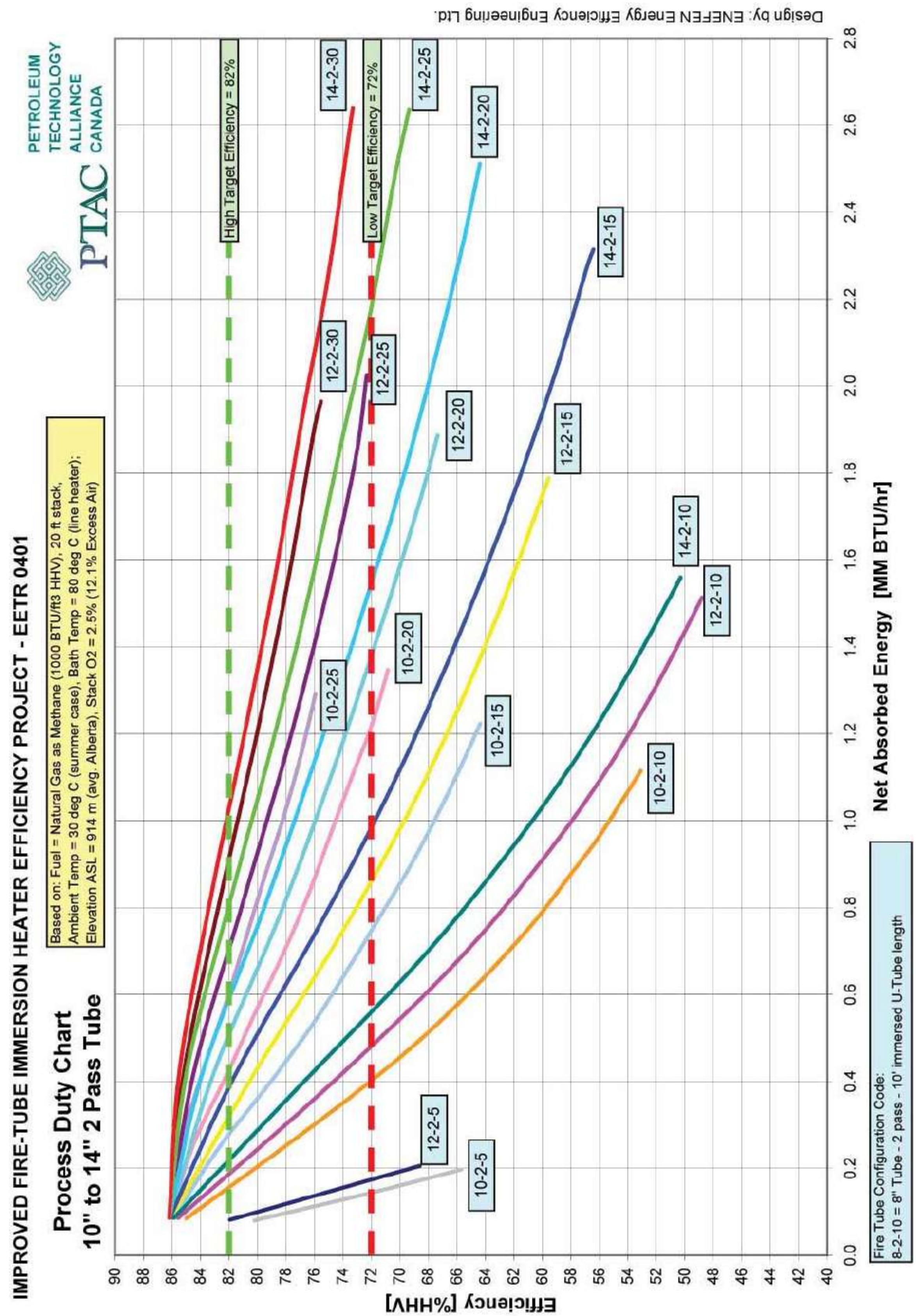


FIGURE 11.2 Process Duty Chart for 2 Pass 10" to 14" Fire Tube with Natural Draft

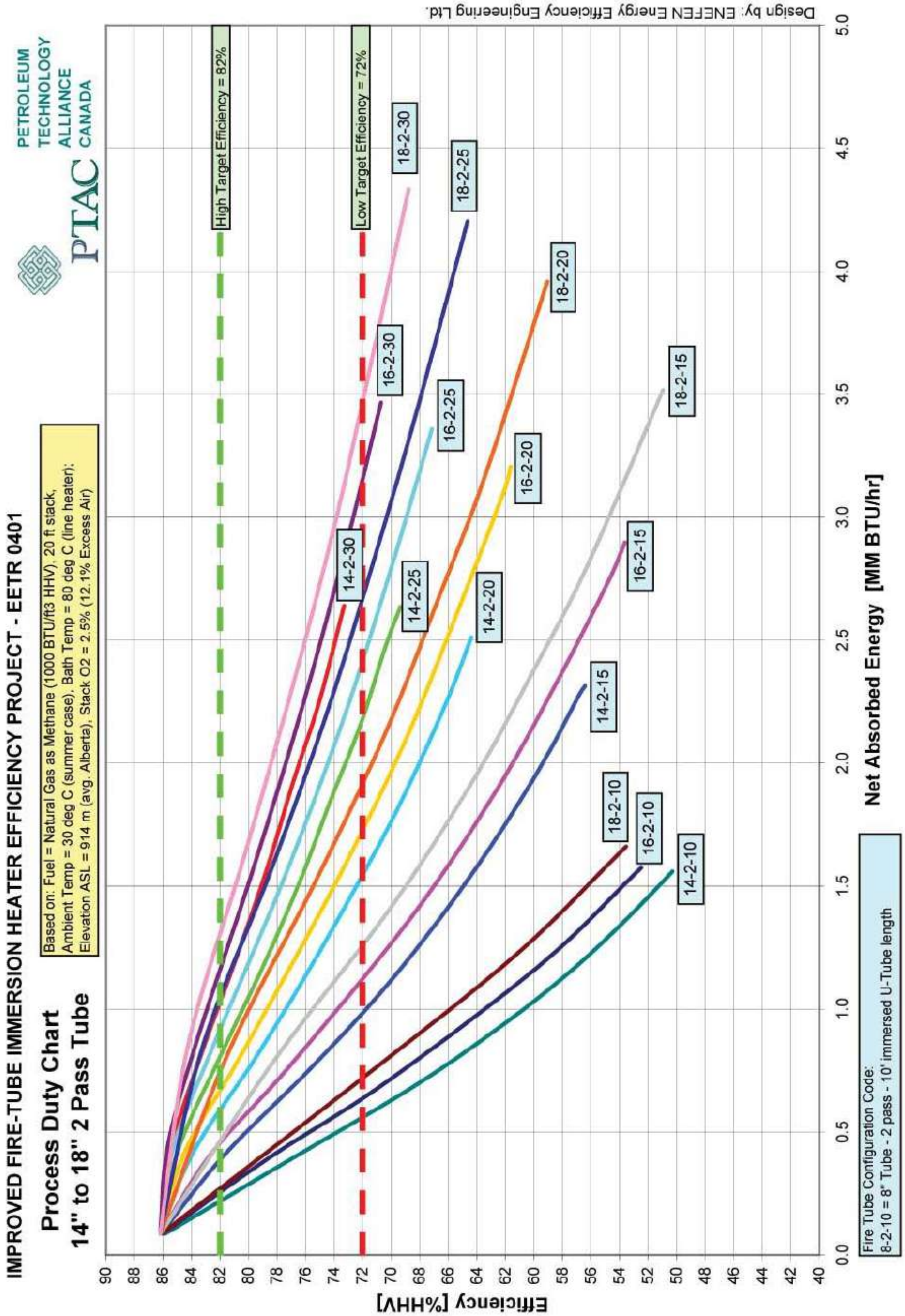


FIGURE 11.3 Process Duty Chart for 2 Pass 14" to 18" Fire Tube with Natural Draft

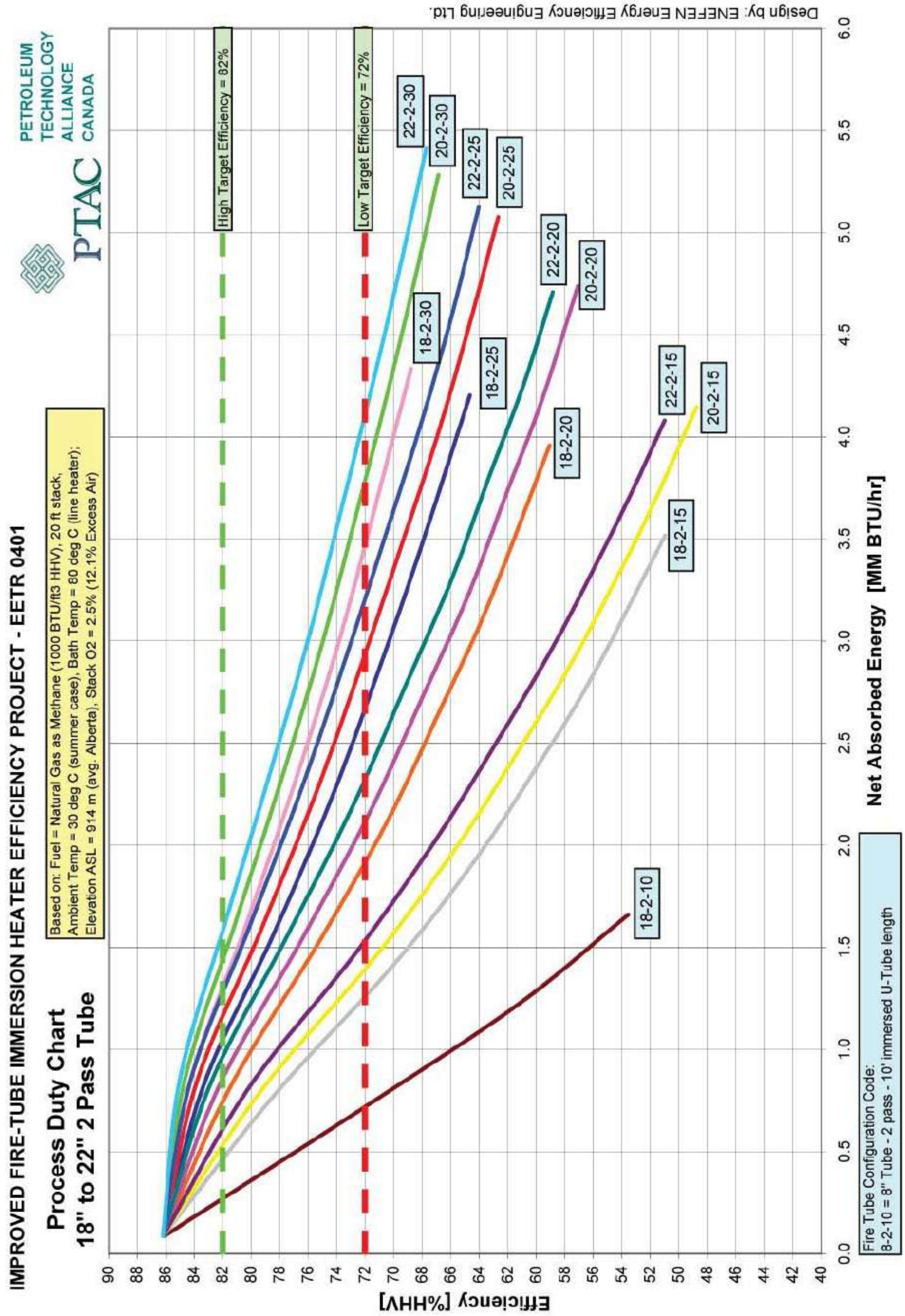


FIGURE 11.4 Process Duty Chart for 2 Pass 18" to 22" Fire Tube with Natural Draft

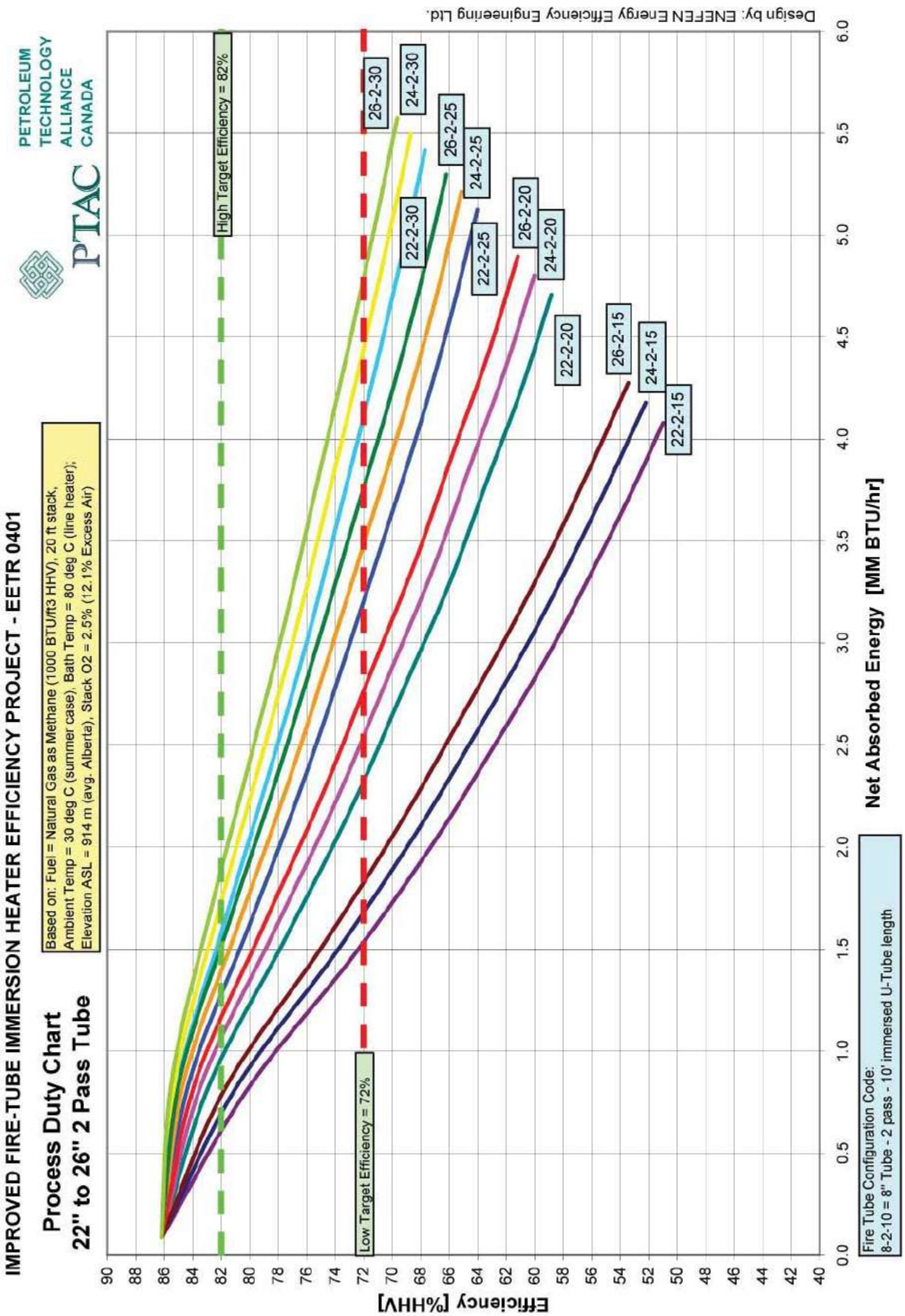


FIGURE 11.5 Process Duty Chart for 2 Pass 22" to 26" Fire Tube with Natural Draft

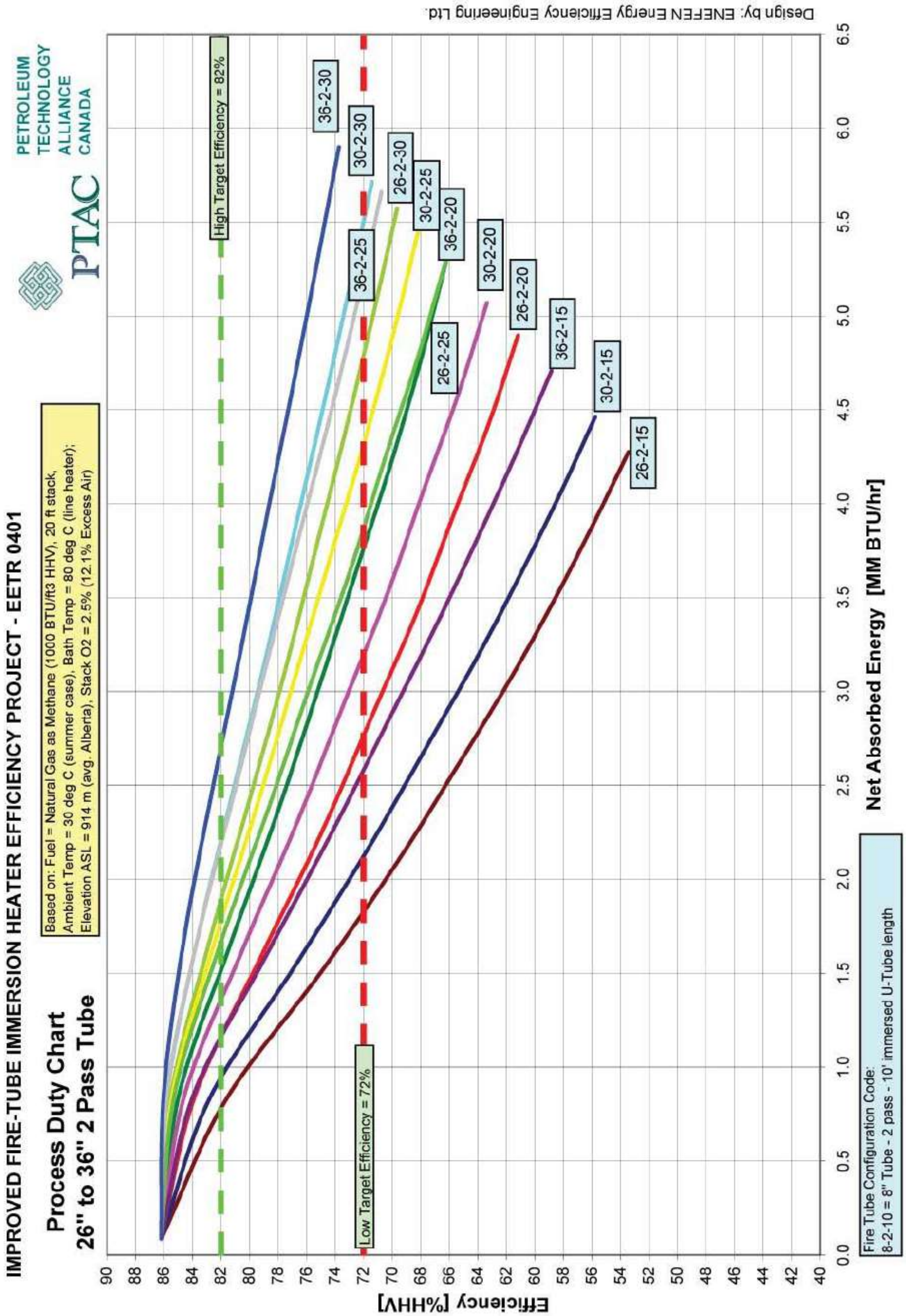


FIGURE 11.6 Process Duty Chart for 2 Pass 26" to 36" Fire Tube with Natural Draft

11.2 Burner Input Charts for 2 Pass Fire Tube with Natural Draft

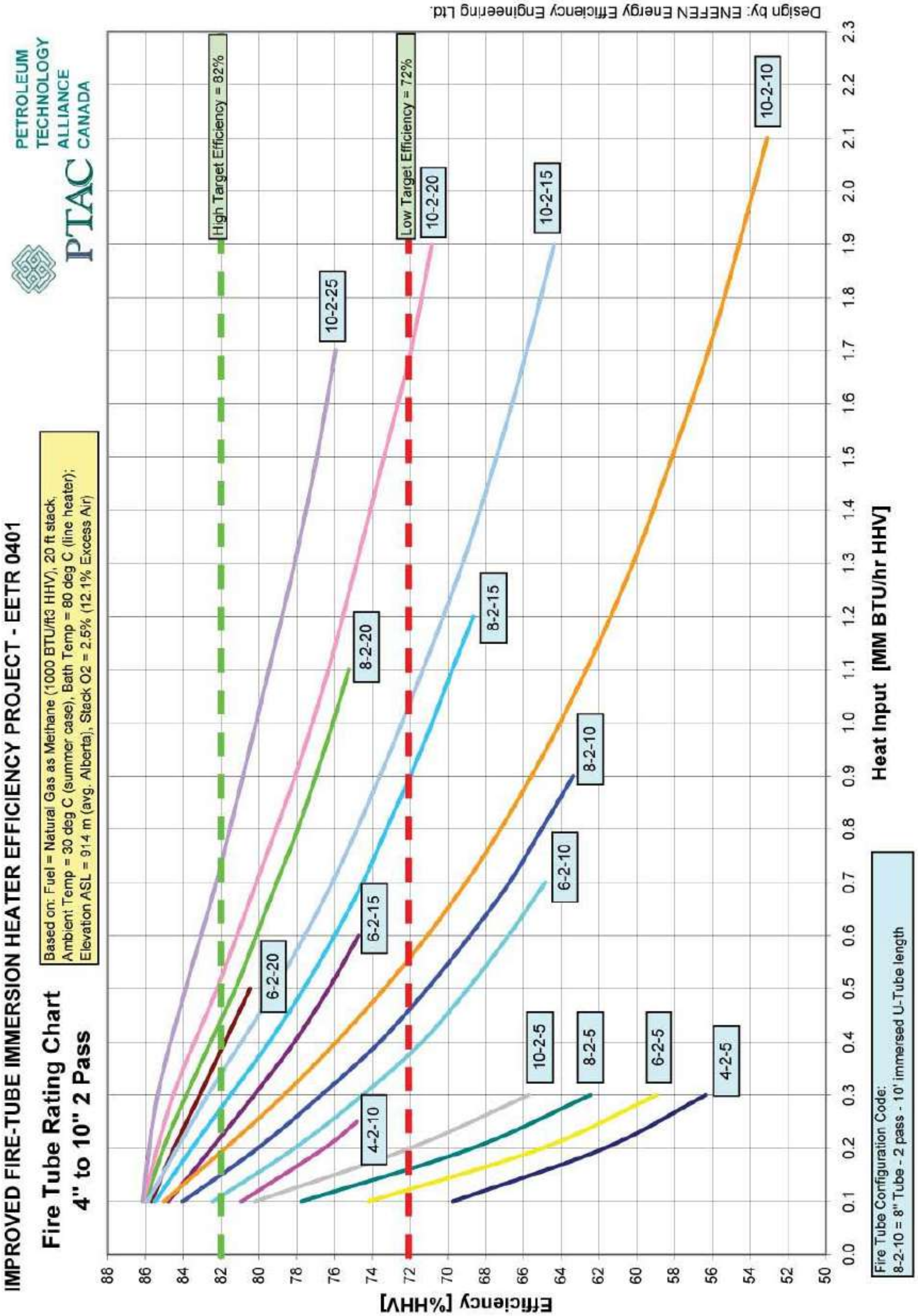


FIGURE 11.7 Burner Input Chart for 2 Pass 4" to 10" Fire Tube with Natural Draft

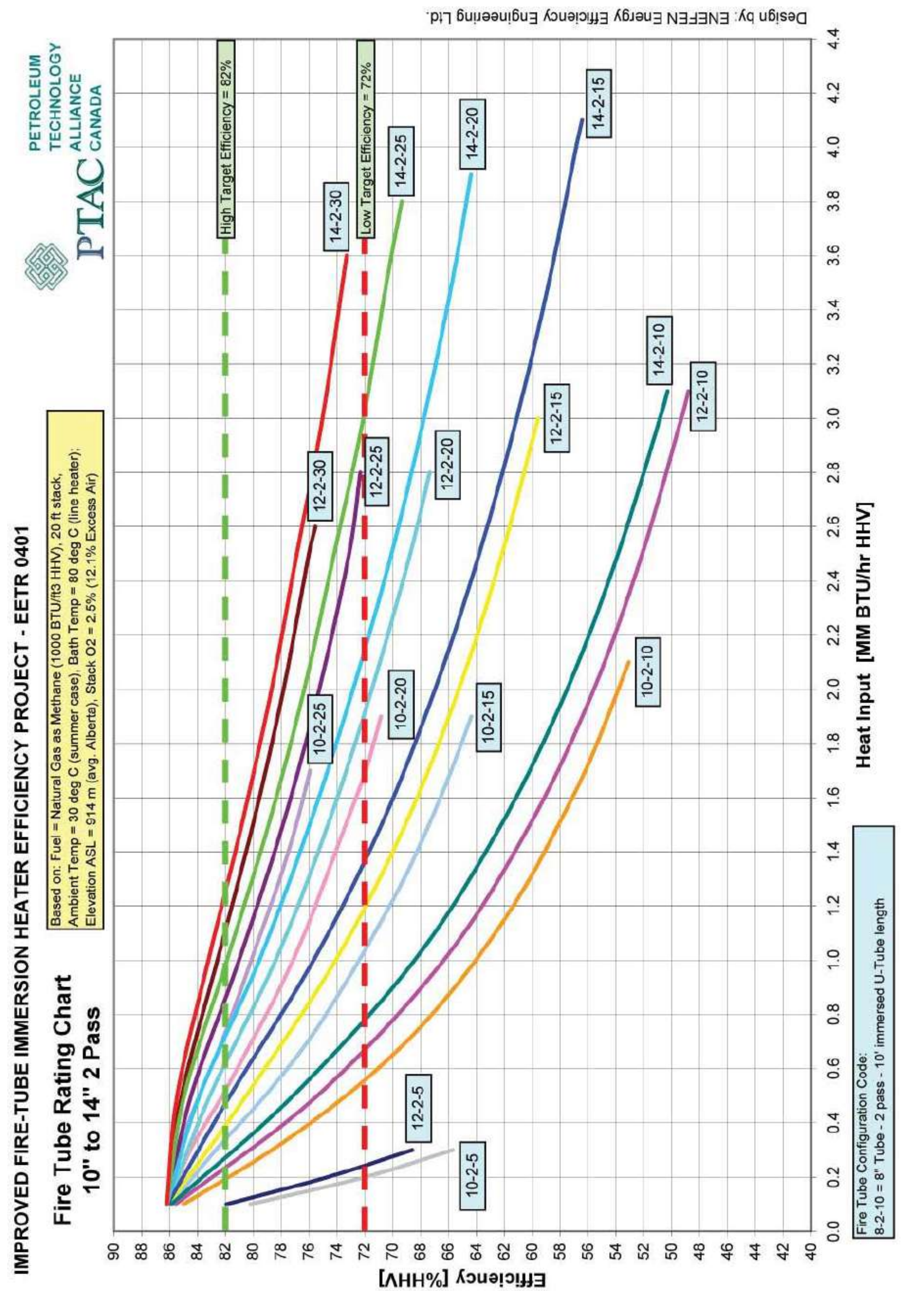


FIGURE 11.8 Burner Input Chart for 2 Pass 10” to 14” Fire Tube with Natural Draft

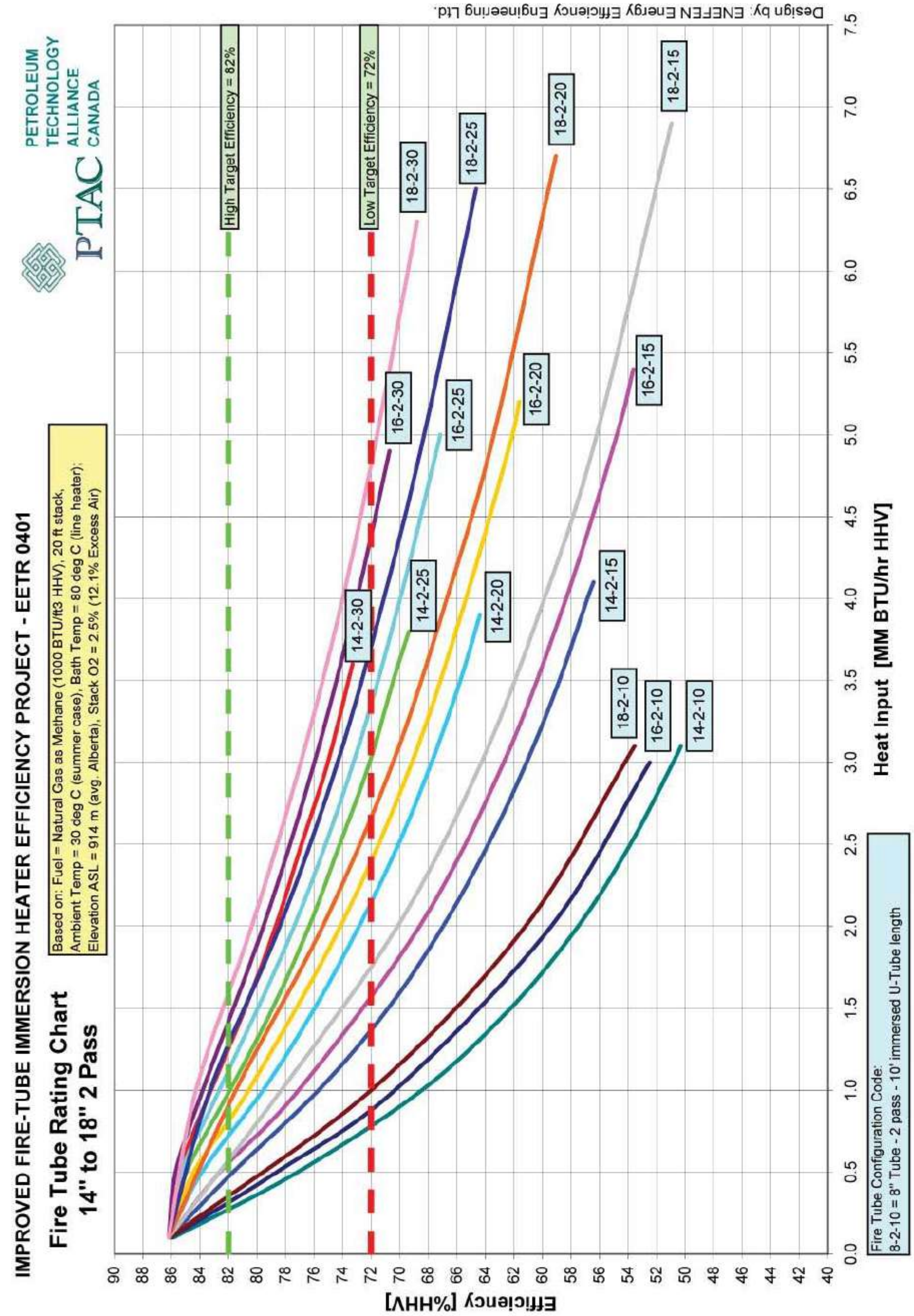


FIGURE 11.9 Burner Input Chart for 2 Pass 14" to 18" Fire Tube with Natural Draft

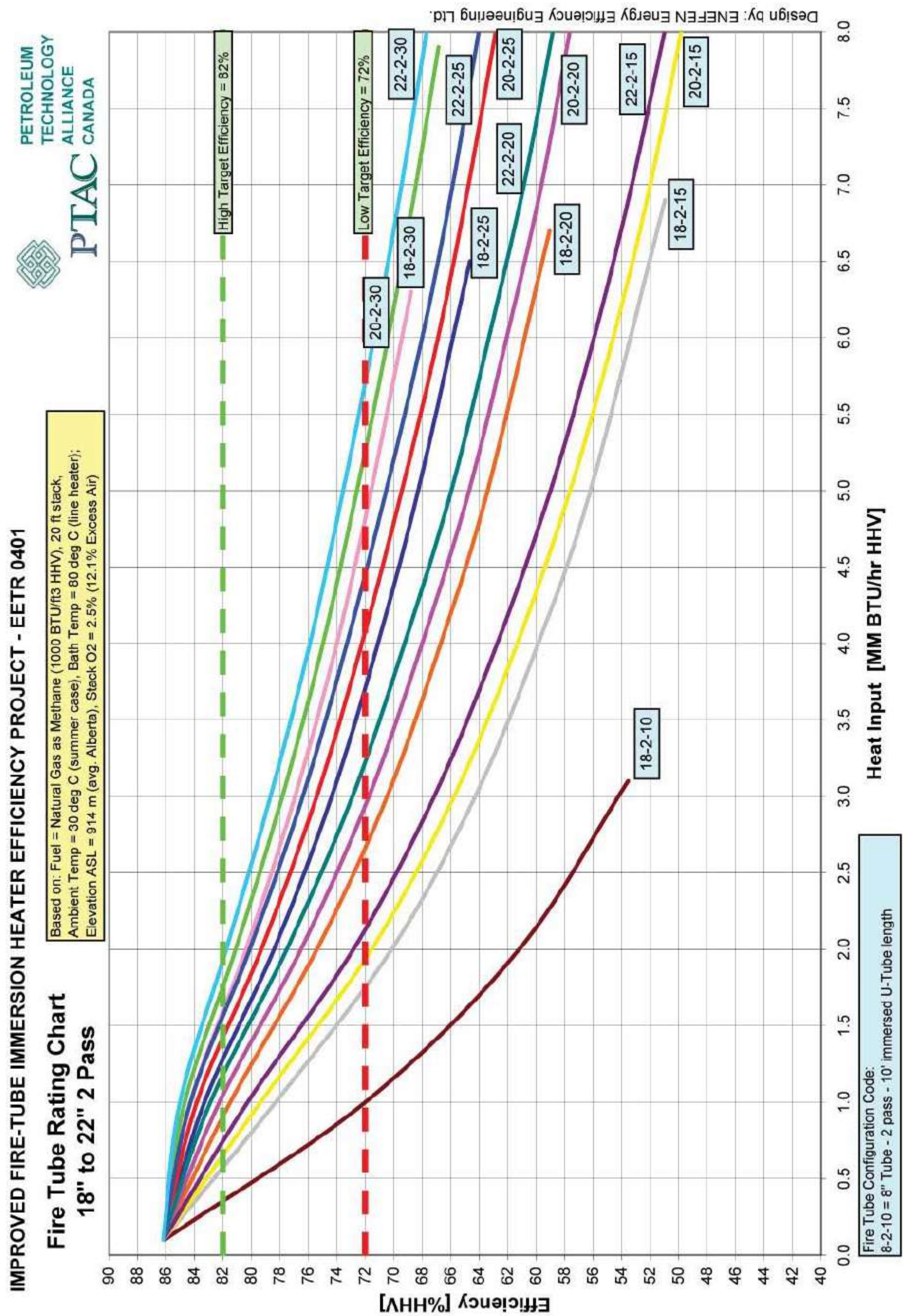


FIGURE 11.10 Burner Input Chart for 2 Pass 18” to 22” Fire Tube with Natural Draft

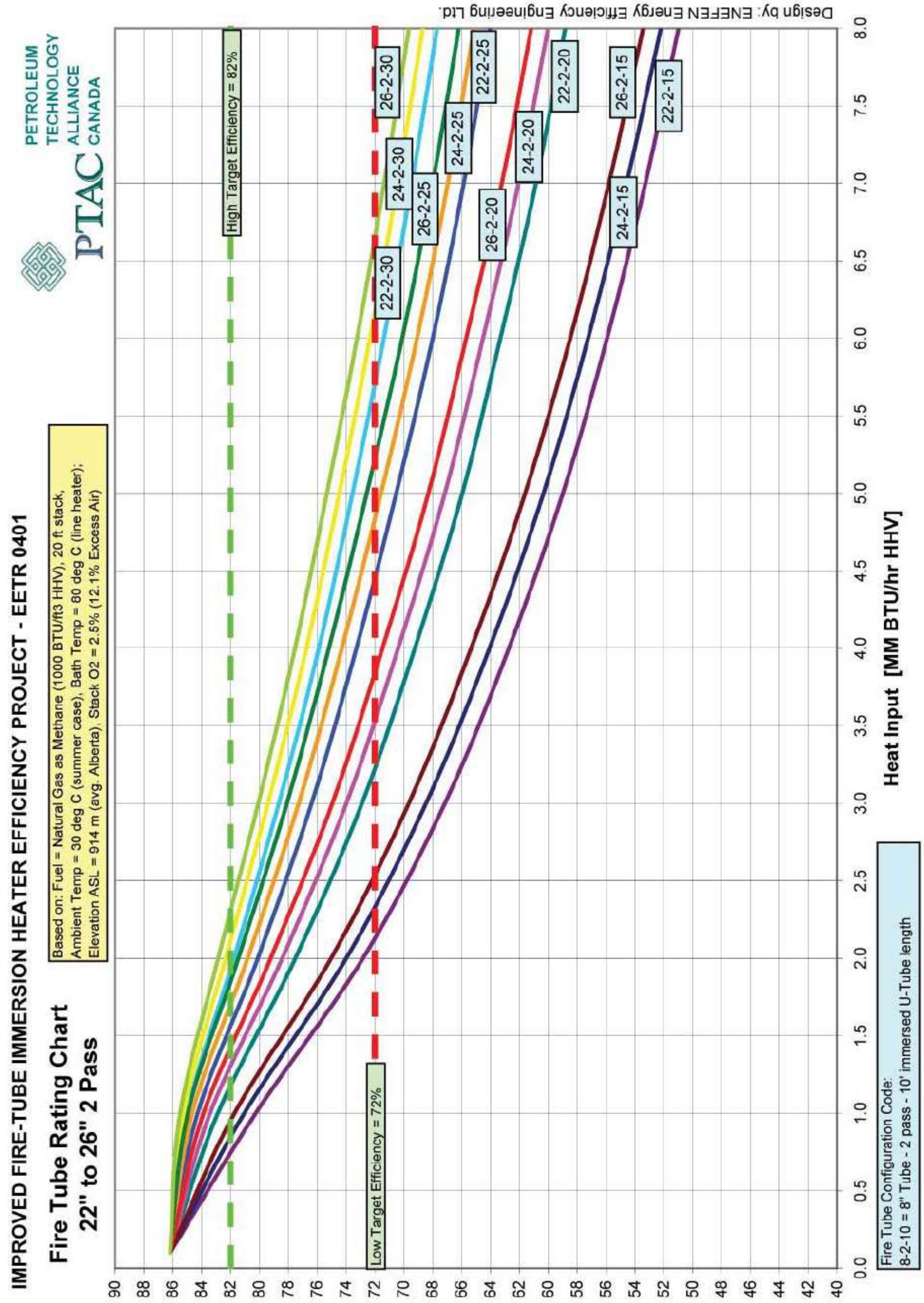


FIGURE 11.11 Burner Input Chart for 2 Pass 22” to 26” Fire Tube with Natural Draft

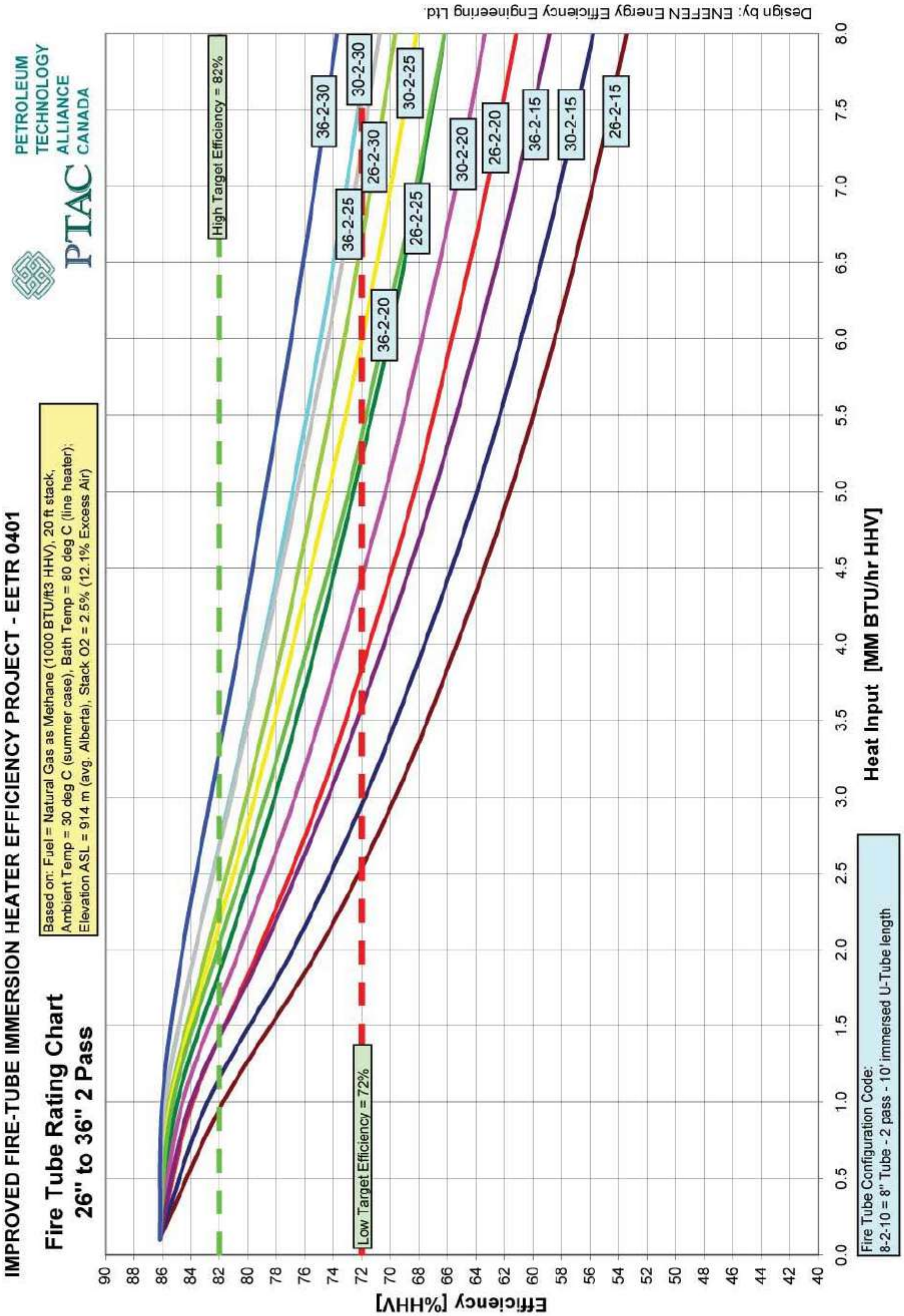


FIGURE 11.12 Burner Input Chart for 2 Pass 26” to 36” Fire Tube with Natural Draft

11.3 Surface Heat Flux Charts for 2 Pass Fire Tube with Natural Draft

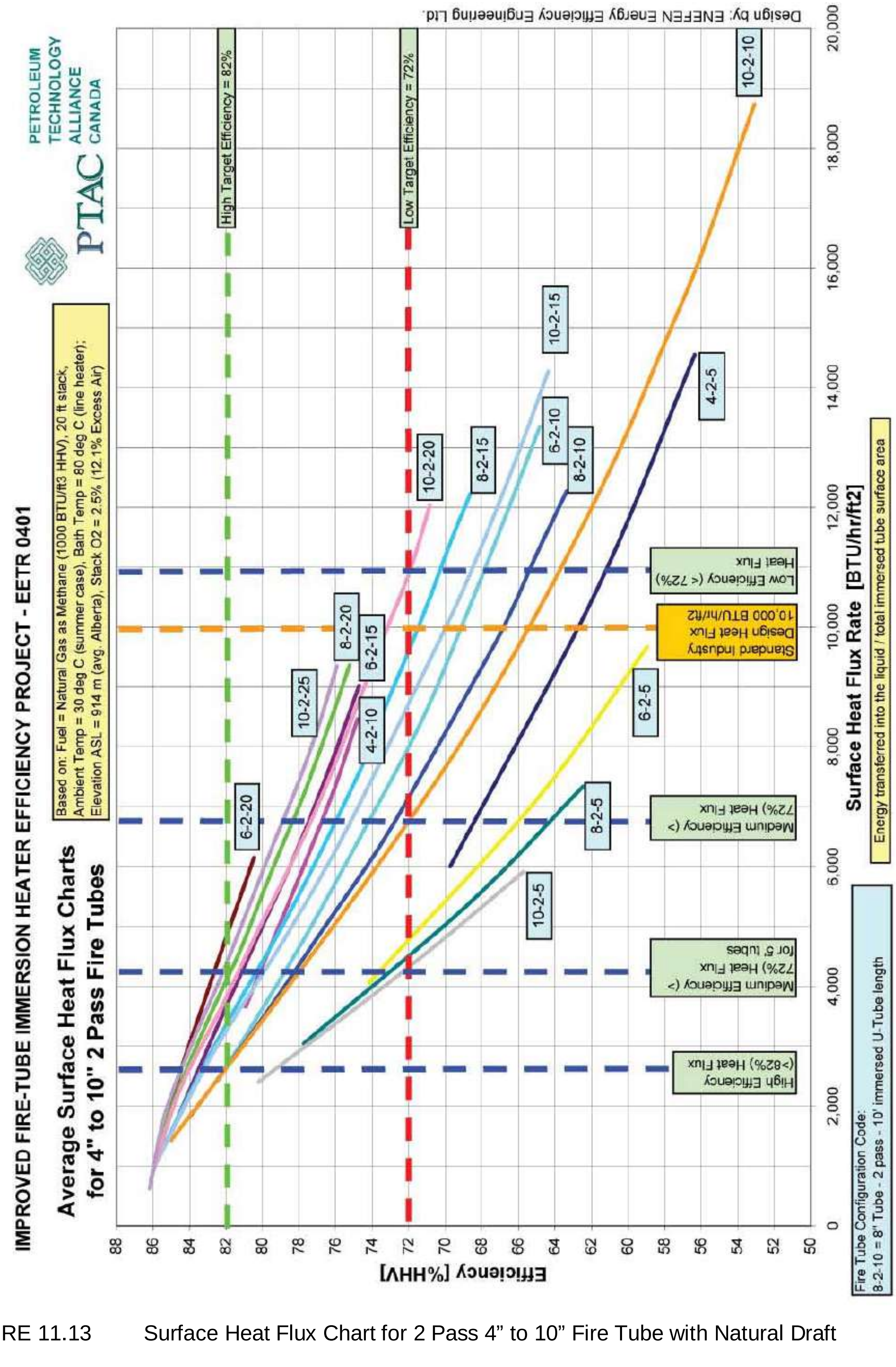


FIGURE 11.13 Surface Heat Flux Chart for 2 Pass 4” to 10” Fire Tube with Natural Draft

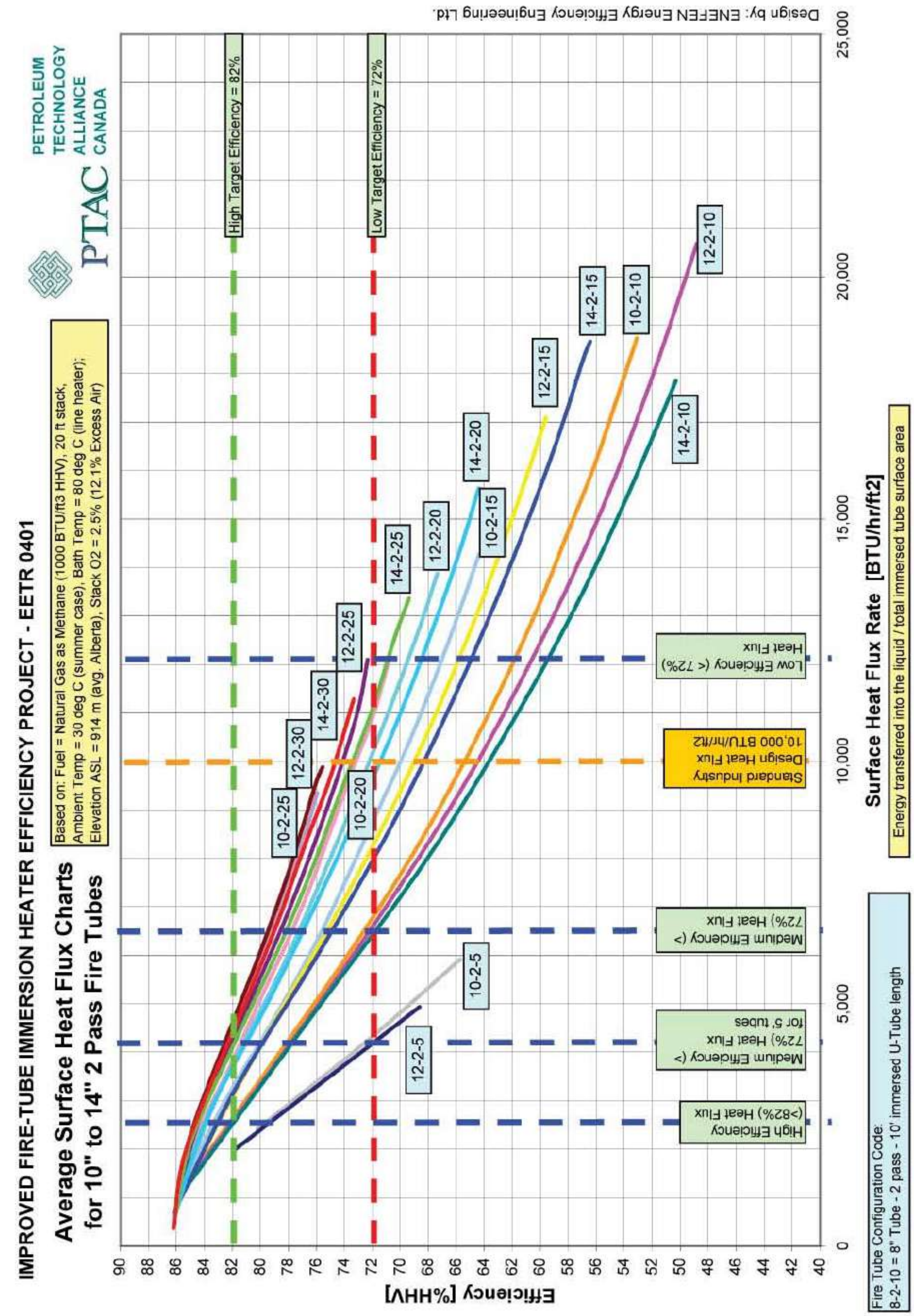


FIGURE 11.14 Surface Heat Flux Chart for 2 Pass 10" to 14" Fire Tube with Natural Draft

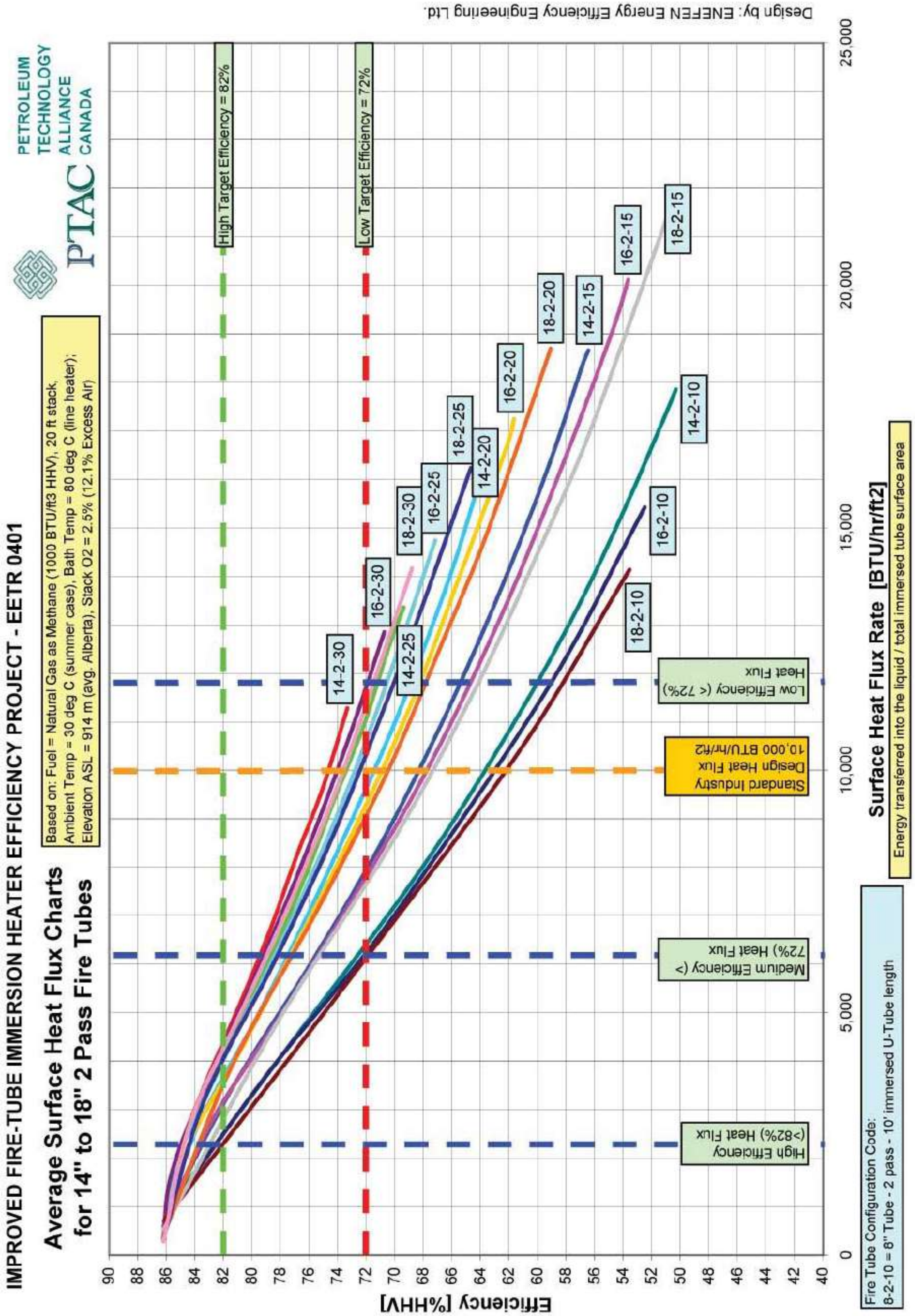


FIGURE 11.15 Surface Heat Flux Chart for 2 Pass 14” to 18” Fire Tube with Natural Draft

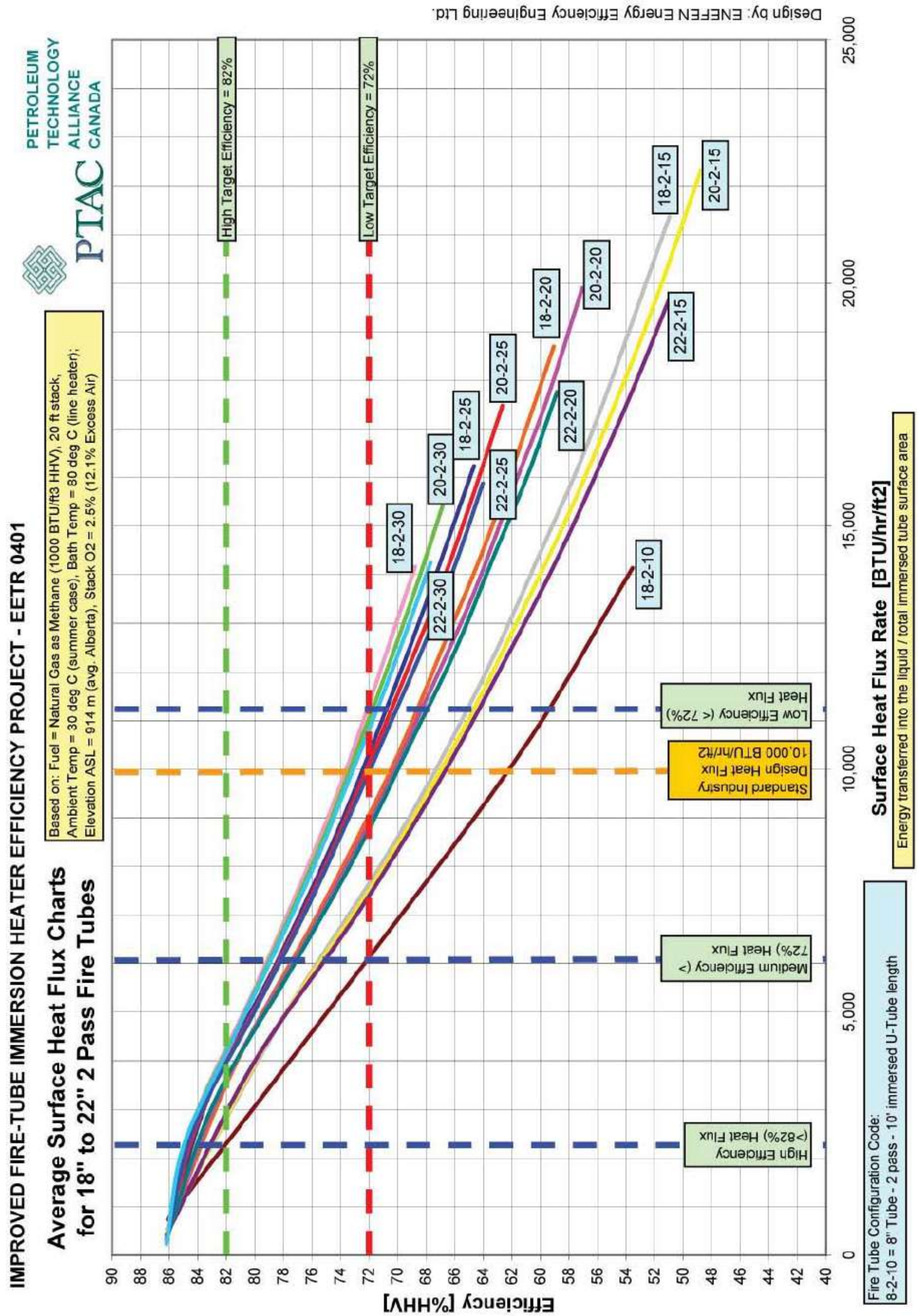


FIGURE 11.16 Surface Heat Flux Chart for 2 Pass 18" to 22" Fire Tube with Natural Draft

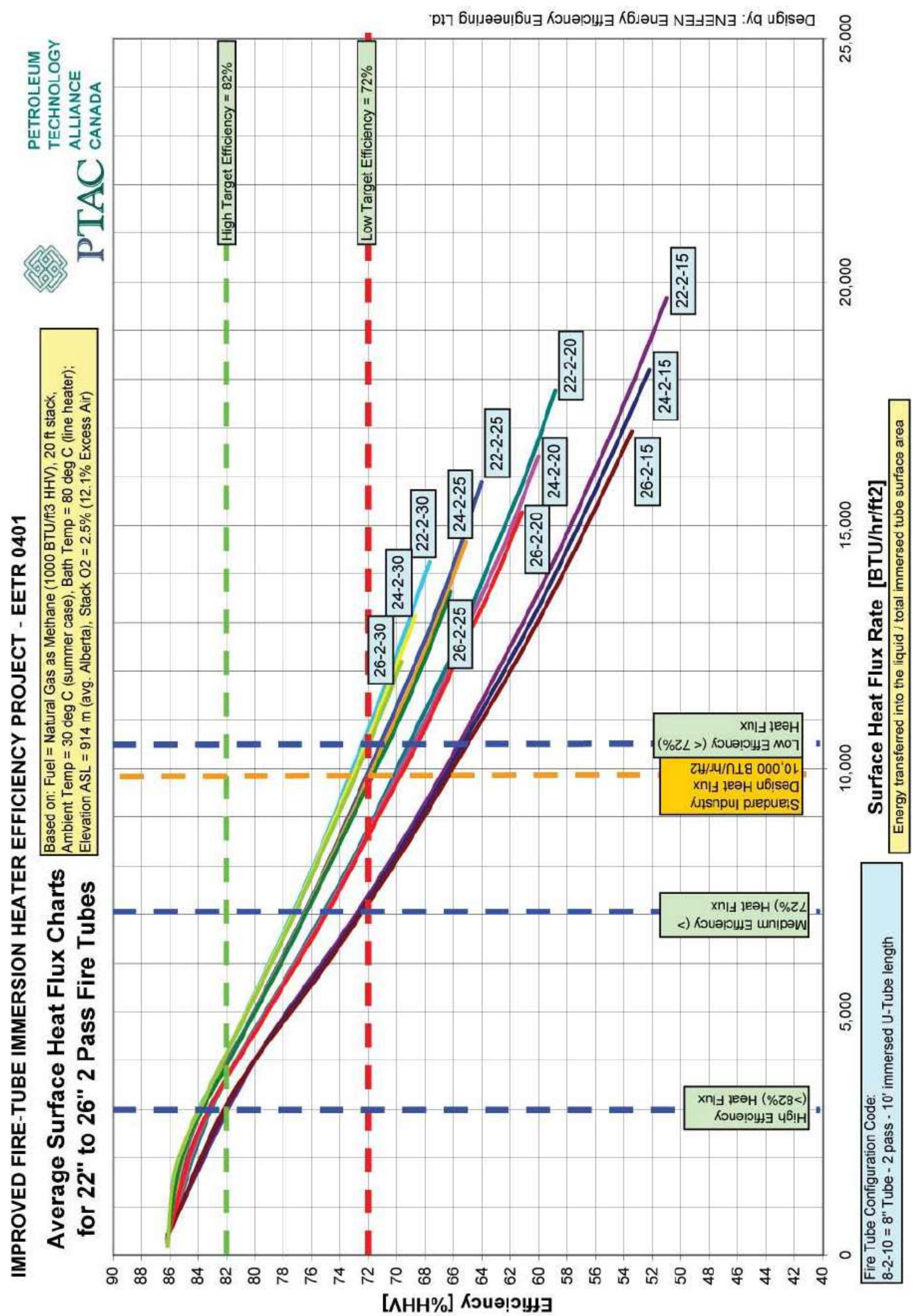


FIGURE 11.17 Surface Heat Flux Chart for 2 Pass 22" to 26" Fire Tube with Natural Draft

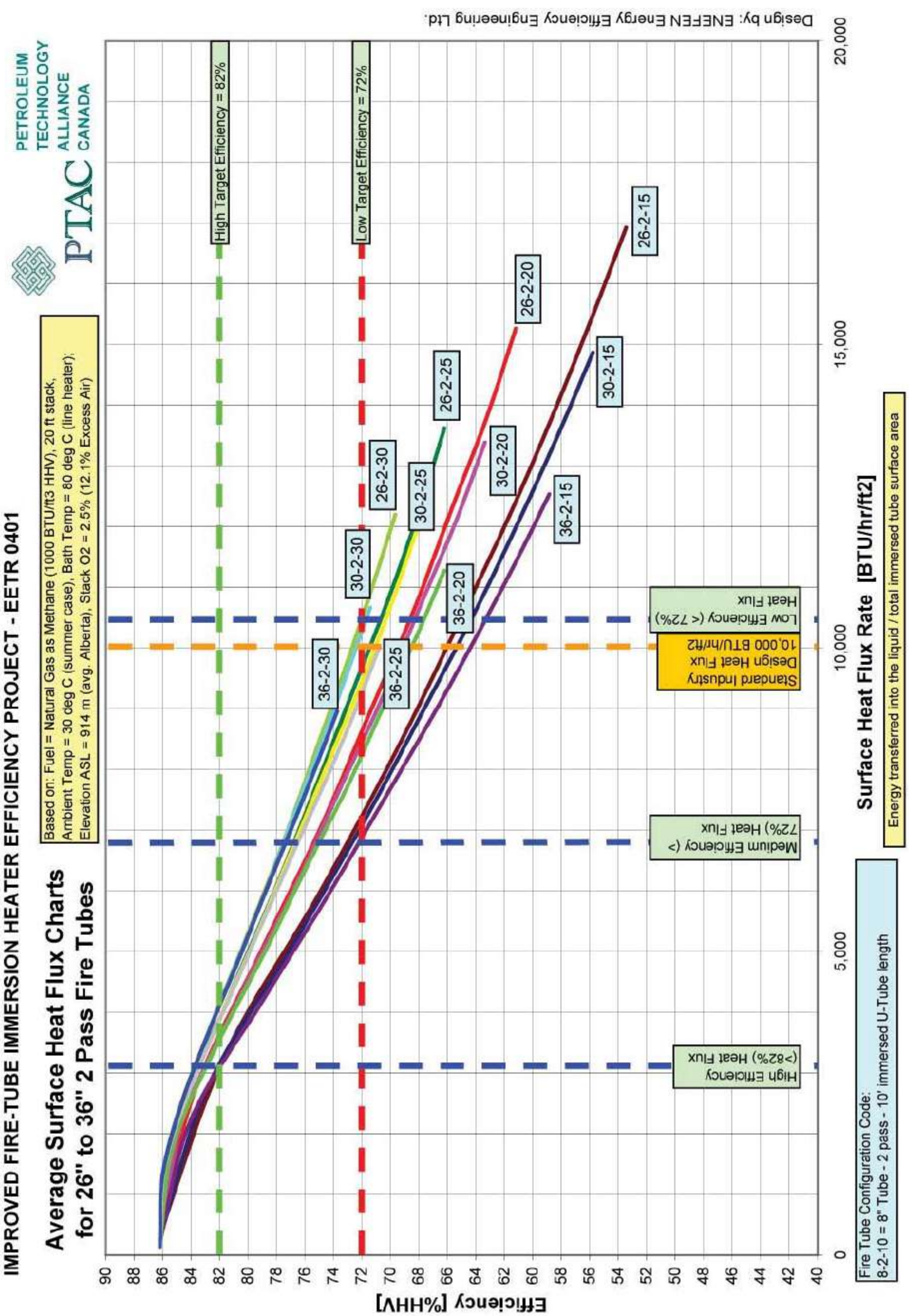


FIGURE 11.18 Surface Heat Flux Chart for 2 Pass 26” to 36” Fire Tube with Natural Draft

11.4 Process Duty Charts for 4 Pass Fire Tube with Natural Draft

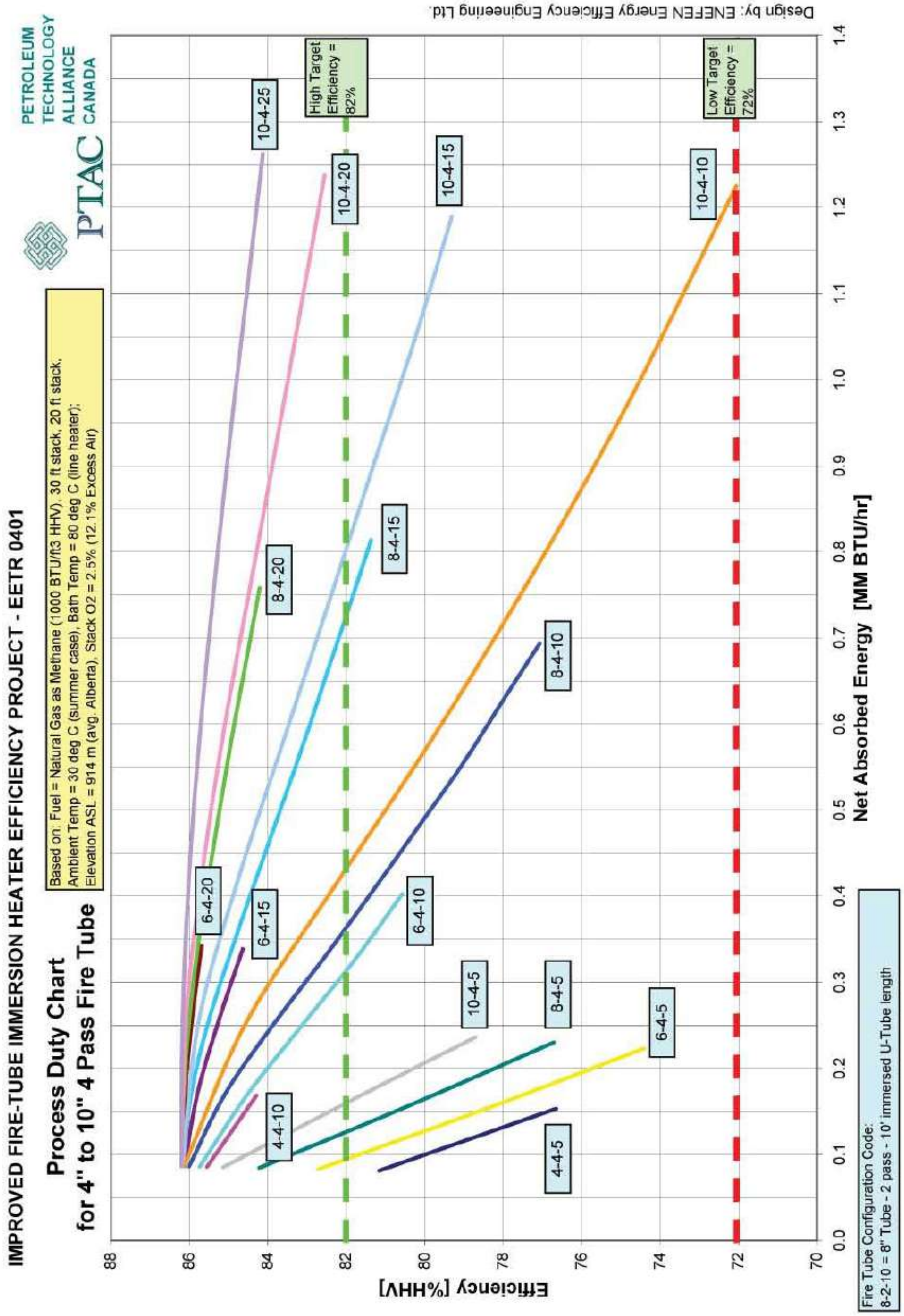


FIGURE 11.19 Process Duty Chart for 4 Pass 4” to 10” Fire Tube with Natural Draft

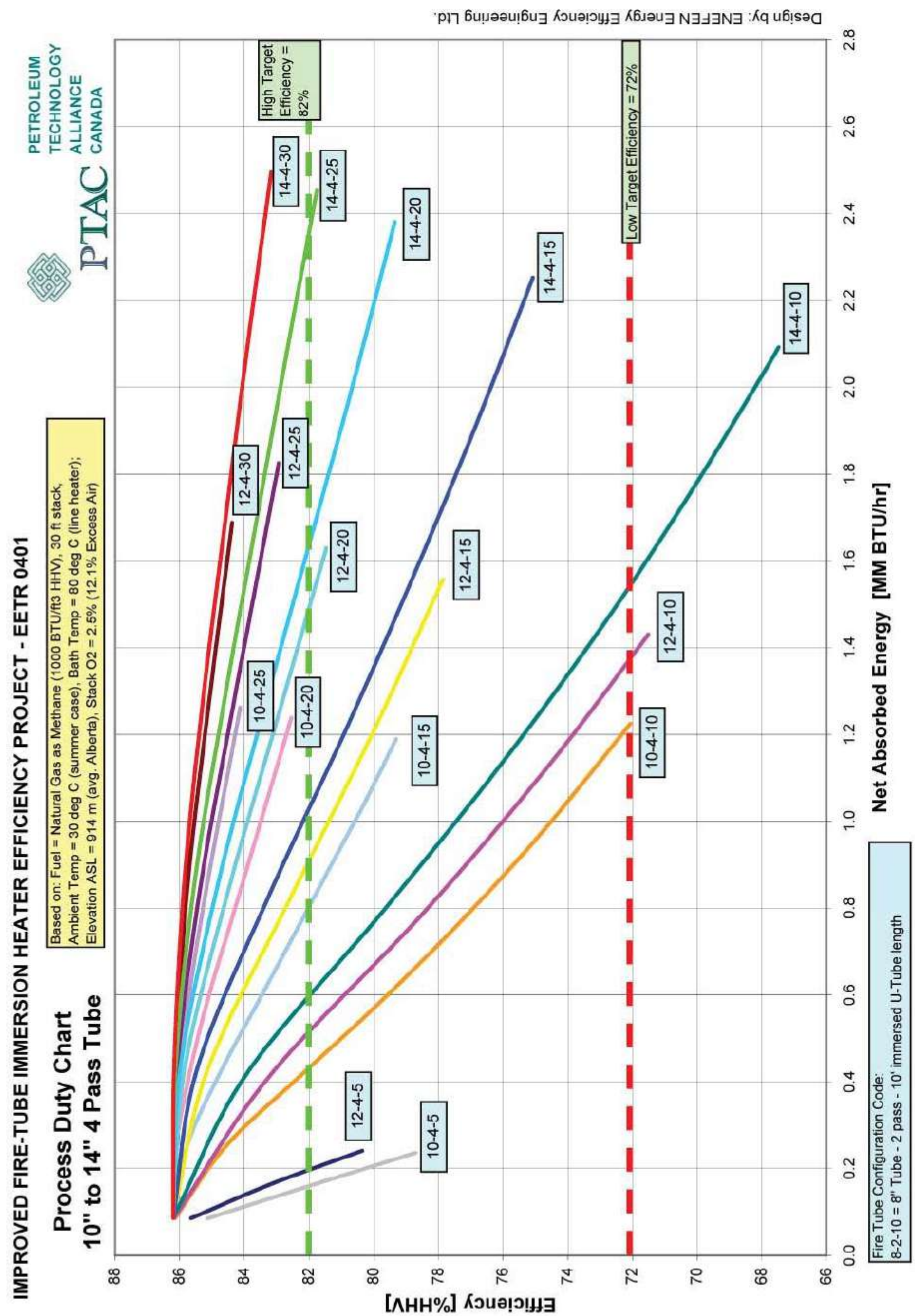


FIGURE 11.20 Process Duty Chart for 4 Pass 10" to 14" Fire Tube with Natural Draft

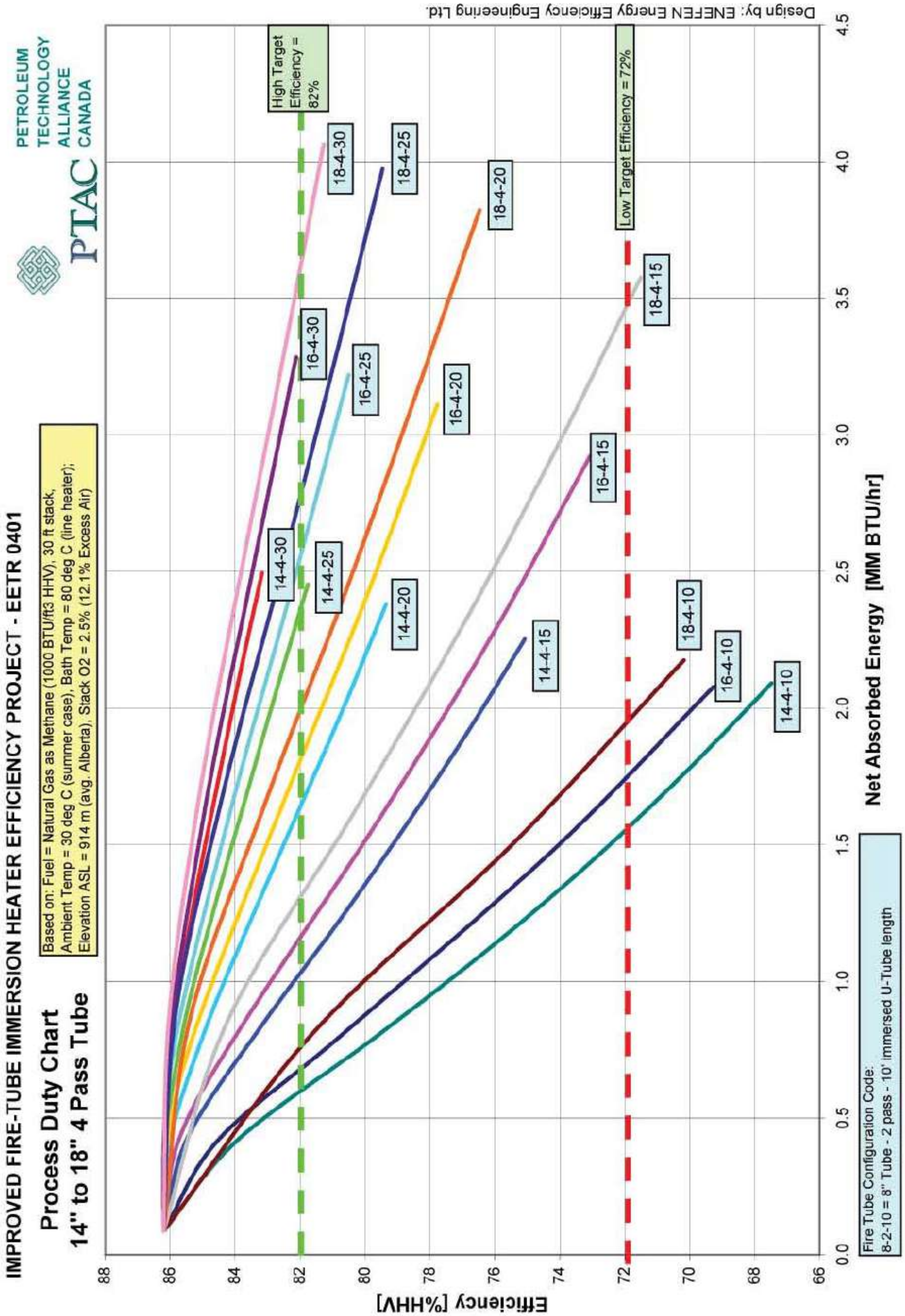


FIGURE 11.21 Process Duty Chart for 4 Pass 14” to 18” Fire Tube with Natural Draft

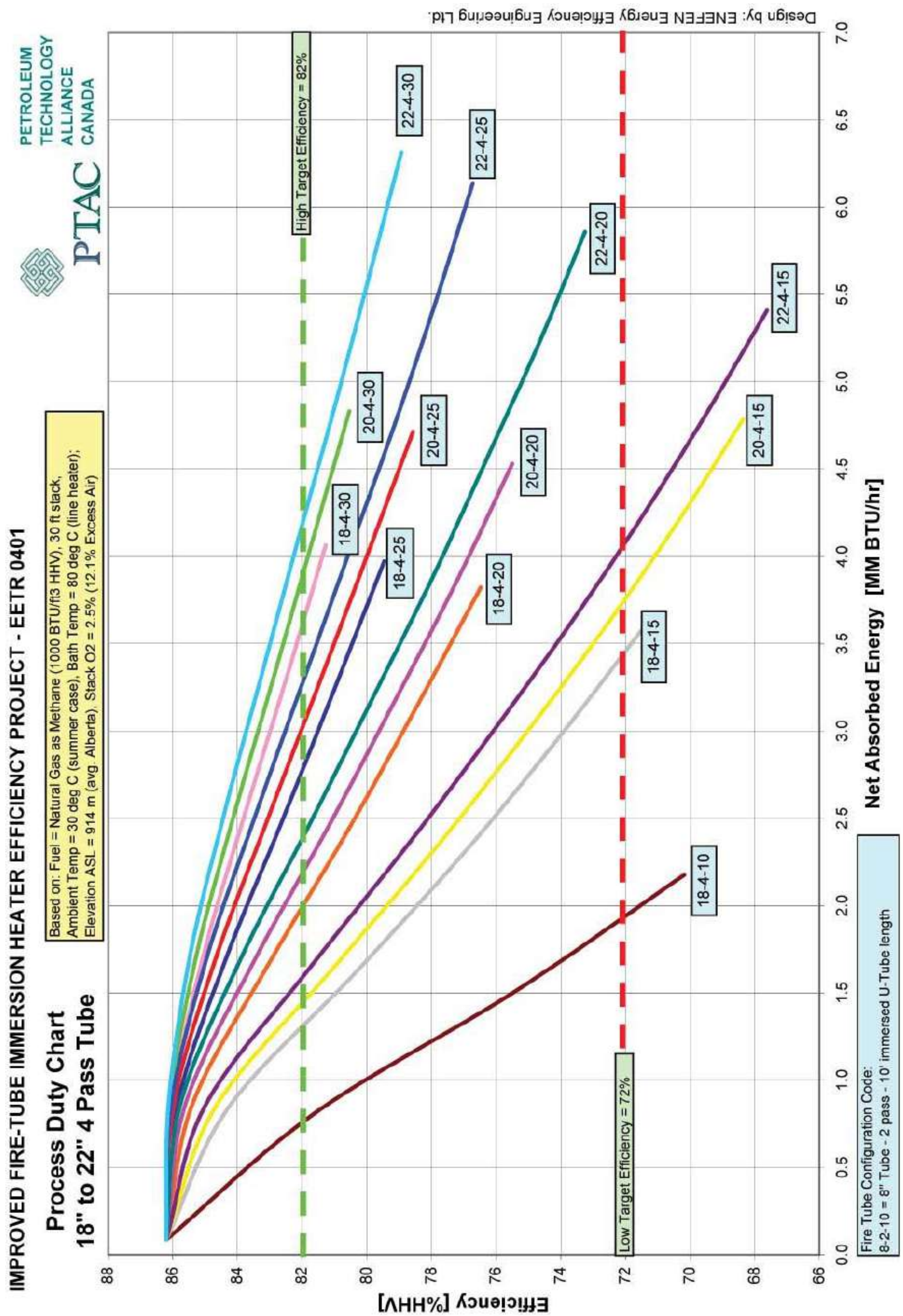


FIGURE 11.22 Process Duty Chart for 4 Pass 18" to 22" Fire Tube with Natural Draft

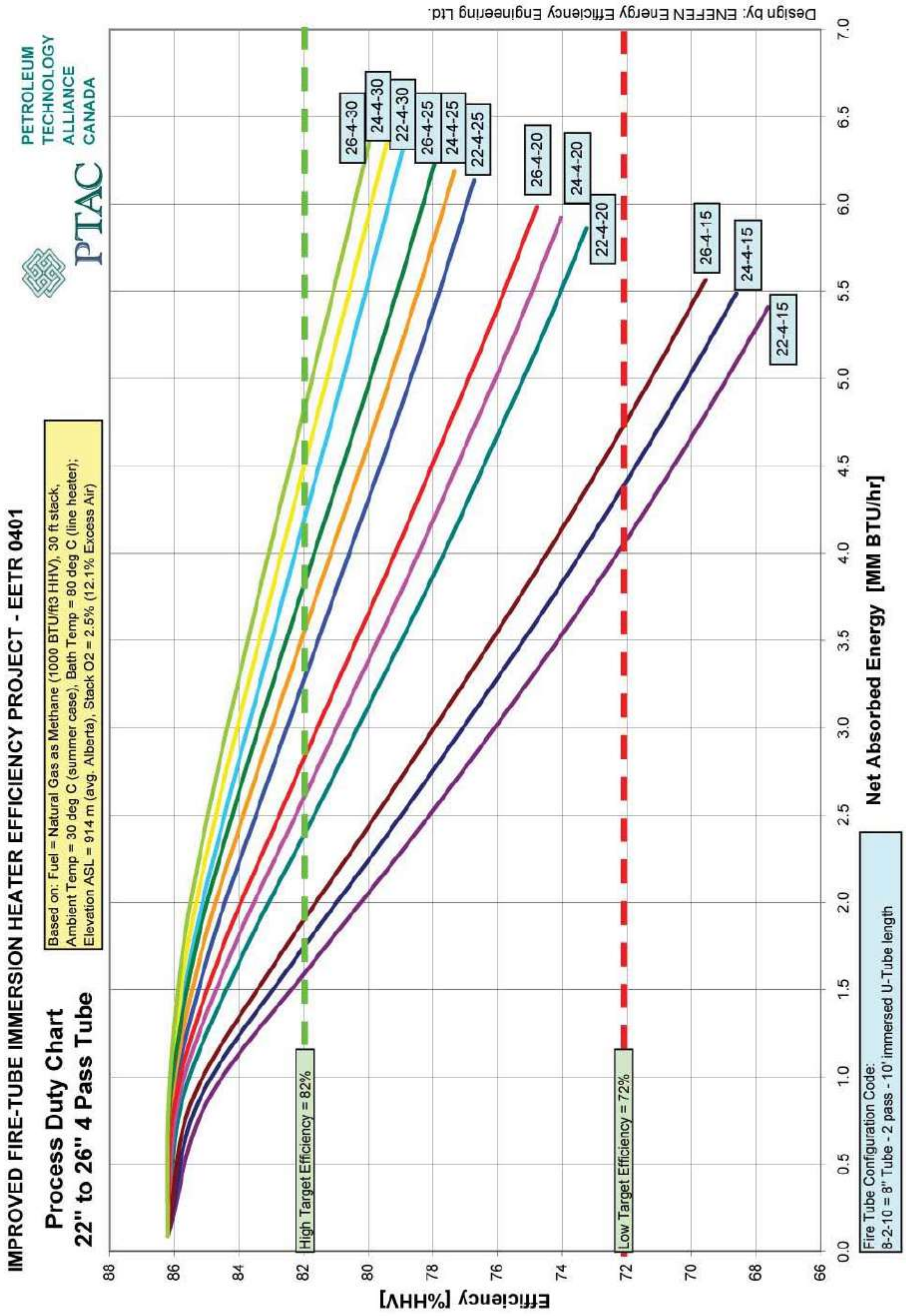


FIGURE 11.23 Process Duty Chart for 4 Pass 22" to 26" Fire Tube with Natural Draft

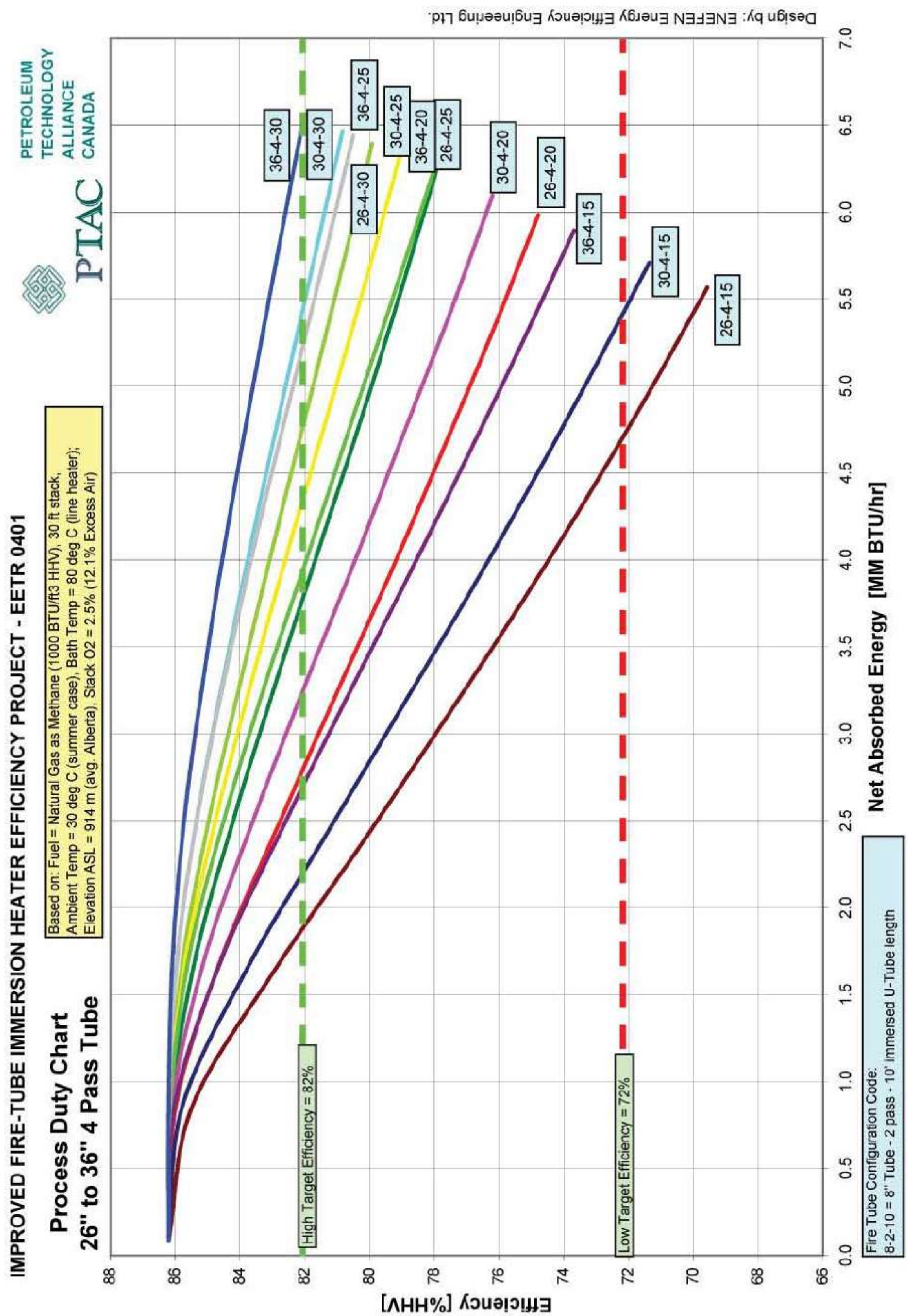


FIGURE 11.24 Process Duty Chart for 4 Pass 26” to 36” Fire Tube with Natural Draft

11.5 Burner Input Charts for 4 Pass Fire Tube with Natural Draft

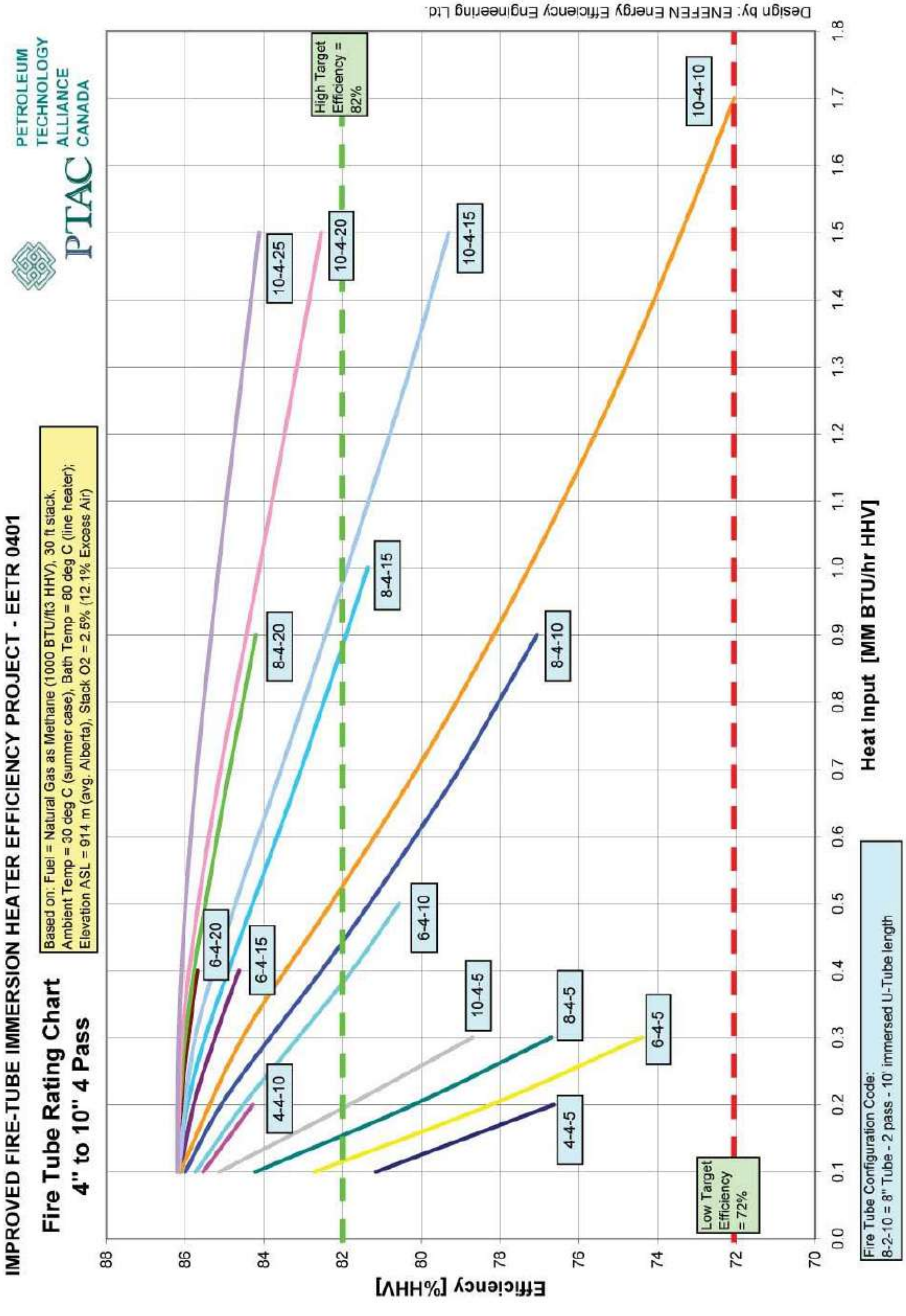


FIGURE 11.25 Burner Input Chart for 4 Pass 4” to 10” Fire Tube with Natural Draft

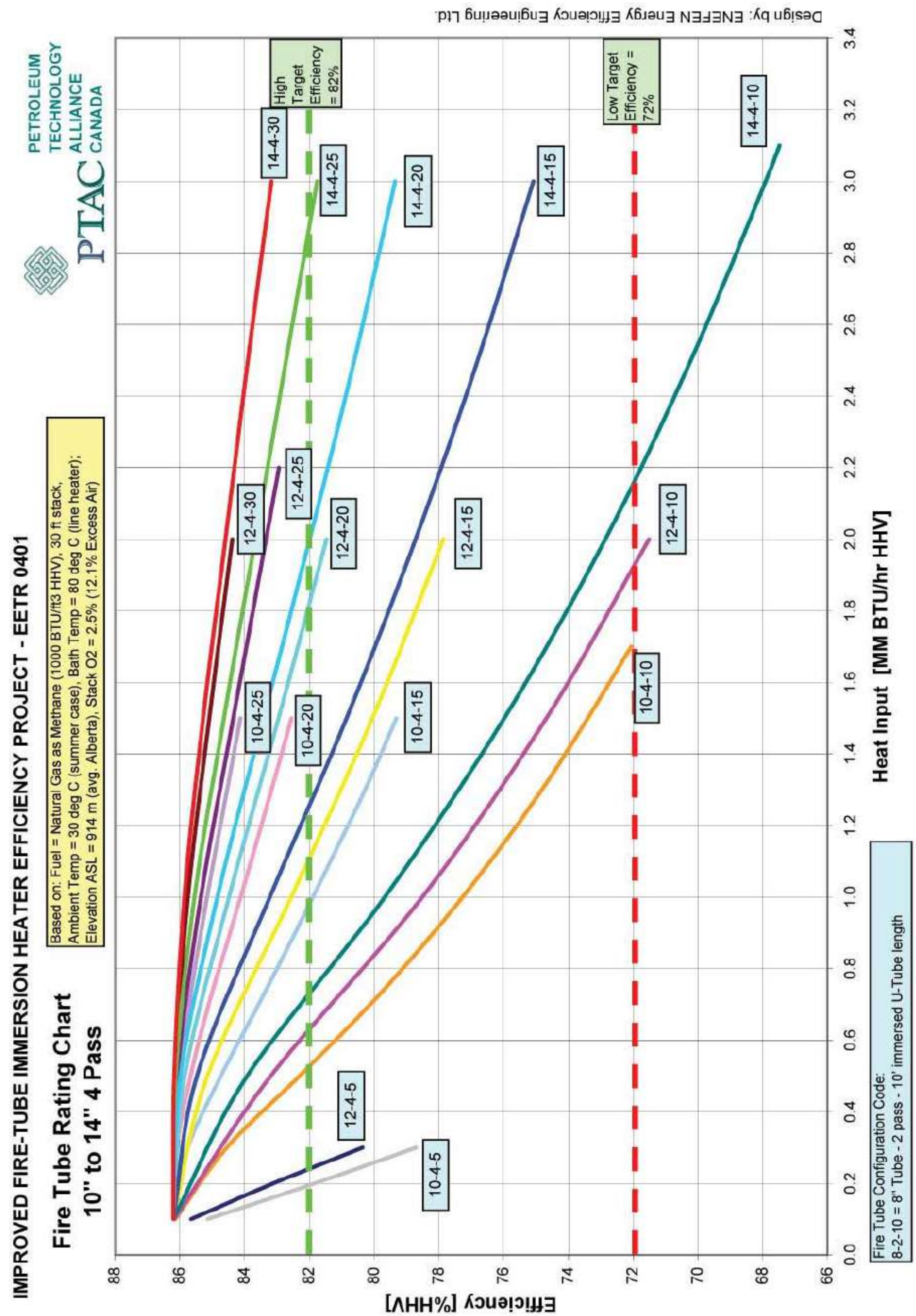


FIGURE 11.26 Burner Input Chart for 4 Pass 10" to 14" Fire Tube with Natural Draft

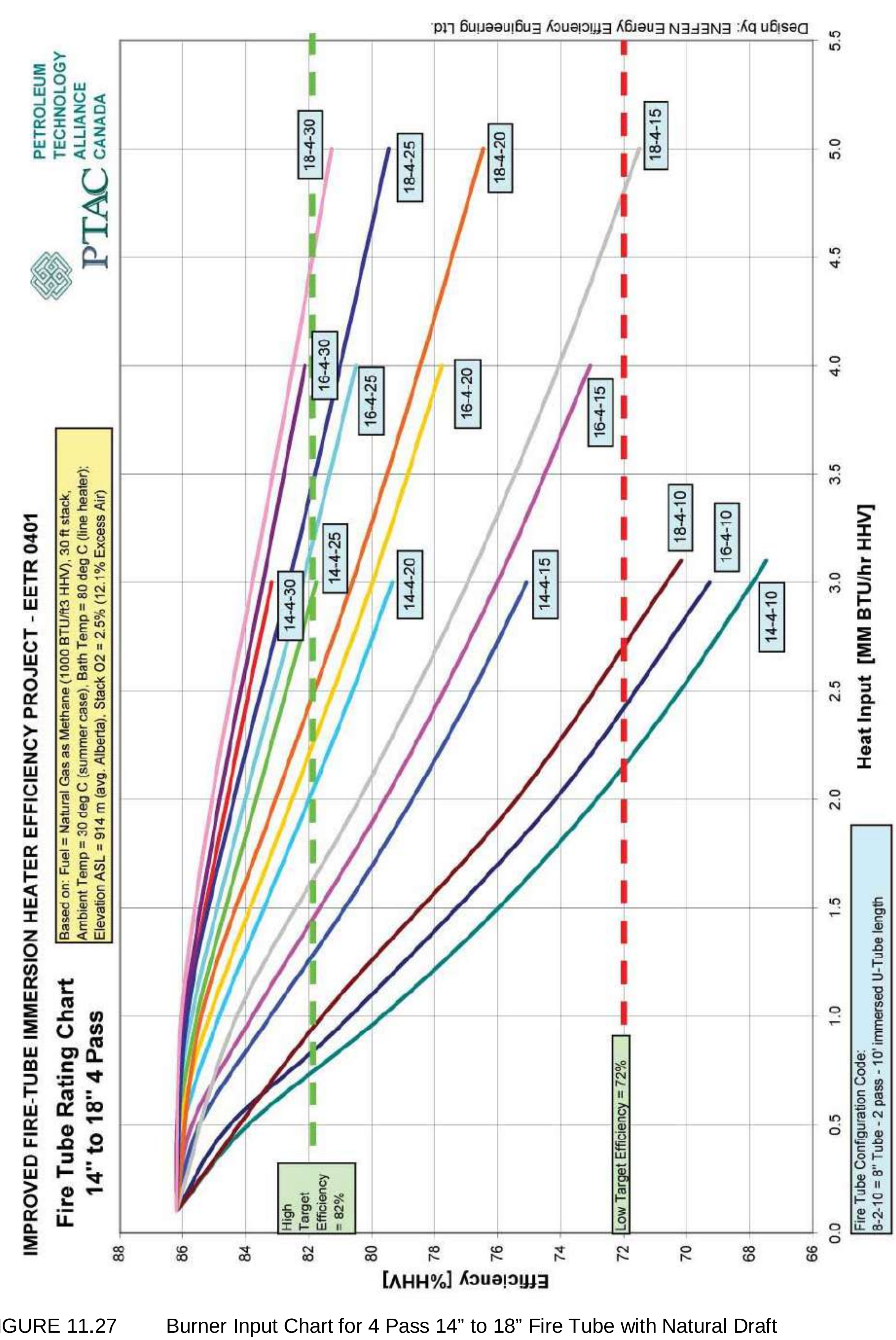


FIGURE 11.27 Burner Input Chart for 4 Pass 14" to 18" Fire Tube with Natural Draft

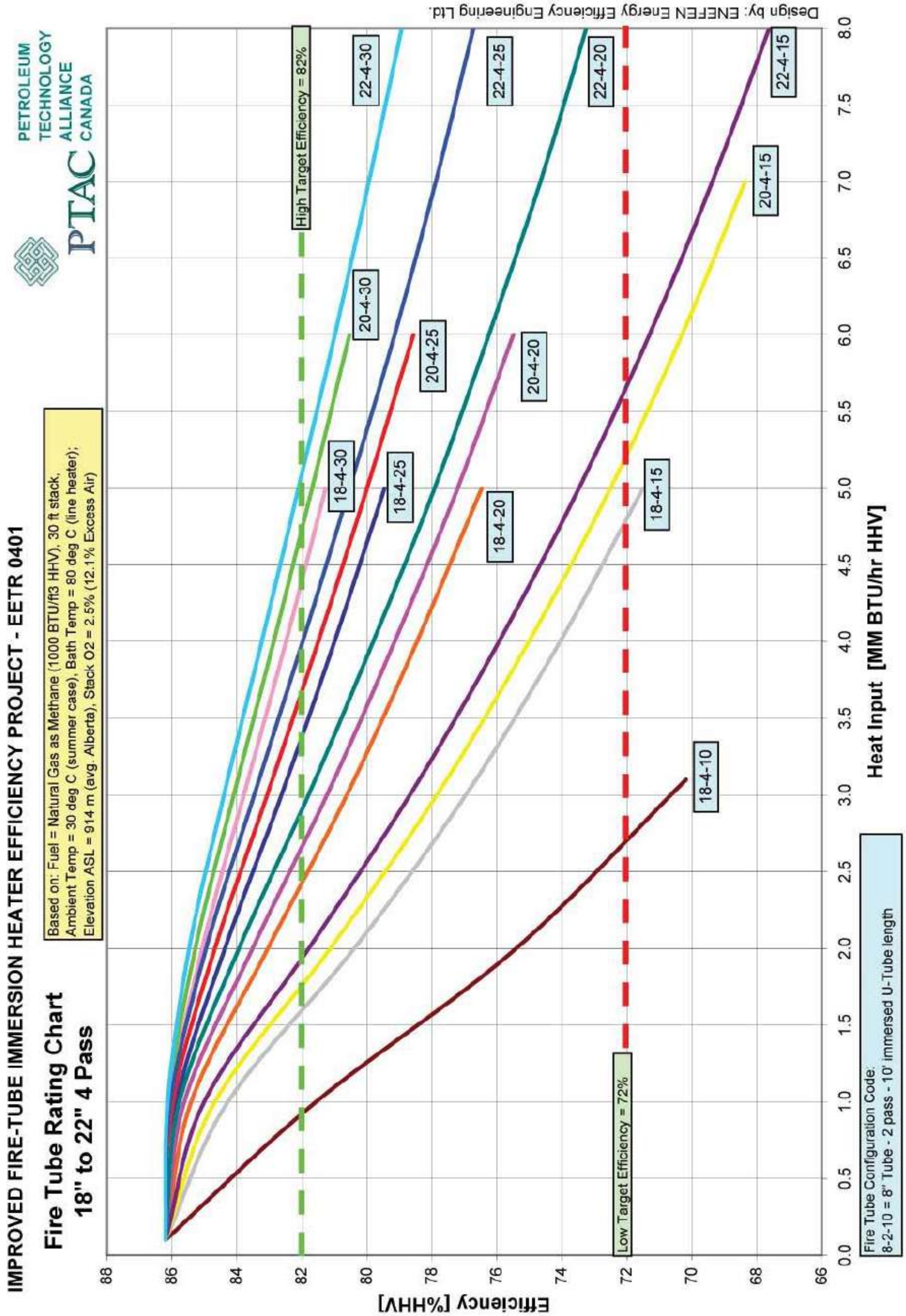


FIGURE 11.28 Burner Input Chart for 4 Pass 18" to 22" Fire Tube with Natural Draft

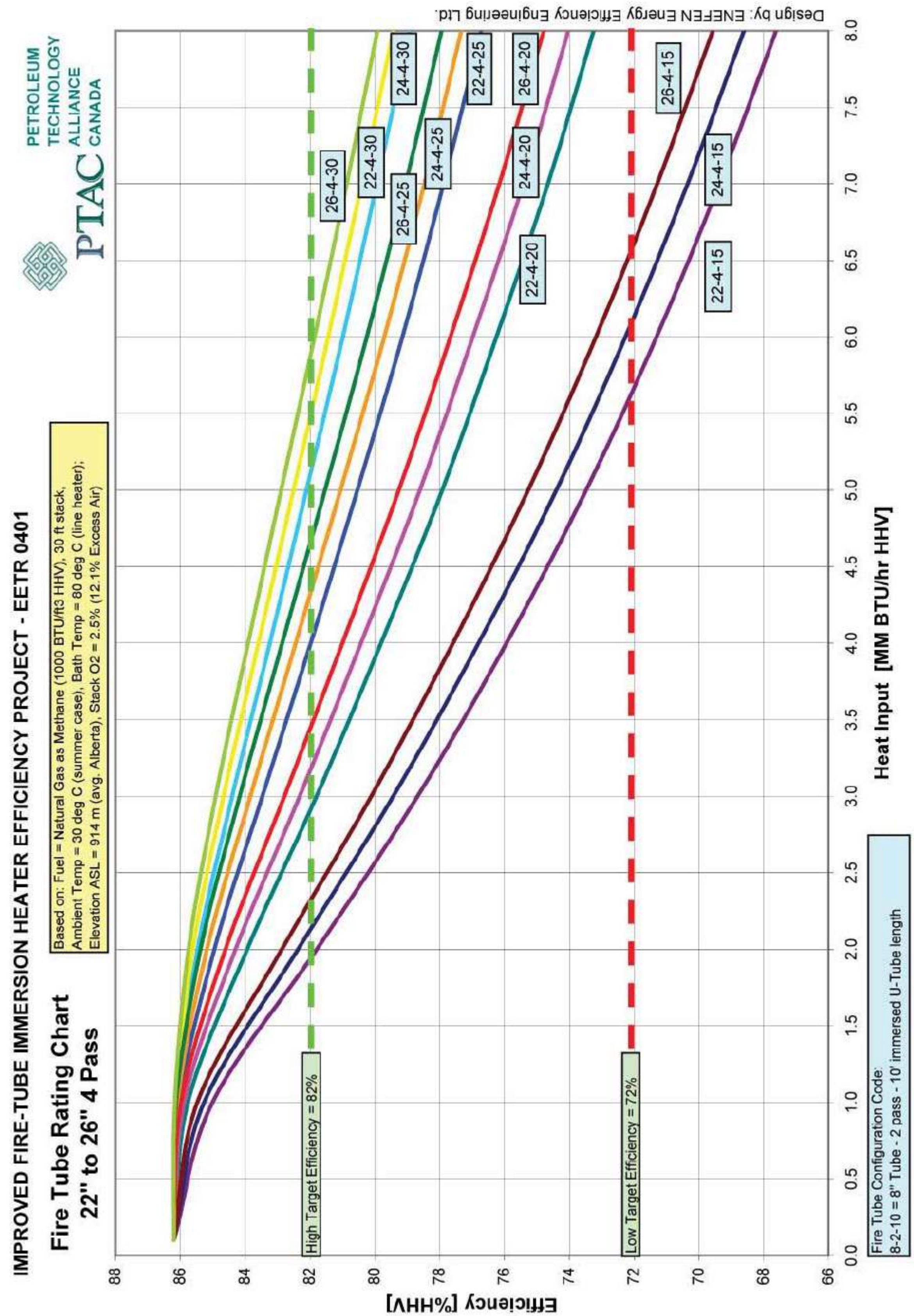


FIGURE 11.29 Burner Input Chart for 4 Pass 22" to 26" Fire Tube with Natural Draft

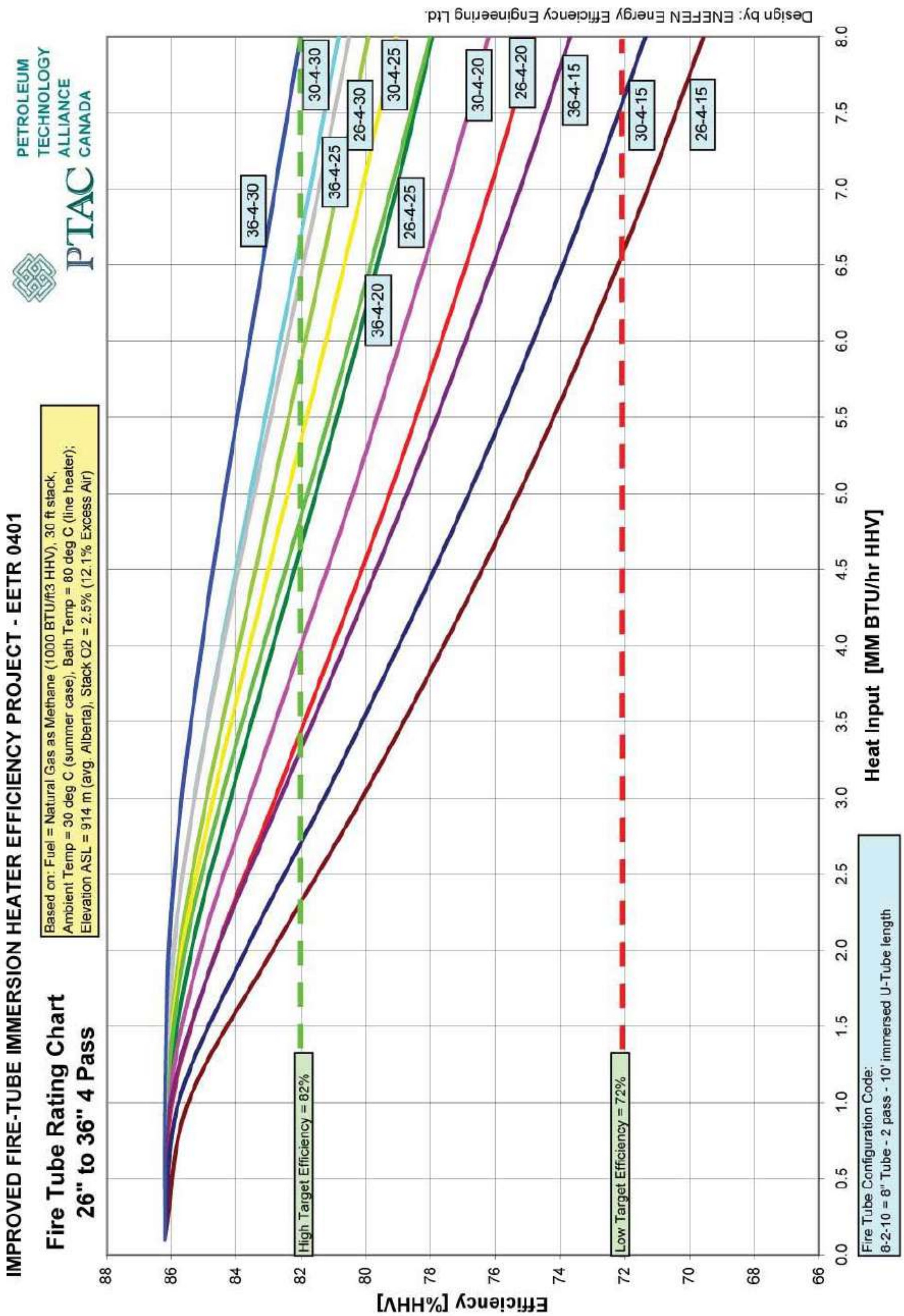


FIGURE 11.30 Burner Input Chart for 4 Pass 26” to 36” Fire Tube with Natural Draft

11.6 Surface Heat Flux Charts for 4 Pass Fire Tube with Natural Draft

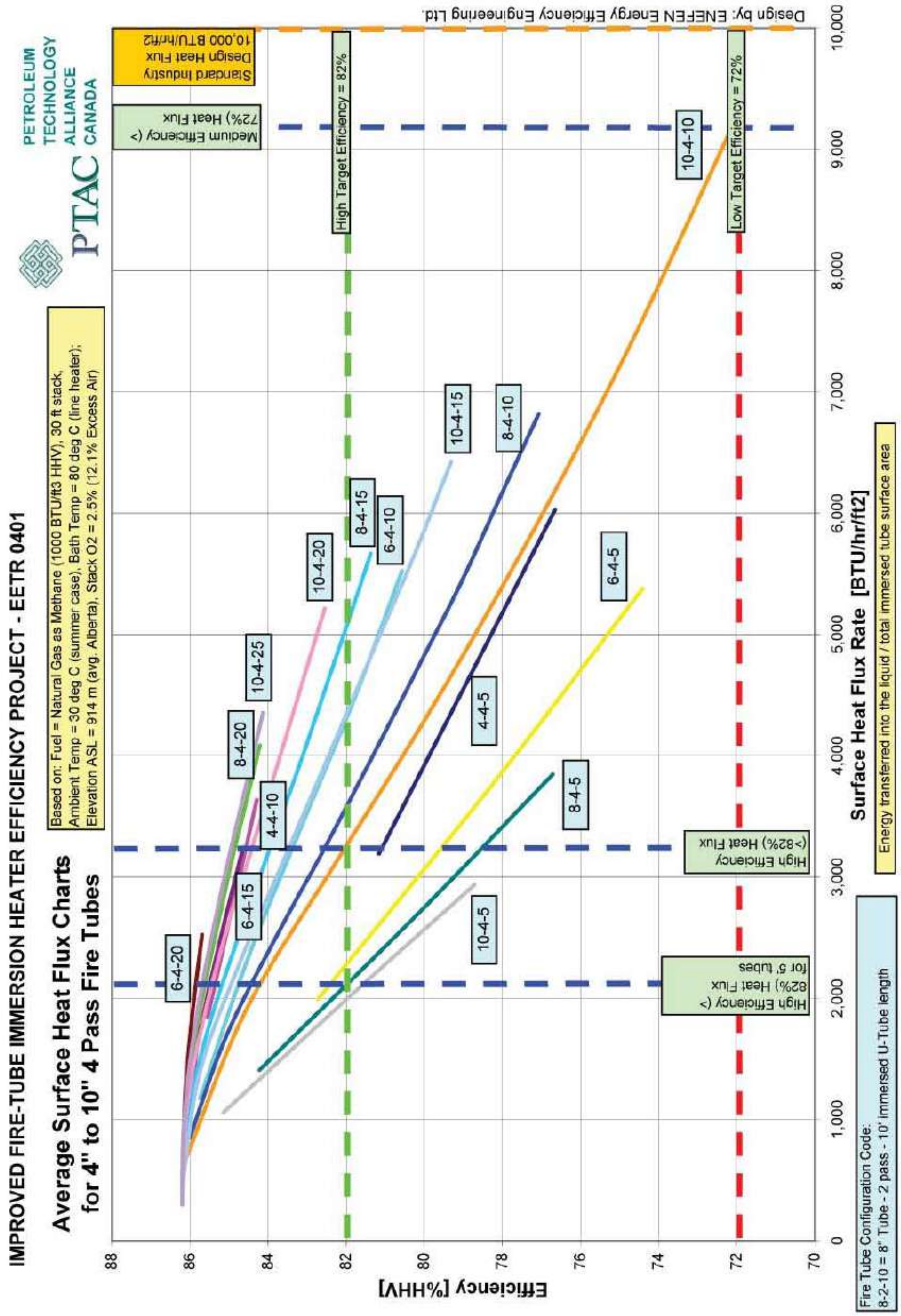


FIGURE 11.31 Surface Heat Flux Chart for 4 Pass 4" to 10" Fire Tube with Natural Draft

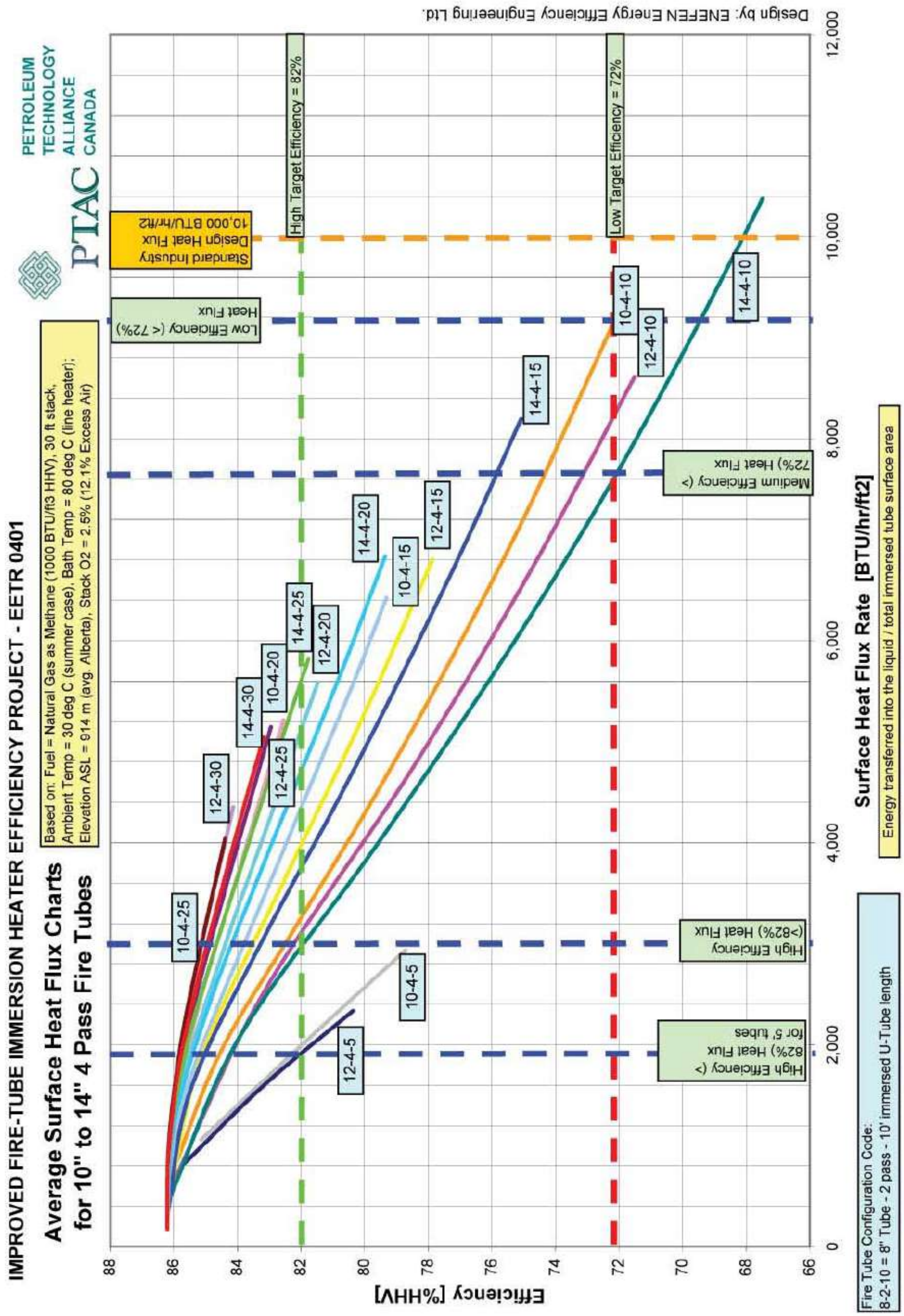


FIGURE 11.32 Surface Heat Flux Chart for 4 Pass 10" to 14" Fire Tube with Natural Draft

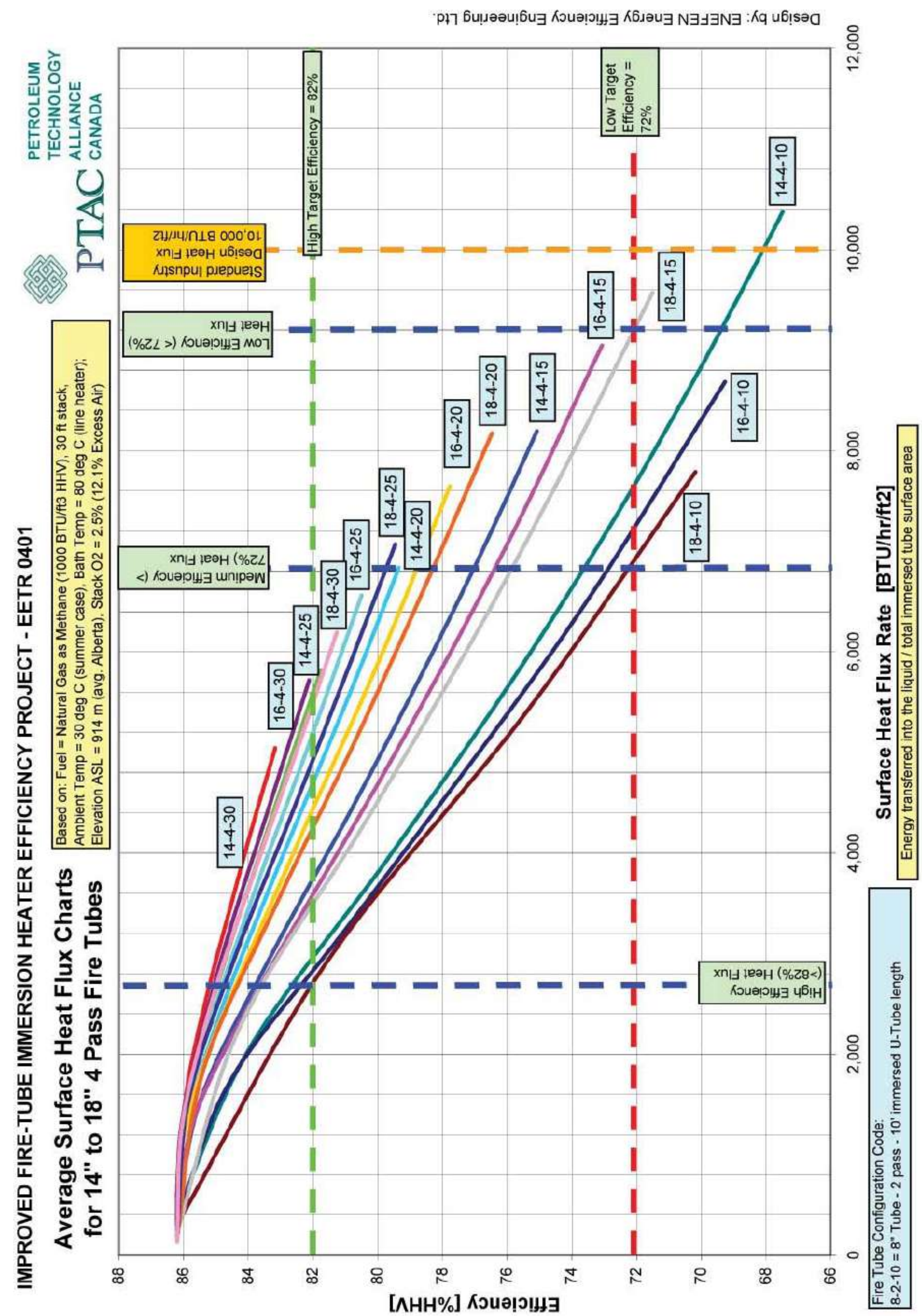


FIGURE 11.33 Surface Heat Flux Chart for 4 Pass 14” to 18” Fire Tube with Natural Draft

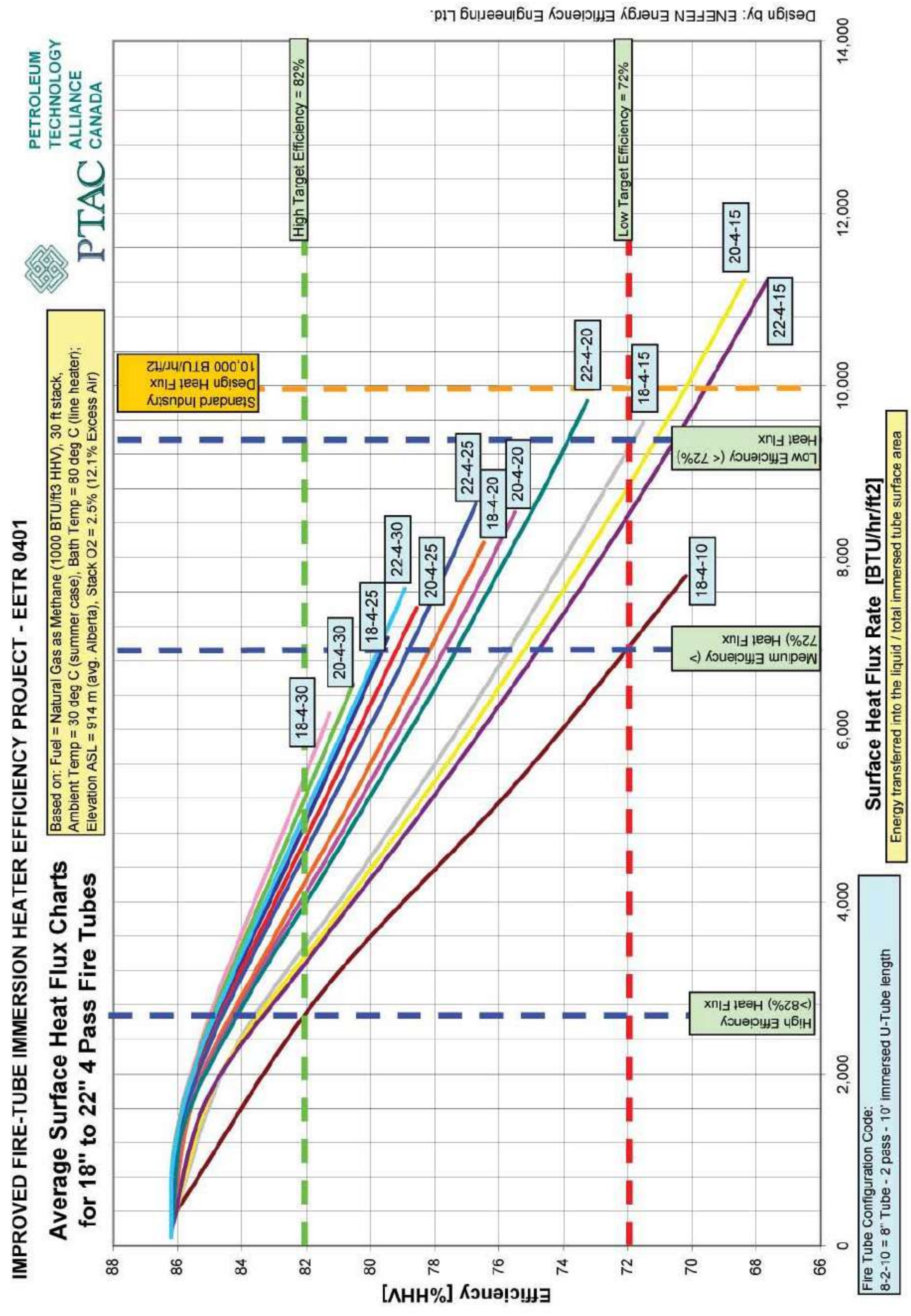


FIGURE 11.34 Surface Heat Flux Chart for 4 Pass 18" to 22" Fire Tube with Natural Draft

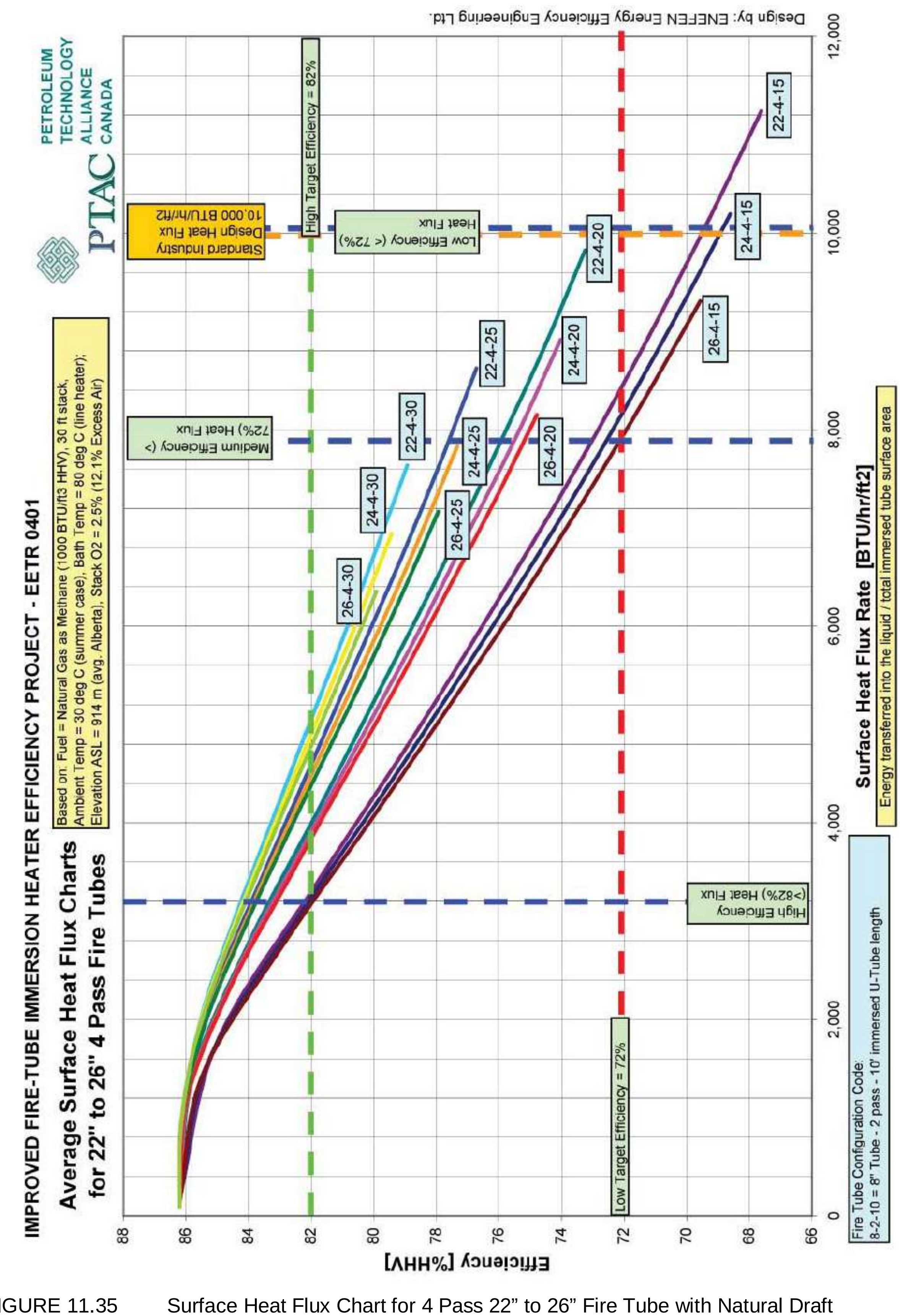


FIGURE 11.35 Surface Heat Flux Chart for 4 Pass 22” to 26” Fire Tube with Natural Draft

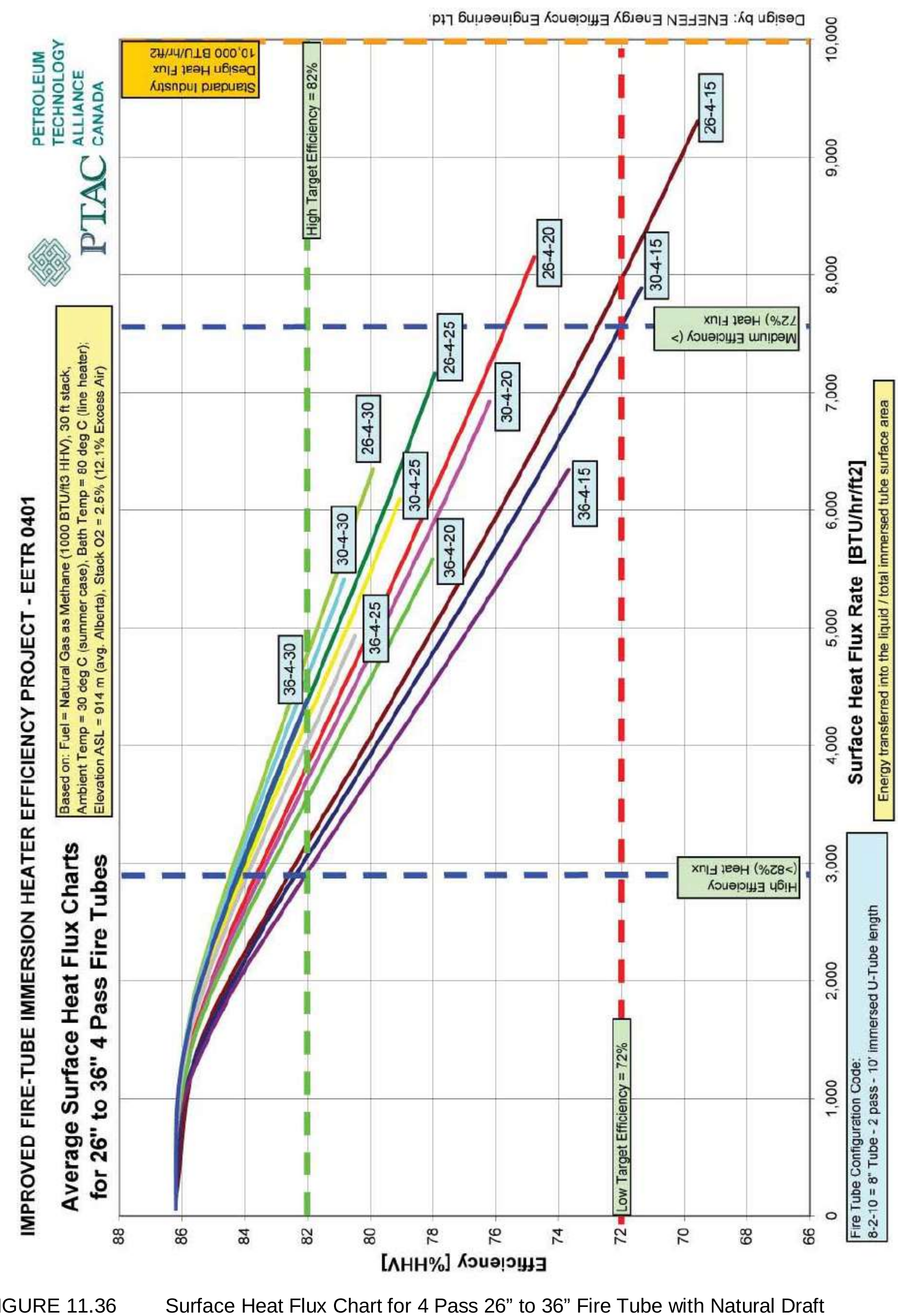


FIGURE 11.36 Surface Heat Flux Chart for 4 Pass 26” to 36” Fire Tube with Natural Draft

11.7 Process Duty Charts for 4 Pass Fire Tube with Forced Draft

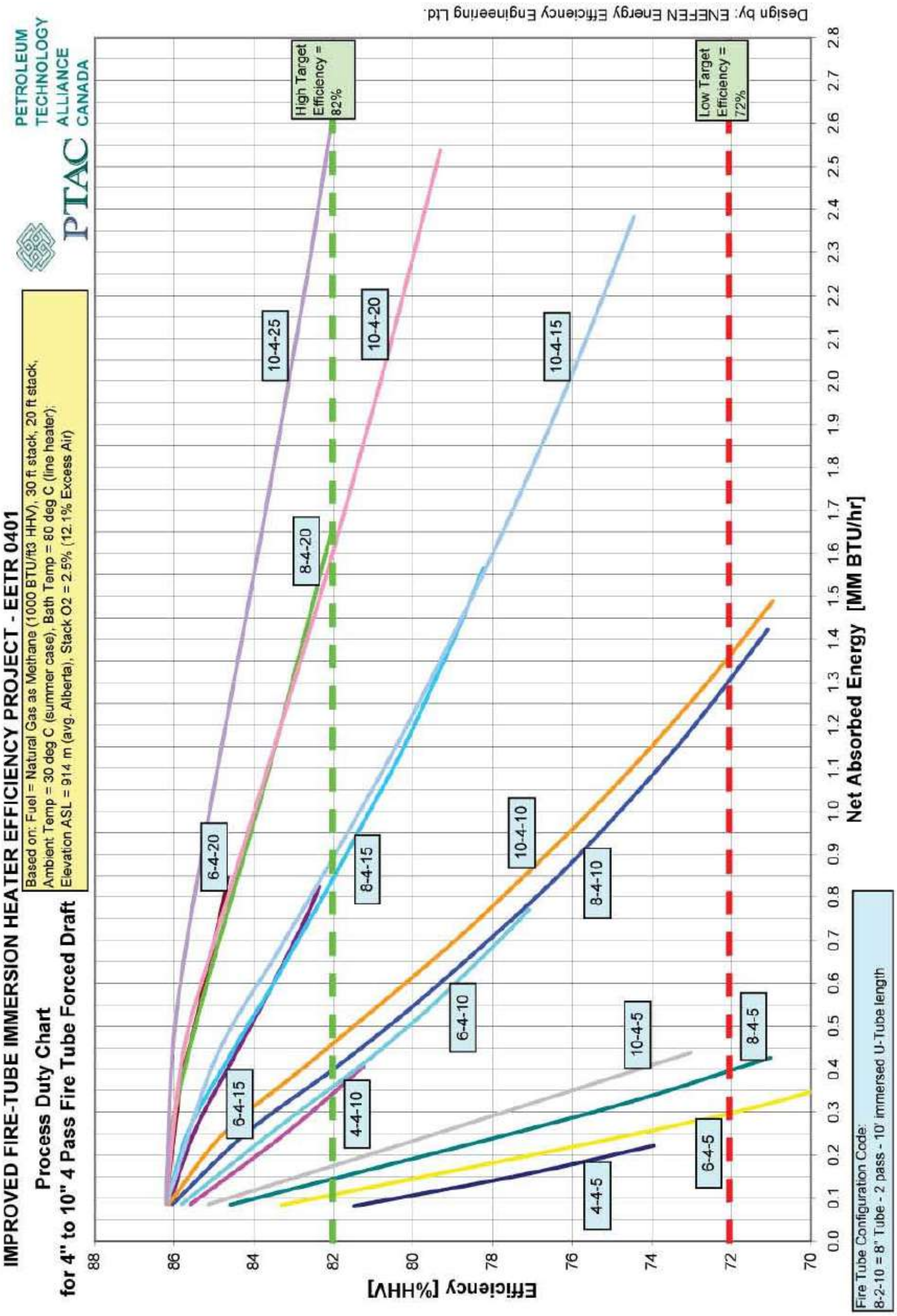


FIGURE 11.37 Process Duty Chart for 4 Pass 4” to 10” Fire Tube with Forced Draft

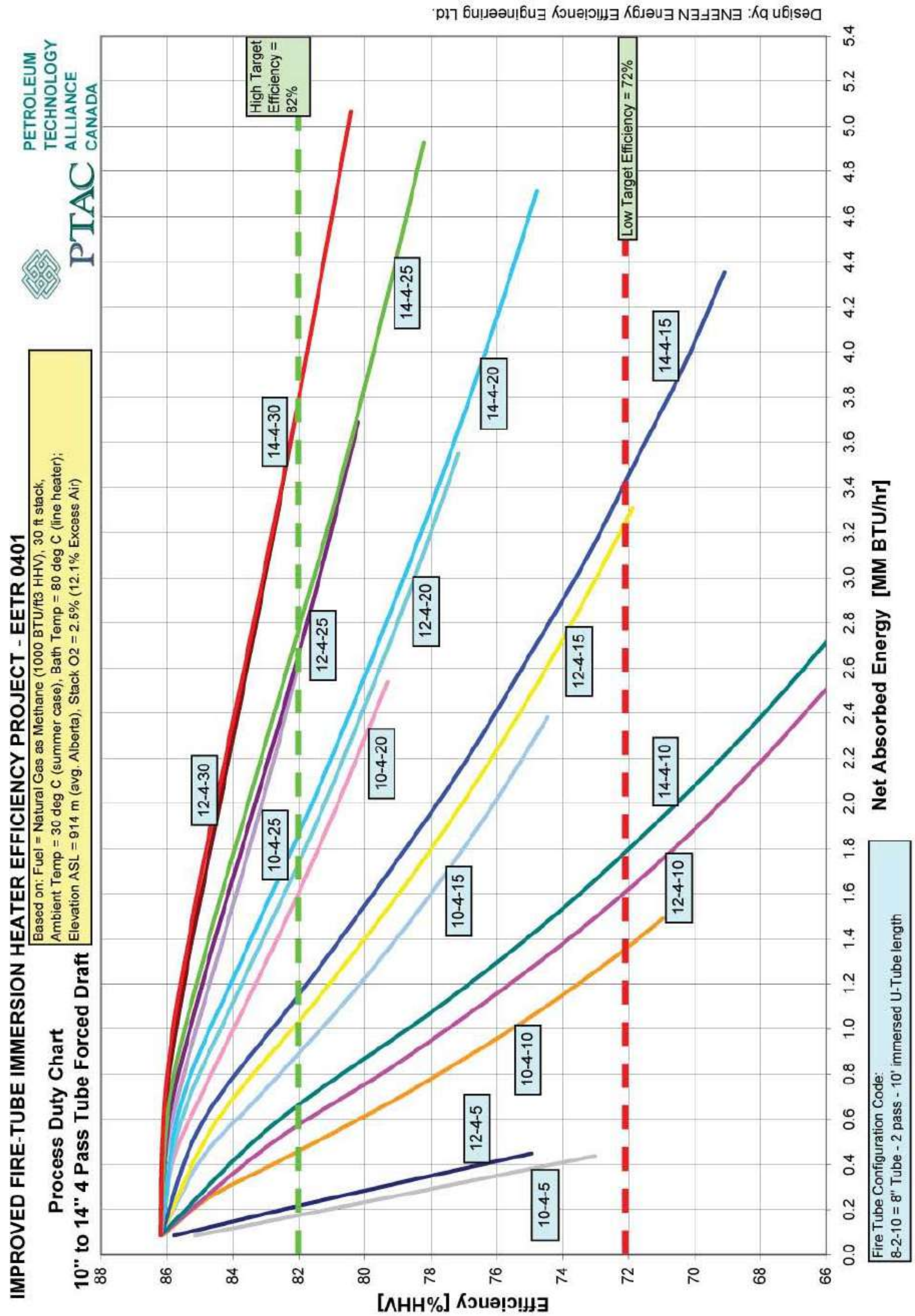


FIGURE 11.38 Process Duty Chart for 4 Pass 10” to 14” Fire Tube with Forced Draft

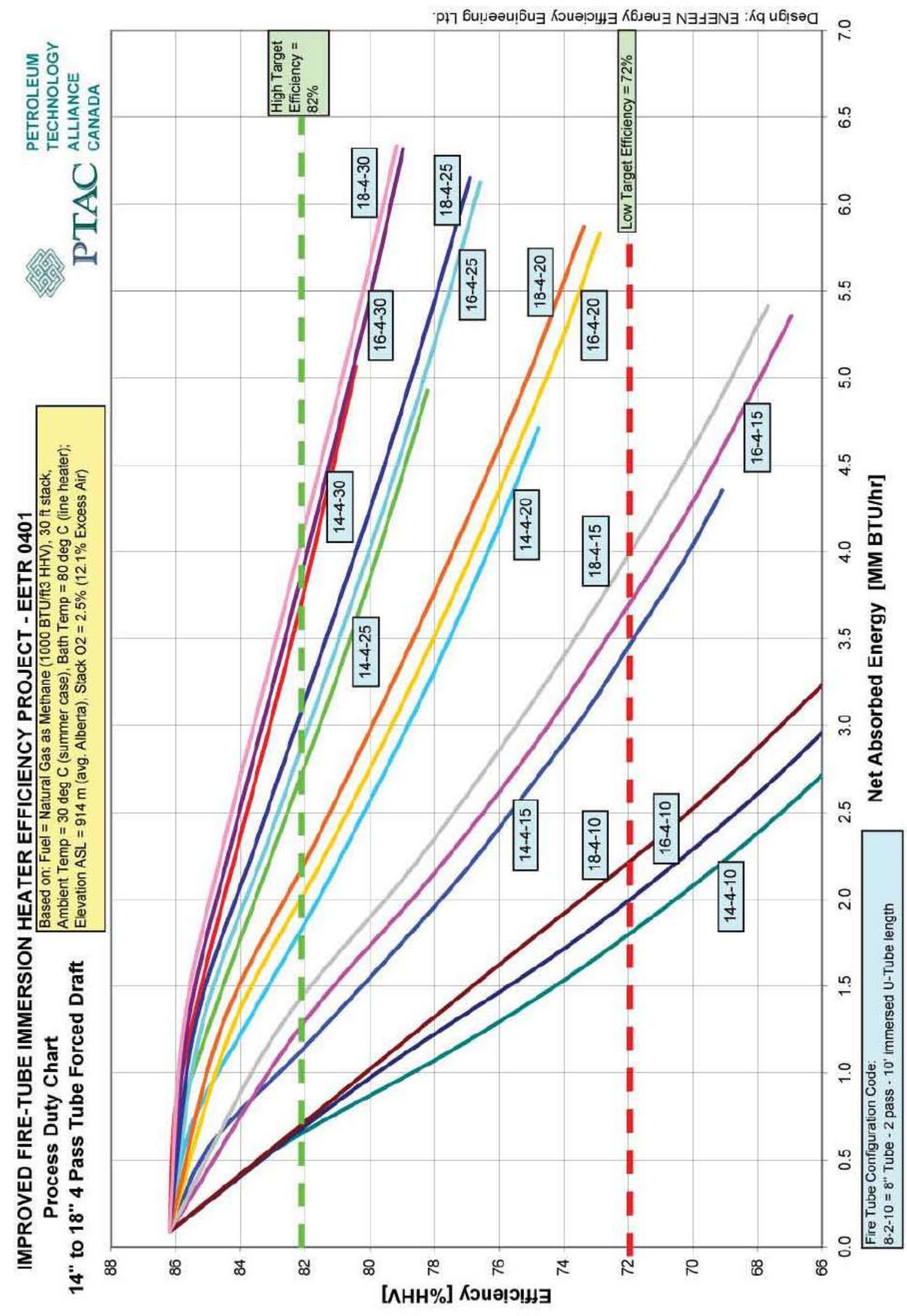


FIGURE 11.39 Process Duty Chart for 4 Pass 14” to 18” Fire Tube with Forced Draft

11.8 Burner Input Charts for 4 Pass Fire Tube with Forced Draft

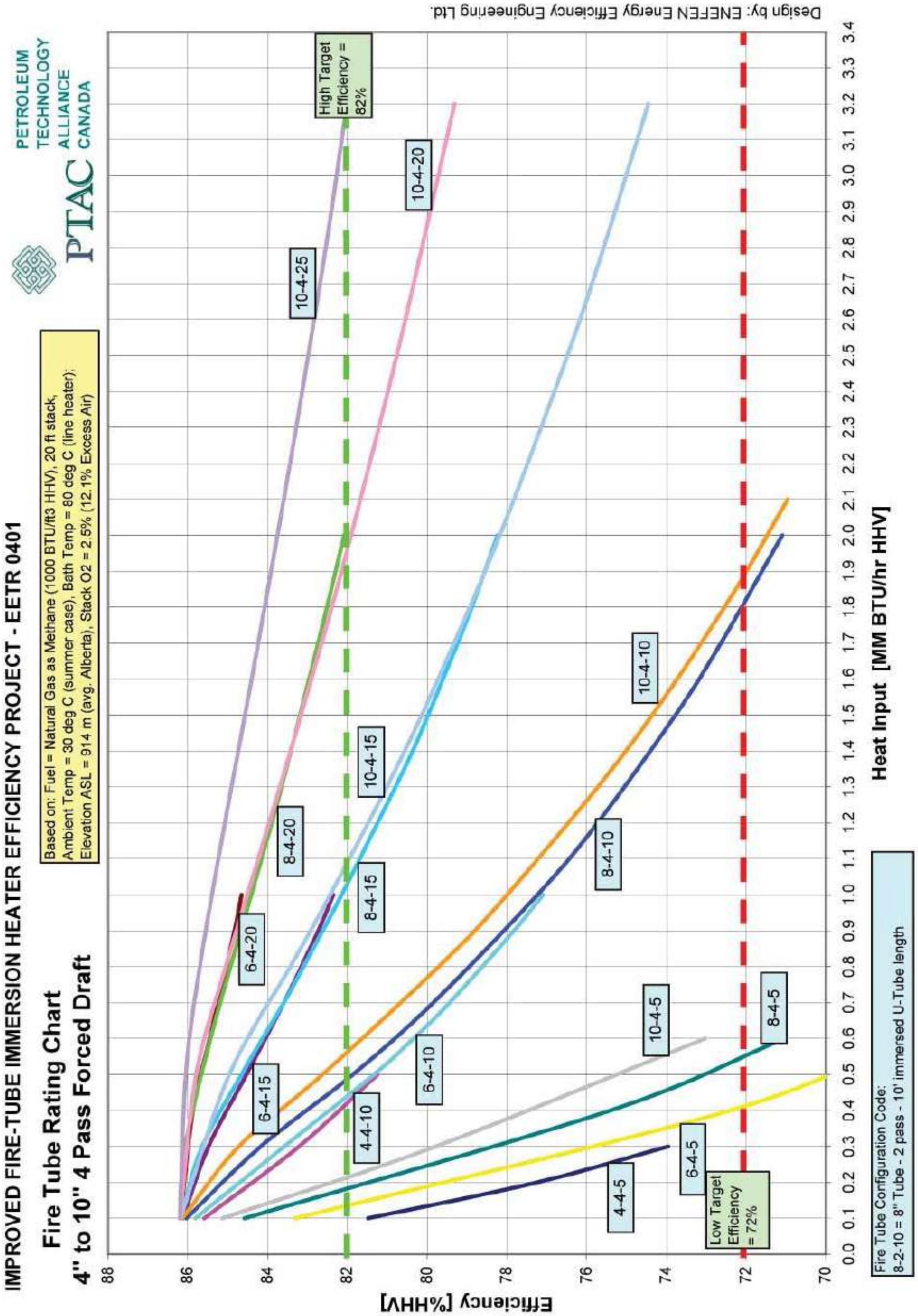


FIGURE 11.40 Burner Input Chart for 4 Pass 4” to 10” Fire Tube with Forced Draft

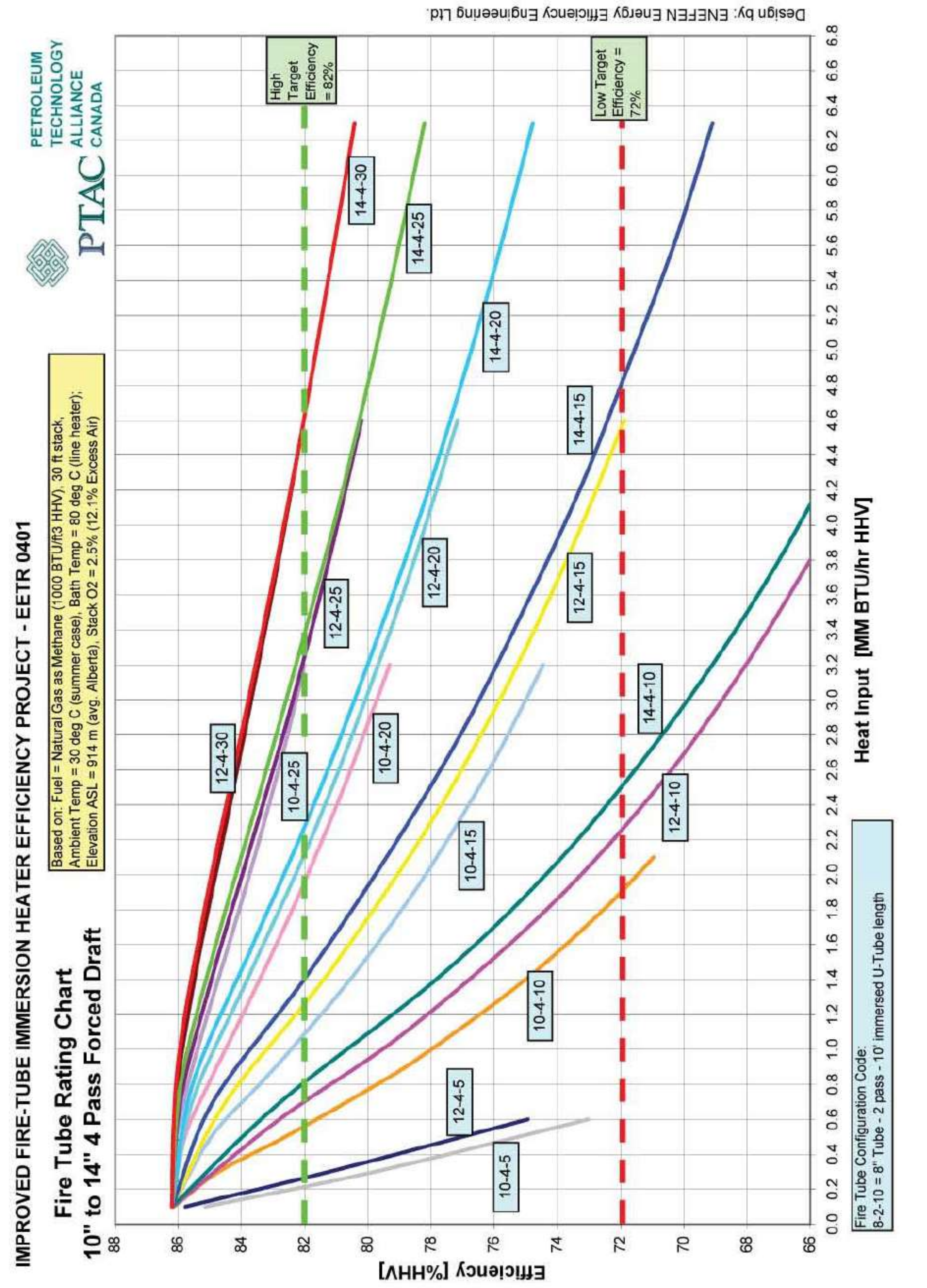


FIGURE 11.41 Burner Input Chart for 4 Pass 10" to 14" Fire Tube with Forced Draft

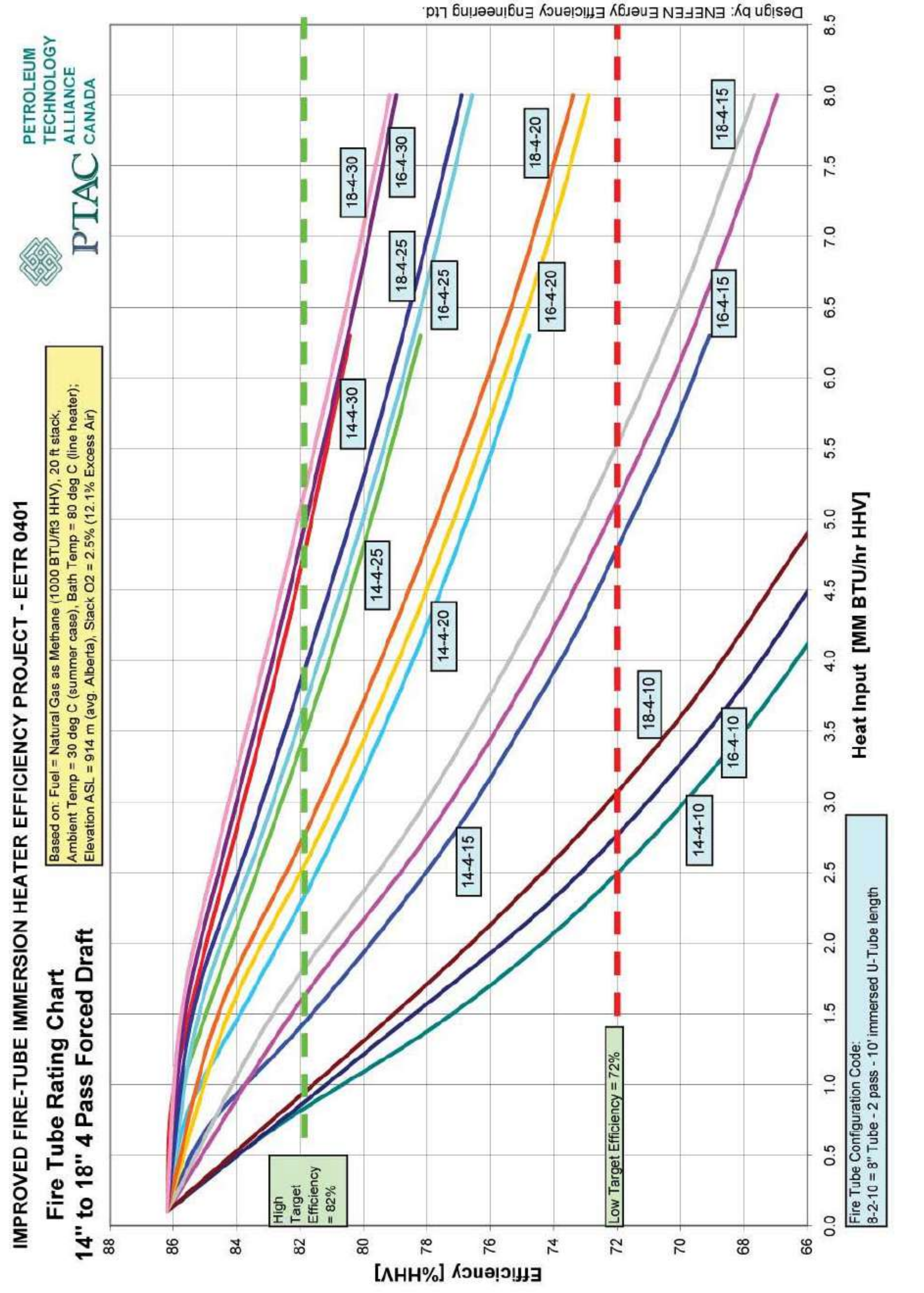


FIGURE 11.42 Burner Input Chart for 4 Pass 14” to 18” Fire Tube with Forced Draft

11.9 Surface Heat Flux Charts for 4 Pass Fire Tube with Forced Draft

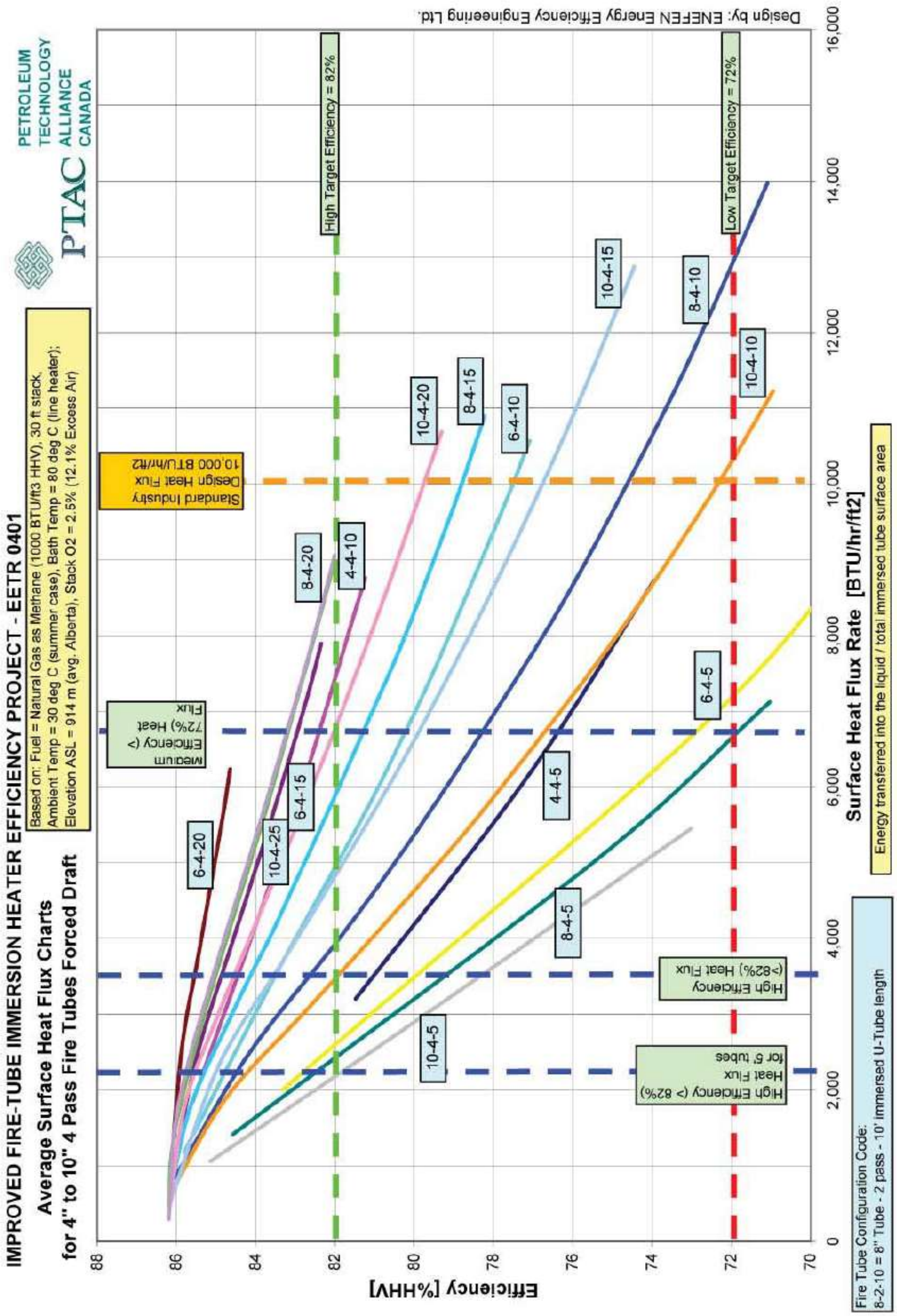


FIGURE 11.43 Surface Heat Flux Chart for 4 Pass 4" to 10" Fire Tube with Forced Draft

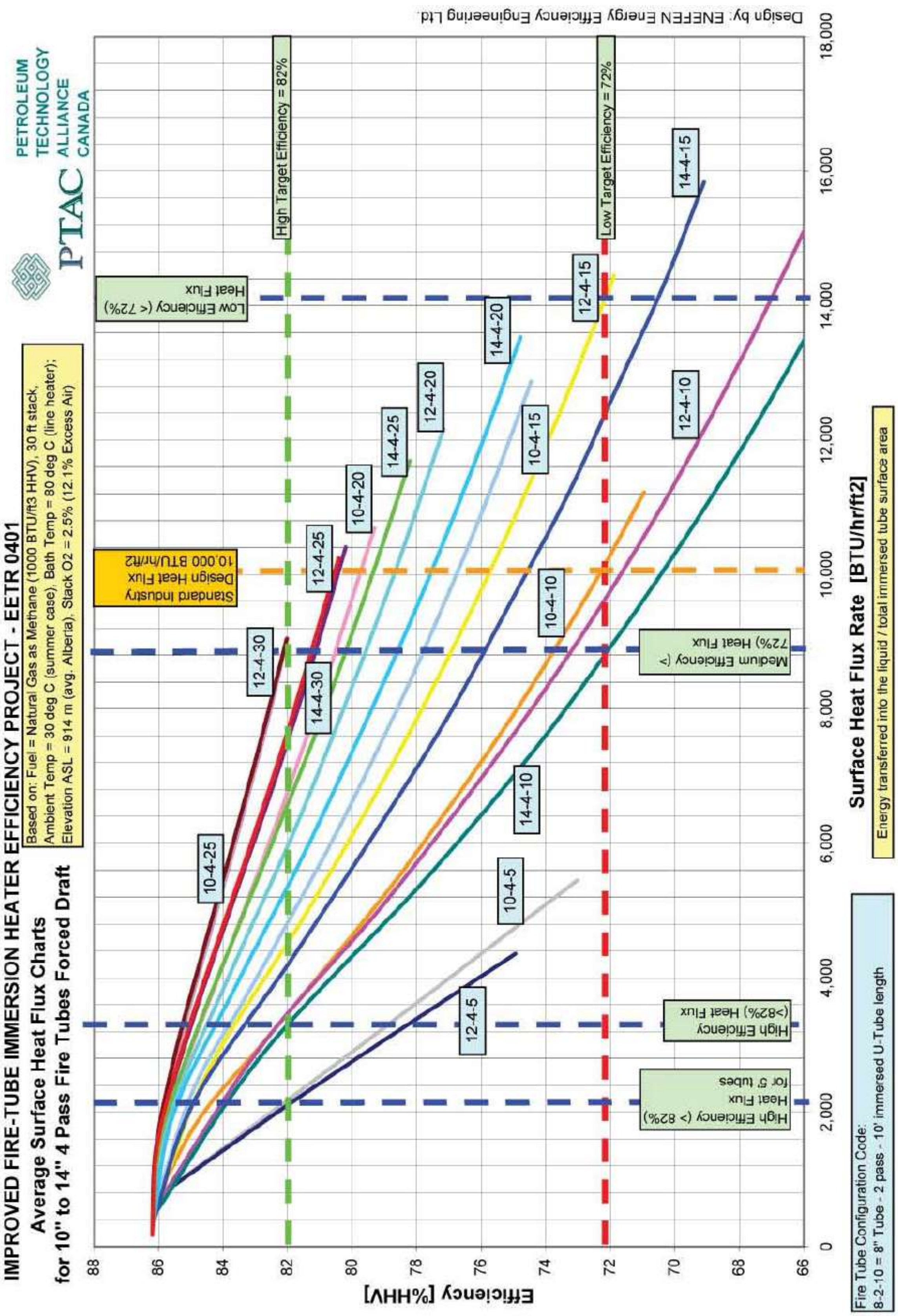


FIGURE 11.44 Surface Heat Flux Chart for 4 Pass 10” to 14” Fire Tube with Forced Draft

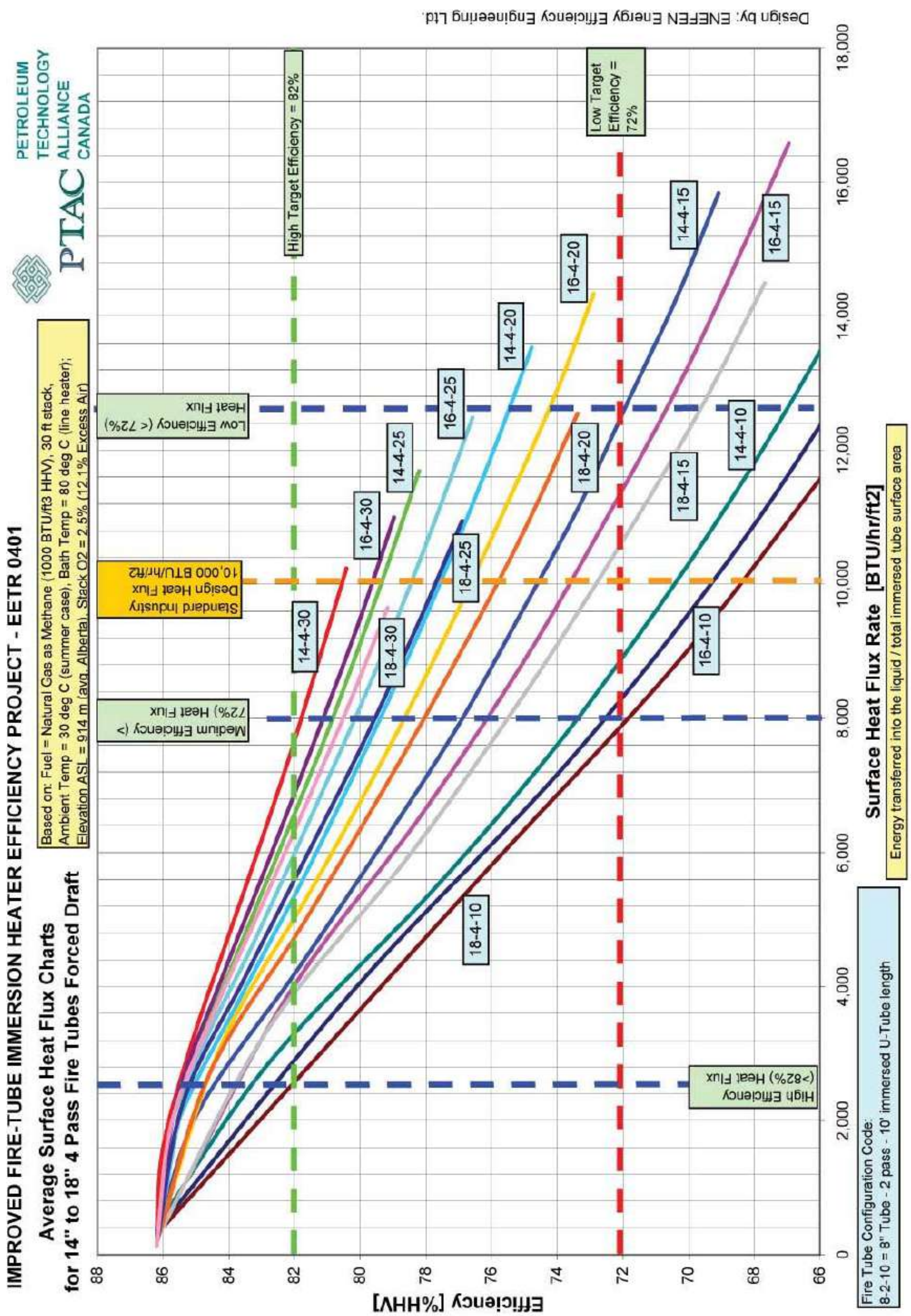


FIGURE 11.45 Surface Heat Flux Chart for 4 Pass 14” to 18” Fire Tube with Forced Draft

12 FIRE-TUBE HEAT FLUX RATE ANALYSIS

The fire-tube rating software program was calibrated using the data from the previously described heater tests. The program was then extensively tested to predict the thermal performance of a wide range of fire-tube configurations at various firing rates. This data was used to create the fire-tube rating charts discussed in the previous chapter.

In this chapter, we addressed the impact of heat flux rates on the fire-tube heater efficiency.

Figure 12.1 illustrates the trend of the relationship between an average heat flux rate and heater's gross (%HHV) efficiency. All of the data points, used in the previous chapter to create surface heat flux rates for 2 pass natural draft fire tubes (4" to 36"), were plotted here on a single chart. A black line represents an average trend. A green horizontal line is shown to represent high efficiency target of 82%, and a red horizontal line is shown to represent a low efficiency target of 72%. Vertical lines are used to mark the following trends:

a) At a standard industry 10,000 BTU/hr/ft2 surface heat flux rate, almost all of the data point fall underneath the red low efficiency line. This means that this standard industry design guideline (per API and many other publications) is almost "guaranteed" to result in a low efficiency, regardless of the fire-tube configuration. At 10,000 BTU/hr/ft2 this efficiency could be as low as 62%.

b) At heat flux rates exceeding 10,000 BTU/hr/ft2 efficiencies can be significantly lower than the 72% low target and down to 50% range. These designs represent overfired fire-tubes, which simply do not have sufficient heat transfer surface area to effectively transfer the heat.

c) Between 6,000 and 10,000 BTU/hr/ft2 fire-tube designs can produce results which either exceed or are below the 72% low efficiency target, hence, careful consideration must be given to chose the designs with higher efficiencies

d) Between 3,200 and 6,000 BTU/hr/ft2 fire-tube designs are almost "guaranteed" to fall within the 72% and 82% target efficiency range. The exception to that rule are very small (4") and short tube diameters.

e) Below 3,200 BTU.hr/ft2 all fire-tube designs exceed the 82% high efficiency target. Note that the 85% efficiency point is considered to be a limit for condensation problems and potential flooding of the fire-tube with condensate.

Figure 12.2 illustrates a similar analysis of surface heat flux rates for 4 pass natural draft fire tubes (4" to 36"). The following trends can be observed:

a) Most of the 4 pass designs not exceeding 10,000 BTU/hr/ft2 will result in efficiencies higher than the 72% low efficiency target.

b) At 9,200 surface heat flux rate, the average trend line exceeds 72% efficiency indicating that any tube design will provide 72% or better efficiency.

c) Between 4,000 and 7,800 BTU/hr/ft2 fire-tube designs are "guaranteed" to fall within the 72% and 82% target efficiency range.

d) Below 4,000 BTU.hr/ft2 all fire-tube designs exceed the 82% high efficiency target. Note that the 85% efficiency point is considered to be a limit for condensation problems and potential flooding of the fire-tube with condensate.

Figure 12.3 illustrates a similar analysis of surface heat flux rates for 4 pass forced draft fire tubes (4" to 18"). Computations indicate that for this heater application, limited to a maximum of 6 MM BTU/hr process duty per fire-tube, there is no benefit to thermal transfer in using fire-tubes exceeding 18" in diameter. The large diameter 2-pass tubes do not utilize the blower pressure, which has to be "dissipated" by the means of dampers, orifices, etc. Consequently, the flow velocities are slow, and the effect of forced draft on heat transfer is negligible. As a result, there is no benefit to the simple conversion projects of natural draft heaters to forced draft burners, unless such forced draft is combined with heat transfer augmentation techniques, such as turbulators, multi-pass tube designs, or stepped-tube designs. For these augmentation methods to have any noticeable effect, a minimum of 1" W.C. pressure drop on the gas side must be used.

The following trends can be observed with 4 pass forced draft designs:

a) Most of the 4 pass designs not exceeding 12,800 BTU/hr/ft2 heat flux rates will result in efficiencies higher than the 72% low efficiency target.

b) Between 5,000 and 9,900 BTU/hr/ft2 fire-tube designs are “guaranteed” to fall within the 72% and 82% target efficiency range.

c) Below 5,000 BTU.hr/ft2 all fire-tube designs exceed the 82% high efficiency target. Note that the 85% efficiency point is considered to be a limit for condensation problems and potential flooding of the fire-tube with condensate.

Figure 12.4 illustrates a side-by-side comparison of the above three trends for 2 pass and 4-pass natural draft designs and 4-pass forced-draft designs.

The following conclusions can be drawn from this comparison:

a) 4-pass natural draft fire-tube designs offer on average a better utilization of the heat transfer surface than the conventional 2-pass natural draft designs of the same surface area. For example at 10,000 BTU/hr/ft2 heat flux rate, 4-pass design will provide 76.3% HHV efficiency, where the 2-pass design will only provide 70% efficiency.

b) 4 pass forced draft fire-tube designs offer a similar utilization of the heat transfer surface to the conventional 2-pass natural draft designs of the same surface area. In other words, in order to accommodate a certain heat transfer rate, a 4-pass forced draft fire-tube must have a surface area equal to a 2 pass natural draft fire-tube, except the forced-draft tube must be smaller in diameter in order to work properly (not exceeding 18”). Such smaller diameter fire-tube may be easier to accommodate inside the heater’s vessel.

c) Forced draft fire tube design (with 4” to 5” W.C. blower pressure) offers also opportunities for enhanced heat transfer using turbulators, ribbed tubes and other heat transfer augmentation techniques, which are not available and not effective with a natural draft design (with only 0.1 to 0.3” W.C. natural draft available)

d) With any fire tube design a 7,000 BTU/hr/ft2 average heat flux rate is almost “guaranteed” to provide thermal efficiency in excess of the 72% low target.

e) Efficiencies higher than 72% must be addressed through proper engineering assessment of the fire-tube design using fire-tube rating charts or the fire-tube rating software program.

f) Lower average heat flux rate can be “designed into” the fire-tube on new installations by allowing for longer (possibly 4 pass tubes), or obtained through lowering of the burner firing rates on existing installations, which often are oversized. Such increase in the duty cycle of the heater is a very effective way of obtaining significant efficiency gains without any major changes to the existing equipment. If for example, an existing heater designed originally for 10,000 BTU/hr heat flux rate is operating at 50% duty cycle (burner is on only 50% of the time), then by simply re-tuning this burner to a 50% firing rate, the heat flux will drop to 5,000 BTU/hr/ft2, and the efficiency will increase accordingly. In doing so it is essential to address at the same time the impact of the secondary air infiltration as described previously.

12.1 Distribution of Thermal Efficiency Results for Various Heat Flux Rates in a 4” to 36” Two Pass Natural Draft Fire Tube

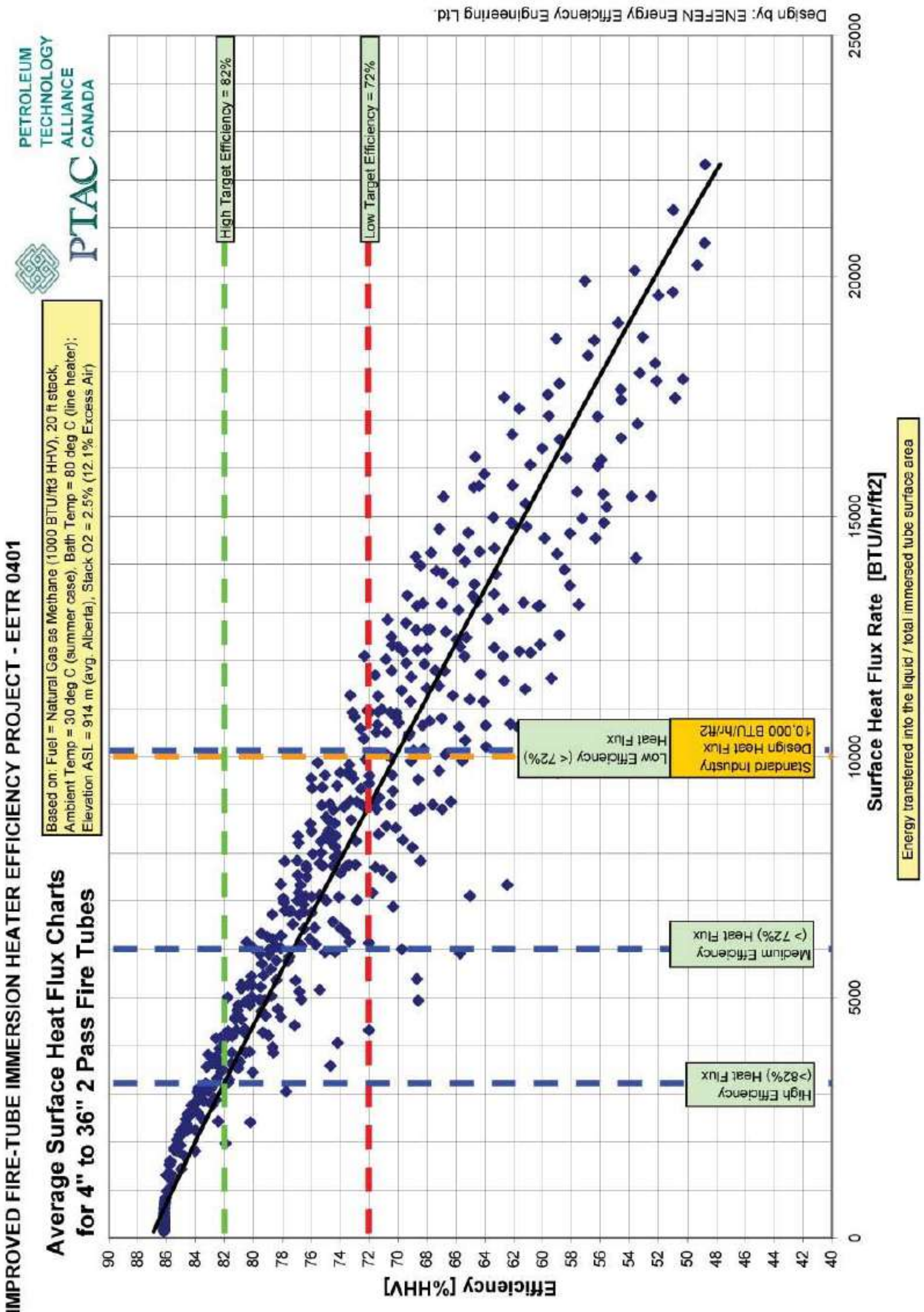


FIGURE 12.1 Distribution of Thermal Efficiency Results for Various Heat Flux Rates in a 4” to 36” Two Pass Natural Draft Fire Tube

12.2 Distribution of Thermal Efficiency Results for Various Heat Flux Rates in a 4" to 36" Four Pass Natural Draft Fire Tube

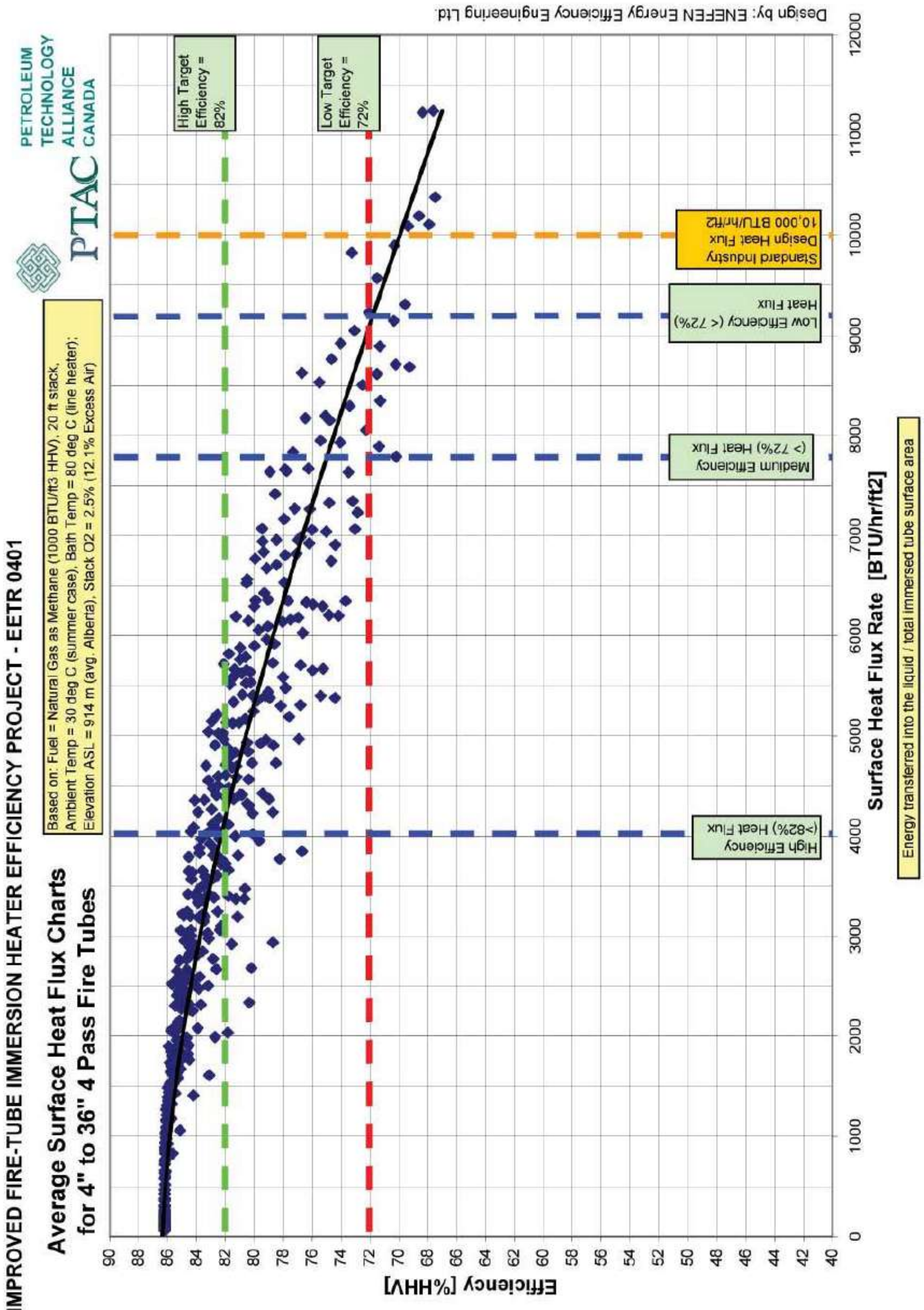


FIGURE 12.2 Distribution of Thermal Efficiency Results for Various Heat Flux Rates in a 4" to 36" Four Pass Natural Draft Fire Tube

12.3 Distribution of Thermal Efficiency Results for Various Heat Flux Rates in a 4” to 18” Four Pass Forced Draft Fire Tube

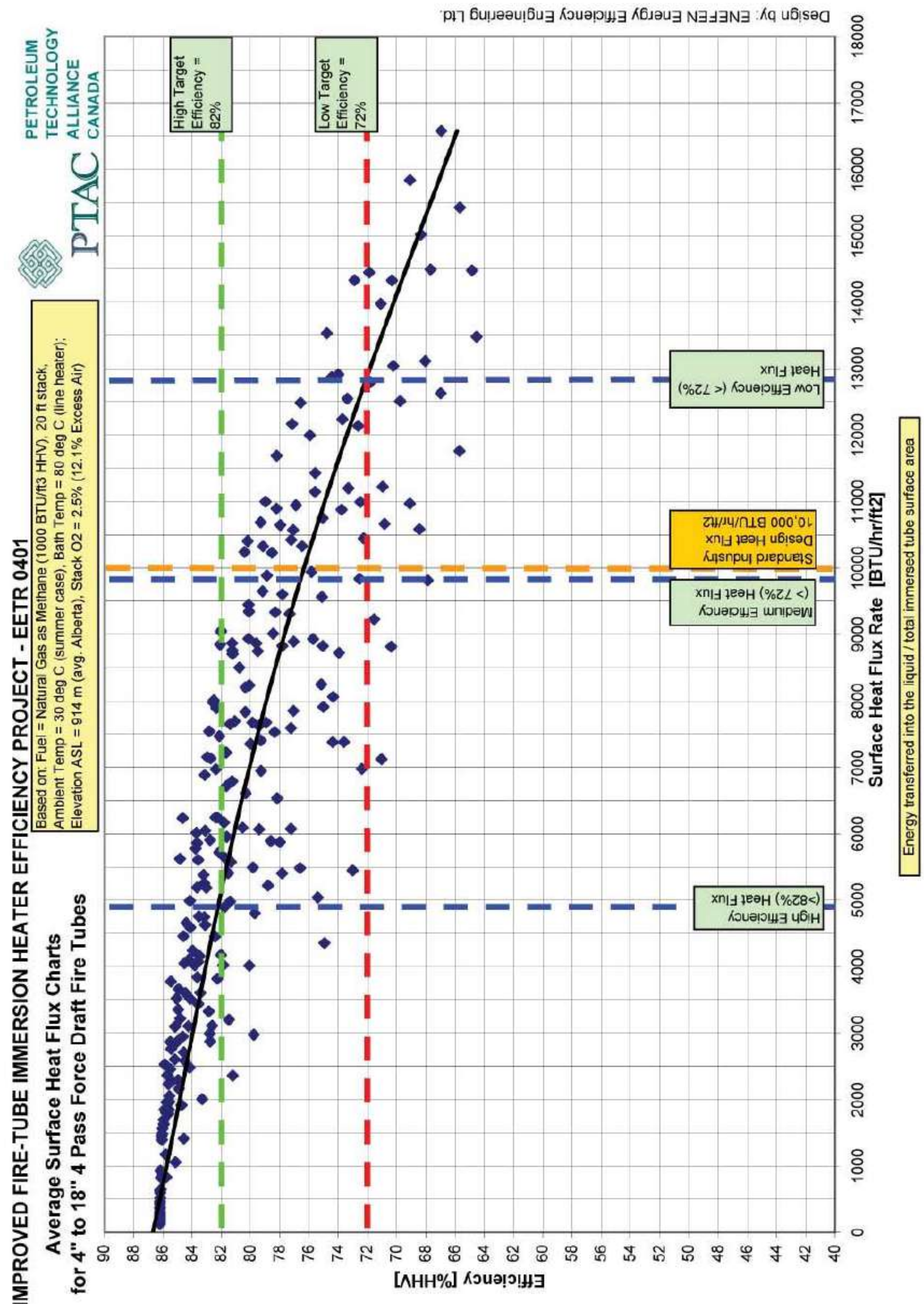


FIGURE 12.3 Distribution of Thermal Efficiency Results for Various Heat Flux Rates in a 4” to 18” Four Pass Forced Draft Fire Tube

12.4 Comparison of Efficiency Distribution in a 2-, and 4-Pass Natural Draft and 4-Pass Forced Draft Fire Tube

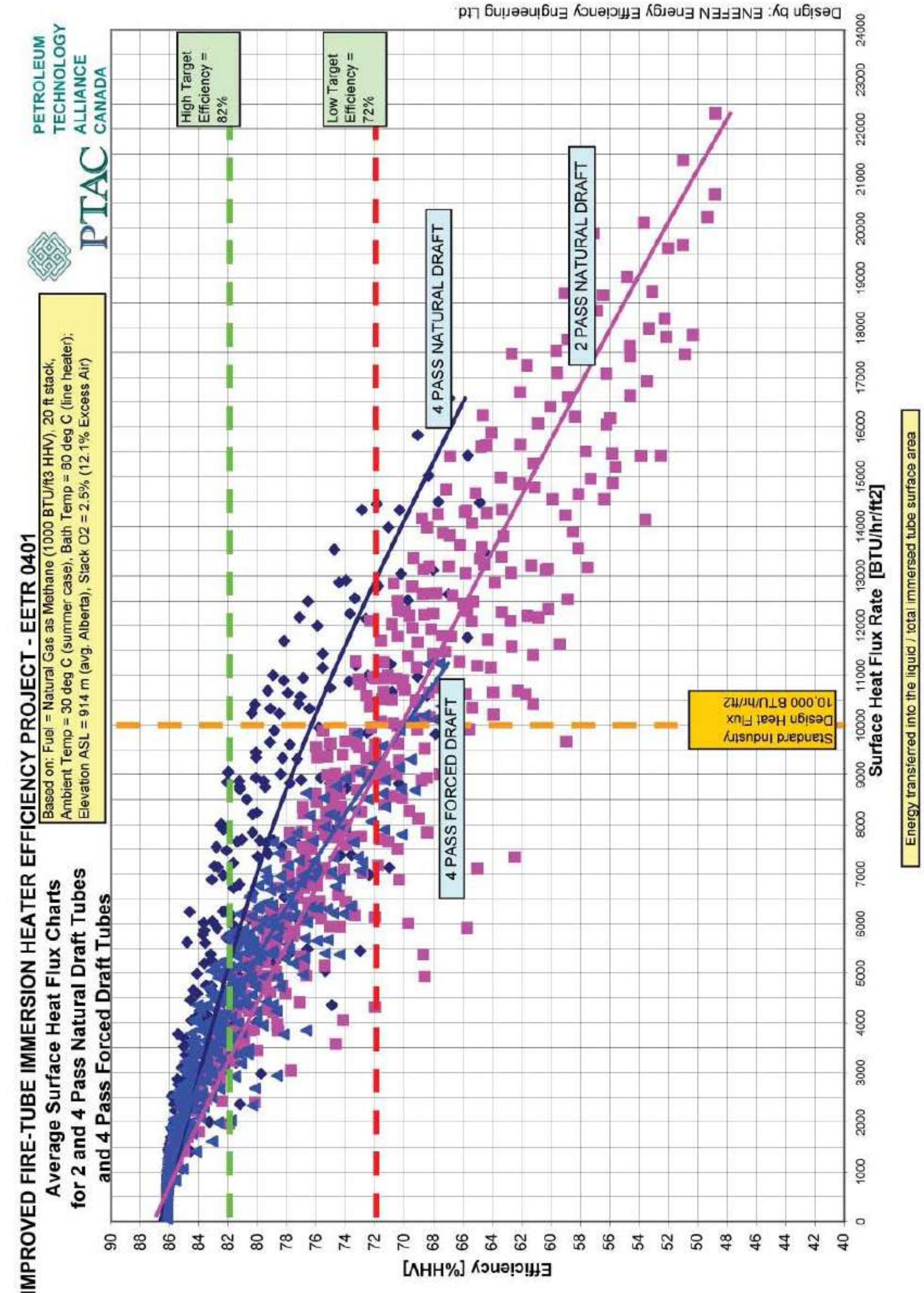


FIGURE 12.4 Comparison of Efficiency Distribution in a 2-, and 4-Pass Natural Draft and 4-Pass Forced Draft Fire Tube

12.5 Cross-sectional Heat Flux

Figures 12.6 to Figure 12.11 illustrate the relationship between the cross-sectional heat flux rate of a fire-tube and its efficiency for various sizes of 2-pass natural draft fire-tubes from 4” to 36” diameter. The purpose of this analysis is to address the commonly used “rule of thumb” for designing the fire-tube for 15,000 BTU/hr/in2 of tube cross-sectional area.

Based on the curves, the following table illustrates the cross-sectional heat flux rate values at which gross thermal efficiency is either always-below 72%, always within the 72% to 82% target range or always above 82%.

	Gross Efficiency [%HHV]		
Fire-Tube Diameter	<72%	72% to 82%	>82%
4" to 10"	22,000	7,000	2,000
10" to 14"	24,500	5,000	1,500
14" to 18"	23,000	4,000	1,300
18" to 22"	19,000	4,000	1,500
22" to 26"	15,100	4,800	1,800
26" to 36"	12,500	3,500	1,500
Average	19,350	4,717	1,600

Although the cross-section al heat flux rate values change with tube sizes, their calculated average values are a good guideline for evaluating a 2-pass natural draft fire-tube performance:

a) Rates higher than 19,000 BTU/hr/in2 will result in gross efficiencies lower than the low target of72%HHV;

b) Rate of 4,700 BTU/hr/in2 will result in efficiencies within the target range of 72% to 82%

c) Rates below 1,600 BTU/hr/in2 will result in efficiencies exceeding the high 82%HHV efficiency target.

For the purpose of “guaranteeing” that the fire-tube design will fall within the 72% to 82% target efficiency range, we can combine the above 4,700 BTU/hr/in2 cross-sectional heat flux rate with the previously established 7,000 BTU/hr/ft2 surface heat flux rate to achieve an “ideal” 2-pass fire-tube design. As a result we obtain an “equal-diameter-length” curve illustrated in the Figure 12.5.

The burner heat input expressed in BTU/hr HHV is shown on the horizontal X-axis of the graph. The vertical Y-axis shows the tube diameter in inches and also the U-tube length in feet. For example: according to the graph an “ideal” 2-pass natural draft fire-tube designed for 1 MM BTU/hr HHV burner heat input should be 16.5” in diameter and 16.5 feet long (i.e. approximately 33 ft total tube length). According to the rating charts from the previous chapter, such fire-tube would provide indeed 74% HHV thermal efficiency.

The purpose of this section is not to provide a single curve which can be used to design all sizes of fire-tubes for all application, but to illustrate how the knowledge of cross-sectional and surface heat flux rates could be used for “rough estimates” of the heater’s efficiency.

As explained previously, there is simply no single heat flux value, which would address all applications with a reasonable accuracy. The heat transfer model of a fire-tube heater, unfortunately has too many variables and is too complicated, to be able to condense it into a simple formula or a single value.

As the “equal-diameter-length” curve leads to somewhat oversized designs, so do commonly published and used practice of 10,000 BTU/hr/ft2, and the 15,000 BTU/hr/in2, surface and cross-sectional heat flux rates, do not take under consideration a number of factors needed for the optimization of the fire-tube thermal performance. As demonstrated in this chapter the use of either one of the two heat flux values will almost certainly lead to heater designs with efficiencies lower than our target range of 72% to 82% HHV.

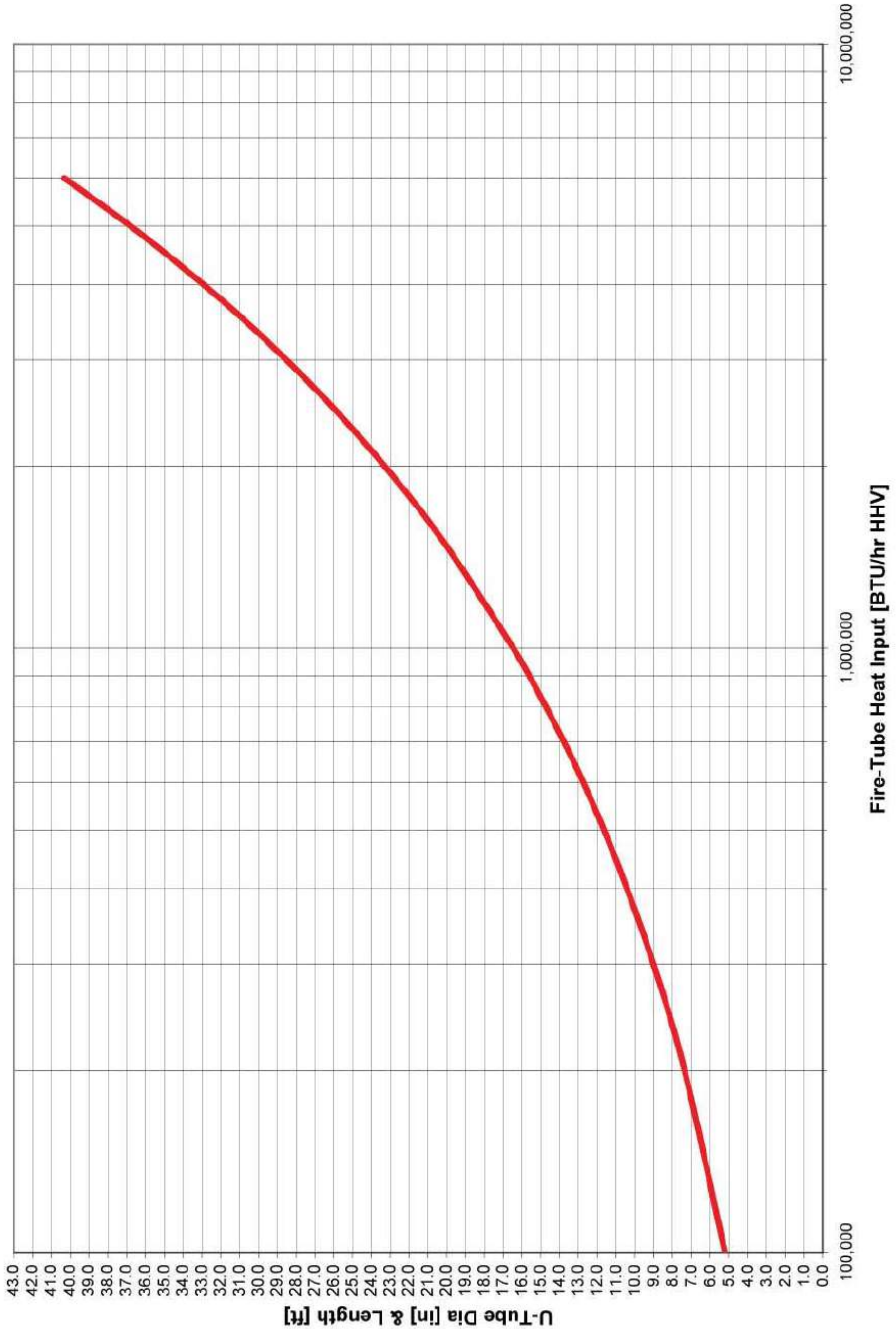


FIGURE 12.5 “Equal-Diameter-Length” Curve for a 2-Pass Natural Draft Fire-Tube

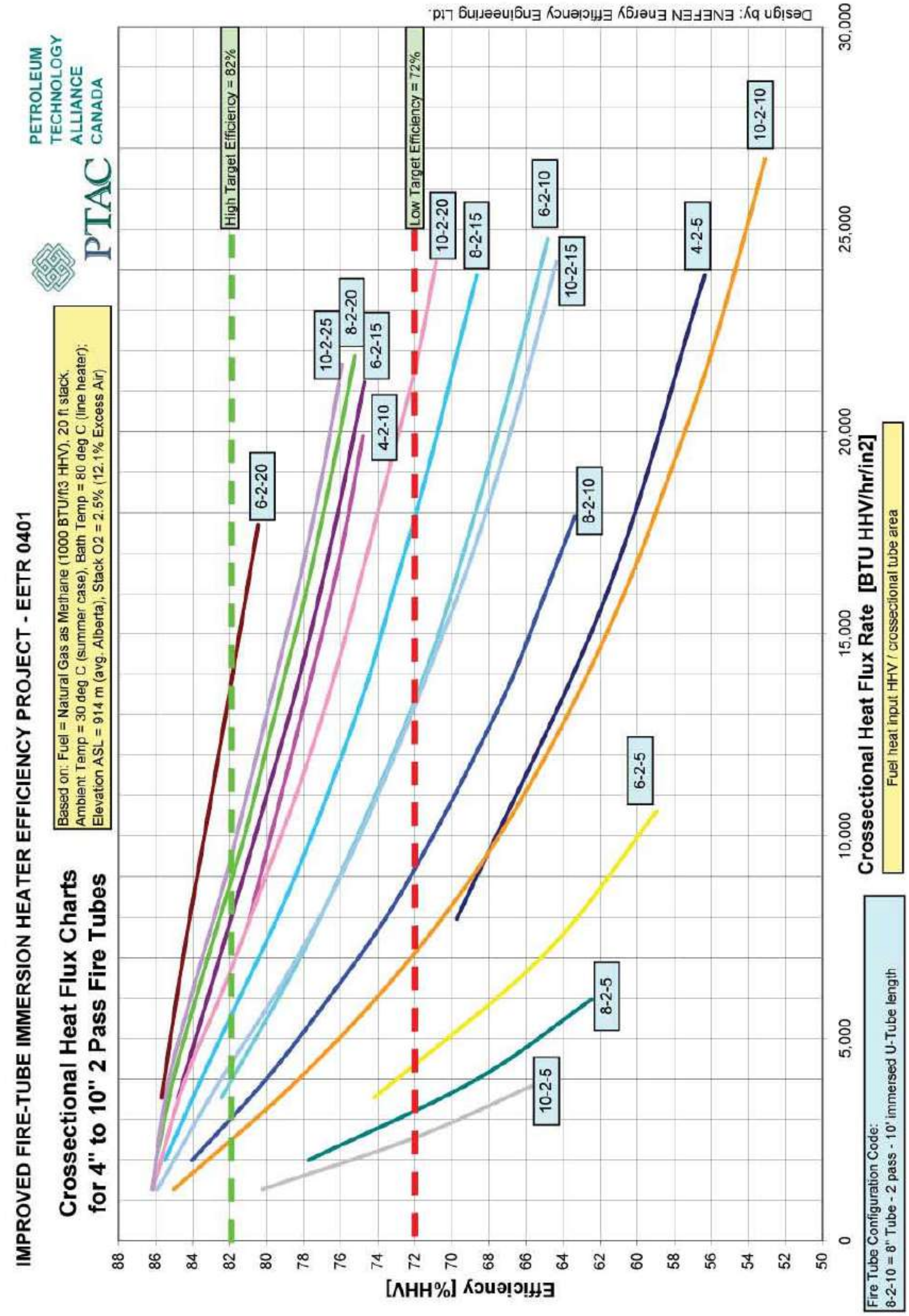


FIGURE 12.6 Cross-sectional Heat Flux Rate for 4" to 10" Fire Tubes

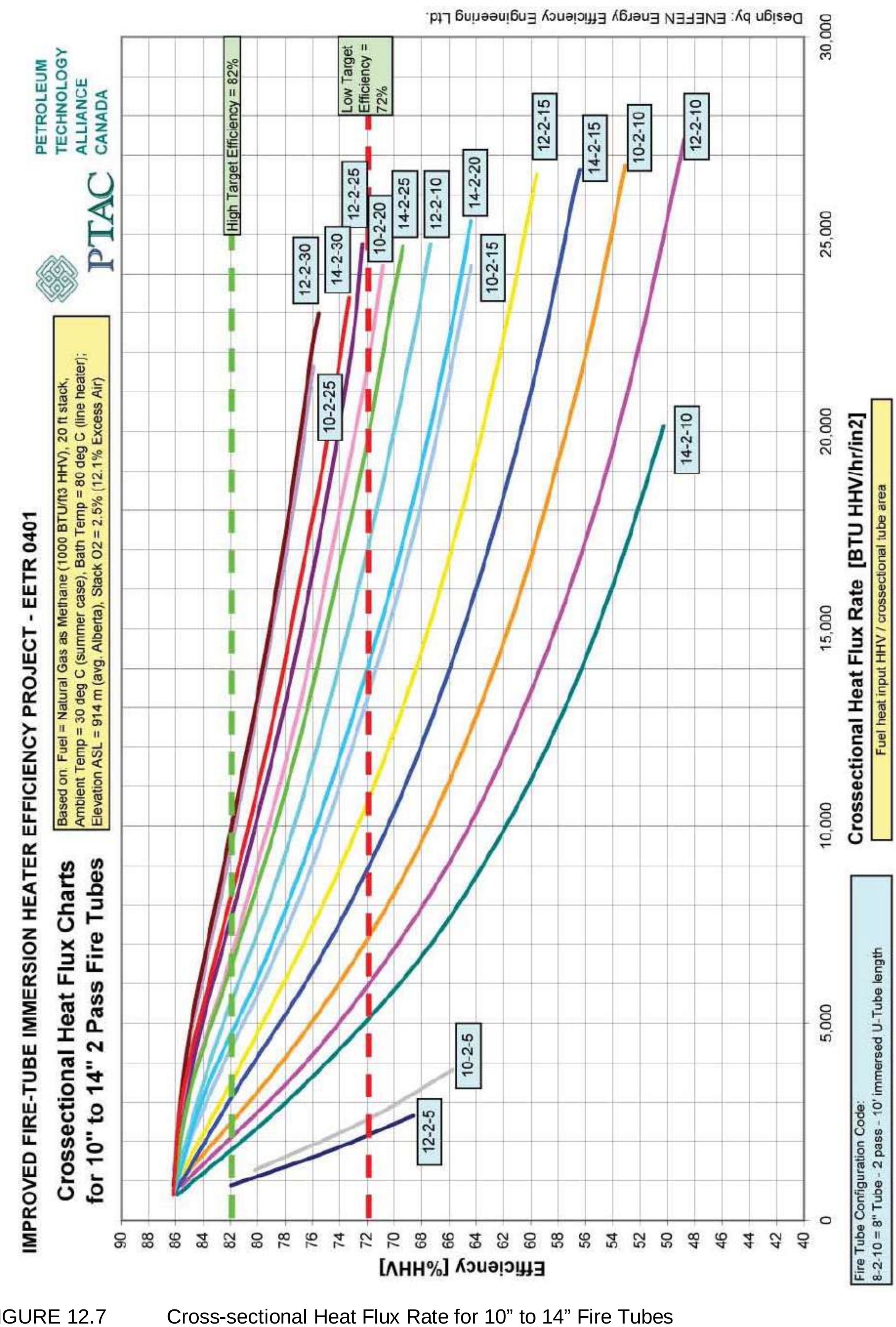


FIGURE 12.7 Cross-sectional Heat Flux Rate for 10" to 14" Fire Tubes

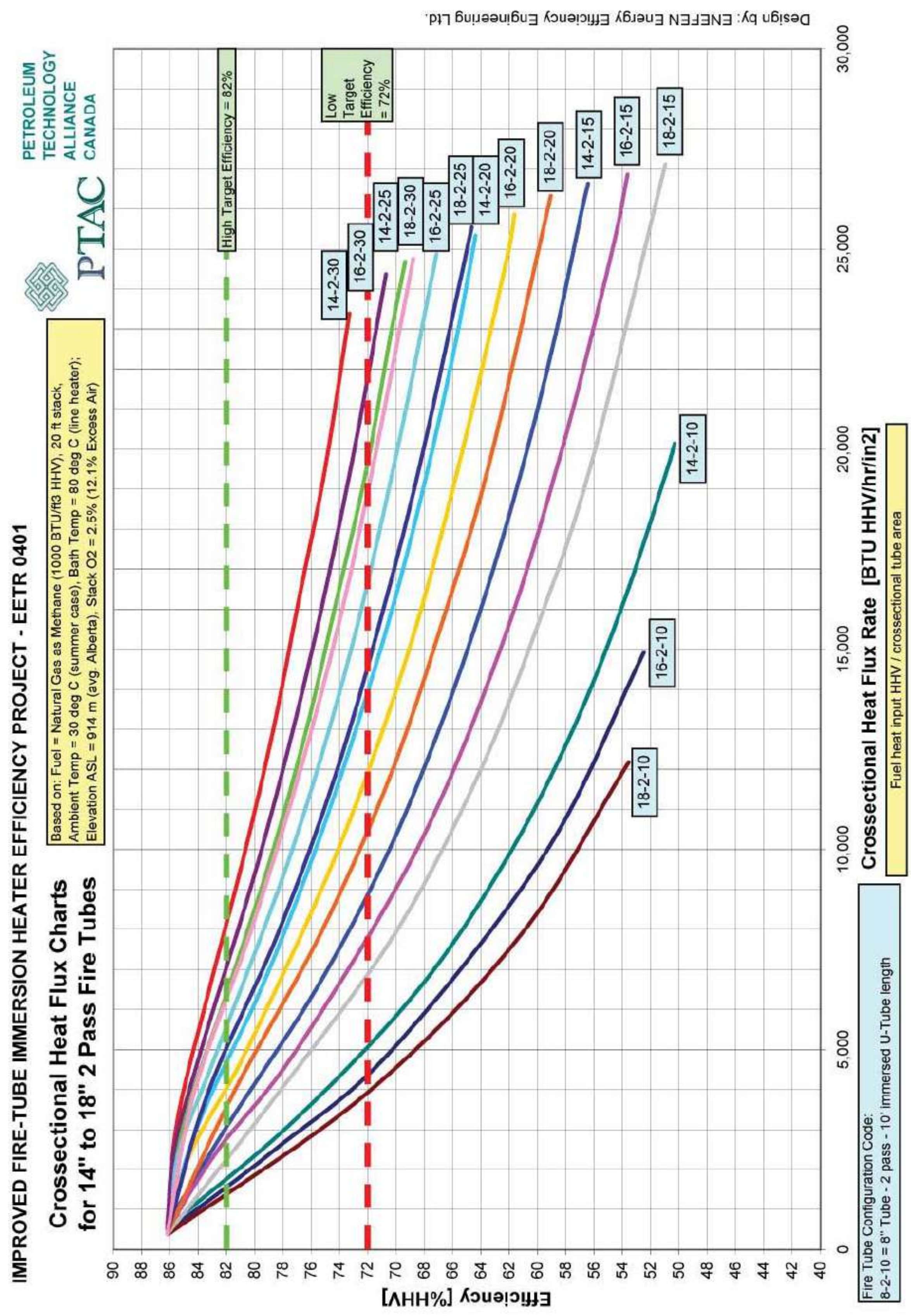


FIGURE 12.8 Cross-sectional Heat Flux Rate for 14" to 18" Fire Tubes

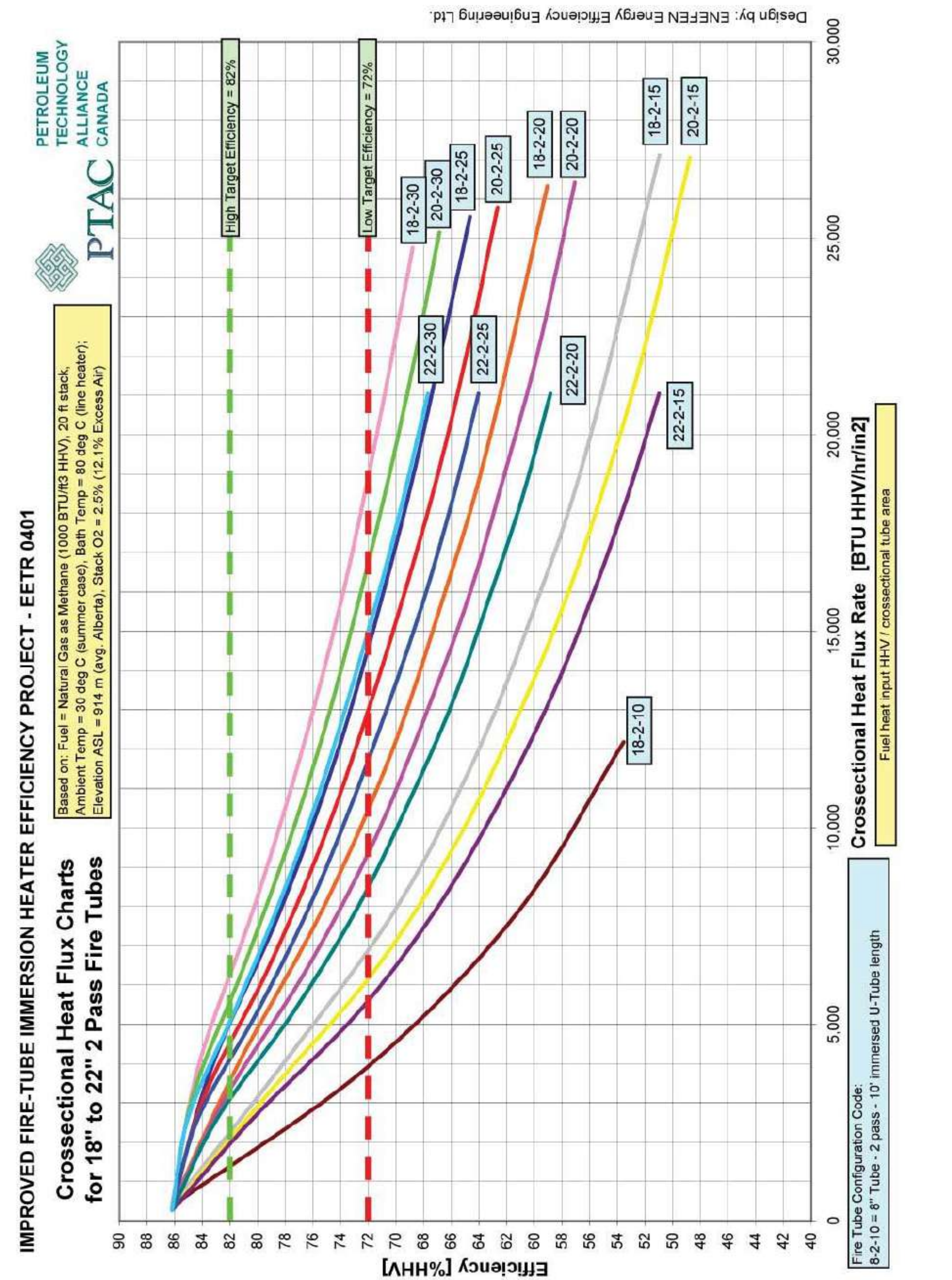


FIGURE 12.9 Cross-sectional Heat Flux Rate for 18" to 22" Fire Tubes

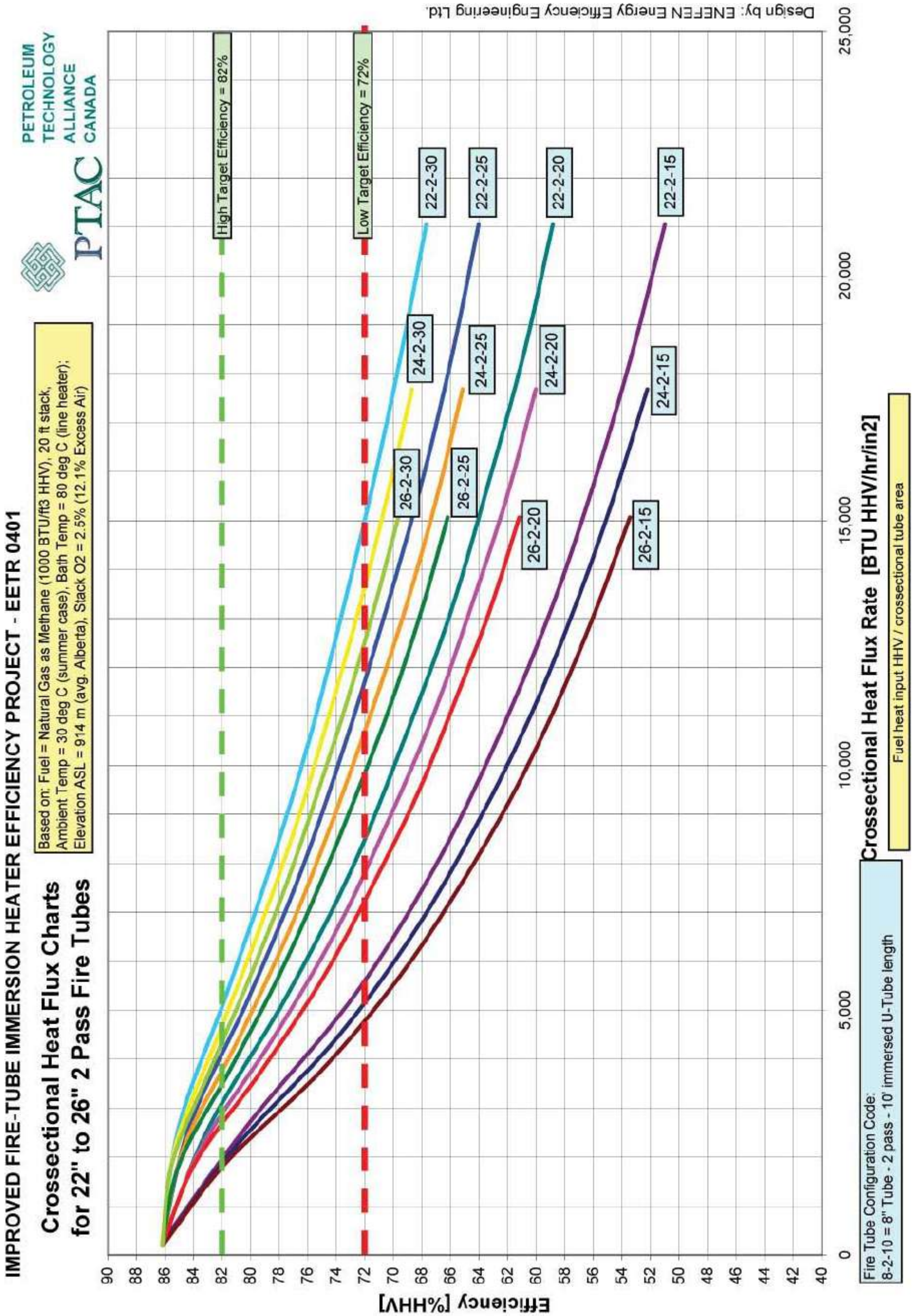


FIGURE 12.10 Cross-sectional Heat Flux Rate for 22” to 26” Fire Tubes

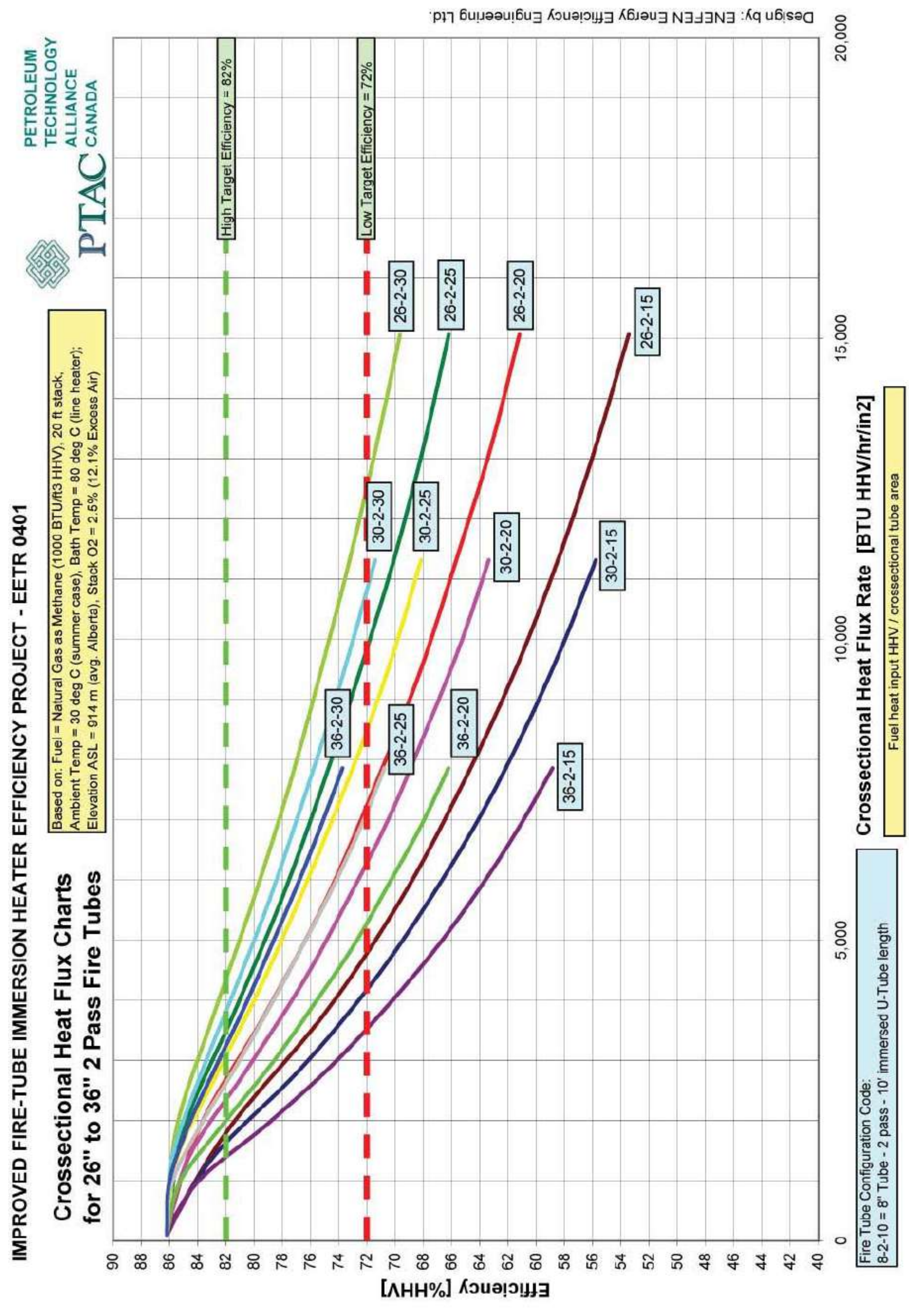


FIGURE 12.11 Cross-sectional Heat Flux Rate for 26” to 36” Fire Tubes

12.6 Impact of Fire Tube L/D Ratio on Thermal Efficiency

Another "rule of thumb" found in the some of the references is the L/D (length / diameter) ratio, which will provide best fire-tube design.

For the purpose of testing this concept, a comparative graph of L/D ratios for 1 MM BTU/hr firing in fire-tube sizes from 12" to 36" is illustrated in the Figure 12.12.

For low efficiency target of 72% the L/D ratios are as follows: 12" L/D = 27; 14" L/D = 21; 16" L/D= 17; and 18" L/D = 13.5.

For high efficiency target of 82% the L/D ratios are as follows: 12" L/D = 54; 14" L/D = 44; 16" L/D= 35; 18" L/D = 28; 20" L/D = 23 ; 22" L/D = 20 ; 24" L/D = 14.5.

There does not seem to be any specific L/D value, or correlation, which would be common to the above results. Consequently, we concluded that the L/D design rule of the fire-tube design is incorrect.

12.7 Fire Tube Efficiency with Constant Length

Figure 12.3 was designed to test another "rule of thumb" found in the literature, claiming that the heat transfer does not change with tube diameter but only with tube length.

The horizontal X-axis of the graph shows tube diameter, the vertical Y-axis the thermal HHV efficiency. Individual curves represent fixed fire U-tube length in 5' increments from 10' to 30'. For each constant length efficiency changes for different tube diameters, for example for a 15' long U-tube following are the fire tube efficiencies: 8" = 71%; 10" = 72.5%; 12" = 73"; 14" = 76%; 16" = 77%; 18" = 78.5%, etc.

Based on the above, the fire-tube thermal efficiency changes both with the fire-tube length and diameter. Consequently, we conclude that the "constant fire-tube length" rule of heat transfer is incorrect.

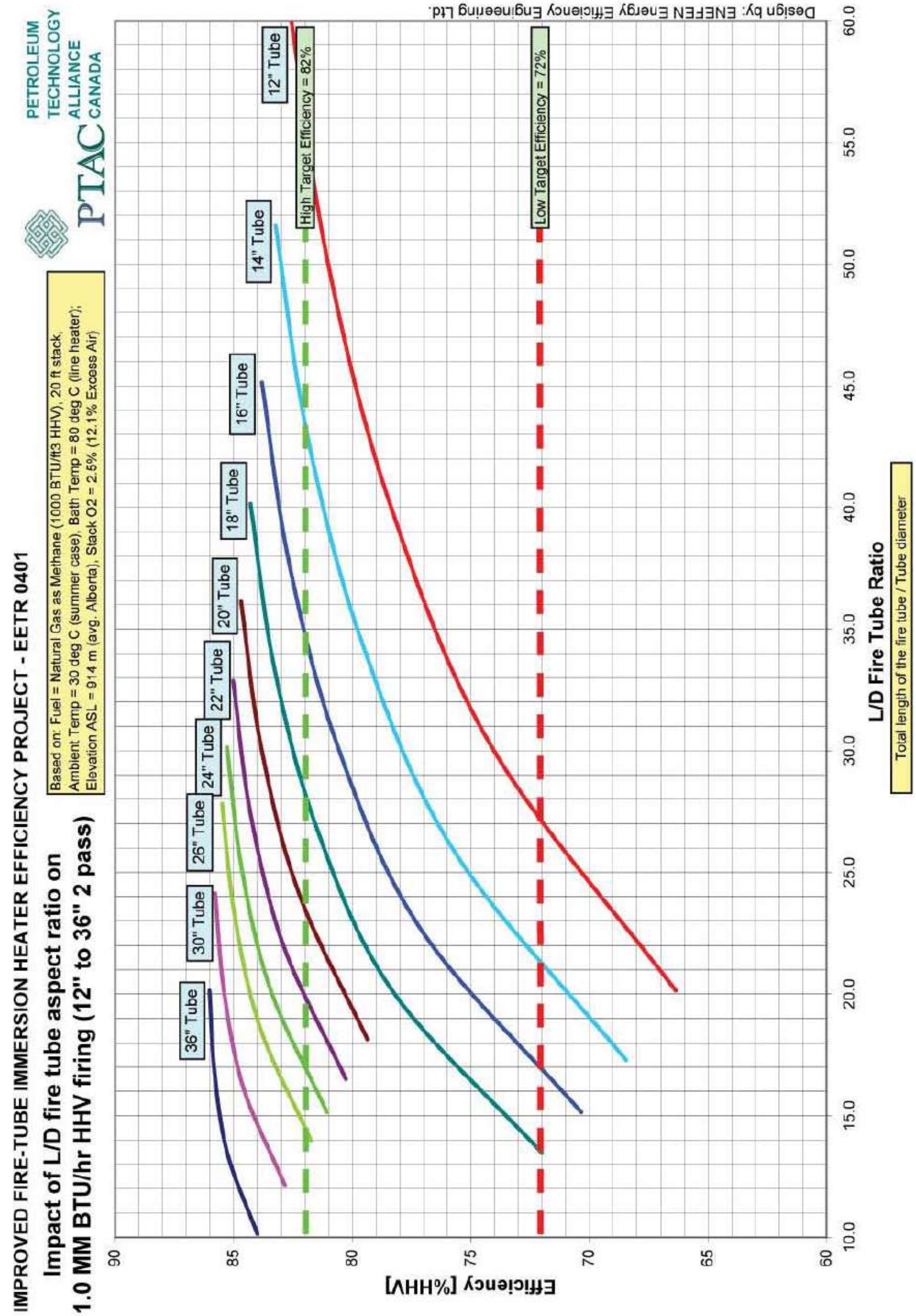


FIGURE 12.12 Impact of Fire Tube L/D Ratio on Thermal Efficiency

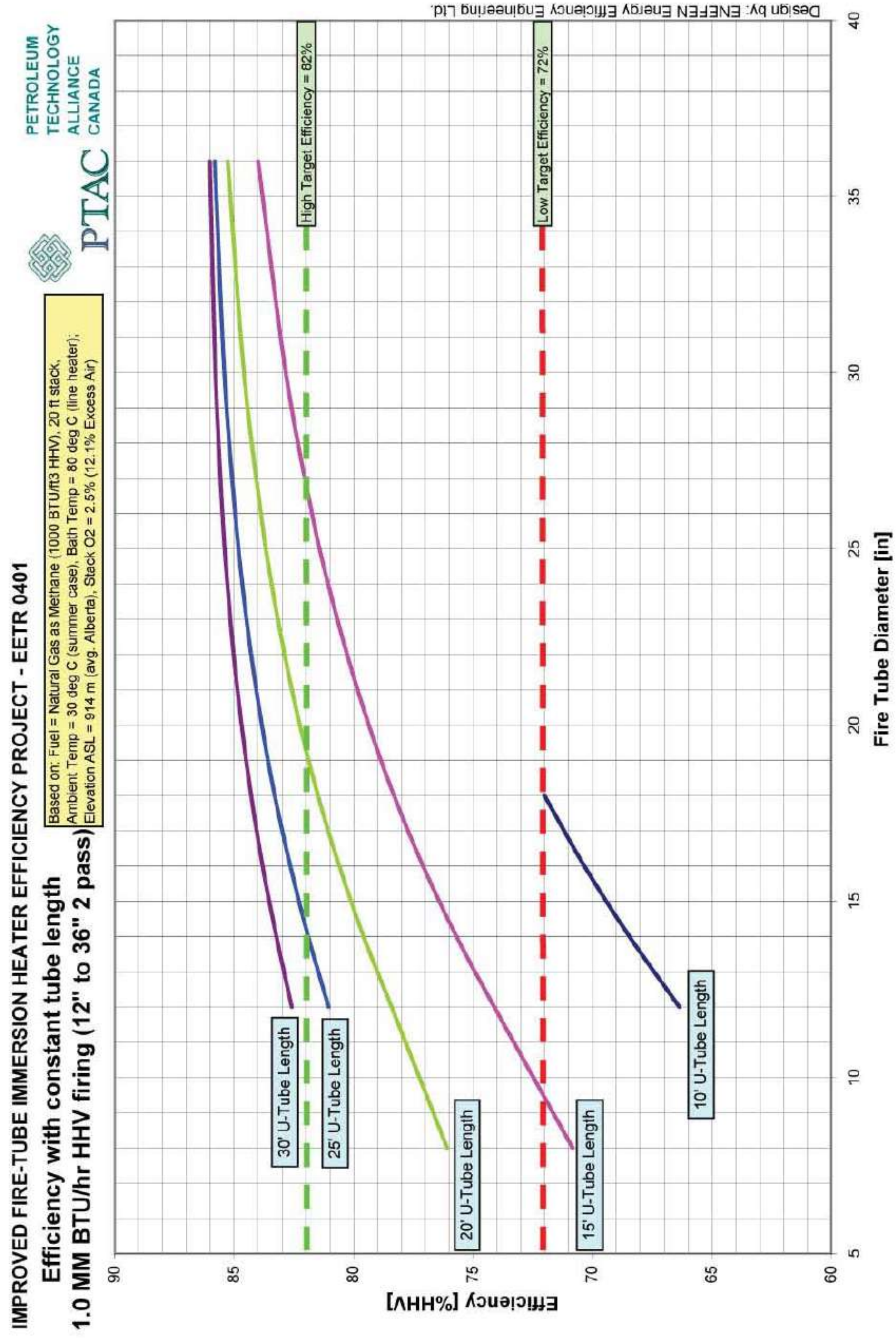


FIGURE 12.13 Efficiency of Fire Tube with Constant Length

13 FIRE-TUBE HEATER EFFICIENCY, RELIABILITY, AND TUNE-UP GUIDELINES

This chapter contains the following two guidelines intended for the operating and maintenance personnel:

a) Combustion Efficiency, Emissions And Reliability Guideline – This guideline is of general nature and designed to provide the operating and maintenance personnel with basic information on this topic; and,

b) Fire-Tube Heater Tune-up and Inspection Procedure – Provides simple, step-by-step procedure for evaluating and tuning-up fire-tube heaters for best immediate efficiency gains. In the process, appropriate design and performance data is recorded, which can be forwarded by the operator to the engineering department for an in-depth evaluation. Note that the procedure assumes the availability of a combustion analyzer to the person performing it.

The above two guidelines are intended to help in a time-effective data collection and evaluation process, which has been tested not to exceed more than 30 minute per heater. During this evaluation, basic burner adjustment can be performed, in order to eliminate obvious cases of fuel overfiring, or combustion air deficiency, thus yielding a "reasonable" performance data record. Installations, were such improvement cannot be achieved through simple adjustment can be immediately reported to a combustion technician for specialist servicing. Data from heaters with "reasonable" readings can by further analyzed for potential energy and emission savings.

These guidelines should be used as part of the training program discussed later in this report.

13.1 Combustion Efficiency, Emissions, and Reliability Guidelines

IMMERSION HEATER FIELD INSPECTION AND EFFICIENCY EVALUATION REPORT COMBUSTION EFFICIENCY, EMISSIONS AND RELIABILITY GUIDELINES	PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA Design by: ENEFEN Energy Efficiency Engineering Ltd

1	**EFFICIENCY DEFINITION**: Efficiency is defined as the percentage of gross BTU input that is realized as useful BTU output of a heater. There are two ways of calculating this efficiency: the HHV efficiency uses the higher heating value of fuel input, and the LHV efficiency uses lower heating value of fuel input.
2	**LHV AND HHV BASED EFFICIENCY CALCULATIONS** For example pure methane HHV = 1012 BTU/cuft and LHV = 911 BTU/cuft, and the difference is the amount of energy used to evaporate water produced during the combustion process from the hydrogen contained in the fuel. Hence for the same combustion process using methane as a fuel the LHV efficiency value is about 10% higher than the HHV efficiency value. Where the LHV efficiency is easier to use for evaluation of traditional style heaters which do not condense water out of the products of combustion, it cannot be meaningfully used for newer condensing type heaters. In addition, since fuel is measured and sold based on its HHV value, only the HHV based efficiency should be used for the economic evaluation of the heater performance. LHV based efficiency is typically used in the US and the HHV efficiency is more commonly used in Canada. All regulatory requirements in Canada related to burner and fuel controls rating are based on HHV of fuel. Since many heater specifications and many combustion analyzers do not clearly state the basis for efficiency calculations, caution should be exercised when using these efficiency values.
3	**COMBUSTION EFFICIENCY - OVERALL COMBUSTION EFFICIENCY - FUEL EFFCIENCY - HEATER THERMAL EFFICIENCY**: These terms are used in the industry interchangeably, although with a fair amount of confusion. To clarify: any of these efficiency terms is based on the calculation of 100% of energy input into the heater (expressed in either LHV or HHV terms) <u>minus</u> the summation of all the losses from that heater, which <u>equals to</u> the useful heat output to the process load. The losses can be either combustion related or heater design specific.
4	**COMBUSTION LOSSES FROM THE HEATER**: These losses include: - latent heat of evaporation to moisture in the stack formed from oxidation of hydrogen in the fuel - unburned fuel (VOC's in the stack) including hydrocarbons, CO, soot (free carbon), H2S or any other combustible compound which did not get oxidized to form CO2 or H2O - sensible heat lost to heat the product of combustion above the ambient air temperature. Products of combustion include also nitrogen, excess oxygen and H2O vapour from ambient air humidity and possibly the unburned fuel which do not take part in the combustion process but are also heated to the stack temperature. Note that besides combustion air, ambient tramp air can also infiltrate the heater through cracks and openings, however that tramp air would be then included in the products of combustion.
5	**HEATER DESIGN SPECIFIC LOSSES**: These losses include: - wall / piping / insulation losses - the energy which radiates out of the heater into the surroundings and is carried away by air (wind), foundations, or connecting equipment. Note that only the heat loss from the portion of the stack surface below the location of the thermocouple used for the efficiency measurement would be considered as a loss for this calculation. - opening losses include any products of combustion leaks from the heater other than stack gas. - conveyor losses include heat carried away by any form of process "conveyor" which does not stay in the process "product". This would also include heat loss through the piping connecting process to the heater. - heat storage losses - the energy which is stored in the heater steel, insulation, heat transfer medium, connected equipment, foundation, etc. For heaters, which operate continuously the amount of stored energy remains constant after the initial heatup. For heaters which operate in batch mode or which cycle on/off, the amount of stored heat changes and must be replenished every time the heater is refilled and restarted.
6	**STACK OXYGEN**: Stack oxygen level should be maintained between 2% and 4%, which corresponds to between 9.5% and 21.1% excess air. Below 2% oxygen, sharp increase in CO emissions is expected; above 4% oxygen additional excess air "taking a free ride" through the heater decreases the combustion efficiency
7	**STACK CO:** Stack CO levels should be maintained below 400 ppm safety ceiling. Ideally, in a properly tuned system CO levels below 100 are desirable. Typically, depending on the burner design, CO readings increase at low (below 2%) or high (above 11%) oxygen levels. High CO readings indicate incomplete combustion due to insufficient air flow or due to flame quenching with too much air.
8	**STACK NOx:** Stack NOx levels are a function of burner design and specifically flame shape and temperature. Smaller and hotter flames tend to produce higher NOx levels. Also burners with a single fuel injection port tend to produce higher NOx levels than those with multiple smaller and spread out ports (fuel staging effect). Typically, properly designed natural draft burners produce between 60 ppm and 80 ppm corrected to 3% oxygen (V/V dry basis) in the stack. Within a given burner design NOx formation is pretty well fixed and cannot be changed by regular tune up techniques.

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FIGURE 13.1 Combustion Efficiency, Emissions and Reliability Guidelines Page 1 of 4

IMMERSION HEATER FIELD INSPECTION AND EFFICIENCY EVALUATION REPORT	PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA
COMBUSTION EFFICIENCY, EMISSIONS AND RELIABILITY GUIDELINES	Design by: ENEFEN Energy Efficiency Engineering Ltd.

9	**STACK NOx READINGS CORRECTION:** It is important to understand that the increased air flow through the system will result in lower NOx readings from the combustion analyzer simply by the dilution effect. However to get a true NOx production levels these readings must be corrected to 3% (V/V dry basis) O2 readings or otherwise expressed in mg of NOx produced per 1.00 MM BTU fuel input. Some combustion analyzers provide such correction capability.
10	**FLAME COLOUR:** With natural gas firing, uniform blue flame indicates proper air fuel/mixing and efficient combustion. Orange flame indicates rich combustion with insufficient oxygen and high CO and in extreme cases is accompanied by a visible dark smoke from the vent stack. Purplish flame areas or orange streaks (sparklers) indicate incomplete fuel air mixing, and are common even with correct fuel/air ratios.
11	**FLAME SHAPE:** Uniform, "tight" flame bushel indicates proper mixing and fuel to air ratio. Depending on the type of the burner nozzle this flame can be either narrow and long ("pencil flame"), reaching further into the tube or shorter and "bushy". Typically flame length could be between 1.0 and 6.0 feet . Exceedingly long and inconsistent ("branching out") flame shape is an indication of poor air and fuel mixing and poor flame shaping capability of the burner. A small and "lazy" "candle-like" flame indicates too large burner for given fuel input.
12	**FLAME SOUND:** Uniform "humming" sound of the burner in operation indicates proper air fuel/mixing and efficient combustion. Pulsations in the flame indicate improper fuel/air ratio and mixing, with either "too much" or "not enough" air or gas flow or a restriction in the flow path of the products of combustion.
13	**FLAME ANCHORING:** Flame should appear as if it was solidly attached ("anchored") to the burner nozzle. In extreme cases at really low firing rates pulsation will be accompanied by pulling the flame back into the burner and combustion inside the burner tube. On the other side of this spectrum with really high heat releases from the burner flame may be pulling off the burner nozzle and "floating" in front of it. In both cases flame detection and burner trips due to "snuff-outs" are to be expected.
14	**PILOT OFF TEST:** Although most of the heaters are equipped with a pilot which stays lit during main burner operation, properly adjusted main burner should maintain stable and well anchored flame without pilot flame being present. This may be difficult to test on systems with burner management systems which rely on the pilot flame sensing to maintain the main shutoff valves open, unless the main valves are temporarily forced open while the pilot is turned off.
15	**FLAME ORIENTATION:** Flame size, shape and orientation should prevent flame bushel from "licking" the fire tube surface. Such flame impingement on cold metal surface leads to interruption of the combustion process and incomplete combustion, formation of CO, formaldehyde or formic acid, or free carbon (soot), which in turn reduce heat transfer to the tube and increase tube corrosion rate. Since the flame has a natural buoyancy to rise, a slight tilt downwards of the burner may help in avoiding flame impingement on the tube.
16	**BURNER CAPACITY:** Typically, natural draft burners are limited to between 3:1 or 4:1 turndown and can only work efficiently within about 3 closely matched orifice sizes. In a properly sized Venturi style burner, higher gas pressure creates high gas velocity through the orifice which in turn creates negative suction pressure inside the Venturi, which, induces primary air into the burner. If the Venturi is oversized or gas orifice is undersized this principal does not work. Even with properly sized burner, fuel gas pressure in excess of 20 PSIG may be required to induce 100% combustion air into the burner. At 10 to 15 PSIG only 50% of air is induced, and below 5 PSIG gas pressure Venturi in ineffective.
17	**STACK HEIGHT:** Secondary air flow induced by natural draft action of the stack are needed to supplement the primary air induced by the Venturi. The draft available at the burner depends on the stack height, diameter, and the difference between stack gas temperature and ambient temperature. More draft is available on a cold day, and with higher stack gas temperatures. On the other hand cold wind blowing against exposed stack surface cools the stack gas and reduces the natural draft, hence the stack insulation is considered to be an effective way of maintaining the stack draft and also preventing moisture condensation inside the stack. As a "rule of thumb" each 10' of stack height above the burner centerline elevation provides 0.1" W.C. natural draft, and a minimum 20' of stack height (0.2" W.C. draft) is recommended.
18	**IMPACT OF FLAME ARRESTOR ON AIR FLOW:** In most cases, flame arrestors (flame cells) tend to be oversized and have a large open surface to the air flow, thus not creating any significant restriction. With time however, the flame cells can become plugged with foreign matter such as dust and effectively restrict the air flow. Under certain atmospheric condition a frost buildup on the outer face of the flame cell may also restrict the air flow. Annual cleaning of the flame cell is recommended.

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FIGURE 13.2 Combustion Efficiency, Emissions and Reliability Guidelines Page 2 of 4

IMMERSION HEATER FIELD INSPECTION AND EFFICIENCY EVALUATION REPORT

PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA

COMBUSTION EFFICIENCY, EMISSIONS AND RELIABILITY GUIDELINES

Design by: ENEFEN Energy Efficiency Engineering Ltd.

19	**PRIMARY VS. SECONDARY AIR ADJUSTMENT:** The primary air induction into the burner mixer and thorough mixing of the fuel and air within the burner body is the key to the successful operation of a natural draft burner. This mixing using high kinetic energy and turbulence of the fuel gas is more effective than the subsequent mixing provided by the relatively slow moving stream of secondary air. It is therefore recommended that the primary air mixing capability of the burner be utilized as much as possible and only then "trimmed" with secondary air flow to obtain optimal O2 and CO readings.
20	**SECONDARY AIR FLOW CONTROL:** Secondary air flow control measures are considered to be an effective way to increase heater efficiency by trimming the total air flow to the burner. To be effective, secondary air control must be adjustable and must allow fine tuning. A fixed air flow restrictor at the entrance to the fire tube or a large diameter adjustable cover or band around the flame arrester housing do not allow such adjustment. As a general rule, a 1% reduction in the excess oxygen reading in the stack corresponds to approximately 1% thermal efficiency increase.
21	**BURNER & HEATER NOISE:** Burner and heater noise are a function of the natural resonance frequency of the burner and that of the fire tube and stack assembly. If the two frequencies match, a natural amplification of the burner noise by the tube occurs in a very similar way a musical instrument such as a trombone amplifies the vibrations of the mouthpiece, in this case resulting in a typical heater "rumble". Since the burner is the source of the noise originating from the pulsations of the flame front, modifications to the burner fuel/air ratio, mixing technique, and other combustion issues are the most effective way to deal with "noisy" heater installations. In some instances an improvement can be achieved by changing the ratio between the primary and secondary air. Third on the list of noise abatement techniques is the modification to the fire tube, in form of a baffle plate(s) placed strategically to change the acoustic characteristics of the tube. The external methods of noise abatement are usually less effective and most costly.
22	**STACK PLUME:** Typically white plume from the heater stack indicates that the heater is running with lower excess air and therefore more efficiently. If the excess air is high even on a cold winter day the plume is less visible. Dark plume from the stack indicates incomplete combustion through formation of free carbon (soot). On a sunny warm day, blue haze coming from the stack indicates elevated NOx levels.
23	**EFFICIENCY MEASUREMENT:** Heater efficiency can be quickly established by taking proper stack readings with a combustion analyzer plus the fuel flow measurement. Such evaluation is based on an assumption that if the stack loss is known, the balance of the heat input goes to the process. This is true with majority of the heaters which have a reasonable insulation. Typically 3-5% of fuel input is assumed as a loss though the insulation. By taking the O2 reading in the stack we establish the amount of excess air going through the burner. Taking the CO reading we establish the effectiveness of the combustion process itself in terms of how well it oxidizes the fuel. So ideally we do not want any CO in the stack or in practical terms less then 100 ppm. Then we take the stack base temperature reading to see how effective is the fire tube in transferring the energy from the products of combustion to the process. Based on the ExA (excess air) and FT (flue temperature) minus ambient air temperature we calculate the thermal efficiency of combustion then subtract from it 3 to 5% radiant and convective losses through insulation to obtain the thermal efficienc
24	**EFFICIENCY GUIDELINE:** As a general guideline the O2 in the stack should be between 2% and 4%, CO in the stack should be less than 100 ppm and stack base temperature should be between 100 deg C to 150 deg C above the bath temperature. So for a line heater with say 65 deg C glycol temperature setpoint, stack temperature should be between 165 deg C and 215 deg C. For an oil treater with 140 deg C oil temperature the stack temperature should be between 240 and 290 deg C. At winter ambient temperature of say -40 deg C, the gas side temperature rise will be therefore between 205 deg C and 330 deg C. As a result of these O2, CO and stack differential temperatures the combustion efficiency will be between 75% and 81%.
25	**HIGHER STACK TEMPERATURES:** Is flue temperatures measured at the base of the stack exceed the above guidelines of 100 deg C to 150 deg C above the bath temperature, there is a good chance that either the heater is overfired or that the fire tube is not transferring enough heat to the process.
26	**OVERFIRED HEATER:** Fuel flow should be checked against the heater process rating divided by a nominal efficiency of 0.65, and if found to be excessive, it should be lowered to within the design parameters. Since most of the heaters are not equipped with a fuel meter, either an installation of a turbine meter, metering orifice, or even pressure drop measurement through a known fuel gas orifice in the burner could be considered.

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FIGURE 13.3 Combustion Efficiency, Emissions and Reliability Guidelines Page 3 of 4

IMMERSION HEATER FIELD INSPECTION AND EFFICIENCY EVALUATION REPORT	PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA
COMBUSTION EFFICIENCY, EMISSIONS AND RELIABILITY GUIDELINES	Design by: ENEFEN Energy Efficiency Engineering Ltd.

27	**FIRE TUBE NOT TRANSFERING ENERGY:** If the fuel flow is found to match the appliance rating but the stack bottom temperature is still higher than the above efficiency guideline, then the performance of the fire tube should be investigated. This performance can be reduced by the inside of the tube fouling with either soot or corrosion or by a mismatch between the flame and products of combustion flow and the tube size. Knowing the tube configuration, fuel input and excess air, theoretical tube performance can be computed using combined radiative and convective heat transfer models. Although not a simple calculation, the fire tube rating software is being developed to address this requirement.
28	**FIRE TUBE PERFORMANCE COMPUTATION:** Knowing the tube configuration, fuel input and excess air, theoretical tube performance can be computed using combined radiative and convective heat transfer models. Although not a simple calculation, the fire tube rating software is being developed to address this requirement and graph based tools will be available to the industry in the near future.
29	**FIRE TUBE REMEDIAL ACTION:** If poor fire tube performance is proven, which cannot be improved by either internal or external tube cleaning, other efficiency improvement methods can be utilized. These include the maximization of the heater duty cycle or modifications to the tube design.
30	**HEATER DUTY CYCLE:** Heater duty cycle can be measured by trending TIME ON and TIME OFF of the heater. If heater is ON all the time duty cycle is 100%. If duty cycle is found to be significantly less than 100%, the firing rate of the heater can be reduced. The reduction of the firing rate lowers the stack temperature and increases efficiency. In addition, elimination of the time OFF also reduces heat loss to atmosphere due to natural draft and convection of ambient air through the tube. Ideally heater should be run continuously at a lowest firing rate required by the process demand, and with the lowest possible excess air and CO levels. To achieve this goal, physical improvements to heaters air control may have to be implemented.
31	**MODIFICATION TO THE TUBE DESIGN:** If duty cycle is already maximized and stack bottom temperature is still very high, the tube surface area is of inadequate size and or configuration for the job. An alteration to the tube should be considered based on the computations described above. The economic viability of such modification can be establish based on projected efficiency improvements.

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FIGURE 13.4 Combustion Efficiency, Emissions and Reliability Guidelines Page 4 of 4

13.2 Fire-Tube Heater Tune-up / Inspection Procedure

IMMERSION HEATER FIELD INSPECTION AND EFFICIENCY EVALUATION REPORT

HEATER TUNE UP / INSPECTION PROCEDURE

PTAC

PETROLEUM TECHNOLOGY ALLIANCE CANADA

Design by: ENEFEN Energy Efficiency Engineering Ltd.

1	**Gas Leak Test:** Check area around the heater and inside the fuel train or control enclosure (if present) for safe H2S, O2 and LEL levels
2	**Visual Inspection:** Inspect heater for obvious signs of deterioration, corrosion, damage to instrumentation or fuel train components
3	**Pilot observation:** Check if heater main burner is firing. If not, check if the pilot is on. If pilot is not on check if the fuel to the pilot is turned on and if so turn the pilot fuel off and wait a few minutes for the fire tube to ventilate. Check with the control room if there is any reason why the heater is turned off. Once safe to do so, turn the main burner manual fuel valve off, relight the pilot and observe. The pilot should be at least 4" to 8" in length, if smaller, try to increase fuel flow to pilot until "solid" pilot is established.
4	**Record Heater Data:** Record heater data such as make, model, year built, serial number, design process duty, burner type and size, burner orifice size, fire tube OD and length, stack OD and height, etc. as per enclosed inspection and evaluation report sheet.
5	**Main flame observation:** Check all heater permissives such as liquid level LO, temperature HI shutdown, bath temperature setpoint. If everything is OK, open the main burner manual valve. Observe main flame shape, colour, stability, anchoring, noise, impingement on the tube surface.
6	**Fuel Pressure Measurement:** Measure and record fuel gas supply pressure, and main burner pressure (after regulation) while it is firing.
7	**Fuel Flow Measurement:** If available measure fuel gas flow to the main burner by timing the gas meter or measuring pressure drop across the fuel metering orifice. Another simple method is the measurement of the burner gas orifice size and calculation of the gas flow using orifice pressure drop charts. Since the mixture pressure inside the burner Venturi is typically negligible compared to the burner inlet pressure, the burner inlet pressure can be used as an approximation of the pressure drop in the charts. Note, that this method cannot be utilized if the fuel gas orifice is used in conjunction with an adjusting needle valve as it is often the case with Eclipse mixers.
8	**Heater bath temperature check:** Locate bath temperature gauge and record bath temperature. Record also the temperature control setpoint of the temperature controller.
9	**Stack Measurements:** Locate sampling port in the straight length of stack above the fire tube exit from the heater. If no port is available, drill and tap 3/8"UNC hole in the stack. Using combustion analyzer take reading of: Flue Temperature, O2, CO, NOx and efficiency. Record also the ambient air temperature. After taking the sample install a 3/8" bolt using high temperature anti-seize compound or a brass bolt.
10	**HI CO / LOW O2 with air passages closed:** If CO reading is high (in thousands of ppm) and O2 reading very low (close to zero), the heater is being fired substoichiometrically without sufficient oxygen. Remove sample probe from the stack immediately to prevent damaging the CO analyzer cell. Let analyzer purge the cell until CO reading drops to zero. Open access port in the flame arrestor to allow more air flow. Insert analyzer probe back into the stack and observe CO readings. If readings have improved, with the access port open, there is a good possibility that the flame cell is plugged up and needs cleaning. Check also position of any secondary air control devices to make sure that they are not blocking the air flow into the burner.
11	**HI CO / LOW O2 with air passages open.** Burner primary air is misadjusted and must be opened. Open slowly watching the analyzer CO readings until CO levels are low. If there is no or slow reaction, reduce fuel gas pressure to main burner gradually also watching for changes in CO. On some burner models (Eclipse) there could be also a fuel needle valve present which could be adjusted. Note that overfiring of the heater without sufficient combustion air does not increase the heat transfer and it may even decrease it through tube sooting or decrease in the flame temperature. It is also unsafe and may lead to a premature heater failure.
12	**HI CO / HIGH O2** The indication is that there is too much combustion air. Reduce the primary and secondary air down to 3 to 4% oxygen in the stack.

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FIGURE 13.5 Fire Tube Heater Inspection and Tune-up Procedure – Page 1 of 2

IMMERSION HEATER FIELD INSPECTION AND EFFICIENCY EVALUATION REPORT	PTAC PETROLEUM TECHNOLOGY ALLIANCE CANADA
HEATER TUNE UP / INSPECTION PROCEDURE	Design by: ENEFEN Energy Efficiency Engineering Ltd.

13	**HI stack temperature:** If stack temperature is more than 150 deg C above the bath temperature, the fire tube is not removing the heat from the products of combustion due to overfiring or fouling. Check if the tube is fouled on the inside with soot, or possibly on the outside and perhaps needs cleaning.
14	**HI stack temperature with clean tube:** Fire tube is unable to transfer heat to the process. Compare the fuel flow to the process rating divided by 0.65 (nominal efficiency). If fuel flow is higher that that figure, reduce fuel flow.
15	**Measure heater duty cycle:** Leave data logger with thermocouple in the stack to record the Heater ON/OFF cycle. Alternately, heater bath temperature data trend from the plant control system could be used. Divide average time that the heater is ON by the total length of the ON/OFF cycle. If heater is on all the time the duty cycle is 100%. If duty cycle is significantly lower than 100% reduce firing rate to extend the time ON as much as possible. In some case this can be achieved simply by reducing the fuel pressure to the burner. In other cases burner orifice or the entire burner assembly should be replaced with a smaller one.
16	**Record all heater setup data on site on the rating plate "Last tune-up data" area (if available).**

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FIGURE 13.6 Fire Tube Heater Inspection and Tune-up Procedure – Page 2 of 2

14 INSTALLATION, OPERATING AND MAINTENANCE PERSONNEL TRAINING PROGRAM CONCEPT

Recent changes in Alberta legislation impose qualification requirements on personnel involved in the installation and startup of fired heaters. These requirements encompass not only new installations but also alteration and upgrade projects to the existing equipment. This definition includes immersion fire-tube heater efficiency upgrade projects discussed in this study.

In the following chapter, we propose a paradigm designed to address these projects and we identify a similar need for education and training programs for personnel that are involved in these projects. This need is not only based on a legal perspective but also on the general lack of experience in the industry with respect to energy conscious installation, startup, operation and maintenance of immersion fire-tube heaters. The primary concern is that in order to achieve verifiable long-term efficiency improvements both owner's and manufacturer's personnel need to be educated in the principles and details of this essential efficiency work. Without an educational component, the proposed paradigm is destined to fail like numerous similar projects undertaken in the past by various industries. It is our conviction that through proper training, the industry can raise the awareness in their employees of practical ways to improve the existing processes with both a positive environmental and economic outcome.

As part of this project, we discussed this training concept extensively with the Petroleum Industry Training Service (PITS) and consulted with the Alberta Municipal Affairs. In order for such a training program to be effective and legally acceptable, it would have to be endorsed by Alberta Advanced Education and with collaboration with our neighboring provinces it could also be extended to cover similar activities in BC and Saskatchewan. This program would respond to both the requirements of the current Alberta legislation and the proposed paradigm of the immersion fire-tube heater efficiency improvement program.

PITS have proposed the creation of a sub-trade called: Oilfield Gas-Fired Appliance Technician (OGFAT).

The following paragraphs are a conceptual description of this proposed program.

14.1 Oilfield Gas-Fired Appliance Technician (OGFAT) Sub-Trade Model

The development of the OGFAT program could be modeled after the three special sub-trades previously developed by PITS as follows: Special Oilfield Boiler Operator, Special Well site Boom-truck Operator, and, Electrical Work for Non-Electricians Program.

14.2 Sub-Trade Legal Acceptability

The important aspect of the program is that it would have the endorsement of the Alberta Advanced Education and the legal acceptability of the Alberta Municipal Affairs, and similar counterparts in BC and Saskatchewan.

This acceptability would alleviate current the liability exposure faced by the operating companies from the point of view of both the provincial and federal legislations.

14.3 Objectives of the OGFAT Training Program

The following is a summary of the objectives of the proposed OGFAT training program

a) To provide workers competency targeted at installation, operation and maintenance of oilfield gas-fired process appliances;

b) To utilize existing experienced petroleum personnel by expanding their knowledge to deal with these appliances;

c) To obtain program accreditation with Alberta Advanced Education and Alberta Municipal Affairs;

d) To provide legal solutions to the current provincial and federal requirements for minimum competency level when dealing with gas-fired appliances;

e) To ensure the inter-provincial reach of the new training program;

f) To include new technical solutions and products in the training program; and,

g) To combine elements of safety, energy efficiency and environmental impact in the training program.

14.4 Course Pre-Requisites

To address the above objectives, the following are the proposed student pre-requisites for this program

a) A letter from the employer stating a minimum 6 months work experience on gas fired appliances in the petroleum industry; or,

b) A gas fitting license.

14.5 Outline

The proposed OGFAT training program would include the following curriculum:

DAY 1 (5 hrs class + 3 hrs practical)

a) combustion fundamentals

b) safety regulations

c) permitting requirements

d) scope of competency

e) introduction to gas-fired petroleum appliances

f) subsystem and component identification.

DAY 2 (4 hrs class + 4 hrs practical)

a) gas piping

b) gas piping pressure drops

c) pipe fitting

d) gas fitting

e) gas piping testing

f) gas piping leaks

g) gas piping purging

h) odorant / signage requirements.

DAY 3 (4 hrs class + 4 hrs practical)

a) fuel train basics

b) gas pressure regulation

c) fuel flow/temperature control basics

d) safety devices

e) component assembly.

DAY 4 (4 hrs class + 4 hrs practical)

a) burners basics

b) burner start / stop

c) burner adjustment

d) burner modulation

e) combustion analyzer basics

f) efficiency

g) emissions.

DAY 5 (4 hrs class + 4 hrs practical)

a) Control systems

b) Wiring to end devices

c) functional tests

d) startup procedures

e) tune-up procedures

f) maintenance procedures

g) troubleshooting

h) course review.

14.6 Course Completion

To complete the OGFAT training program would require the following:

a) Attendance of all classes;

b) Passing mark on daily quizzes and on the final exam;

c) Satisfactory assembly of a fuel train, controls and burner;

d) Satisfactory startup and tune-up of a heater;

e) Upon completion of the above 4 steps, a temporary certificate would be issued;

f) Students would be given a checklist to be signed by the employer upon completion of all practical tasks outlined on the checklist; and,

g) Once the signed checklist was received, a permanent certificate would be issued.

14.7 Training Program Development Process

The following steps must be undertaken to develop the OGFAT training program:

a) Industry recommendation to be formalized (letter from relevant Association);

b) PITS to form an industry committee;

c) Committee to develop skill profile;

d) PITS to develop training outline;

e) Outline to be approved by Alberta Municipal Affairs, ABSA, Advanced Education;

f) Outline and process to be consulted with BC, Saskatchewan and NWT;

g) Complete training program pilot; and,

h) Training delivery.

15 AREAS FOR IMPROVEMENT AND SOLUTIONS - NEW PARADIGM AND FINAL RECOMMENDATIONS

Based on the literature study and previously presented detailed research of heater efficiency basics, we established that the subject of immersion fire-tube heaters efficiency is related to a great number of factors, many of which are not purely technical nature.

Some of these non-technical factors, which we mentioned before include:

a) efficiency requirements and environmental pressure are relatively new issues with these heaters;

b) heater designs are typically 30-40 years old and are rarely updated;

c) design standards such as GPSA (Ref A23) or API Spec 12K (Ref A3) represent these old, low efficiency designs;

d) the large infrastructure in Alberta of both existing installations and heater manufacturers using these outdated standards;

e) project specifications rarely question immersion fire tube heater efficiency, and manufacturers rarely specify fuel consumption;

f) heater rating is based on the net heat (useful energy) transferred to the process and there are no thermal efficiency guarantees implied;

g) heaters are not equipped with appropriate test equipment or even test connections. For example: many heaters do not have a stack connection for a combustion analyzer;

h) the inertia of the industry to try new solutions which may be “unreliable”;

i) the lack of commitment to high efficiency by operating companies;

j) the expectation by operating companies that heater manufacturers should come up with “better” solutions is countered by manufacturers statements that operating companies are not willing to pay for “better” solutions;

k) the offers by manufacturers to provide efficiency solutions are “hard to sell”;

l) a lack of on-going maintenance programs, some heaters are not maintained at all until they fail;

m) the unfamiliarity of operating and maintenance personnel with proper operating and tune-up procedures;

n) the lack of combustion testing equipment at the plant level;

o) many burners are set “by eye” without making any measurements or recording any performance data;

p) the reliance on outside contractors to do occasional maintenance and tune up of equipment;

q) no combustion-related formal qualifications or education is required from contractors offering tune-up services;

r) a lack of good literature on the subject; and,

s) a lack of educational programs on the subject.

These are just some of the non-technical challenges, which must be overcome in order to achieve sustainable efficiency improvements of immersion fire-tube heaters. And no single technical solution no matter how efficient will solve the problem in the long term until a more holistic approach is used, which includes but also reaches past the “nuts and bolts” of the immersion fire-tube heater design.

In our research, we have encountered a number of innovative efficiency solutions, which were tried in the past. There certainly is a sufficient knowledge base from other industries to offer effective and reliable technical solution for improved efficiency of immersion fire-tube heaters.

In order to address both the technical and non-technical issues related to these heaters, we propose a paradigm, which encompasses the entire process of evaluating, specifying, designing, installing, commissioning, operating, maintaining, and monitoring activities aimed at the most safe, reliable and efficient operation of immersion fire tube heaters.

The concept of this paradigm is illustrated in Figure 15.1. This paradigm proposes the following there concentric circles:

CORPORATE & ENGINEERING - This outer circle encompasses the activities of operating companies leading to the specification and procurement of heaters and provides both framework and control to the other two circles.

EQUIPMENT MANUFACTURERS – This middle circle encompasses the heater equipment manufacturers for both final assemblies and subcomponents. This circle responds to and is controlled by the outer circle through specification and procurement activities. In economic and business terms, it is a market demand driven relationship.

PLANT OPERATIONS – this inner circle encompasses the heater end-users who install, operate, and maintain these heaters. Although some of the procurement activities maybe done on the plant level, we propose to treat them independently as they rely on what the manufacturers offer and typically do not have the policy setting powers to change the existing practices related to the heaters.

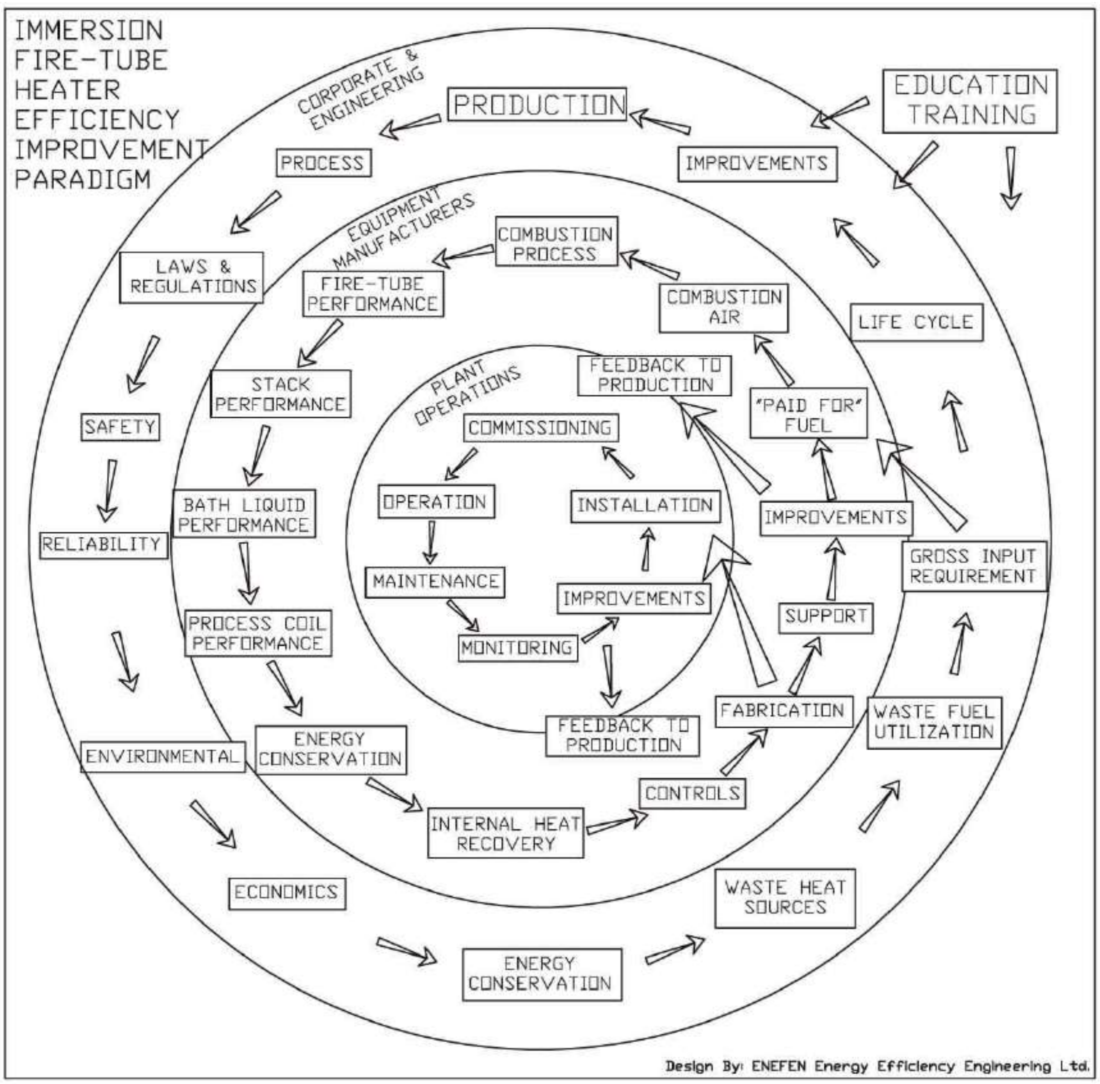


FIGURE 15.1 Immersion Fire-Tube Heater Efficiency Improvement Paradigm

Each circle is defined individually from the point of view of its potential impact on heater efficiency. The paradigm is designed to follow the actual logical sequence of all specified activities and their interdependence. The circular nature of the paradigm indicates that this is a continuing iterative process capable of adapting to new regulations, corporate goals or technological advancements in this field. In addition, all three circles are interconnected in a spiral fashion. Each circle has a feedback point to the controlling activity of production.

15.1 Corporate and Engineering Activities Circle

The outer circle of the paradigm consist of the following 13 activity areas:

a) production requirements;

b) process design concept;

c) laws and regulations (compliance);

d) safety requirements;

e) reliability requirements;

f) environmental considerations;

g) economics;

h) energy conservation;

i) waste heat sources;

j) waste fuel utilization;

k) gross process heat input requirement;

l) life cycle of the process; and,

m) improvements to the process.

These activities are described in greater detail in the following paragraphs.

15.1.1 Production Requirements

The starting and ending point of this circle is the PRODUCTION, which controls all of the other activities in the paradigm. What we mean here is that the production requirements (in corporate sense) set the production goals and allocate resources to meet these goals. Production requirements also set policies related to such issues as safety, legal framework, reliability, economics or environment. These policies are the key to the implementation of efficiency improvements in immersion-fire tube heaters.

15.1.2 Process Concept

The next step in the paradigm is the PROCESS, which dictates how the production goals are achieved. An energy conscious process design is by far the most effective method of efficiency improvements. In other words; don't produce thermal energy, which does not have to be produced. The efficiency measures, which may address this goal, are:

a) analyze the process to confirm its usefulness. If not useful, simply eliminate or reduce the process; note: it should not be assumed up front that all processes are essential or that they serve some useful purpose. An analogy could be given in a simple example like keeping the lights on during the day, or heating a room while all doors and windows are open. Strangely enough, there are many similar examples in the industrial applications;

b) if possible, equalize the load so that the heater operates constantly at a lower firing rate, instead of high/low fire cycling;

c) optimize heater performance to match this equalized actual process demand instead of optimizing is maximum rating point which may never be utilized;

d) minimize thermal process overrun by relocating process control sensors (usually thermocouple) to places which directly reflect energy demand and allow firing rate adjustment and fast response; and,

e) minimize thermal process overrun by bypassing part of the process stream around the heater without heating it, so that the combined downstream temperature setpoint is maintained regardless of the process turndown.

15.1.3 Compliance With Laws and Regulations

- Requirements, which must be considered when analyzing possible efficiency improvements, must comply with federal, provincial and local legislated standards or codes. In many cases, there are also certain regulations imposed by insurance underwriters, associations, trade unions, and other non-governmental bodies, which must be observed. Finally, there are the regulations and standards imposed by owner companies themselves. A clear distinction must be made here between the legislated codes and other recommended practices and standards, which are not required by law. Since some of these non-legislated recommended practices are outdated and possibly at the core of inefficient heater designs, a decision must be made to abandon these practices or at least their portions which are the reason for inefficiencies. On the other hand, even the best technical solution cannot be used if it violates the legislated requirements.

15.1.4 Safety Requirements

- This requirement is usually paramount to all other requirements, since the improvement in efficiency cannot come at a cost of reduced safety.

15.1.5 Reliability Requirements

- This requirement is essential to meeting the production goals and usually cannot be traded for efficiency gain. The reduced reliability argument is the most common argument in the industry for not implementing efficiency improvements. Therefore, any efficiency improvements must ensure that the reliability is not sacrificed.

15.1.6 Environmental Requirements

- Efficiency improvements of fire-tube heaters are usually viewed as a means to reduce fuel consumption and greenhouse gas (GHG) emissions and to help in achieving emission and energy utilization reduction goals. These reductions may in the near future, translate into tangible GHG credits under Kyoto protocol. However, in certain situations efficiency improvements may be viewed as reducing system reliability and creating a potential for environmental damage or perhaps even a safety concern larger than the benefits of GHG reductions. Such situations include: release of sour gas, or hydrate formation in the case of system failure. Such concern must be addressed when designing efficiency improvement solutions for fire tube heaters.

15.1.7 Economic Requirements

- Barring all of the previously mentioned consideration, economic requirements are the most important driver behind efficiency improvements. Most of the operating companies require that efficiency improvement projects are economically justifiable within an acceptable payback period. The larger the installation and corresponding fuel cost, the easier it is to meet this goal. For the majority of small installations such as oil tank heaters with small burners working on an intermittent basis with only a small gas input, these savings may be very small and the efficiency improvements may be difficult to justify economically.
- The main problem of economics is that the majority of installations do not have any fuel metering, hence the “before” versus “after” energy consumption difference is difficult to prove. Efficiency improvement project must therefore include some means of their verification.

Once the proposed efficiency improvement project goes through the above scrutiny of acceptability requirements, it should be also reviewed for possible process efficiency solutions described in the following paragraphs.

15.1.8 Energy Conservation

Analyze the process to identify energy losses and inefficiencies. If possible, reduce the process temperatures, add insulation, reduce fuel vents, eliminate leaks, recycle heat, etc.

15.1.9 Waste Heat Sources

- Try utilizing existing waste heat sources for the process before adding more heating capacity in the fire-tube heaters.

15.1.10 Waste Fuel Utilization

- Consider using waste fuel which otherwise would be flared or vented, such as casing gas. Consideration should be given to the negative aspect of those fuels such as safety, moisture, corrosive properties, or changes in the heating value. Use gas glycol and amine scrubbers and drip pots. In larger systems waste gas could be mixed with normal fuel gas to improve its quality.

15.1.11 Gross Process Input Energy Requirement

Once an energy conscious process review is complete with all of the “peaks and valleys” of the process energy requirement identified and addressed and all of the possible energy conservation means applied, then a gross process input may be established. This optimized value is used as an input into the middle circle of efficiency improvements, which we will discuss below.

But first to complete the outer circle of our paradigm, we need to consider two more aspects of the fire-tube heater efficiency considerations.

15.1.12 Process Life Cycle

Since many of the processes encountered in the oil and gas industry are subject to the depletion of the maturing resource, not only the present energy demand must be taken under consideration but also a projection must be made of the impact of this natural depletion on the process efficiency and energy demand in the future. In some cases, there may not be enough life left in the process to justify any improvements.

15.1.13 Process Improvements

These future projections are used for possible process improvements, which are the last consideration of the outer circle. Improvements may be undertaken a number of times during the life-cycle of the process. Solutions may involve, for example, combining flows from two adjacent wells into one heater and shutting the other heater off, or reducing the heater capacity.

From the point of view of energy efficiency, this iterative nature of the process evaluation should lead to proactive decisions aimed at energy conservation, elimination of excess heating capacities, heat losses, vent or leak losses, thermal overruns or any other situation which otherwise leads to the production of thermal energy which in reality does not have to be produced.

15.2 Equipment Manufacturers Activities Circle

The same process presented below, can be used for energy efficiency optimization of new and existing equipment. For new equipment, the process could be used by the original equipment manufacturer (OEM). For existing heaters, it could be used by a contractor, an engineering company, or owner’s own engineering department. For simplicity, we will consider all parties mentioned above as “OEM”.

Once an optimized gross energy input requirement to the process is defined, this value can be used by the OEM to arrive at the most efficient equipment design to fulfill this requirement.

Taking under consideration the energy efficiency requirements addressed in the outer circle, such as, the use of waste fuel, or other sources of waste energy, as well as, constraints related to system compliance, safety, reliability, environmental and economic guidelines, the OEM can now propose various solutions aimed at optimizing the efficiency.

15.2.1 “Paid-For” Fuel Considerations

This work starts with establishing how much “paid for” fuel is required to run the heater. In addition to switching to waste fuel sources, which were discussed above, efficiency ideas may include the following:

a) lowering the firing rate so the heater operates all the time, at a lower rate instead of cycling OFF and ON to high firing rate; and,

b) turning the pilot off if heat is not required.

15.2.2 Combustion Air Considerations

The next step in heater design is to look at the combustion air. To maximize the efficiency the following measures need be taken:

a) limit excess air at full fire to 2.5% O_2 in the stack;

b) run as much air as possible through burner primary air inlet to maximize fuel/air mixing. This will also limit the excess air at turn down;

c) reduce the secondary air flow as much as possible to maintain 2.5% O_2 in the stack. This can be done by the use of adjustable plates installed in the fire tube at the burner inlet. In some cases with grossly oversized tubes a tight stack damper may be also helpful. The secondary air adjustment must be very precise (+/- 1 in^2. of open air flow area). Traditional adjustable flame arrester lids or bands on are not effective. Also partial blocking of flame arrestor cell renders it ineffective, and,

d) consider preheating combustion air if stack temperature is high (above 500 deg F)

15.2.3 Combustion Process (Burner) Considerations

The air and gas mixing, delivery and stabilization of the combustion process is performed by a burner, therefore the next set of efficiency improvement apply to the burner. Although we show fire-tube sizing subsequent to the burner selection, it is clear that the two have to match in order to maximize the efficiency. Therefore, the burner and fire-tube sizing has to be viewed as an iterative and parallel process, where one component affects the other.

In simplified terms, the flame has to fit inside the tube without impingement, but the tube has to provide desired heat transfer to the bath liquid and not to be too large for the flame size. Under-sizing the fire tube leads to both tube and bath liquid overheating and deterioration, where over-sizing the tube leads to partial flows and partial use of the heat transfer area.

Also, the burner selection must be based on the thermal efficiency of the fire-tube design thus providing adequate gross heat input to cover the heater losses. The firing rates discussed in this section represent the total input and not the heat transfer to the bath liquid.

Based on these principles following are the burner selection considerations:

a) Choose burner with a proper conical Venturi and a large smooth bell shaped primary air inlet providing a low entrance loss coefficient. Maximizing the primary air flow is the main objective to achieving controllable excess air levels, good fuel/air mixing, and flame shaping. Ideally, the burner should provide 110% of stoichiometric flow though the mixer, thus allowing the elimination of secondary air. Although this may not always be achievable, the burner should be able to provide at least 80% of stoichiometric flow through the mixer at full fire;

b) If the burner Venturi diameter is too small, its pressure drop will be too high for the air flow and will not induce an adequate amount of primary air. In extreme cases, small burners will work as a raw gas burner relying totally on the secondary air and fuel/air mixing inside the fire tube. This leads to poor air/fuel mixing, uncontrollable flame shape, flame lifting and impingement on the tube surface;

c) If possible, use at least 15 PSIG (for natural gas) pressure. 20 PSIG is considered ideal for this application and below the high noise threshold. This should allow a minimum 3:1 burner turndown, in some cases 4:1 turndown may still provide a stable flame;

d) Recognize that every burner has a minimum fire, below which the flame snuffs out. Allow for snap acting shutoff, which does not allow the burner to go below this minimum stable setting. Test this minimum during system commissioning;

e) Recognize that every burner has a maximum fire, above which the flame lifts off. Make sure that the controls are set not to allow burner to overfire;

f) Burner sizing should maximize the primary air induction, which means that the diameter of the mixer and Venturi must be adequate to pass 110% stoichiometric air. Typically this translates to about 100,000 to 120,000 BTU/hr/in^2 of nominal Venturi cross-sectional area. Figure 15.2 offers a general guideline for maximum and minimum burner HHV inputs (based on 4:1 turndown), and gas orifice sizing. Check with burner supplier that their product will work properly within the specified maximum and minimum range while maintaining its primary air induction capability;

g) Avoid exceeding the maximum recommended heat inputs because of the resulting reduction of primary air induction. Avoid operating burner below the specified minimum input because of the concern for flame stability;

h) For burner capacities falling between the specified ranges choose the next larger burner size and adjust the orifice diameter accordingly to maintain the recommended 20 PSIG pressure drop. For example, for a 1 MM BTU/hr gross HHV input requirement we would chose a 4" burner and adjust the orifice size to 5/32" (0.1562);

i) While reducing the orifice size keep in mind that under—sized orifice in an over-sized burner reduces its air induction capability;

j) The above recommendations are based on natural gas firing and on the assumption that there is sufficient fuel pressure available to the burner i.e. in excess of 20 PSIG. See Figure 15.2 below.

- Burner Nominal Size	- Maximum Fuel Input BTU/hr (HHV)	- Minimum Fuel Input BTU/hr (HHV)	- Orifice Size for 20 PSIG Natural Gas	- Burner to Orifice Cross-sectional Area Ratio
- 1/2"	- 24,000	- 6,000	- #73 ; 0.024"	- 434
- 3/4"	- 52,000	- 13,000	- #64 ; 0.036"	- 434
- 1	- 96,000	- 24,000	- 3/64" ; 0.047"	- 453
- 1-1/4"	- 148,000	- 37,000	- #53 ; 0.0595"	- 441
- 1-1/2"	- 212,000	- 53,000	- #49 ; 0.073"	- 422
- 2"	- 380,000	- 95,000	- #41 ; 0.096"	- 434
- 3"	- 848,000	- 212,000	- #27 ; 0.144"	- 434
- 4"	- 1,500,000	- 375,000	- #11 ; 0.191"	- 439
- 5"	- 2,400,000	- 600,000	- C ; 0.242"	- 427
- 6"	- 3,400,000	- 850,000	- L ; 0.290"	- 428
- 8"	- 6,000,000	- 1,500,000	- W ; 0.386"	- 430

FIGURE 15.2 Recommended Burner And Gas Orifice Sizes

k) For applications using other fuels, or low pressure fuels, these specific recommendations must be adjusted by a proper engineering assessment, while maintaining the overall objective of maximizing the primary air flow and the elimination of the secondary air flow;

l) The gas orifice should be easily accessible from the back of the burner without having to remove the burner assembly from the heater. Use proper orifice sizing charts to establish orifice diameter;

m) Orifice fine-adjustment needles are not recommended, as they are difficult to adjust in the field conditions without proper instrumentation. In some cases they may also contribute to orifice plugging or freezing up. Consequently, the adjustable needle valve may create more problems than benefits. Use of a properly sized gas orifice is preferred. If adjustment is necessary simply replace or redrill the orifice;

n) Check orifice diameter against the nominal burner diameter. If properly sized, at maximum burner ratings, the ratio between burner cross-section area and orifice cross-section area should be approximately 430:1 for natural gas. Figure 15.2 shows that ratio;

o) Burner must have primary air adjustment, and this adjustment must be equipped with a positive lock and be accessible from the back of the burner. Electrical locking crown-nut used typically on burners is ineffective as it does not provide positive lock, especially when used with cast iron burner components. In most heaters, the locking nut cannot be easily accessed and tightened through the access port in the back of the windbox or flame arrester;

p) Specify burner nozzle providing sharp straight and short and stable flame envelope. Long lazy flames or wide flames are not recommended since they are affected by buoyancy, impinge on the tube and do not contribute to the radiant heat transfer, which is related to gas emmisivity rather than to presence of a visible flame. In other word combustion should be completed as soon as possible so optimal heat transfer (radiative and convective) between the hot products of combustion and the fire tube surface can take place;

q) Ideally, there should be a distinct clearance of about 3" between flame bushel and the tube surface all around the flame. Under no circumstances should the flame be allowed to touch the tube surface. For estimating purpose it can be assumed that the flame diameter is on average 2 to 3 times the nominal burner diameter;

r) Ensure that burner materials are compatible with the fuel. Use of brass should be avoided if sulfur is present in the fuel. Specify stainless steel gas orifice if sour gas is present;

s) When selecting a burner, consideration must be given to noise characteristics and susceptibility to plugging and freezing; and,

t) When installing a burner and dependent on the actual flame shape, consider locating the burner nozzle below the tube centerline (at about 1/3 diameter) and pointing is slightly down (about 10 to 15 degrees) in order to minimize the potential of flame lifting by buoyancy and impinging on the tube's top invert. If possible, external adjustment should be provided to change the burner centerline elevation and angle.

15.2.4 Fire Tube Design Considerations

- As explained in the previous section, although we show fire-tube sizing subsequent to the burner selection, it should be clear that the two have to match in order to maximize the efficiency. Therefore the burner and fire-tube sizing has to be viewed as an iterative and parallel process, where one component affects the other. In simplified terms, the flame has to fit inside the tube without impingement, but the tube has to provide desired heat transfer to the bath liquid and not be too large for the flame size. Under-sizing the fire tube leads to both tube and bath liquid overheating and deterioration, where over-sizing the tube leads to partial flows and partial use of the heat transfer area. Also the burner selection must be based on the thermal efficiency of the fire-tube design thus providing adequate gross heat input to cover the heater losses.
- The following should be considered when designing an energy efficient fire-tube for a specific process application:

a) Base the thermal design on sound engineering principles, which include both the radiative and convective heat transfer;

b) Recognize the fact that although the main objective of the fire-tube is to transfer the energy to the bath-liquid, its main limitation in achieving such heat transfer is in the boundary layer heat transfer coefficient on the gas side. Therefore, the conventional surface heat flux rating of the tube heat transfer to the bath liquid (such as 10,000 BTU/hr/ft2 rule-of-thumb) is in reality secondary to, and a result of, what happens to the heat transfer on the gas side. This means that the heat flux rate is not "guaranteed" just by providing sufficient fire-tube area and the fire tube design must be first optimized on the gas side in order for the average heat flux rate to be realized;

c) Avoid using generalized design "rules-of-thumb" such as average heat flux rate, or average cross-sectional flux rate. Using a shell and tube heat exchanger design analogy there is no single "optimal" heat transfer coefficient for heat exchanger sizing. Similarly, there is no single "best" heat flux rate for fire-tube design. For example, using a traditional approach to a 1 MM BTU/hr heat transfer requirement to the bath liquid, we would divide this value by a standard heat flux rate of say 10,000 BTU/hr/ft2 and obtain a 100 ft2 fire tube surface specification. We could take this specification and make the tube "short-and-fat" or long-and-skinny" and obtain a totally different thermal heat transfer and pressure drop performance. Similarly, if we applied the commonly used cross-sectional heat flux of 15,000 BTU/hr/in2, we would have not addressed the non-linear nature of fluid dynamics and thermodynamics principles involved in the flow of hot gases through the fire-tube;

d) Customize fire-tube designs based on heat input, bath liquid type and temperature, fuel composition, type of burner used, desired thermal efficiency and available draft;

e) Use Gross (HHV) thermal efficiency guideline between 72% and 82%. Ideally 82% gross efficiency should be used, except for designs where such specification would result in excessively large surface area requirements for example in high temperature salt bath heater applications;

f) Avoid designs exceeding 85% gross efficiency due to a potential for condensation and tube flooding problems, unless special measures are undertaken to deal with this condensation. Fire tube should be equipped with a low point drain connection, which could be used in case of excessive condensation;

g) Ideally, design fire-tube flame zone to match the selected burner's maximum flame diameter plus approximately 6". If this is not feasible for larger heat inputs, use the smallest possible tube diameter;

h) Use a general guideline that smaller diameter but longer tubes result in more efficient designs, as long as, the additional friction due to extra tube length does not exceed the available draft;

i) If possible, consider using a smaller diameter, 4 pass tube instead of larger diameter 2 pass tube. In 4 pass design an external return elbow should be considered between 2nd and 3rd pass for access;

j) If feasible, consider using forced draft burners to overcome additional friction loss from longer and multi-pass tubes;

k) Thermal design principles are the same for both natural and forced draft burners. Forced draft burner applications in fire-tubes can be seen simply as an extension of natural draft designs into areas where there is not enough natural draft available from the stack. Typically, natural draft is limited to 0.2" W.C. negative pressure, where forced draft systems can handle pressure drops as high as 4" to 5" W.C.;

l) Forced draft burners allow not only the use of smaller tube diameters and higher velocities and heat transfer coefficients, but also the use of various heat transfer augmentation techniques such as turbulators, fins, baffles, etc.;

m) On the other hand, using forced draft systems in oversized tubes with low pressure drop will not enhance the heat transfer. Although some enhancement can be claimed through more turbulent and further reaching outlet flow from forced draft burners, this turbulence usually does not extend past the first return elbow and has no effect on the rest of the fire tube;

n) Similarly, any air-flow control devices on the natural draft burners such as spinners, or spiral vanes may help in the fuel and air mixing but are ineffective in increasing the heat transfer to the fire-tube;

o) Designs involving only replacement of natural draft burners with forced draft burners without changing the design of the fire-tube itself will not significantly increase the heat transfer and fire tube efficiency. Since a natural-draft fire-tube has a very low pressure drop, the additional pressure available from the forced draft burner will have to be throttled either at the burner or the stack end, thus making the forced draft burner "emulate" the natural draft burner performance;

p) For such conversion projects to improve efficiency they must include measures aimed at significantly increased turbulence and inside surface “scrubbing” action throughout the entire fire-tube length rather than dissipating this kinetic energy with dampers;

q) Fire-tube surface heat transfer augmentation techniques aimed at increased turbulence are only effective in highly turbulent regions with Reynolds numbers between 10,000 and 200,000, and have a negligible effect with laminar flows. Any augmentation technique must increase the turbulence and “scrubbing” effect on the gas boundary layer by redirecting the kinetic energy of the gas flow. This change is achieved at the cost of pressure drop. As a practical guideline any such redirection, which uses less than 1” W.C. pressure drop will not result in significant heat transfer gains;

r) The use of turbulators with natural draft fire-tube designs, which are inherently based on laminar flows, and have only 0.1” to 0.2” W.C. draft available is not effective, as these designs do not have sufficient kinetic energy to create the desired turbulence;

s) Use of spiral turbulators should not be considered even with forced draft systems, as the spiral flow tends to pull the gases towards the centre of the spiral and away from the tube wall, possibly reducing the heat transfer;

t) Tube surface extensions such as fins may be effective only if they are in solid contact with the tube wall, spot welding or friction fit does not provide such contact therefore fins, if used, must be continuously welded to the internal tube wall;

u) The use of finned economizer tubes welded on the inside of the fire tube has been suggested in the literature. Theoretically, this idea has a potential although we have not found any data showing where this concept has been successfully used;

v) Since the gas boundary layer film coefficient controls the heat transfer in the fire tube, and the tube surface enhancements must protrude past the boundary layer to be effective, the tube roughness (for example in form of small indentations or grooves) cannot enhance heat transfer in mostly laminar flow region of a fire tube;

w) Any heat transfer enhancements must affect the inside of the fire tube rather than its outside, because this is where most of the resistance to the heat transfer is located;

x) For all tube designs including any heat transfer augmentation additions, access to all passes for cleaning must be assured;

y) If longer tubes or any augmentation techniques are used, check friction loss to make sure that it does not exceed the available draft;

z) Use formed round return elbows or at least 5-piece miter elbows in the tube design. Elbows are the main source of pressure drop through the tube and the main cause for draft problems. 3-piece (square) miter return should not be used as it creates a large pressure drop and may contribute to noise problems;

aa) Consider using a stepped tube design to maintain tube velocities. Flame zone should be of the largest diameter specifically designed to avoid flame impingement. First diameter reduction could be considered after the first return elbow;

bb) The use of natural draft burners, which rely heavily on secondary air, creates an inherent problem due to secondary air keeping the entrance and first few feet of the fire tube cold and therefore not participating in the heat transfer. In fact the longer the flame, the longer it takes for the products of combustion to develop to full temperatures, and the greater is the tube length not fully utilized for heat transfer. Our burner selection guidelines, aimed at eliminating the secondary air flow by choosing burners with high primary air flow, address this problem. In addition, there is also a potential opportunity to fully utilize the fire-tube entrance by physically moving the burner back out of the tube. Although, this may not be fully possible with existing fire tube and flame arrester designs, an ideal solution aimed at maximizing the heat transfer in the fire tube would be to remove fully or partially, the combustion out of the fire tube so only the completely oxidized and mixed products of combustion enter the tube. This idea would eliminate flame impingement, hot spots and flame quenching problems; and, cc) For applications involving fuels containing sulfur or fuels, which may be subject to dew point condensation, fire-tube made out of corrosion resistant material could be considered. The reduction of corrosion would result in a better heat transfer even taking under consideration the lower conductivity of the alloy material than the traditional carbon steel. Recent increases in carbon steel prices relative to alloy steel plus increased energy cost may make such use of alloy steel fire-tubes a possibility.

15.2.5 Stack Performance Considerations

The following should be considered when designing an energy efficient stack for a specific process application:

a) Design the stack in conjunction with the fire-tube to provide sufficient draft and minimal friction loss;

b) For higher draft applications (such as a forced draft design) incorporate draft control measures in the stack design such as a tight stack damper with a maximum –1/4" tolerance on stack diameter. The mechanical design must ensure that the damper does not bind in the stack due to thermal expansion and that it is equipped with a positive locking mechanism. Locate damper in a straight run of the stack, away from the elbow, in a location, which can be easily accessed (using a step ladder) for adjustment;

c) For applications where the stack temperature is expected to either exceed 600 deg F or where water vapor condensation is expected, consider using a lighter gauge alloy material (304 SS or similar) instead of heavy wall carbon steel pipe. This will not only increase stack resistance to corrosion and oxidation at high temperatures, but it will also reduce stress on the mounting flange;

d) Use a minimum stack height of 20 ft, and in special cases when dictated by friction loss and the draft calculations, consider using a 30 ft stack height;

e) Provide 1" mineral wool insulation with thin gauge aluminum or stainless steel jacket over the entire stack length in order to maintain draft and prevent condensation and freezing;

f) Provide two (2) 1/2" test ports near the stack bottom for combustion analyzer and Pitot tube measurements. Avoid using carbon steel NPT connection, which tends to seize permanently due to high temperature and corrosion; and,

g) Use a low pressure drop rain cap with stainless steel bird screen to prevent water, snow, and birds from entering the stack.

15.2.6 Bath Liquid Performance Considerations

The following should be considered when designing an energy efficient liquid bath for a specific process application:

a) Bath liquid must be suitable for the process application from the point of view of thermal rating and heat transfer properties, such as: conductivity, specific heat, and specific gravity, as well as, its resistance to breakdown, coking, or deterioration when in contact with the hot fire tube surface;

b) Use of water is not acceptable due to the potential for freezing;

c) Corrosion properties must be compatible with heater internal materials thus preventing external tube surface fouling;

d) Use of corrosion inhibitors can be considered as long as they are not susceptible to deterioration when in contact with the hot fire-tube;

e) Since the heat transfer, in an immersion fire-tube heater is controlled by the gas side, the effect of higher bath liquid conductivity is negligible, and the use of special heat transfer liquids (such as Thermogreen) has been proven to be ineffective in increasing the overall heat transfer in the heater;

f) Comparative tests conducted on the same fire tube and burner configuration with water, 50% ethylene glycol, and light oil did not show any significant difference in heat transfer to the bath liquid, again confirming the controlling nature of the gas side;

g) Heavy oil or oil/water emulsion application requires special consideration from the point of view of the potential for coking, however, with a clean tube these emulsion applications do not significantly influence the heat transfer. Therefore, the heater design for these applications is less a question of an overall heat transfer but more a question of high tube wall temperatures caused by inappropriate burner selection, installation, and setup;

h) Although heavy oil is especially susceptible to coking around any “hot spots” on the tube, such hot spots must be avoided for all applications in order to minimize bath liquid deterioration and to extend fire-tube life;

i) For applications involving liquids containing impurities and solids such as sand, in oil treaters, special measures must be taken to prevent sand accumulation on the tube top tangent. Excessive accumulation of sand will result in a decrease in heat transfer, and premature tube failure. Using smaller diameter fire tubes (which have less “flat” top tangent than a larger diameter tube) for these applications could be considered as a means of reducing sand/silt accumulation. At the same time, smaller and longer tubes may provide a better heat transfer and higher thermal efficiency;

j) Thermal siphoning, liquid conduction and natural convection through the bath liquid should be considered when designing a process coil and locating it above the fire tube;

k) The amount of bath liquid is essential for applications, which are unpredictable and experience frequent load cycling, and which need an energy “accumulator” to draw the energy from during high peaks of the process load;

l) An excessive volume of bath liquid increases the maintenance cost (when liquid has to be replaced), and it decreases the thermal efficiency due to thermal overrun during the low process load. Using conventional controls with fixed bath liquid temperature setpoint the process fluid flowing through the fixed surface area of the process coil may absorb more energy than needed from the bath liquid; and,

m) Smaller volumes of bath liquid combined with appropriate controls such as process coil bypass valve, can contribute to increased efficiencies by avoiding thermal overruns and responding faster to the energy demand.

15.2.7 Process Coil Performance Considerations

The following should be considered when designing an energy efficient process coil for a specific process application:

a) Consider thermal siphoning, liquid conduction and natural convection through the bath liquid when designing a process coil and locating it above the fire tubes. Ensure that the entire coil surface is immersed in the “thermally accessible” part of the heater and that there are no “cold dead pockets” of the bath liquid;

b) Consider the impact of the difference in heat transfer from the first fire-tube pass and all subsequent passes into the liquid bath and the process coil. As the products of combustion cool down and the temperature gradient decreases so does the heat transfer. Consequently, one end, or one side of the heater is warmer than the other. If feasible, consider running a process flow counter-current to the heat distribution in the bath liquid;

c) Consider the impact of bath-liquid volume on the time it takes for the heat to travel between the fire tube and the process coil. This is important in the case of sudden process load changes. Efficiency measures such as, reduction in the bath liquid volume or bypassing part of the process flow around the heater were discussed in previous sections; and,

d) Consider using a larger surface area of the process coil in order to lower the bath temperature. Lower bath temperature will be reflected in lower stack temperature and will result in a thermal efficiency increase.

15.2.8 Heater Energy Conservation Considerations

The following heater energy conservation measures should be considered:

a) Insulation – there is a significant reduction in heat losses between uninsulated and insulated heater surfaces. This heat loss is especially high with outdoor installations, in winter and high wind velocity conditions. Consideration should be given to insulating the entire heater including the end heads;

b) The thickness of the insulation is not as important as insuring that the surface is fully insulated and isolated from the wind, rain, snow and cold temperatures. A minimum 1" insulation should be used. With higher bath temperatures 2" insulation thickness should be considered;

c) Insulating materials, which do not absorb moisture, are preferable over porous materials, although any insulation (as long as it meets temperature rating criteria) is better than none;

d) Insulation must be covered by a water tight aluminum jacket, with all seems properly sealed using appropriate high temperature sealing compound;

e) Wind-shield around the shell reduces the heat loss but is not as effective as sealed and jacketed insulation material;

f) The stack should be insulated to maintain draft and minimize the potential for condensation, freezing and corrosion;

g) Insulate process piping, connections and any major heat conductive surfaces protruding from the heater; and,

h) Consider locating the heater inside an insulated and heated building. Usually this is feasible for most of the heater length except for the burner end.

15.2.9 Internal Heat Recovery Considerations

The following internal heat recovery measures should be considered:

a) An energy conscious design from the point of view of the process itself, fuel usage, combustion air control, combustion process, fire-tube design, stack, bath liquid, process coil, or insulation should result in the maximum economically justifiable energy recovery. In other words, if the heater design was focused on achieving the maximum efficiency of 85%HHV without causing condensation, and eliminating all heat losses, there would be no viable energy source left to recover the energy from;

b) From a thermal design point of view it is more efficient to extract the energy from the process within the process itself than to allow the energy to leave the process and then to try to recover it afterwards in order to put it back into the same process. Any such energy recovery concept is subject to its own efficiencies, temperature gradients and losses;

c) Consequently, the only reason for the possibility of heat recovery is that the original thermal design is inefficient. Such is the case with many existing immersion fire-tube heaters;

d) The focus of the heat recovery should first be on the elements internal to the process in order to eliminate the losses as much as possible. In other words, instead of starting by trying to recover the waste energy from the stack, we should start by trying not to let the energy go into the stack in the first place. This could be done by changing the burner, combustion air control, perhaps enhancing the heat transfer inside the fire tube or even by changing the fire tube, or using any of the other recommendations addressed previously. This is not to say that implementing any or all of these improvements will be economically viable. However, only after we prove that there are no feasible solutions left, aimed at keeping the energy inside the system we should look for external improvements;

e) Those improvements are site specific and may include, for example, a combustion air preheat from the stack, fuel preheat from the stack, or even building heating with the stack energy. Just by running the stack pipe partially through the building (if there is one) we could conceivably heat it, thus eliminating the energy consumption from Catadyne heaters; and,

f) Any of the energy recovery alternatives, both internal and external, must meet the general objectives and restraints defined previously in the outer circle of this paradigm.

15.2.10 Controls Considerations

When designing an energy efficient control system for a specific process application, the following should be considered:

a) Control system design should flow out of, and be subsequent to, the previously discussed efficiency measures for the process, burner and fire tube. Without addressing these design aspects first, any control system no matter how sophisticated cannot fully compensate for the inefficiencies inherent to inefficient process, thermal or mechanical heater design;

b) A clear understanding of the optimized process operating range, as well as, burner turndown requirements must be matched by a corresponding controls strategy;

c) Eliminate the use of instrument gas for control, instrument gas venting, and electric control power generation from fuel gas. Consider the use of all electric controls powered by solar power;

d) Recognition must be given to the fact that the burner has a limited turndown, which in the best scenario does not exceed 4:1, however this turndown comes at a price of decreased thermal efficiency due to the impact of secondary air. Although proper burner selection maximizing the primary air flow and precise control of the secondary air can address this problem, the turndown should be limited to a maximum 3:1 in order for the combustion to stay close to its peak efficiency point;

e) ON/OFF temperature control should be avoided as it results in efficiency losses during the ON cycle with an oversized burner and OFF cycle with natural draft pulling cold air through the tube;

f) At the same time, excessive modulation should be also avoided as it increases the energy loss to secondary air;

g) Ideally, if the process load could be “evened-out”, and proper burner selection and setup made to ensure that the burner is neither grossly oversized nor undersized, that it runs at its highest efficiency point, and that the secondary air flow is minimized, only a small amount of modulation would be required to maintain this process at its peak efficiency and without the need to cycle the burner on and off;

h) To address the exact process energy requirement and eliminate thermal overrun, the control strategy should include the review of the location for the temperature control element so the heater responds quickly to any changes in the energy demand;

i) In addition, the control strategy should look at the possibility of bypassing part of the process flow around the heater in order to maintain a constant temperature setpoint of the recombined flow downstream of the heater; and,

j) In order to meet the requirements identified in the outer circle of the paradigm, any control strategy must be reviewed for its compliance with legal, regulatory, safety, reliability, environmental, and economic constraints.

15.2.11 Fabrication Considerations

The following should be considered for the procurement and fabrication activities associated with the immersion fire-tube heaters:

a) Include efficiency specifications and requirement for efficiency guarantees in the project specifications;

b) Specify that energy efficiency calculations must be submitted with the product bids;

c) Develop and publish energy efficient design techniques for the industry;

d) Encourage innovation and more efficient designs and allow departure from old low efficiency design “standard”;

e) Create effective “market pull” for energy efficient designs for the heater manufacturers to respond to;

f) Include life cycle efficiencies of equipment in the bid evaluation process;

g) Consider use of modern and more expensive high efficiency control methods and equipment in the heater design instead of rudimentary low efficiency and low-cost controls; and,

h) Create a partnership between equipment purchasers and manufacturers aimed at increasing the efficiency and reducing the emissions from fire-tube heaters;

15.2.12 Support Considerations

The following should be considered for the support activities associated with fire-tube heaters:

a) Not only must the more efficient heater design or strategy be developed, engineered, specified, and, fabricated, but it must be also supported;

b) As new energy efficient heater solutions are developed, demonstrated, evaluated, and included in the production programs from various manufacturers, there has to be a parallel development of support to this infrastructure. This includes qualified engineers, designers, sales personnel, installers, startup technicians, troubleshooters, as well as, component stocking suppliers who all will be familiar with the new methods and requirements;

c) Without this support infrastructure the more efficient installations may follow the previous attempts in this area, and slowly through lack of monitoring, maintenance an repair revert to the “old ways”;

d) The development of such support can only start with appropriate education and training methodologies and their delivery; and,

e) Appropriate funding should be allocated to the continuing development of the support infrastructure personnel, tools, training, procedures, etc) for the high efficiency equipment.

15.2.13 Ongoing Heater Design Improvements Considerations

Heater design improvement considerations with respect to the more efficient immersion fire-tube heater designs are as follows:

f) As the new, more efficient heater solutions are developed there will be an ongoing process of improvements;

g) This means, that not only must the new solution be delivered, but it must also be followed up, monitored, reported and analyzed. Without actually checking the efficiency gains and providing a forum for discussing the knowledge gained in the process there will be no continuity of improvements and the original ideas will most likely be lost;

h) With the introduction of new gas safety regulations in Alberta there is a legal requirement for safety improvements to the field equipment including the immersion fire-tube heaters. It seems logical that such safety requirement could be combined with the energy efficiency aspects of the heaters, thus satisfying the legal requirement and providing at the same time economic justification for the upgrades through energy savings.

i) This process completes the middle circle of the paradigm through simultaneous feedback to the manufacturers as well as it ties it back to the outer circle through feedback to the main controlling activity of the paradigm which we called production.

15.3 Plants Operations Activities Circle

The final chain of activities in our paradigm circle is related to the actual implementation of the energy improvements to the fire-tube heaters in the field.

15.3.1 Heater Installation Considerations

After the improved heater is delivered to the site the following should be considered:

a) Availability of qualified installation personnel who understand the improvement concepts;

b) Availability of special materials and tools which may be required for installation of the improved designs;

c) Appropriate documentation such as Installation and Operating Manuals, and installation check list; and,

d) Availability of training and technical support

15.3.2 Heater Commissioning Considerations

Similar considerations apply to startup and commissioning activities of new equipment, which is often performed by the owner, sometimes with the assistance of the manufacturer or consultant. For efficiency gains to be realized appropriate education and training of all parties involved is required.

15.3.3 Heater Operation Considerations

The release of the new improved heater to plant operations marks the most important point of the process, and also starts the verification phase of the project. Not only must the improvement be embraced by the operations, but also it must be used on a daily basis to prove its long-term benefits. The change will involve modifications of old operating procedures. Without the acceptance of this process and the changes it brings with it by the operators the new solution has a good chance of failure. The education and training is crucial and operators must be included in this process.

15.3.4 Heater Maintenance Considerations

Similar comments apply to maintenance activities and personnel. With any new equipment there must be a change in the maintenance procedures. There is a tendency with some maintenance personnel to “fix” things and reset them to the old familiar ways. This tendency must be addressed by appropriate equipment protection. Similar to operators, maintenance personnel must also be trained in any new procedures related to the high efficiency heaters. In addition, they must be provided with appropriate equipment to conduct this maintenance. To address these requirements, appropriate funding should be included in the operating and maintenance budgets for the continuing support of the high efficiency equipment.

15.3.5 Heater Monitoring Considerations

The next important activity of the fire-tube heater efficiency improvement paradigm is the monitoring of new equipment. This aspect of the process is essential for the verification that the improvement actually works. Quite often various process improvements do not address this aspect and there is no way of telling if the project is successful or not. Until sufficient level of confidence is built up for the new solutions, there must be a monitoring system in place, which would keep track of the progress. Ideally, such monitoring system should include a “before” and “after” comparison, where the equipment is monitored for a while before the conversion and then continues to be monitored after the conversion so the “before” and “after results can be compared.

Such monitoring should include as a minimum: stack temperature; bath temperature; gas pressure to the burner; fuel flow; ambient temperature; and, process load. There also must be a permanent record of combustion performance of the heater available on site, so this performance can be intermittently checked. A simple idea of such record is a sticker, which would be placed in an appropriate location on the heater, and which includes:

a) date and technician’s name;

b) stack readings (O_2, CO, NO_x, stack bottom temperature);

c) gross thermal efficiency (% HHV);

d) burner gas orifice size;

e) burner fuel pressure;

f) fuel flow; and,

g) bath control temperature setpoint.

If available, process inlet temperature and process outlet temperature should be also recorded. Since such monitoring may require special instrumentation, it should be done close to the plant and in conjunction with existing trending capabilities in the plant DCS or PLC. If these are not existing, other continuous monitoring techniques should be considered.

The collected data must be analyzed to show the impact of the energy improvement and long-term benefits.

15.3.6 Ongoing Heater Improvements Considerations

The final step of the paradigm is the ongoing heater improvement in the field. This is a very important step, which proves the long-term feasibility of the installation. Besides data monitoring, there should also be a procedure in place to record observations, experiences, adjustments to the heater, etc. This could be done in the form of a log book left at the site where all these observations, changes or adjustments would be logged. It is essential that such a log book be periodically reviewed and recommendations made regarding possible modifications to the heater. Such feedback could be provided to plant management, manufacturer, as well as, to our main controlling activity of production.

This last item completes the paradigm by connecting all three circles of activity together thus providing verifiable results which may be used in future upgrade projects of a similar nature.

15.4 Education / Training Requirements of the Efficiency Improvement Paradigm

As explained above, the whole process of heater efficiency improvements is iterative and includes various levels of management engineering and operations.

The key element, which has been repeated again and again throughout this analysis and which connects it altogether is the education and training.

This education and training should be designed primarily to create an awareness of energy efficiency and to provide tools for working with and assessing this efficiency.

15.5 Final Conclusions and Recommendations

The principal objective of this project was to define practical methods for increasing energy efficiency and reducing emissions of gas fired immersion fire-tube heaters used in the petroleum industry. In addition, these methods were designed, to provide the improvement to the largest number of both the existing heaters, and new installations, at the lowest cost and with a minimum of modifications.

To meet this objective, a detailed study of the existing technology was conducted including a survey of background information, literature, and the existing standards. A short synopsis of 44 references is included in this report. <u>This research, led to the conclusion, that many relevant references are outdated, incomplete, unclear, or sometimes even lacking on the topic of fire-tube heaters energy efficiency and emissions. In fact, the existing references and standards may in some cases, be partially to blame for the lower efficiencies.</u> The study compiles the information from various references and combines it with our own experience in this technology in order to identify the reasons for the low efficiency.

To address the "information-gap" in the published literature and to further deepen the understanding of the subject, a detailed guideline of the fire-tube heater efficiency principles was prepared. The guideline addresses the theoretical principles of the laws of thermodynamics, the convective, conductive and radiative heat transfer, mass/energy balances, all in the context of the practical application of these principles to various performance parameters encountered in fire-tube heater operations. Numerous graphs are included to help in estimating the impact of these parameters on the heaters efficiency.

The intent of this work was to illustrate, that <u>heater efficiency is not just a random result of simplified design methods but also a quantifiable result of all of the various operating parameters.</u> An analogy was drawn between the fire-tube heater design and a shell and tube heat exchanger design, with the exception that the fire-tube design is much more complicated due to the simultaneous presence of the combustion reaction, radiative, convective and conductive heat transfer. <u>To address this complexity with any level of design predictability of heater efficiency, all the proper engineering principles, methods and tools must be used.</u>

In addition to providing the basic theoretical information necessary to properly assess the fire-tube heater designs, operation, and maintenance, the study was also aimed at addressing the numerous “myths” that currently surround this subject. An example of such a myth is the idea that a long visible and orange burner flame reaching far into the fire-tube is of benefit to the radiant heat transfer. This study shows that this myth and 20 others are not relevant.

This project has identified an achievable theoretical target gross efficiency for fire-tube heaters at between 72% and 82% depending on the bath liquid temperature. Although some references have identified typical efficiencies, as poor as 30% to 40% we don’t believe it to be the norm as indicated by field measurements.

To confirm the reality of higher efficiency targets, a detailed survey of 43 field installations in various applications was conducted and compared to data from another 60 installations. Among the 43 heaters tested there were indeed eight installations with much lower efficiencies down to the 30% range. The reason for such low efficiencies was due to incomplete combustion, fouling, misadjustment or lack of maintenance. Simple readjustment of all eight of these units during the survey returned them to a “more reasonable” (higher) range of efficiencies. Subsequent to this adjustment, the actual gross efficiency range of all tested heaters was found to be between 64% and 82%, with an average efficiency of 72.3%.

Besides the confirmation that the actual gross efficiencies encountered in the field installations correspond to the theoretical target gross efficiencies, this part of the project also produced guidelines and data collection methods for evaluating fire-tube heater efficiencies in the field. These evaluation methods were successfully tested and documented on all 43 fire-tube heaters.

In addition to the theoretical guidelines of the fire-tube efficiency principles, and the field data collection methods, a software program was also developed as part of this project, to aid in the evaluation of the fire-tube performance. This fire-tube rating program was designed to resemble a standard heat exchanger rating program with the addition of the simultaneous radiative and convective heat transfer. The computation was based on relatively complex heat transfer models as used in other applications, such as, in the gas turbines. Instead of a commonly used average heat transfer value (heat flux) for the entire fire-tube, a progressive integration of the varying heat transfer along the entire tube length and the stack is applied. This enabled the computation to include a temperature, pressure, and heat flux profile along the fire-tube in addition to average heat flux value.

The software program features a configurable fire-tube and stack geometry with up to 4-pass tube configurations, where the diameter of each tube pass can be different. Upon entering various process and ambient parameters, this program predicts temperature, pressure and the tube surface heat flux profile. By changing either the geometry of fire-tube or the stack, or the process parameters, a thermal design and the efficiency of the heater can be predicted and optimized. Due to this novel approach the software program does not differentiate between natural and forced draft fire-tube designs, except that the pressure drop is shown as exceeding the theoretical draft value, thus requiring a combustion air blower to make up the difference between the two values.

To calibrate the above software program and also to test the impact of various burner designs on the heater efficiency, a fire-tube test unit was designed, constructed, and operated at the PITS facilities in Nisku. The test unit featured configurable tube geometry with 2-, 3- and 4- pass configuration and extendable stack, as well as, 65 pressure, temperature, and flow sensors interfaced via analog channels to the plant’s DCS. This data stream, which was recorded at 10 seconds intervals includes: fuel, combustion air, and bath liquid flows and temperatures, fire-tube and stack temperature profiles, burner parameters, and stack emissions. This test unit was extensively fired between 100,000 BTU/hr and 500,000 BTU/hr fuel input, with water, 50/50 ethylene glycol, and with oil through the “bath side” of the fire-tube.

Twenty-five (25) burner configurations from various manufacturers were tested to establish their flame shape, primary airflow, air/gas mixture pressure and sound pressure levels. These burners were first bench tested in the open-air firing in order to measure and photograph the physical size of the flame, and later fired inside a 2-pass fire-tube configuration of the test unit.

The testing of individual burners led to the following conclusions as stated below:

a) Once properly selected, and adjusted, most of the tested burners could be fired reliably with at least a 4:1 turndown.

b) At maximum fire, all burners (with the exception of radiant type metal fibre burners) could be set to provide acceptable levels of CO, NO_x, and excess O_2 in the stack. At a fixed firing rate and based on similar burner settings, burner design did not have any significant effect on the stack bottom temperature (fire-tube exit) and the heater efficiency.

c) Radiant metal fibre burners (three sizes tested) when used with third party fuel/air mixers did not provide the expected flame retention at the mesh surface, nor did they provide forward velocity to ensure proper flame shaping and products of combustion flow inside the fire-tube. This resulted in an uncontrollable flame flow both forward and backward in the fire-tube.

d) The most significant difference in burner performance was attributed to their ability to induce (inspirate) primary air. Burners with higher primary air aeration have a more complete air/fuel mixture delivered directly from the mixer to the burner nozzle and rely less on the presence of the secondary airflow around the burner. This results in a shorter, more intense, and more controllable flame, and more complete combustion. It also helps in avoiding flame lifting and impingement on the tube surface.

e) The high primary air burners allowed operation with minimal secondary airflow. This resulted in higher heater efficiencies through turndown as primary airflow decreases proportionally to the fuel flow. The aerodynamic properties of the fuel/air mixer were therefore, used effectively to “modulate” the airflow, without the need for any external mechanical secondary air modulation devices.

f) <u>In conclusion, an “ideal burner” for a fire-tube application should have all of the combustion air including the excess air go through the primary air port. This ensures a “perfect” homogenous air/gas mixture to the burner’s nozzle, resulting in a short controllable flame without impingement on the fire-tube wall, and the ability to “aerodynamically” modulate the combustion airflow by modulating the fuel flow.</u>

The results of the firing tests of various burners inside a 2-pass fire tube configuration provided valuable data of tube temperature profiles indicating for each burner the high and low temperature spots. In general, all burners with higher primary air induction provided a more uniform temperature profile in the first 5 feet of the fire-tube. The burners with lower primary air induction typically operated with a “cold entry zone” due to the inrush of the secondary air around the burner and its shielding effect. Approximately 4 to 5 feet down from the tube entrance a high temperature hotspot was observed in an area where the secondary air and the raw fuel finally were mixed. In general, the temperature profiles from various burners start converging around the first return elbow of the fire-tube and are almost identical at the stack bottom.

<u>A general conclusion from this part of the study was that none of the 25 burner designs submitted for evaluation made a significant difference on the overall heat transfer in the fire-tube or on the stack bottom temperature. The difference in the burner performance occurs however at the tube entrance due to “cold entry zone” and a “hot spot”. The impact of the “cold entry zone” is expected to be more noticeable with short tubes.</u>

A series of heat transfer tests were conducted at almost identical temperature, flow, and firing rate conditions, in 2-, 3-, and 4-pass fire-tube configurations using water, then 50/50 ethylene glycol and finally oil on the bath side of the test unit. The resulting fire-tube temperature profiles show the efficiency gains due to the extension of the tube length from two to three, and then to four passes. At the same time the thermal performance of the heater was almost identical for all three liquids tested.

In addition to providing calibration data for the fire-tube rating software program, the above tests confirmed the early assumptions of this project that <u>the heat transfer in the fire-tube is controlled by the gas side with very little impact of the bath liquid type on the heater performance</u>, and that <u>extending fire-tube length from 2 to 4 passes (3 being not practical) can indeed produce significant gains in the heaters thermal efficiency</u>.

The heater was also tested with two different types of turbulators inside the fire-tube, leading to the conclusion that with low flow velocities and pressure drops inherent to the natural draft operation, turbulators in the gas path offer little improvement in the overall efficiency.

The data collected from the above tests at PITS were then compiled and analyzed and the results were used to calibrate the fire-tube rating software program in a way that the software output results matched the actual test results. The calibrated program was then used to predict performance of tube diameters, between 4” and 36”, U-tube lengths between 5’ and 30’, and for 2-pass natural draft, 4-pass natural draft, and 4-pass forced draft fire-tube configurations.

This part of the project produced fire-tube rating charts, which are intended to simplify the preliminary selection of various fire-tube configurations for a specific process application and with a specific thermal efficiency goal in mind, without having to run the fire-tube rating software. The fire-tube configuration can be chosen based on the heat transfer to the process, or based on the heat input to the burner. In addition, the effect of various surface heat flux rates on the heater efficiency can be investigated. Since the graphs were produced for a specific bath temperature, stack height, fuel composition, ambient conditions, and excess air levels, the final results should be confirmed by running the tube rating software program.

The impact of the surface heat flux rate on the heat efficiency with various fire-tube configurations was investigated in order to address the applicability of the currently used common design value of 10,000 BTU/hr/ft2. This analysis showed that with a 2-pass design in line heater application the above 10,000 BTU/hr/ft2 is almost guaranteed to produce heater efficiencies lower than the 72% low efficiency target.

In order to achieve the high efficiency target range of between 72% and 82%, the following approximate heat flux rates ranges should be considered:

a) 2 pass conventional natural draft heaters – between 10,000 and 3,200 BTU/hr/ft2;

b) 4 pass natural draft heaters – between 8,200 and 4,000 BTU/hr/ft2; and,

c) 4 pass forced draft heaters – between 12,800 and 4,900 BTU/hr/ft2.

Within each of these heat flux ranges there are variations in the performance of various fire-tube configurations, but generally, smaller diameter and longer tubes offer higher efficiencies than larger diameter and shorter tubes of the same surface area. The above heat flux ranges also depend on the actual process and ambient conditions. Consequently, instead of using a traditional design method based on a fixed assumed heat flux rate (for example 10,000 BTU/hr/ft2) a more accurate assessment can now be performed using the fire tube rating charts and the fire-tube rating software.

A very important aspect of both existing and new installations is that many of them are already, or very likely will become, oversized for the actual process energy requirement, due to the natural depletion of the resource. Many of the heaters cycle ON/OFF with long OFF periods. During these OFF periods heaters loose significant amounts of energy due to the continuous action of the natural draft, fueled by the warm stack and by the warm bath liquid. At the same time, the fire-tube heat transfer area is often overfired by the original high burner input setting during the ON period and then idle during the OFF period. Such frequent fire-tube ON/OFF operation offers an excellent opportunity for energy savings with minimal modification to the existing heater. If for example, a given heater is fired 50% of the time (50% duty cycle) to maintain the process energy requirement, then the same energy requirement could be satisfied by firing this heater 100% of the time at 50% of the original firing rate. Not only would this modification eliminate the heat loss during the OFF periods, but it would also half the heat flux rate during the ON period, thus making the fire-tube work more efficiently. In other words, the same fire-tube, which was designed originally for a nominal heat flux rate of 10,000 BTU/hr/ft2, would start working at 5,000 BTU/hr/ft2, and therefore closer to the 82% high efficiency target.

Although a standard engineering solution to this concept would be to use a conventional method of burner fuel modulation, our research shows that this method is not effective without addressing the secondary airflow control at the same time. This is due to the significant decrease in the heater efficiency with burner fuel turndown while the natural draft is maintaining the secondary airflow at, more or less, the constant rate. As discussed above, the solution to this challenge is in the application of a burner, which does not require secondary air for operation, and which, provides “aerodynamic modulation” of the primary air, naturally responding to the fuel flow modulation.

The general concept of maximizing the efficiency of the fire-tube heater is by the proper matching of the fire-tube configuration, burner size and design, and modulating controls, so that the heater “percolates” at a constant firing rate, which matches the process energy demand, without shutting the heater down and while maintaining its low excess air operation (between 2% and 3% oxygen in the stack).

Additional energy efficiency measures which can be considered, include turning the pilot OFF when the main burner is OFF; eliminating the use of pneumatic controls, which constantly vent the instrument gas, and by using solar or wind power to generate energy necessary to operate heater controls instead of fuel powered thermoelectric generators (TEGs).

The research described in this study also led to a conclusion that energy efficiency issues related to the fire-tube heaters often go beyond the technical aspects of fire-tube sizing, burner selection or controls design. They are also influenced by the operational and maintenance aspects and concerns about heater reliability, availability, and safety. These concerns often overrule the requirements for higher efficiencies and lower emissions. It is the conclusion of this study that all of these aspects Reliability-Safety-Efficiency can and should go hand-in-hand when all engineering and organizational aspects are properly addressed. To help with this task, this study proposes an organizational paradigm consisting of three concentric circles entitled: Corporate and Engineering, Equipment Manufacturers, and Plant Operations. These circles are broken down into activities related to fire heater application, specification, procurement, design, fabrication, installation, commissioning, operation, monitoring, and maintenance. Only through the coordination of these activities and continuing feedback, can significant energy efficiency gains be achieved and maintained throughout the lifecycle of a heater.

One of the recurring topics of this research is the need for education related to the energy efficiency of the fire-tube heaters. To address this requirement, this study proposes the development under the auspices of PITS of a sub-trade given a working name of: “Oilfield Gas Fired Appliance Technician” (OGFAT). An industry and government sanctioned sub-trade would provide a suitable knowledge base in the industry aimed at the proper installation and maintenance of thousands of high efficiency fire-tube heater solutions and their sustainable high efficiency operation.

This study contains information, design tools, evaluation and maintenance guidelines, as well as, both engineering and organizational concepts and recommendations, which could be used to solve the fire-tube heater energy efficiency and emissions challenge on an industry wide scale.

There is no question that technology exists to make the immersion fire-tube heaters more efficient. Many of these techniques have been tried in the past and can be seen in the older installations. The principles of the heat transfer and combustion processes used in this application are available and can be applied though proper engineering assessment and due diligence. In this study, we tried to develop tools (such as tube-rating software of fire-tube performance charts) and methodology, which may help in achieving this goal.

We are confident that the efficiency of any existing heater can be improved, if resources and time can be allocated to such project. This approach however does not address the majority of the installations and definitely does not offer a long-term verifiable solution.

As this study demonstrated there are a number of variables, which must be considered, many of which are of a non-technical nature including corporate and plant-level commitment to energy efficiency and emission reduction projects, operating and maintenance practices, allocation of resources and funding, and most importantly lack of knowledge of advanced combustion and heat principles.

These non-technical issues combined with inertia of current outdated standards and the existing infrastructure of installed assets, heater design manufacturing, and support cannot be addressed by a single technical solution, no matter how efficient.

Additionally, there are many technical issues which fall outside of the “battery limit” of a heater, but which determine its effectiveness in the process. These issues must be reviewed and identified before a decision is made regarding the feasibility of a heater upgrade.

All of these concepts were discussed in detail in this report. Additionally, we proposed a new paradigm aimed at achieving true, long-term and verifiable results not just for one installation but also for the entire industry.

Following are the final "high level" recommendation from this project:

a) use the technical recommendations of this report to develop tools for the assessment and improvement of immersion fire-tube heaters;

b) implement the proposed paradigm concept to the immersion fired-heaters efficiency improvement projects in order to encompass a full range of activities including corporate and engineering activities, heater manufacturers, and plant operations;

c) conduct a survey of the existing installations to identify the worst cases of heaters, which would be the best candidates for the upgrades. Prioritize upgrades starting with the largest capacity heaters;

d) start developing upgrade trial projects which would bring verifiable results, and which could be easily monitored with existing control systems (DCS, PLC or portable data collection devices);

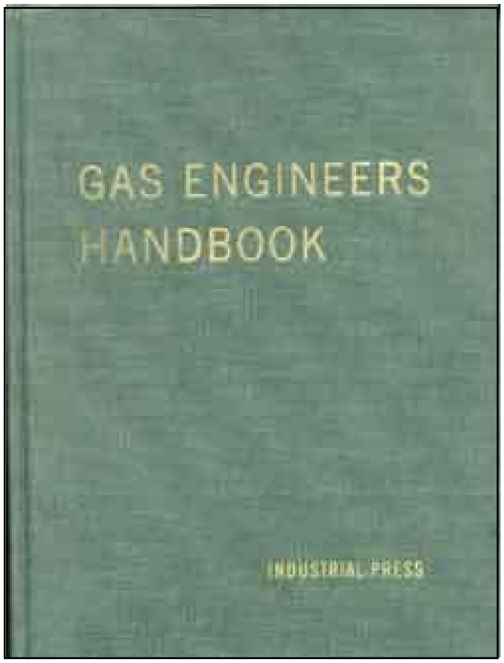
e) prove the efficiency savings on the above trial projects;

f) based on the above proven savings and experience gained in the trial projects continue upgrades while improving and standardizing this improvement process; and,

g) formalize industry recommendations through a relevant industry association such as CAPP or PTAC for development of OGFAT sub-trade training program by PITS with endorsement and funding from Alberta Advanced Education.

APPENDIX A – LITERATURE STUDY DETAILS

A1 Gas Engineers Handbook

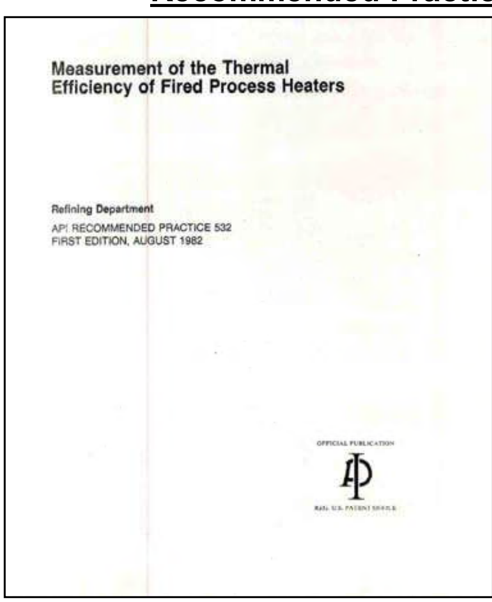


American Gas Association, *Gas Engineers Handbook – Fuel Gas Engineering Practices*, Industrial Press Inc, New York, NY, 1969

Section 2 entitled Fuels, Combustion and Heat Transfer provides a comprehensive compendium of knowledge related to this subject. It addresses gaseous, liquid and solid fuels, as well as their combustion, emissions and losses. Excellent source of combustion information and data this source was extensively used in our research. Chapter 6 describes conductive, convective, and radiative heat transfer. Excess air is identified as a main cause of heat transfer reduction. Authors state that the effects of reduced flame temperature and increased heat content carried off in the flue products are always greater than the effect of increasing the heat transfer coefficient. The amount of heat lost by the flame before the maximum temperature is reached ranges from 15 to 25% of the gross heating value of the fuel burned. Forced draft burners with turbulent flames produce higher flame temperatures than natural draft burners.

Section 12 entitled Utilization of Gas discusses various types of heating appliances and principles of burner design.

A2 Measurement of the Thermal Efficiency of Fired Process Heaters, API Recommended Practice 532

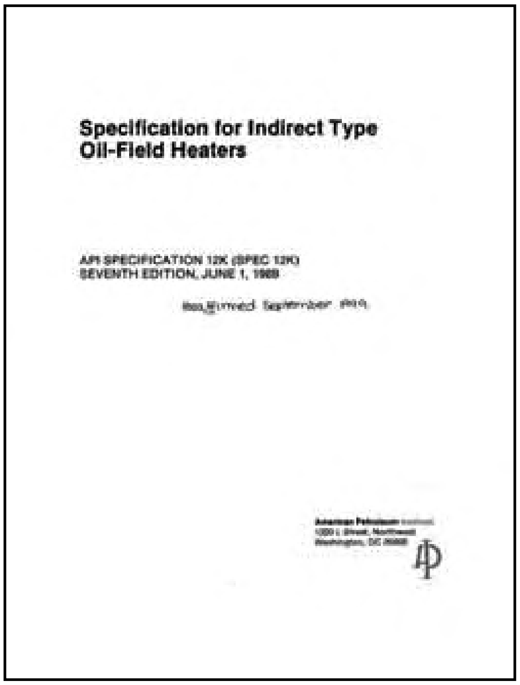


American Petroleum Institute, Refining Department, *Measurement of the Thermal Efficiency of Fired Process Heaters, API Recommended Practice 532*, First Edition, API, August 1982

Provides guidelines for measurements required to establish heater efficiency. Suggests special multi-shielded thermocouple. Discusses wet and dry flue gas measurements. Includes good explanation of both gross an net efficiency.

Recommends measurements both on the flue gas and process side. Provides formulas for efficiency calculations. Includes worksheets for calculations. Does not give efficiency recommendations. Assumes high temperature differentials on the process side and sets measurement tolerances accordingly.

A3 API SPEC 12K, Seventh Edition, Specification For Indirect Type Oil-Field Heaters


Specification for Indirect Type Oil-Field Heaters

API SPECIFICATION 12K (SPEC 12K)
SEVENTH EDITION, JUNE 1, 1989

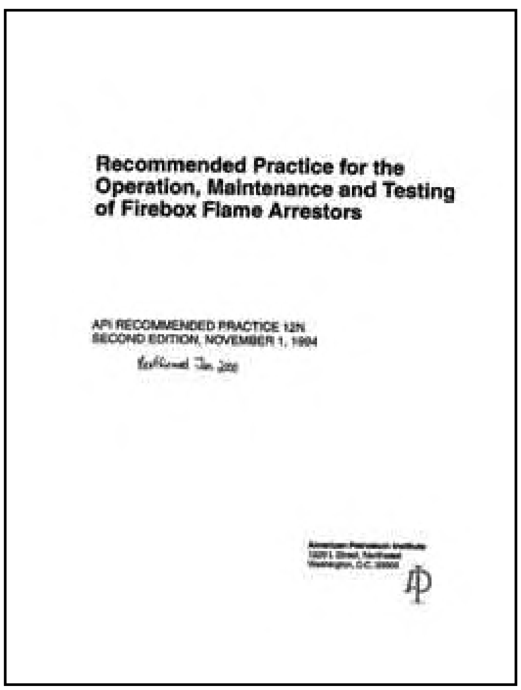
API-Production Department, *API SPEC 12K, Seventh Edition, Specification For Indirect Type Oil-Field Heaters*, American Petroleum Institute, June 1989

Provides terminology for fired heaters. Discusses the minimum requirements for design, fabrication and testing of oil field type indirect fired heaters. Concentrates on pressure coil design including heat transfer and corrosion guidelines. Shows layouts of recommended rating plates for heaters.

Performance can be measured by flue-gas analysis and temperature measurements from the base of the stack

Fig C.1 is a useful chart for checking determining gross HHV efficiency. For sulfur free fuels recommends minimum stack temperature of 250 deg F. For fuels containing 0.05 to 1.0% V/V sulfur recommends 300 to 400 deg F stack temperature. It stack is insulated this temperature can be lowered by 50 deg F. Gives formulas for convective heat transfer. Shows recommended values for both surface and cross-sectional heat flux rates.

A4 API Recommended Practice 12N, Second Edition, Recommended Practice For The Operation, Maintenance and Testing Of Firebox Flame Arrestors


Recommended Practice for the Operation, Maintenance and Testing of Firebox Flame Arrestors

API RECOMMENDED PRACTICE 12N
SECOND EDITION, NOVEMBER 1, 1994

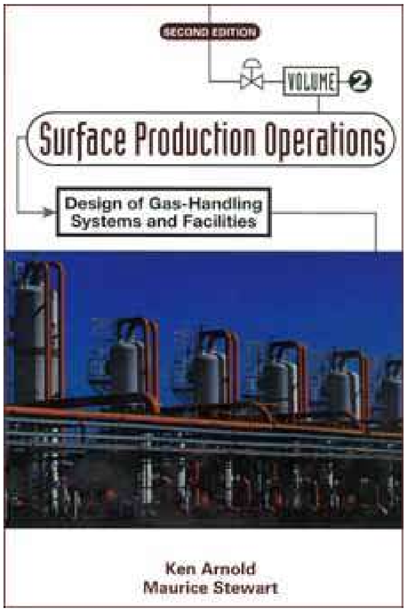
API, *API Recommended Practice 12N, Second Edition, Recommended Practice For The Operation, Maintenance and Testing Of Firebox Flame Arrestors*, American Petroleum Institute, Washington, DC, November 1994

Describes flame arrestor nomenclature and theory.

Includes guidelines for operation, maintenance and inspection methods to test flame arrestors operation, but not to test pressure drop.

Excludes systems with electrical spark ignition, forced and induced draft. Does not address burner setup or system efficiency.

A5 Surface Production Operations: Design of Gas-Handling Systems and Facilities



Arnold, Ken, Stewart Maurice, *Surface Production Operations: Design of Gas-Handling Systems and Facilities,* Second Edition, Volume 2, Gulf, 1998

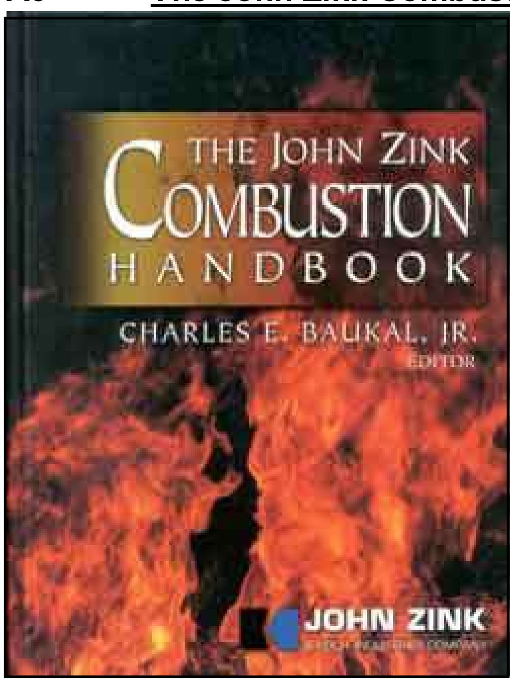
Chapter 2 Heat Transfer Theory – Discusses 3 methods of heat transfer.

Deals mostly with tube heat transfer from bath liquid to process coil. For fire tubes suggests standard heat flux rates: water 10,000, crude oil 8,000, glycol 7,500, and amine 7,500

Outlines principles of heat transfer related to immersion heaters. Gives maximum cross-sectional heat flux rate of 21,000 BTU/hr/in2 but does not recognize the negative effect of oversized fire tubes on the heat transfer rates.

Chapter 5 – LTX Units and indirect Fired Heaters gives conventional simplified methods of fire tube sizing using average heat flux rates, but does not deal with efficiency.

A6 The John Zink Combustion Handbook



Baukal Charles E., Jr., *The John Zink Combustion Handbook*, John Zink Company LLC, Tulsa, Oklahoma, CRC Press, 2001

A very comprehensive source of combustion information. Discusses basic laws, and combustion calculations, flame temperatures, products of combustion, conductive, convective and radiant heat transfer, fluid dynamics, fuel properties and emissions. Discusses burner design principles. Heater design recommendations mostly oriented towards refinery equipment.

Excellent in theory of combustion but weak in smaller heater applications.

A7 Fired Heaters - I, Finding The Basic Design For Your Application


FIRED HEATERS—I

Finding the basic design for your application

Berman Herbert L., *Fired Heaters-I, Finding The Basic Design For Your Application*, Chemical Engineering, 19 June 1978

Focuses on design of fluid tubing type heaters with some general comparisons

The most efficient arrangements include horizontal tubes in a vertical convection zone

Discusses various types of heaters used in the petroleum industry and methods of combustion air control. First article of series of four.

A8 Fired Heaters- II, Construction Materials, Mechanical Features, Performance Monitoring


FIRED HEATERS—II

Construction materials, mechanical features, performance monitoring

This second of four parts looks closely at some of the design options and mechanical features that are available in today's fired heaters. Items covered include refractories, tube coils, extended-surface devices, tube supports and burners.

Berman Herbert L., *Fired Heaters-II, Construction Materials, Mechanical Features, Performance Monitoring,* Chemical Engineering, 31 July 1978

The discussion of extended surfaces, convection zones and flue-gas analysis is applicable. Discusses types of finned surfaces.

Some data on extended surfaces, see Table II

Extended surfaces are never installed in the radiant zone

Various methods of insulation discussed. Talks about type of burners: premix inspiriting and raw gas. Premix burners aspirate 50% to 60% of stoichiometric air. Disadvantages of premix burners: higher noise, possibility of flashback, high gas pressure required. Discusses burner noise reduction techniques. Talks about stack dampers and materials (carbon steel up to 900 deg F, 304 SS 1500 deg F, 310SS 1800 deg F. Stresses importance of cleaning and performance monitoring including process flow rate, fuel flow, process temperatures, stack data, stack draft, tube skin temperatures.

A9 Fired Heaters - III, How Combustion Conditions Influence Design And Operation

FIRED HEATERS—III

How combustion conditions influence design and operation

third of four articles highlights some of the major process … that affect the design of fired heaters. Basic combustion … are reviewed, as well as methods for determining coil … surface area, fluid pressure drops, and stack height.

Herbert L. Berman, Caltex Petroleum Corp.*

Berman Herbert L., *Fired Heaters-III, How Combustion Conditions Influence Design And Operation*, Chemical Engineering, 14 August 1978

Discusses the relative importance of different design considerations for a typical heater, but does not look at other options

Discusses combustion basics, fuels, combustion calculations. Includes design details and formulas. Includes net efficiency calculations. Defines radiant rate (flux rate) for various types of applications (between 6000 and 10000 BTU/hr/ft2). Suggests that higher radiant rates result in higher maintenance costs and potential for coking.

Convection zones in heater designs are almost always equipped with extended surface. Gives examples of heaters calculations including stack, pressure drop, tube wall thicknesses, etc. Discusses stack temperature loss at average 75 deg F. Stack should provide 25% overcapacity.

A10 Fired Heaters - IV, How To Reduce Your Fuel Bill

FIRED HEATERS—IV

How to reduce your fuel bill

This final article in a four-part series takes a look at how energy conservation has affected the design and operation of fired heaters. Items of concern include excess-air reduction, enhanced heat recovery, combustion-air preheating, and the conversion of gas-fired heaters to liquid firing.

Herbert L. Berman, Caltex Petroleum Corp.*

Berman Herbert L., *Fired Heaters - IV, How To Reduce Your Fuel Bill*, Chemical Engineering, 11 September 1978

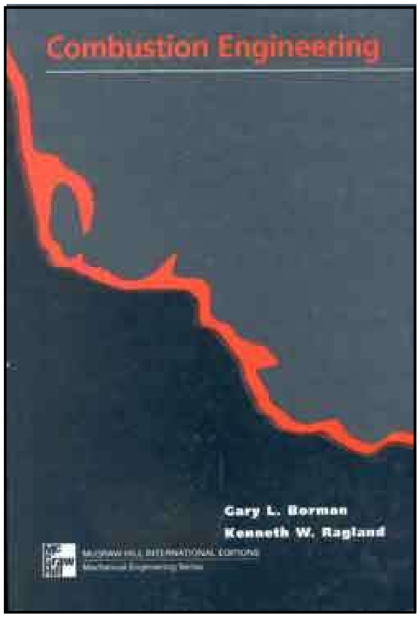
Proven methods of reducing fuel consumption for typical heaters.

Excess air is the most important combustion variable affecting efficiency

Adding extended surfaces can improve efficiency by up to 10% but might require additional stack height. Recommends use of finned tubes. And heat recovery from flue gases/

Automatic draft control can increase efficiency.

A11 Combustion Engineering



Borman, Gary L., *Combustion Engineering*, McGraw Hill, Singapore, 1998

Good source of information about principles of combustions, fuels, thermodynamics of combustion. Application of Laws of Thermodynamics to combustion, chemical kinetics, flame characteristics. Ignition and quenching theory. Discussion of mass energy balances in a furnace.

Efficiency calculation should be always based on higher heating value. Explains principles of pulse combustion, and suggests as good method for high efficiency designs. States that over 80% of extra energy, which does not go to heat, transfer ends up in the exhaust gas. Therefore exhaust gas recovery has the biggest potential for improvements.

A12 The Influence of Prandtl Number on Heat Transfer And Pressure Drop Of Artificially Roughened Channels

THE INFLUENCE OF PRANDTL NUMBER ON HEAT TRANSFER AND PRESSURE DROP OF ARTIFICIALLY ROUGHENED CHANNELS

E. BURCK

Burck, E., *The Influence of Prandtl Number on Heat Transfer And Pressure Drop Of Artificially Roughened Channels*, Augmentation of Convective Heat and Mass Transfer, ASME, New York, 1970

Discusses various methods and analyzes both integral surface roughness and surface mounted roughness.

The heat transfer rate is influenced more by good thermal contact of the roughness with the tube, and not the shape of the roughness element.

The amount of heat transferred by turbulence is limited by conduction through the thermal boundary layer. Includes data on different surface roughness efficiency. Good thermal contact between the roughness element and the heat transfer surface is essential; therefore integral roughness is more effective. The amount of heat transported by turbulence is the bulk flow is limited by the amount of heat, which can be transported by conduction through the boundary layer.

A13 Experimental Heat Transfer And Pressure Drop With Two-Dimensional Discrete Turbulence Promoters Applied To Two Opposite Walls Of A Square Tube

Burggraf, F., *Experimental Heat Transfer And Pressure Drop With Two-Dimensional Discrete Turbulence Promoters Applied To Two Opposite Walls Of A Square Tube*, Augmentation of Convective Heat and Mass Transfer, ASME, New York, 1970

Investigates the effect on heat transfer rate of a square duct with extended surfaces. The heat transfer rate increases by up to 80% with a rib of height 5.5% of duct width. Turbulence promoters are an effective way of increasing heat transfer in a tube if the flow is turbulent and Reynolds number is between 13,000 and 130,000.

A14 The Roughness Effects On Friction and Heat transfer In The Fully Developed Turbulent Flow In Pipes

The roughness effects on friction and heat transfer in the fully developed turbulent flow in pipes

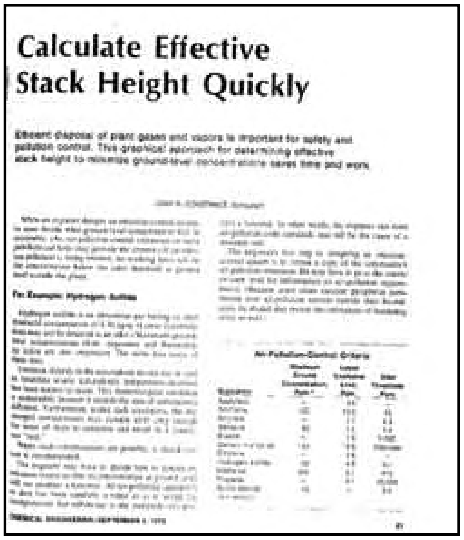
Kadim Ceylan, Gulnur Kelbaliyev

Ceylan, Kelbaliyev, *The Roughness Effects On Friction and Heat transfer In The Fully Developed Turbulent Flow In Pipes*, Applied Thermal Engineering, 8 November 2002

An analysis of the effects of surface roughness and fouling on heat transfer with supporting data and practical conclusions. Applies only to turbulent flows. Turbulence devices and surface roughness increase the heat transfer rate, but turbulators also increase drag. Solutions should maximize the heat transfer by minimizing drag, such as rough tube instead of smooth. Surface roughness can increase heat transfer through laminar layer by up to 350%. The effects of fouling resistance can't be generalized; they are dependent on fouling type and tube geometry.

Includes some valuable data: Figures 3,5,6; equations 10,22; references 10,11,12,22

A15 Calculate Effective Stack Height Quickly


Calculate Effective Stack Height Quickly

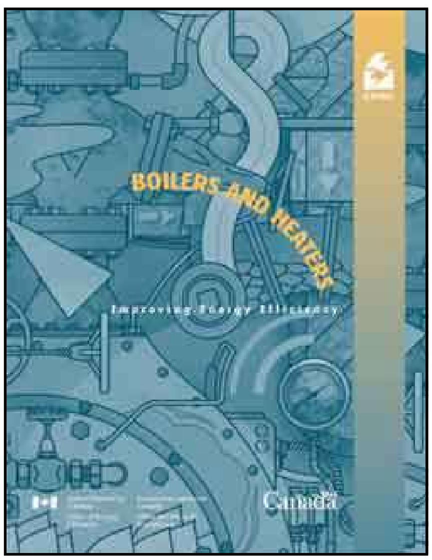
Efficient disposal of plant gases and vapors is important for safety and pollution control. This graphical approach for determining effective stack height to minimize ground-level concentrations saves time and work.

Constance John D., *Calculate Effective Stack Height Quickly*, Chemical Engineering, 4 September 1972

Discusses stack design for pollution emissions.

Provides stack calculation methods but only from the point of view of emissions and not draft. May have application with sour fuel combustion.

A16 Boiler & Heaters – Improving Energy Efficiency



Dockrill, Friedrich, *Boiler & Heaters – Improving Energy Efficiency*, Natural Resources Canada, August 2001

Practical options which go beyond the boiler to consider plant efficiencies. Calculation of heat losses and efficiencies base on fuel HHV.

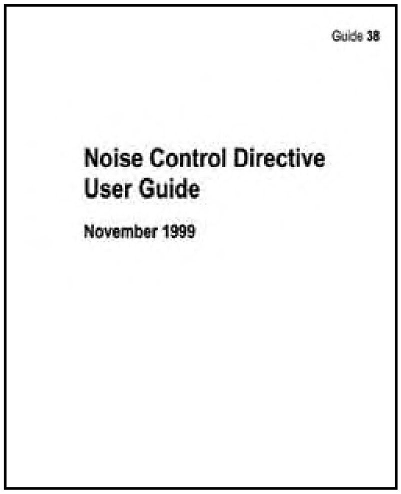
Includes many tips and "energy management actions"

Excess air identified as the most important tool for managing energy efficiency. Typically reduction in O2 in the stack by 1% gives 2.5% increase in efficiency. Discusses various methods of fuel/air control. Precise air and fuel control is worth the cost, see Fig 1. Provides emission guidelines.

Quantifies where heat loss typically goes in a boiler: flue: 18%, radiation & convection 4%, blow-down 3%, thermal efficiency 75 to 77%. Trying to reduce process heat requirement is a very effective way to improve fuel efficiency. And it must be continually reevaluated.

Quantifies fouling effects and recommends checking via flue-gas temperature changes, see pg 9,10. Methods for improvement: equipment sizing, process requirement, cleaning/maintenance, excess air control, reduction or other losses and heat recovery, insulation, reduction in heat distribution losses. heat cascading.. (1mm scale on tube increases fuel consumption by 2%, 36degF reduction in flue gas temperature improves efficiency by 1%.

A17 Noise Control Directive User Guide


Guide 38

Noise Control Directive
User Guide

November 1999

EUB, *Noise Control Directive User Guide, Guide 38*, Energy Utilities Board, November 1999

Provides guidelines for noise measurement, allowable noise levels. Does not specifically address noise problems associated with heaters.

A18 The Experimental Study Of The Heat Transfer Intensification Under Conditions Of Forced One And Two Phase Flow in Channels


THE EXPERIMENTAL STUDY OF THE HEAT TRANSFER INTENSIFICATION UNDER CONDITIONS OF FORCED ONE- AND TWO-PHASE FLOW IN CHANNELS

Kalinin E.K., *The Experimental Study Of The Heat Transfer Intensification Under Conditions Of Forced One And Two Phase Flow in Channels*, AOCHMT

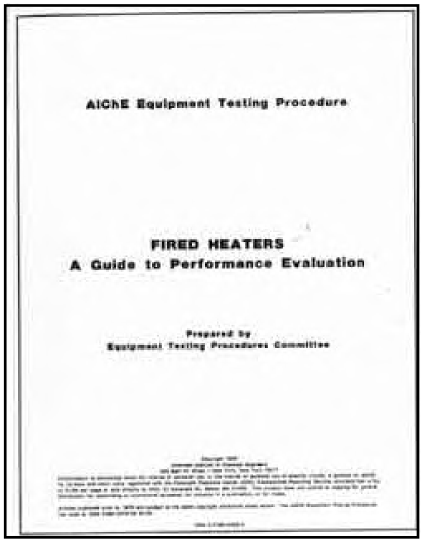
Investigates the use of formed grooves in a tube to promote heat transfer, in the turbulent flow region.

The outside grooves and subsequent inner diaphragms generate eddies and turbulence, thereby increasing the heat transfer rate with moderate pressure drop

This method was found to decrease by 1.5-2 times the size and weight of tubes

Data is given for multiple groove configurations, see Fig 12

A19 Fired Heaters - A Guide to Performance Evaluation



AIChE Equipment Testing Procedure

FIRED HEATERS
A Guide to Performance Evaluation

Prepared by
Equipment Testing Procedures Committee

Equipment Testing Procedures Committee, *Fired Heaters - A Guide to Performance Evaluation*, American Institute of Chemical Engineers. 1989

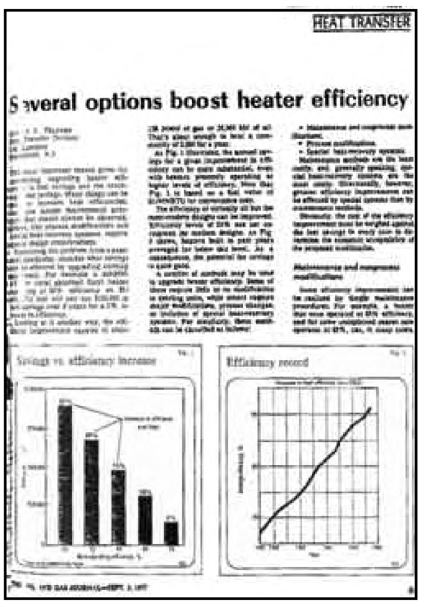
An analysis of combustion chemistry and the recommended protocol to test performance. Including both the process side and combustion measurements.

Explains combustion calculations, and mass balances. Provides heat capacity data.

Lists the measurements required to evaluate heater performance in Tables 304.1-304.3 (p4)

Very useful reference for heater evaluation but does not include practical efficiency recommendations.

A20 Several Options Boost Heater Efficiency



HEAT TRANSFER

Several options boost heater efficiency

Savings vs. efficiency increase

Efficiency record

Feldner, George F., *Several Options Boost Heater Efficiency*, The Oil and Gas Journal, September 1977

The heater efficiency methods of Maintenance, Process Modifications, and Heat Recovery should be tackled in that order, as the maintenance methods are least costly, heat recovery most costly.

Efficiency rule: the higher the heater efficiency, the greater the % of heat absorption in the convective zone. Air leakage and excess air should be minimized.

The highest heater efficiencies are usually attained with air pre-heat equipment. Table on pg 4 quantifies the benefit of high convective zone heat absorption

A21 Flue Gas Analysis – A Storehouse of Information – Here's a step-by-step procedure to determine heater performance


PLANT UTILITIES/HEAT TRANSFER SPECIALREPORT

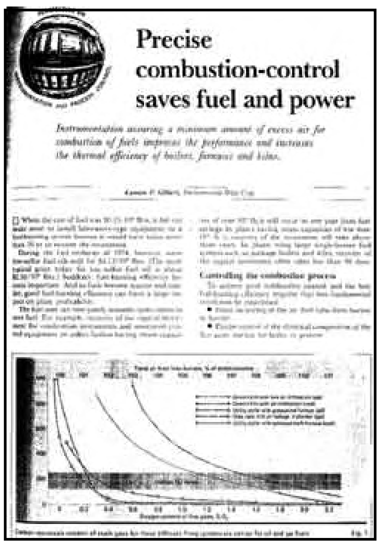
Flue gas analysis—a storehouse of information

Here's a step-by-step procedure to determine heater performance

Ghosh R.K., Haldia Refinery, Indian Oil Corp, West Bengal, India – *Flue Gas Analysis – A Storehouse of Information – Here's a step-by-step procedure to determine heater performance*, Hydrocarbon Processing, Houston, TX, July 2003

Provides combustion calculations based on hydrocarbon combination molecular formula $C_xH_yS_z$. Estimates heat losses and mass balances based on heat content coefficients. Calculates net and gross efficiencies. Also calculates gas dew point base on small amount of sulfur in the fuel. Provides good example of calculations, although it seems to be more customized towards boiler operation with fuel oil firing.

A22 Precise Combustion Control Saves Fuel And Power


Precise combustion-control saves fuel and power

Instrumentation assuring a minimum amount of excess air for combustion of fuels improves the performance and increases the thermal efficiency of boilers, furnaces and kilns.

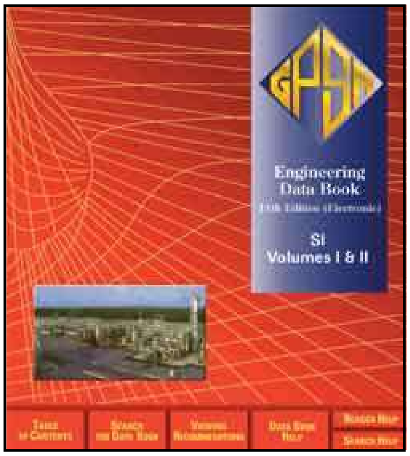
Gilbert, Lyman F., *Precise Combustion Control Saves Fuel And Power*, Chemical Engineering, 21 June 1976

Promotes application of combustion instrumentation as a cost effective means to efficiency. Explains how measuring flue-gases can help guide burner operation proper air/fuel ratio and flue-gas composition control.

States that CO is a better indicator than O_2 in troubleshooting combustion problems including plugged up or oversized burners, poor mixing or inadequate combustion air. CO is only formed during combustion while O_2 can come from other sources as leakage. Therefore O_2 measurement is unreliable. States that reduced O2 levels produce longer flames. Incorrectly assumes that excess air reductions also reduce NOx.

Includes detailed examples of calculating reduced excess air savings

A23 GPSA Engineering Data Book



Gas Processors Association, *GPSA Engineering Data Book – 11th Edition (Electronic), SI Volumes I&II*, Gas Processors Suppliers Association (GPSA), Tulsa, OK, 1998

Good source of information related to fired heaters used by the petroleum industry. Section 8 offers general overview more from a practical than theoretical point of view and not entirely correct. (Use with caution!)

Includes valuable equations and data to calculate fins, conduction, radiation, combustion. Describes fuel net-LHV(NTE) and gross-HHV(GTE) efficiency concepts. States that the combustion efficiency is close to gross thermal efficiency, but there is tendency to use net efficiency because numbers are higher. Discusses draft, types of burners and gas interchangeability. Describes types of heaters and gives examples of calculations. Demonstrates how gross thermal efficiency can be determined from the excess air and stack gas temperature, see Fig 8-17.

The three main efficiency methods for general fired heaters are to add convection surface, use the waste heat, and install an air preheat system. Most of the resistance to convection occurs in a thin film next to the solid surface even if fluid flow is turbulent.

Discusses typical fire tube heater applications: water bath 82-91 deg C; glycol 91-96 deg C; low pressure steam 118-121 deg C; hot oil 149-288 deg C; molten salt 204-427deg C; TEG reboiler 177-204 deg C; amine reboiler 118-132 deg C.

Also provides fire tube flux rates [in BTU/hr/ft2]: water bath 10000-13000; glycol 7900-10000; low pressure steam 15000-18000; hot oil 6000-7900; molten salt 15000 to 18000; TEG reboiler 6000-7900; amine reboiler 6600-10000.

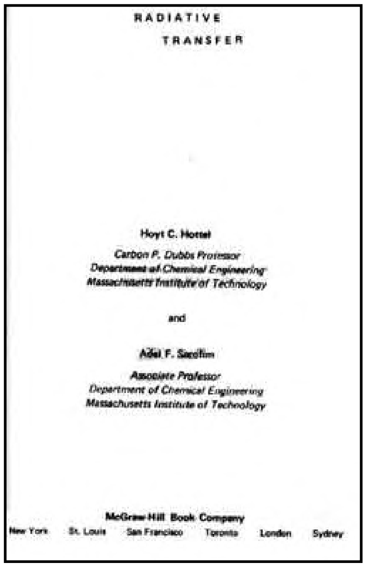
Identifies the corresponding net efficiencies at between 68% and 82% (gross efficiencies 59% to 73% with stack temperatures from 400 to 650 deg C (750 to 1200 deg F).

States that with good excess air control (5 to 10% excess air) 200 deg C stack temperatures and 90% net efficiency is possible, but claims that this increases pressure drop across the tube and decreases draft. (Note: Seems to us like this is exactly the purpose of cutting back excess air).

Shows possible efficiency improvements: economizer (?), turbulator, or waste heat recovery but does not provide any design details.

Stipulates that a long and lazy yellow flame increases the fire tube life and increases radiant flame area, normal length is halfway down first fire tube length.

A24 Radiative Transfer



RADIATIVE TRANSFER

Hoyt C. Hottel
Carbon P. Dubbs Professor
Department of Chemical Engineering
Massachusetts Institute of Technology

and

Adel F. Sarofim
Associate Professor
Department of Chemical Engineering
Massachusetts Institute of Technology

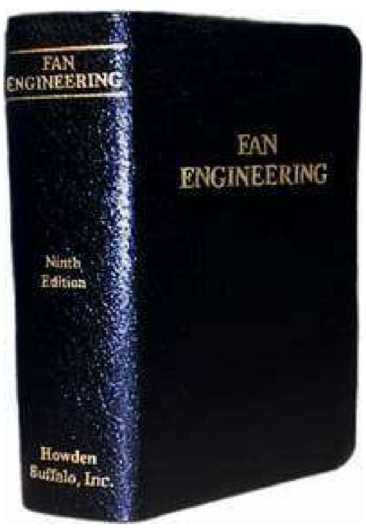
McGraw-Hill Book Company
New York St. Louis San Francisco Toronto London Sydney

Hottel, Hoyt C., *Radiative Transfer*, McGraw-Hill Book Company, New York, NY, 1967

Gives basic formulas and charts for the calculation of flame and hot gas emmisivity. Basic reference material for many subsequent radiative transfer publications. Chapter six explains basic attenuation laws, band emissions, application of various models, compilation of gas emmisivity from various gases, and representation of real gas for engineering calculations. Advanced calculus methods used.

Basis for calculations for the tube rating program developed in this project.

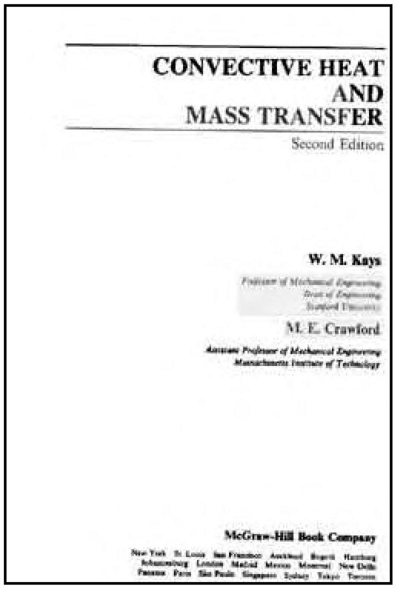
A25 Fan Engineering



Jorgensen, Robert – *Fan Engineering, Ninth Edition*, Howden Buffalo, Inc, Buffalo, NY, 1999

Excellent source of engineering information related to properties of air and other gases, fluid flow, heat and mass transfer. Explains conduction, convection and radiation. Also in Chapter 22 gives practical formulas for combustion, excess air, dew point, natural draft calculations and raft losses. Explains the difference in HHV and LHV and efficiencies. States that fuel in the US is sold on HHV and LHV calculation are common in Europe. Discusses various types of fuels and their properties, combustion air and excess air concepts, flue gas losses. Shows difference between natural and mechanical draft.

A26 Convective Heat and Mass Transfer

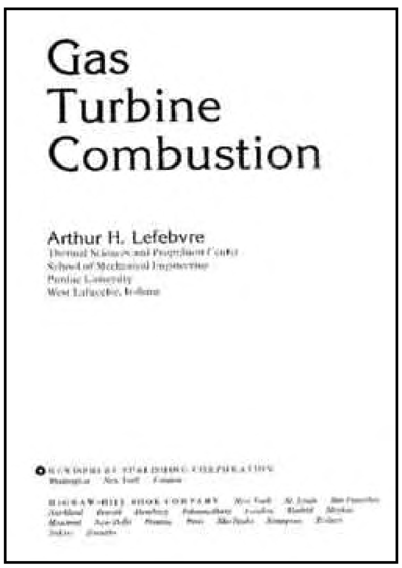

CONVECTIVE HEAT AND MASS TRANSFER
Second Edition
W. M. Kays
M. E. Crawford
McGraw-Hill Book Company

Kays, W.M., *Convective Heat and Mass Transfer, Second Edition*, McGraw-Hill Book Company

Advanced formulas for convective heat transfer calculations, do not offer models for combined radiative/convective heat transfer models.

Advanced text in heat transfer principles. Explains conservation principles, concepts of boundary layer. Provides equations for heat transfer in turbulent flow inside tubes both in terms of entry problems and fully developed flows. Shows impact of Prandtl and Nusselt numbers on heat transfer. Assumes aerodynamics of a smooth tube but show some approximations for tube roughness.

A27 Gas Turbine Combustion


Gas Turbine Combustion
Arthur H. Lefebvre

Lefebvre Arthur H., *Gas Turbine Combustion*, McGraw-Hill Book Company, 1983

Provides basic concepts and formulas for combined radiant and convective heat transfer and more advanced methods of heat transfer computations.

Section 8 is dedicated to heat transfer in the combustion chamber. Discusses internal, external radiation and internal and external convection. Addresses radiation from non-luminous gases. Although explained in the context of gas turbine performance, the principles of radiation from products of combustion can be applied to a fire-tube. Provides calculations and charts of partial/total pressures of water vapour and carbon dioxide as a function of fuel/air ratio, and correction factors for emmisivity. Discusses also impact of fuel composition, operating parameters and size of the combustion chamber.

A28 Augmentation Of Convective Heat Transfer Inside Tubes


Chemical Engineering Journal

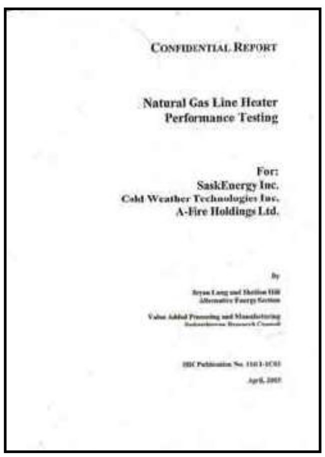
Liao, *Augmentation Of Convective Heat Transfer Inside Tubes*, Chemical Engineering Journal, October 1999

Investigates the combined effect of a turbulator device and three dimensional extended surface configuration on the heat transfer rate

This method was found to be effective for highly viscous fluids only. The majority of total thermal resistance is concentrated in the viscous sub layer and the buffer zone (tube side laminar flow)

Cites another study result of enhanced air heat transfer of 1.8-3.2 times with a corresponding pressure drop of 9-14 times

A29 Natural Gas Line Heater Performance Testing


CONFIDENTIAL REPORT

Natural Gas Line Heater
Performance Testing

For:
SaskEnergy Inc.
Cold Weather Technologies Inc.
A-Fire Holdings Ltd.

Lung, Bryan, Hill, Sheldon, *Natural Gas Line Heater Performance Testing*, Saskatchewan Research Council Publication No. 11611-1C03, April 2003

This study, which was provided to us for evaluation by ColdWeather Technologies, was conducted for SaskEnergy Inc., ColdWeather Technologies, and A-Fire Holdings to assess the efficiency of three line heaters: a conventional design, heat driven loop wet system (HDL) and HDL Dry Unit. The study offered an interesting and non-conventional approach to efficiency calculations based on the indication of the degree of useful heat transferred to the process gas, based on the observation that at reduced process gas flows constant bath temperature control results in over-heating of the process gas. Due to a typically large volume of glycol in the heater a conventional temperature control cannot respond in time to load change. So, although the energy is transferred to the process and under normal evaluation would be considered as a useful energy, it is in fact a thermal overrun and should be considered a waste energy. The greatest fuel savings in the study were attributed to the implementation of gas temperature control instead of conventional bath temperature control. The reduction of the glycol volume to 7% of the conventional volume resulted in temperature recovery rates, which were 21 times faster than in the conventional heater, thus allowing controls to better follow the load demand. Using this concept the measured combustion efficiency of 75% was discounted to 55% thermal efficiency with intermittent firing and 57.7% with continuous firing.

The heater was also tested with Thermogreen heat transfer fluid and a negligible improvement in efficiency was measured, despite the fact that the fluid film coefficients were improved by 22%. The authors concluded that the overall heat transfer is dominated by the heat transfer from gas to the fire tube resulting in minimal impact of fluid side on the overall heat transfer coefficient.

A change of burner also did not produce improvements in overall efficiency. Using gas temperature control instead of bath temperature an efficiency improvement from 38% to 65% was claimed.

The Heat Driven Loop system utilizing steam heated retrofit element installed instead of the fire tube resulted in thermal efficiencies between 49.3% and 54.6% depending on the firing duty cycle.

The best results were obtained with HDL dry unit, which is composed of a unit in which glycol bath is eliminated, and the natural gas is circulated through a tank of steam. With this unit the efficiencies were calculated at between 58.3% and 61.6%. The half-load improvement was attributed to the implementation of gas temperature control.

The recommendations for improvements included better external insulation and gas temperature control.

A30 Efficient and Safe Operation of Indirect Fired Heaters


Efficient and Safe Operation of Indirect Fired Heaters

F.D. MARLETT

Marlett, F.D., *Efficient and Safe Operation of Indirect Fired Heaters*, The Journal of Canadian Petroleum Technology, November 1997

This comprehensive paper describes Northwestern Utilities Limited experience with in-house fabricated conventional, natural draft indirect fired heaters having atmospheric burners and non-electric control systems. Paper outlines unit design features. Two plates with matching air holes are used for air adjustment. Type B double wall vent pipe is placed over the stack to lessen heat loss and to maintain stack draft and to prevent condensation and freezing. A non-down drafting vent cap is used to reduce effect of wind, and prevent rain, snow, objects entering the stack. A flame arrester is used to prevent ignition of outside fuel source from flame source inside the heater. Report elaborates in detail on the importance of flame arresters. Heater sizing is described in general terms and both GPSA and API12K are quoted as sources of heat flux design numbers between 10,000 and 12,000 to 13,000 BTU/hr/ft2, with additional 20% allowance for glycol operation.

For cross-sectional flux rate a maximum 15,000 BTU/hr/in2 is used per API12K. Author states that adequate stack height must be provided for sufficient draft but does not specify how to establish this height. Thermal efficiency of heaters is quoted at between 70 and 75%.

Heater operating and maintenance procedures are discussed. The increase in glycol concentration causes decrease of the overall heat transfer coefficient to the process coil, but also stipulates that similar decrease can be expected from the fire tube. Various considerations regarding glycol are mentioned. Lower bath temperatures are recommended to protect glycol from degradation. Natural loss of water from glycol should be also considered.

Gas stream temperature controller is suggested as potential efficiency upgrade. This involves a three way valve to bypass part of the gas around the heater.

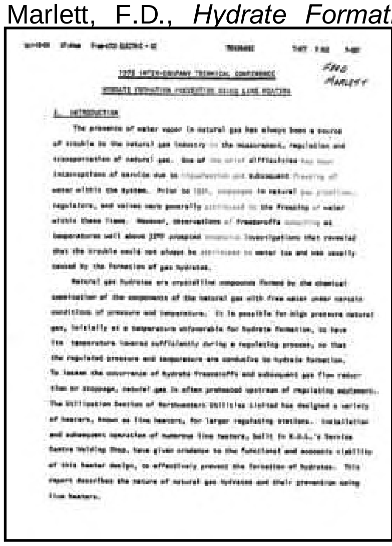
Other efficiency recommendation include: flue gas analysis, cleaning of both air inlet and fire tube, matching burner size and orifice to process requirements, adjusting secondary air flow. Automatic air shutoff may be very effective in reducing heat losses.

Good practices include also checking for gas leaks, checking controls, recording performance data including flue gas analysis.

Both operating and maintenance personnel should be trained and properly equipped. This should be combined with proper heater design and selection criteria and conscious and rigorous inspection and maintenance program. Such measures will prolong heater life; enhance safety to achieve optimal performance, fuel economy and thermal efficiency.

A31 Hydrate Formation Prevention Using Line Heaters

Marlett, F.D., *Hydrate Formation Prevention Using Line Heaters*, 1975 Inter-Company Technical Conference, 28 May 1975



1975 INTER-COMPANY TECHNICAL CONFERENCE

HYDRATE FORMATION PREVENTION USING LINE HEATERS

1. INTRODUCTION

Paper describes in detail history and theory of hydrate formation. Discusses requirements for gas heating to compensate for Joule Thomson effect. Includes information on the design of line heaters, but doesn't deal with efficiency. Briefly mentions a burner upgrade to increase efficiency.

A32 Operation and Maintenance of Indirect Fred Heaters

OPERATION AND MAINTENANCE OF INDIRECT FIRED HEATERS

Prepared For Presentation At

The Canadian Gas Association's
1994 CGA Gas Measurement School
Banff Springs Hotel
Banff, Alberta, Canada
May 16 - 19, 1994

By

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Marlett, F.D., *Operation and Maintenance of Indirect Fred Heaters*, The Canadian Gas Association, 1994 CGA Gas Measurement School, 16 May 1994

Similar paper to reference A30. Excellent overview of practices in design, operation and maintenance of line heaters. Describes features of a line heater with combustion air adjustment and flame arrestor. Stack is protected from outside air using a B-vent pipe. Fuel gas is taken from the outlet of the process coil. No additional fuel preheat is necessary. System uses a 30 millivolt thermocouple to energize valve, which cuts fuel off in case of flame failure.

Surface and cross-sectional heat flux rates are discussed after API503 and GPSA. Suggests that HHV efficiency should be used. Discusses basics of combustion principles. Incomplete combustion is a possibility is there is no sufficient air available. Excessive air should be avoided because of the loss of efficiency.

Flue gas analysis is recommended. Burner orifice must be properly sized. Burner components and their operation are described.

Burner turndown must be also considered. Proper flame color is discussed. System setting should prevent flame lifting, flash-back and excessive yellow tipping. Typical bath temperature setpoint is 82 deg C (180 deg F). Discusses impact of glycol concentration on heat transfer. Bath temperature should be adjusted according to seasonal demand. Recommends use of quick acting shutoff valve to eliminate burner “extinction pop”

Flame colors are described in detail.

Provides detailed maintenance recommendations. And stresses importance of providing proper training and equipment to operators and maintenance personnel to ensure safety, optimal performance, fuel economy and thermal efficiency.

A33 Advances Tighten Fired-Heater Design


Advances tighten fired-heater design

Melton Shannon M., *Advances Tighten Fired-Heater Design*, The Oil and Gas Journal, July 1978

A very practical and technical evaluation of efficiency issues.

Discusses impact of excess air on efficiency. Burner selection must prevent flashbacks, flame instability, port plugging, excessive corrosion and wear. Burner arrangement must be also considered such as distance between burner and tube, direction of firing and combustion volume. Flame impingement must be avoided. Natural draft burners need larger combustion volumes.

Radiant section design has not changed in many years. In some designs it is more appropriate to design to maximum film temperatures or tube-metal temperatures with a combustion-volume limitation. In this case flux rate becomes incidental.

Convective section is important because it dictates the final efficiency. Extended finned surface can be used but all factors must be considered. Tube fouling is a big factor in efficiency reduction.

Spot welded fins or studs were popular in the initial stages of development. Continuous edge welded fins offer the best potential. Flue gas distribution must be considered to avoid flue gas channeling. Using proper thermal design low stack temperatures are possible.

If extended surface design is not possible air preheat system should be considered. Air preheat alters flue-gas temperatures and flux rates and must be considered.

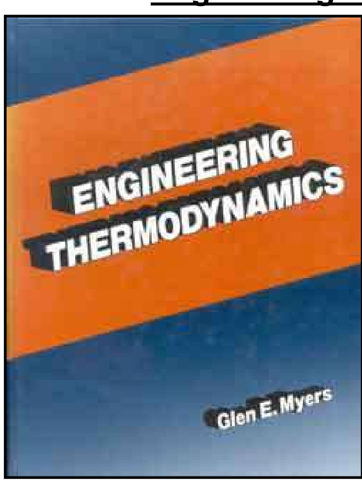
Convective solutions may increase pressure drop and must be considered in the stack design. Stack draft is also affected by elevation and ambient temperature, which must be considered in the design.

Gas composition has an impact on dew point of products of combustion. Presence of sulfur increases the dew point to between 268 and 296 deg F.

Also lower excess air levels lead to higher NOx levels. Increasing energy cost make use of air preheat and waste heat recovery economical. Also additional insulation should be considered

Use of alternate fuels is also feasible.

A34 Engineering Thermodynamics



Meyers Glen E, *Engineering Thermodynamics*, Prentice-Hall, Englewood Cliffs, New Jersey, 1989

Introduction to system concept. Mass nd energy balances. Laws of thermodynamics. Ideal gases. Mass analysis. Availability and entropy. Application of laws of thermodynamics. Reacting mixtures. Adiabatic flame temperature. Availability of fuels. Chemical equilibrium. Various property tables, charts.

Problems and solutions provided.

A35 Radiative Heat Transfer


RADIATIVE HEAT TRANSFER

Michael F. Modest

McGraw-Hill, Inc.

Modest Michael F., *Radiative Heat Transfer*, McGraw Hill, Inc, New York, NY, 1993

Source of advanced radiative transfer theory. Describes nature and laws of thermal radiation. Radiative heat flux. Radiation characteristics of gases. Emmissivity, absorptivity, reflectivity. Effect of roughness. Emmissivity of water vapour and carbon dioxide. Estimation of view factors.

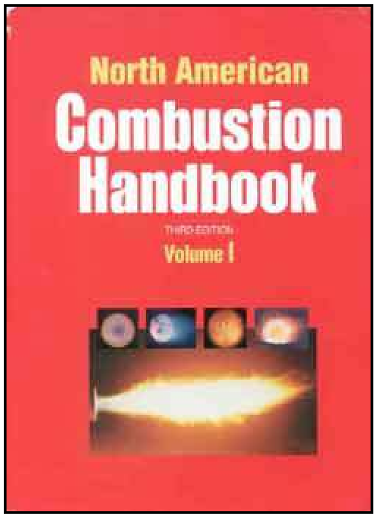
Radiation combined with conduction and convection.

A36 Some Simple Approximate Heat-Transfer Correlations For Turbulent Flow in Ducts With Rough Surfaces

Norris, R.H., *Some Simple Approximate Heat-Transfer Correlations For Turbulent Flow in Ducts With Rough Surfaces*, AOCHMT

Analysis impact of type of roughness elements in the design of a heat transfer duct in the turbulent flow region between Reynolds numbers of 10000 to 200000. Increase in roughness increases heat transfer. Sand grain roughness and few other methods were considered. The differences are relatively small but not negligible.

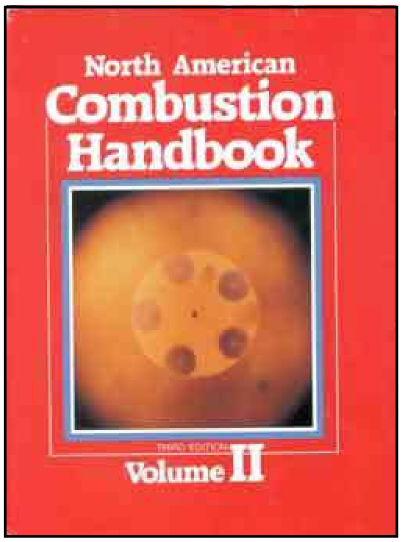
A37 North American Combustion Handbook – Volume I



North American Mfg. Co., *North American Combustion Handbook* – Volume I, Third Edition, North American Mfg, Co., Cleveland Oh. 2001

Excellent source of combustion information. Discusses combustion basics, reactions, perfect combustion and combustion of practical fuels. LHV and HHV values. Flame properties and combustion analysis. Products of combustion. Combustion efficiencies and Sankey Diagrams. Heat contents of various gases. Loss estimation, and heat recovery methods. Conductive, convective and radiative heat transfer. Practical heat transfer problems. Insulation and heat storage. Pressure loss calculations. Draft calculations. Properties of gasses, liquids and solids.

A38 North American Combustion Handbook – Volume II

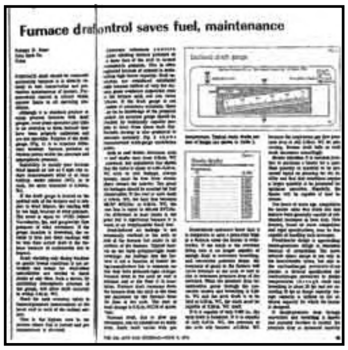


North American Mfg. Co., *North American Combustion Handbook* – Volume II, Third Edition, North American Mfg, Co., Cleveland Oh. 1997

Continuation of Vol I describes fuel burning equipment. Burner characteristics, flame shape, volume, combustion stability, drive, turndown.

Controls, heat recovery. Property tables and various engineering data.

A39 Furnace Draft Control Saves Fuel, Maintenance


Furnace draft control saves fuel, maintenance

Reed, Robert D, John Zink Co., *Furnace Draft Control Saves Fuel, Maintenance*, The Oil And Gas Journal, June 9, 1975

Furnace draft has a direct impact on efficiency. Proper draft gauge should be used. Discusses benefits of draft control for efficiency.

Recommends stack velocity of 25fps, 30fps max. Formulas to calculate stack draft and friction loss.

A40 Effect Of Roughness On Heat Transfer In Conical Nozzles

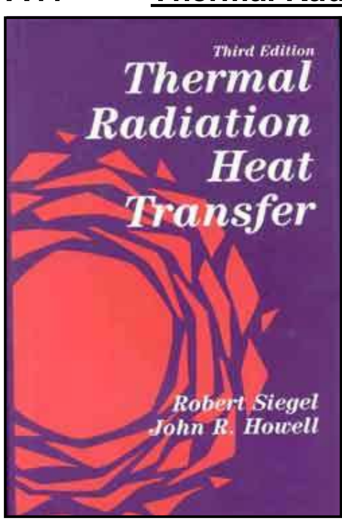
Reshotko, M., *Effect Of Roughness On Heat Transfer In Conical Nozzles*, AOCHAMT

Investigates the effect of a rough conical nozzle surface on heat transfer

When the surface roughness stays within the laminar layer the effects are negligible

An effect is noticed when the surface roughness extends into the turbulent zone.

A41 Thermal Radiation Heat Transfer



Siegel, Robert, Howell John R., *Thermal Radiation Heat Transfer*, Third Edition, Hemisphere Publishing Corporation, Washington, DC, 1992

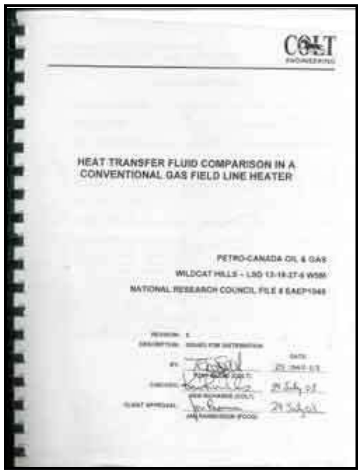
Text in advanced thermal transfer. Explains principles of radiative heat transfer. Emmissivity, absorptivity. Application of mean beam length for radiation in an enclosure. 13-6.

Emmissivity of water and carbon dioxide.

Combined conductive, convective and radiative heat transfer. Radiation from luminous and non-luminous flames. Calculation of adiabatic flame temperatures.

A42 Heat Transfer Fluid Comparison in A Conventional Gas Field Line Heater

Snead Tony, Colt Engineering, *Heat Transfer Fluid Comparison in A Conventional Gas Field Line Heater*, National Research Council File #EAEP1049, Calgary, AB, July 2003

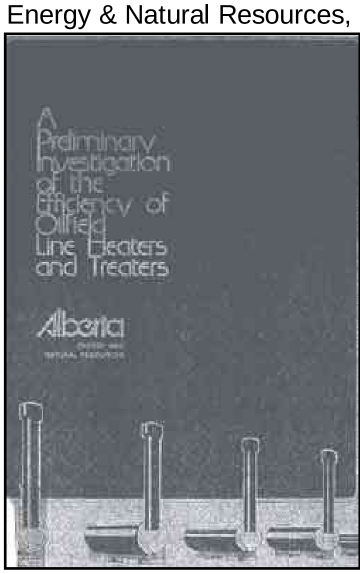


Study designed to quantify the improvement in fuel efficiency with Thermogreen potassium formate blend heat transfer fluid over 50/50 wt% ethylene glycol/water solution in a conventional line heater. The rate of heat input to the heat transfer fluid from the fire tube was unrelated to the rate of heat absorbed to the process fluid. Heater was cycling ON/OFF and process fluid heat sink was buffered by large amount of heat stored in the heater bath to the point that heat transfer fluid properties were rendered unimportant.

The results did not show any conclusive improvement.

A43 A Preliminary Investigation Of The Efficiency of Oilfield Line Heaters And Treaters

Sukovieff R, *A Preliminary Investigation Of The Efficiency of Oilfield Line Heaters And Treaters*, Alberta Energy & Natural Resources, February 1979



This study financed by Alberta Energy and Natural Resources deals specifically with line heater efficiency. The study included literature survey, shop performance tests and a survey of a producing companies.

<u>NOTE: It is our opinion that some assumptions, results and conclusions from this study are technically incorrect, and erroneous. Reader should exercise caution and common sense when considering the recommendations of this study.</u>

Twelve efficiency enhancing modifications were proposed. Authors looked also at the economics of modifying the existing units and incorporating changes in new equipment.

Shop tests included: better insulation, economizer tubes, relocated burner, secondary air baffle, reduced friction fire tube, higher exhaust stack.

Efficiency calculations were both in NET and Gross terms. Author identified that most boiler manufacturers and end users use Gross efficiency, where refineries and oilfield heater manufacturers use NET efficiency.

Shop test of an uninsulated heater showed 78.7% efficiency with 949 deg F stack temperature which was considered unreasonable. Test #2 and #3 showed46.5 and 40.2% efficiency, which was considered more reasonable

Field test was conducted on a sour gas heater. Author reported orange flame, and soot deposit on the tube. Gross efficiency was measured at 20%, which was attributed to 8% unburned hydrocarbons. In test #2 15% O_2 was required to bring the unburned hydrocarbon level to 1.5%. Author explains it by hydrocarbon deposits on the tube. In the following tests gross efficiency with 2.5% O_2 was measured at

27%, and with 16.7% O2 at 16%. All the above tests were done with fuel pressure between 24 to 30 psig. After reducing the gas pressure to 15 psig the O2 was reported at 3.5%, with stack temperature at 1000 deg F and 48% gross efficiency. Subsequent tests showed 46.9% efficiency with 15 psig fuel pressure, 24.5% efficiency with 30 psig fuel pressure and 48.2% with 12 psig fuel pressure. To conclude author summarized the gross efficiencies at between 19.7% and 48.2%, and explained these low efficiencies trough impact of fuel pressure and stack O2.

NOTE: Our explanation of the above results it that the test were done on a totally misadjusted and misapplied equipment and therefore the above results have absolutely no scientific value.

During shop tests temperature at the entrance of the tube were measured at: 1' =140 deg F, 2'=220 deg F, 3'=335 deg F indicating that the beginning of the tube is not being utilized. Moving burner back was considered.

Author stresses the importance of turbulence and high Reynolds numbers, as the gas heat transfer is the limiting factor. To test this a static mixer consisting of 1" pipe with radially welded on a spiral pattern shorter pipes was installed in the return pass.

Author states that the test time was limited, but the trend showed that by reducing fuel pressure from 22 to 15 psig efficiency increased from 43 to 65%. At the same time the secondary air baffle was 90% closed. The "baffled" efficiencies were found to be 6% higher although they may have been influenced by lower bath temperature. Author concluded that direct-fired heaters have higher efficiencies than indirect fired-heater.

NOTE: Our interpretation: the above tests seem to have been conducted outside of standard combustion testing and adjustment practices, and interpretation and analysis does not seem to be in line with engineering standards, therefore the results of these tests are of no scientific value.

During the tests it was concluded that the static mixer had no significant impact on the heater performance.

The subsequent field testing of a treater was based on an assumption that being a direct heater it should have a higher efficiency. The gross efficiencies were measured between 52% and 84%, and a conclusion was made that this was influenced by excess air. By increasing the excess air the efficiency decreased to 52.5%.

The next set of shop tests yielded lower stack temperatures (528 deg F) with no clear trends related to fuel pressure.

Author drew the following conclusions:

a) - variation of efficiency varies widely with type of heater and its degree of tune

b) fuel gas pressure influence the efficiency

c) excess air, firing rate and ambient conditions affect efficiency, but more tests are needed to determine this correlation

d) secondary air can be virtually cut off in a heater without hurting its performance. In addition better mix control is possible

e) heater performance can be improved significantly with relatively minor modifications

f) treaters may operate at efficiency levels which are already high, therefore offer less scope for efficiency improvements.

Heat transfer in the tube is the limiting heat transfer rate

Gas pressure reduction is the most effective efficiency modification?

The economically feasible efficiency increase for natural draft heaters is limited to about 15-20%

Pulsed combustion could raise the typical efficiency by 30% and is the best option for a new system

NOTE: Our interpretation the above analysis shows that the basics of combustion and thermodynamics were not considered in the investigation, therefore the results erroneous are not valid.

Under heater design section author shows basic conductive heat transfer formulas and states that radiant heat should be added to these values but does not show how to do it. Instead suggested using a standard heat flux rate between 7000 to 10000 BTU/hr/ft2. The cross-sectional heat flux is addressed by a statement that cross-section which is too small will prevent products of combustion from being removed quickly enough and the flame will snuff itself out. The lower (?) limit of cross-sectional area is 8000 BTU/hr/in2.

Flame arrestor size calculation formula is provided. The discussion about impact of excess air is included with recommendation to run the heater at 3-5% excess air (0.6 to 1% O2). Author states that this is possible at high fire but then the excess air goes up at low fire.

Some stack calculations are provided, although are not complete. Author concludes that if stack is too tall, too much heat is lost by the flue gas and the draft is lower. Insulation is briefly discussed but insulating stack is not considered.

Study identifies the possible area for improvement:

- process coil – not much can be improved except maybe for helical coil, which has its drawbacks
- economizer coil using finned tubes welded inside fire tube
- static mixer – although there are some suggestions that it could increase efficiency by 5%, tests done in this study did not show any improvement
- J-tube bundle which is a combination of a fire tube and tube heat exchanger - costs may be very high.
- Alternative fire tube shape – difficult to manufacture and subject to thermal stresses,
- Reduced friction fire tube – to reduce pressure drop multi-section miter or round elbow should be used
- Thermosiphon baffle – author expects increased efficiency by improving thermosiphon on the liquid side, this is contrary to his previous observation that the gas side is controlling the heat transfer
- Pressurized heater shell – author suggests running at higher bath temperatures under pressure to improve the bath to process coil LMTD, this is contrary to his previous observation that the gas side is controlling the heat transfer, hence this suggestion would result in lower heat transfer not higher.
- Alternative bath fluids – author suggests that the bath liquid type may increase transfer, this is contrary to his previous observation that the gas side is controlling the heat transfer
- Variable air control baffles – variable baffle at the inlet to the flame arrestor to be adjusted automatically with firing rate. May create reliability issues with moving parts.
- Secondary air control baffle
- Gas driven blower to convert system from natural draft to forced draft without electric power, using a gas turbine – reliability issues.
- Inlet air preheat – author makes some incorrect assumptions about heat transfer coefficients and rejects this idea.
- Glycol stack jacket – using a thermosiphon principle – rejected by author due to complexity and cost
- Insulation – suggests increase of insulation from 1-1/2" fiberglass to 2-1/2" and to include heads in the insulation.
- Corrosion resistant stack and tube
- Natural draft conversion to forced draft – introduces operational and maintenance problems
- Pulse combustion – both valved and valveless type of combustors are described, fire tube would be smaller in diameter but equipped with finned tubes for grater surface area, smaller area, shorter stack. Startup and noise may be a problem. Also pilot use maybe a problem in a chamber with pulsating pressure. Combination of conventional burner and pulse combustor considered in which pulse combustor never shuts off. System is complex and requires development, and would be costly.

- Balanced flue – a design, which balances combustion air with exhaust gas, involving a duct built around the stack. Study does not state how this would be done and how this would increase efficiency except that it would somewhat preheat the air.

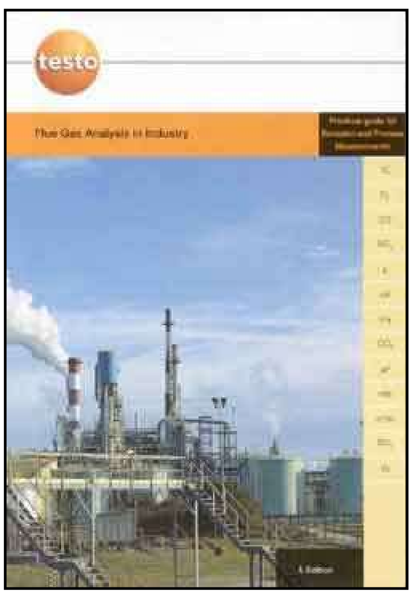
Study included also survey of producers aimed at establishing the quantities of installed line heater and treater equipment. The following results were obtained:

- treaters 1388, on average .81 MM BTU/hr,
- line heaters 3517, on average 1.08 MM BTU/hr
- Economics of the upgrades are also presented in the study, but are of not much value since the efficiency numbers assumed are erroneous efficiency assumptions from the field and shop testing.

Addition conclusions of the study included:

- A large efficiency increase is sometimes possible without physically modifying the heater. Tune-up suggested o semiannual basis.
- Efficiency can be increased by about 15% through: insulation, fire tube economizers, better burner selection and placement, secondary air baffling, these modifications are economical for heater of any size
- Internal bath-side fouling and fire tube corrosion van affect performance, regular inspections are recommended
- The efficiency increase that is economically feasible for natural draft heaters is limited to 15-20% (at high fire)
- Efficiency increases available with a forced draft heater are in the order of 30%. The most practical method of forcing the draft is through pulse combustion in tandem with a standard burner
- Heat pipes do not appear to have a ready, practical application in heater design.

A44 Flue Gas Analysis in Industry – Practical Guide For Emission and Process Measurement



Testo, *Flue Gas Analysis in Industry – Practical Guide For Emission and Process Measurement*, 1st Edition, Testo AG, Lenzkirch, Germany, 2004

Basics of combustion and fuels, excess air, products of combustion. Definition of combustion and furnace efficiencies. Formulas for Gross and Net efficiencies. Heat loss. Stack dew point chart.

Combustion analysis basics. Gas analysis for combustion optimization, process control and emission monitoring. Terms used in gas analysis, Conversion formulas.

APPENDIX B – COEN IMMERSION FIRE-TUBE HEATER RATING SOFTWARE PROGRAM – USER'S GUIDE

Immersion Tube Heater Efficiency Program

User's Guide

Developed by

Coen Company, Inc.

In conjunction with

Petroleum Industry Training Service PITS

and

ENEFEN Energy Efficiency Engineering Ltd.

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Program Operation B-3
Theory B-9

I. INTRODUCTION

This program is a powerful tool that computes heater efficiency, exit temperatures, flame length, heat loss, pressure drop, heat flux, and temperature profile for immersion tube heaters. The use of this program will help determine appropriate sizing and operation of new units as well as reveal ways to increase the efficiency of current units.

II. PROGRAM OPERATION

A. Inputting Information

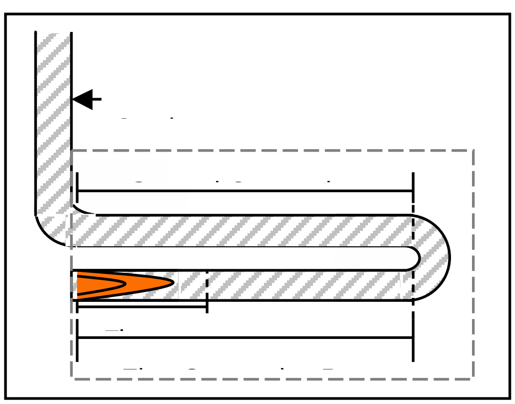
Upon opening the program, the user may either begin entering data by clicking GENERAL INFORMATION, or open an existing set of inputs from the File dropdown menu. To start a new study, choose FILE/NEW to clear the inputs with the option of saving the current project. Included with the software is *ImmersionData.txt*, supplying sample case inputs.

Note: *The program provides output data in metric units by default. If English units are preferred, this option must be chosen on the main form before entering any input data. Additionally, the program performs all calculations in English units and then converts as needed.*

After GENERAL INFORMATION has been opened, the program will lead the user through a series of input forms. If a required piece of information has not been entered before moving on, the program will prompt the user to fill in the empty field. After all information has been entered, the program will then calculate the results. The user is then able to adjust inputs and toggle between English and SI units as desired.

All basic information on the unit to be analyzed is entered here. The only required field is elevation, used to determine composition of air.

This form holds information concerning the dimensions of the heater. The number of convection passes must be between one and four. The length of the first pass *includes* the length of the flame zone, which is later calculated in BURNER SELECTION. A schematic further explaining this is given on the following page. The thickness and thermal conductivity of stack insulation are also specified here.



Immersion Heater Schematic Defining Flame Zone and Convective Passes

Operating Data

Maximum combustion rate, percent firing rate, and percent excess air are entered in this form.

Fuel Data

The program selects natural gas by default as the fuel fired to the immersion heater. The user can specify either gas or liquid firing, as well as alter the fuel composition. #2 oil is used as the default composition for liquid firing.

For gas firing, the program calculates the higher and lower heating value based on the composition of the gas. For liquid firing, the heating value is user defined. For either fuel selection, the user must specify water content.

Boundary Conditions

Ambient conditions as well as the emmisivity of the immersion tube walls are specified in this form.

Burner Selection

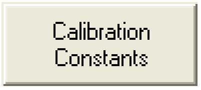
Here the user must define the shape and momentum of the flame in order to determine the flame zone dimensions. There are default values that correspond to high and low momentum and long and short flame. An expert user, however, can redefine these values in the CALIBRATION CONSTANTS form. Default values are as follows.

MOMENTUM ($MMbtu/hr{\cdot}ft^3$)	Hi	0.8 (8.27 MW/m^3)
	Low	0.45 (4.66 MW/m^3)
FLAME $\left(L/D\right)$	Long	10
	Short	5

Modeling

Presented here is a list of choices that help determine the average temperature in the flame zone. It is suggested to initially use the *Auto Gas Zone Model*, which signals the use of Hottel's method, a generally accepted method of determining flame zone temperature. Gas temperatures found by Hottel's, Blizards, Square Root, Long's, Saunders, and Anson's models vary by approximately 4%, but heat transfer variation is larger at 17%[1] The purpose of these choices is to give the user additional tools for calibration.

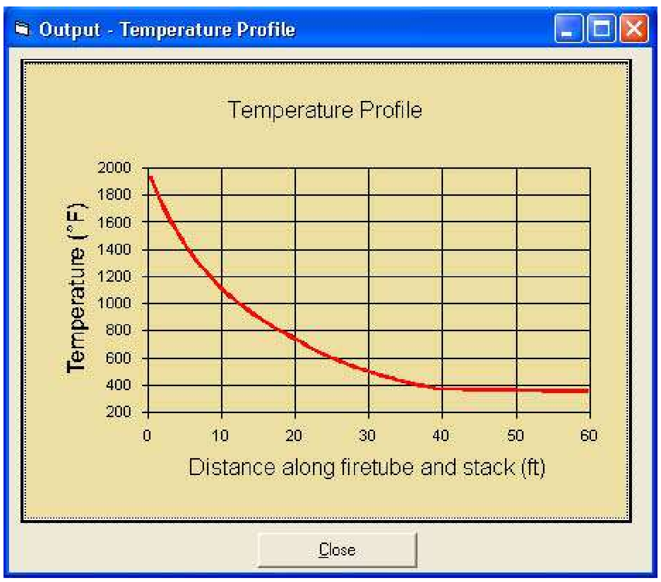
[1] "Heat Transfer in the furnace chamber of pulverized-fuel-fired water-tube boilers" *Journal of the Institute of Fuel* (July 1967) 302.



This form includes expert inputs which aide in fine-tuning the program. The defaults for the flame zone properties were discussed under the *Burner Selection* topic. The convective and radiation coefficient modifiers are adjusted to account for factors the program did not consider, such as frictional heat losses and buoyancy. These constants are saved with the other data and are case specific. Although, each new case will have the default factors of 0.8 for the convective heat transfer coefficient and 1.0 for radiation, for best match use: Convective Coefficient Modifier = 1.3 and Radiation Coefficient Modifier = 2.0.

B. Output Data

After inputting all required information, and clicking FINISH on the MODELING page, the program will then calculate the results and present them on the main form. If pressure losses exceed the stack draft, the user is notified by those values being highlighted in red. The temperature profile, surface heat flux profile, and pressure drop profile are then accessible.



Temperature Profile Display for Immersion Tube Heater

Once results have been obtained, the user can save the input data for later use in the program, or print a summary of the findings. After the initial calculation, subsequent calculations are made each time the user closes an input form.

III. THEORY

The following section describes the theory underlying the software's calculations and is designed to help the user better understand the results of the program.

The immersion tube heater calculations were divided into three basic sections: the flame zone, the convective passes, and the stack. Elevation and humidity levels are required to determine the molecular weight of air. A mass balance is then performed on the system to determine the flow rates of the combustion products. The enthalpy of the various components is calculated from the integration of molar heat capacities at 1 atm.

A. Flame Zone Calculations

The flame length and diameter are determined by specifications made in BURNER SELECTION, as discussed previously. The adiabatic flame temperature is calculated with the use of the Newton-Raphson numerical method, finding the root of the equation

Hcp – Qin = 0 *[1]*

where *Hcp* - enthalpy of the combustion products

Qin - heat of the fuel input to the heater.

Upon obtaining a flame temperature, the temperature of gas exiting the flame zone is obtained through the bisection numerical method analysis. Gas temperature, found by the chosen model, is used in the energy balance around the flame zone, accounting for heat losses due to radiation; Q_r, convection, Q_c, and gas flow of combustion products, ΔH.

For radiation,

$$Q_r = \frac{1}{2}\sigma A(1+\varepsilon_S)\left[\varepsilon_G T_G{}^4 - \alpha T_S{}^4\right] \qquad [2]$$

where σ = Stefan-Boltzmann constant, 5.676 x 10^{-8} W/m^2?K^4 (1.714 x 10^{-9} btu/h?ft^2?±R^4)

A = surface area of flame zone, m^2

ε_S = emmisivity of the sink

ε_G = emmisivity of the gas

T_G = absolute gas temperature, determined from model

α = absorptivity of the gas

T_S = liquid bath absolute temperature.

Carbon dioxide and water emmisivities are determined from emmisivity chart curve fitting, derived from Mark's Standard Handbook for Mechanical Engineers, by E. Avallone and T. Baumeister.

For convection,

$$Q_c = hA(T_G - T_S) \qquad [3]$$

where h = heat transfer coefficient, W/m^2?K. Thermal conductivity and viscosity, used in determining the Nusselt number, were found through curve fitting with the appropriate temperature.

Heat lost due to the flow of combustion products is determined by

$$\Delta H = H_{T_{flame}} - H_{T_E} \ . \ [4]$$

The enthalpies, *H*, are determined from curve fit equations built into the program for flue gas component enthalpies.

B. Convective Zone Calculations

A "marching solution" is performed on the convective zone, where each pass length is divided into 50 segments. For each segment the exiting temperature, heat loss, and pressure drop is assessed. This yields more accurate results in overall efficiency of the tube, accounting for changes in thermal conductivity, density, and specific heat. The effects of radiation and convection are evaluated in the convective passes. The Newton-Raphson method used to determine the temperature exiting each segment.

C. Stack Calculations

Radiation effects are disregarded in the stack, leaving free convection and conduction as factors affecting heat loss. Like the convective passes, the stack is also analyzed in segments. Wind speed is used to calculate the exterior heat transfer coefficient.

APPENDIX C – BURNER MANUFACTURERS LITERATURE

This appendix contains a combination of relevant commercial literature information provided by the burner manufacturers or found on their websites or in product catalogues.

Although we have reviewed the literature and used it during the course of the project, its content does not necessarily reflect the findings of this project. In other words, we have found instances where the manufacturers data could not be confirmed by the test results, especially in the area where data from various burners could be compared against each other.

C1 ACL Literature

ACL Manufacturing

ACL Manufacturing is the leader in the Design and Fabrication of Industrial Burner Ignition Controls, Burners, Pilots, Incinerator Ignition Systems and Flare Stack Ignition Systems. ACL also provides custom systems for all types of burner applications, which provide safe and reliable ignition and control solutions. All ACL electronic ignition systems comply with the current CSA Standards and Guidelines and are CSA B149.3 compatible.

- Burner Ignition Controls
- Incinerator Ignition Systems
- Flare Stack Ignition Systems
- Pilots and Burners (Low and High Pressure)
- Combustion Valve Trains

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Last modified: January 22, 2004

Send mail to aclmfg@telus.net with questions or comments about this web site.

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Burners & Pilots

Burner Controls

Flare Stacks

Incinerator Ignition

Valves

Burner

Low pressure burners save on operating costs

Key Benefits

- Works on propane or casing gas
- Low pressure operation
- Easy installation

Pricing

Description	SKU #	Price
1/2" Pilot	ACL-M50	available on request
3/4" Pilot	ACL-M75	available on request
1" Burner	ACL-M100	available on request
1-1/2" Burner	ACL-M150	available on request
2" Burner	ACL-M200	available on request

Send mail to info@acl-manufacturing.com with questions or comments about these Products

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Send mail to aclmfg@telus.net with questions or comments about this web site.

ACL Burners

The ACL Low Pressure Burner uses a unique design (Patent Pending) to achieve what no other burner of its kind has achieved

Key Benefits

- Low Pressure operation as low as .25 PSI
- Extremely Quiet
- More efficient
- No burn back at low flow rates
- Exceptionally reliable under adverse conditions
- Easy installation and orifice changes
- Can be used as both Pilot and Main Burner in single operations.
- Ignition system adaptable

Pricing

Description	SKU #	Price
3/4" Burner	ACL-M75	available on request
1" Burner	ACL-M100	available on request
1-1/2" Burner	ACL-M150	available on request
2" Burner	ACL-M200	available on request

Send mail to info@acl-manufacturing.com with questions or comments about these Products

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Send mail to aclmfg@telus.net with questions or comments about this web site.

Pilots

ACL-M50

For 1/2" applications

- Steel Reducer Bushing
- 1/2" Aluminum Collar
- 3/4" Aluminum Mixer with 1/8" gas fitting and adjustable Air Shutter /Lock Nut
- 1/2" Sched 160 Nipple (Venturi) with ground connection
- Optional Air Preheat Tube

ACL-M75

For 3/4" applications

- 3/4" Aluminum Collar
- 3/4" Aluminum Mixer with 1/8" gas fitting and adjustable Air Shutter /Lock Nut
- 3/4" Sched 160 Nipple (Venturi) with ground connection
- Optional Air Preheat Tube

Key Benefits

Pricing

Description	SKU #	Price
1/2" Pilot	ACL-M50	available on request
3/4" Pilot	ACL-M75	available on request

Send mail to info@acl-manufacturing.com with questions or comments about these Products

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Home

Up

ACL100

ACL1000

ACL2000

ACL5000

ACL-5000

The ACL Model 5000 provides ignition, flame fail, alarm, shutdown capabilities and solar powered burner management for all gas fired heaters.

Key Benefits

- Simple use, no programming necessary.
- Built in logic allows for re-ignition, shutdown interlocks and alarm out.
- CSA approved for Class1, Div 2 location
- CSA 22.2 199-M89 Combustion safety controls and solid-state Ignitors for Gas & Oil burning equipment
- CSA B149.3 Compatible
- Versatile power supply 12-24 VDC, 120-240 VAC, 50/60hz & Solar
- Nema 4x enclosure, corrosion resistant and weatherproof.
- Easily installed into any burner by utilizing existing pilot.
- One sensor provides for ignition and flame fail.
- No need for expensive retrofits or modifications.
- Fastest flame out time of 0.8 seconds.

Simple Design:

- No programming necessary.
- Two button operation (Start&Stop).
- New innovative design allows ignition and flame fail with the use of one flame rod.
- Control and ignition components are all housed in the Nema 4x enclosure control box.
- All components are CSA approved and can easily be changed out if failure occurs.

Pricing

Description	SKU #	Price
12-24 VDC Ignition System	ACL-5000	available on request
120-240 VAC Ignition System	ACL-5000	available on request
Solar Package		available on request

Top of Page Last modified: May 12, 2004

C2 A-Fire Literature

A-Fire Holdings Ltd.

A-Fire Holdings, Ltd. commenced operations in 1985 with a goal of meeting the oil and gas industries need for fire tube combustion product and service specialists. A-Fire is located in Lloydminster.

A-Fire has grown to include manufacturing facilities for its burner system product line, in-house service repair centre, and has formed affiliations with numerous service and supply companies in order to provide the complete package to the industry client.

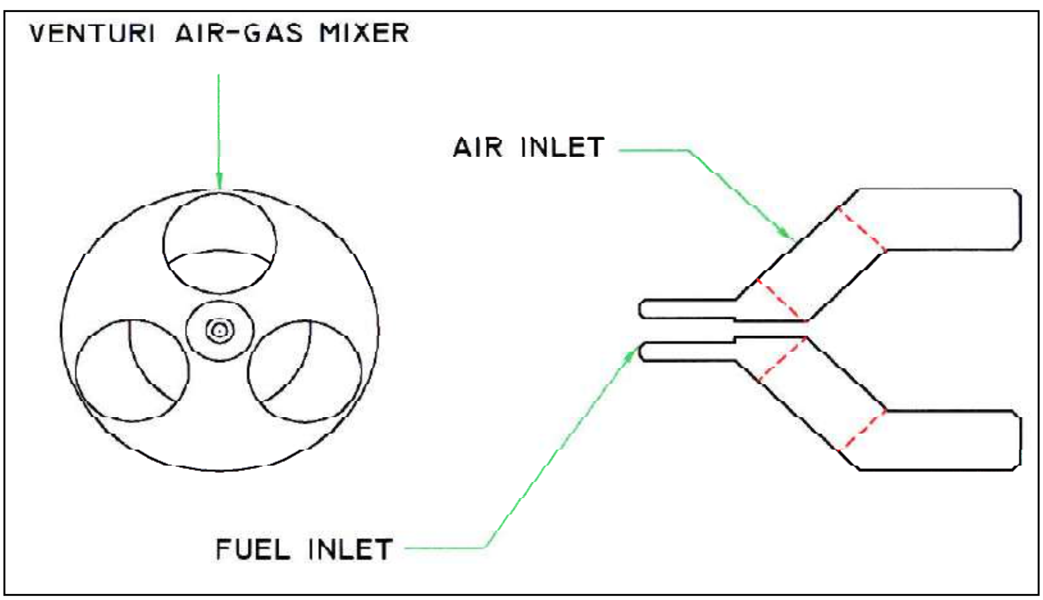
A-Fire specializes in:

- Naturally drafted flame arrested burner systems
- B-149.3 compliant systems
- Ignition and Control Systems
- Flame arrestor supply and testing
- Combustion system design, optimization and service

A-Fire Fire tube Burner Assembly

A-Fire provided the PTAC project with our standard 1" natural gas burner tip assembly.

The A-Fire device has a preset burner design with optional secondary air adjustments. The advantages of the system include very efficient combustion at a wide range of fuel gas supply pressures and rates, as well as an optimal flame structure, which is able to disperse the heat more effectively than conventional systems. The device is very low maintenance and has the ability to be used in a wide range of applications.



All A-Fire burners come factory set for individual applications with a specified BTU rating per hour. This is done in consultation with the client.

Burner Components:

All burner assemblies consist of the following:

a) Air/gas mixer - mixes primary air and fuel gas for combustion

b) Mixing chamber - allows additional time for mixing of primary air and fuel gas

c) Burner Tip - different models produce individual patterns depending on application

The fuel is supplied through a small orifice at the inlet enhancing the Venturi effect and pulling in primary air. The correct amount of primary air is mixed with the fuel in the mixing chamber. The combustion occurs at the burner tip.

Advantages

The A-Fire system is very efficient. With efficient, complete combustion comes better utilization of all the energy in the fuel and clean, soot free emissions. The burner tip has been designed to operate efficiently at various fuel pressures. Also, the combustion temperature is reached very quickly utilizing a greater amount of fire tube and an increased flux rate.

The device can be equipped with an optional primary air adjuster, which will allow the operating staff the ability to tune the combustion if they choose.

The design is efficient, dependable, and economical.

Capacities and Sizes

The A-Fire burners vary from ¾" to 4" in diameter and can be installed in systems from 70,000 BTU/hr – 4 MM BTU/hr. They have been successfully installed in processes with fire tubes from 4" to 32" in diameter.

Fuel for the burner system can vary from lean or rich natural gas and /or propane and butane. Each system is designed for optimal performance and energy utilization based on the heating value and density of the fuel being used.

Fuel pressures can vary from a few inches of water to up to 30 psig.

Applications

A-Fire supplies burners to various industries for use in various process heating applications. Resource industry applications include well site tanks, dehydrators, salt bath heaters, treaters, and natural gas line heaters.

An A-Fire system can be designed for anywhere efficient and dependable industrial process heat is required.

Design

A-Fire believes that burner systems must be designed properly in order to operate properly.

Our approach starts with obtaining as much information as possible from the client to correctly size all the equipment associated with the heating process. The relevance of these variables is vital when it comes to designing the system to perform at its optimum

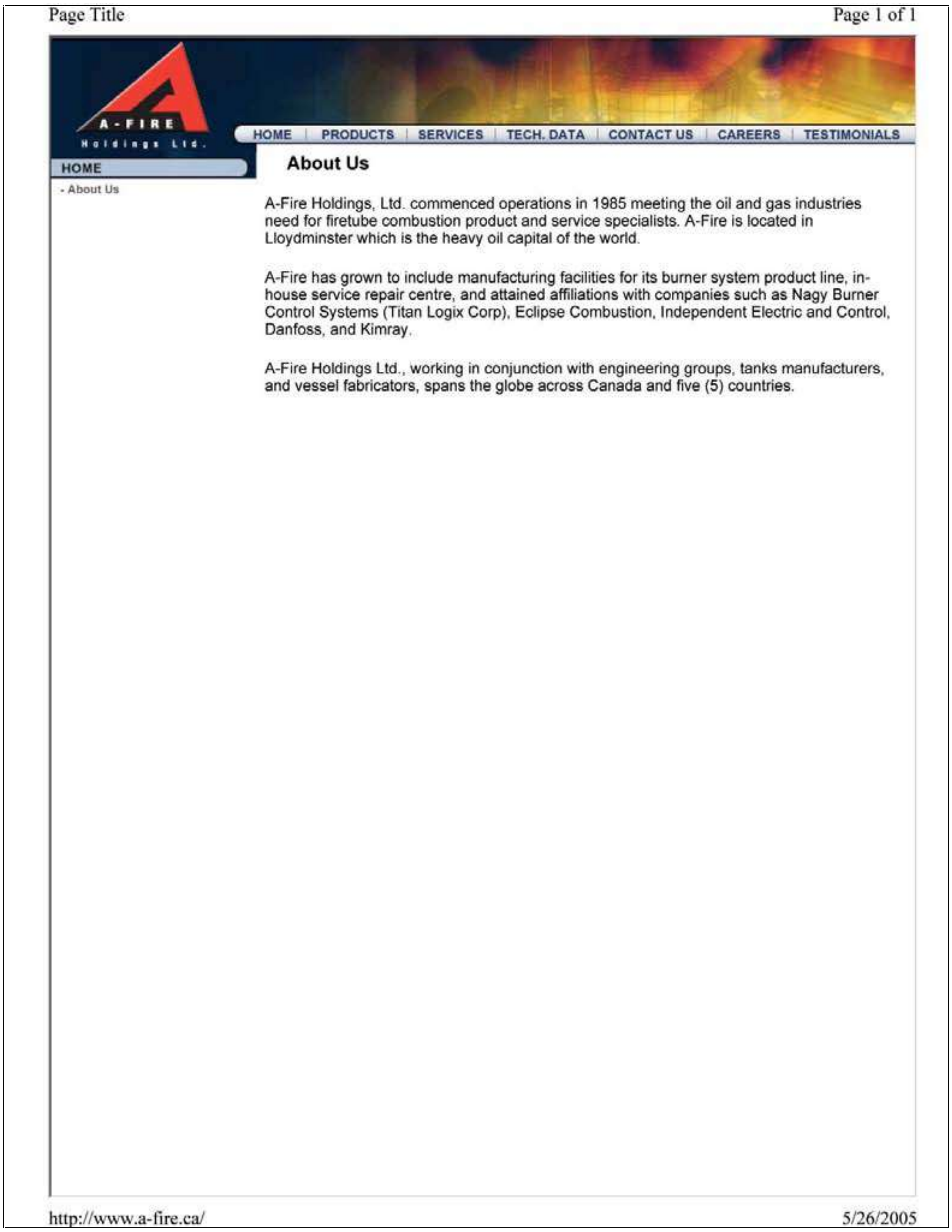
In consultation with client, the system advantages and the disadvantages are reviewed and an optimal system is designed. Heat load, fuel supply and types, and other variables can change over the life of the installation so the design has to anticipate the potential changes and be adaptable enough to provide outstanding service for a long time.

Other Services

A-Fire provides complete burner and heat application services.

Everything including system design, installation, service, and testing are provided. Training and safety orientation is available. Strong technical ability and experienced staff result in best possible design in terms of safety, efficiency, and economy.

A-Fire offers a complete line of additional products that can enhance any retrofit or new installation. The ability of A-Fire is complimented by the expertise of our sister company, Cold Weather Technologies, between the two any heating system can be designed and any process heating problem resolved.



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A-FIRE Holdings Ltd.

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- About Us

About Us

A-Fire Holdings, Ltd. commenced operations in 1985 meeting the oil and gas industries need for firetube combustion product and service specialists. A-Fire is located in Lloydminster which is the heavy oil capital of the world.

A-Fire has grown to include manufacturing facilities for its burner system product line, in-house service repair centre, and attained affiliations with companies such as Nagy Burner Control Systems (Titan Logix Corp), Eclipse Combustion, Independent Electric and Control, Danfoss, and Kimray.

A-Fire Holdings Ltd., working in conjunction with engineering groups, tanks manufacturers, and vessel fabricators, spans the globe across Canada and five (5) countries.

http://www.a-fire.ca/ 5/26/2005

C3 Bekaert Literature

MCI-Enefen testing of Bekaert Combustion Technology's metal fiber burner head

1. General description of burners we supplied for this project:

Bekaert Combustion Technology Corporation (BCT) has supplied Curt Anderson (MCI) with 2 burner head samples to replace the traditional nozzle mix technology commonly used in the field for oil treater application. MCI made a field test in the past with our burner and has foreseen the tremendous benefits for the industry (in terms of combustion efficiency and environmental friendliness) from using BCT's burner technology into this application.

The burner head is a surface combustion burner able to operate both in blue flame mode (from 250,000 to 3,000,000 BTU/h/ft2) and in Radiant mode (from 30,000 to 250,000 BTU/h/ft2). The actual modulation range will be limited by the Venturi & mixer capability placed prior to the burner head.

2. How does our burner work?

It attached to the atmospheric mixing and Venturi system in place of the nozzle mix head. For optimal combustion efficiency results and NOx benefit, our burner head would need to operate in a fully premixed mode, where no secondary air is needed to complete the combustion.

3. What are our burner's main advantages and unique features?

Here are some of the main benefits of BCT' s metal fiber burner head for this application:

- Even heat distribution,
- wide modulation range capability (from radiant to blue flame),
- forgiving design in case of clogging (of the vent of the burner itself),
- wide range of gas qualities,
- durability,
- resistance to thermal shocks,
- fast heat-up and cool-down,
- low CO and NOx emission (in fully premix mode, could be bellow 10ppm at 3%O2),
- high radiant efficiency,
- wide range of shapes and sizes available (cylindrical, cylindrical with active end, conical, flat, dome,)
- high thermal isolating capability of the Metal fiber media.

4. What burner sizes ranges do we offer?

Our burners can operate with a wide range of gas quality, both with propane and natural gas. Most commonly, we are manufacturing burner heads ranging from 50,000 BTU/hr to 5,000,000 BTU/hr, but we can extend our range from less than 10,000 BTU/hr up to 50,000,000 BTU/hr if need be. For very large industrial burners, we do work with Alzeta and Power-Flame to benefit from there experience in industrial burner application.

B	mm	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	1200
A																				
mm	inch																			
50	1.97	x	x	x	x															
63	2.48	x	x	x	x	x	x													
70	2.76	x	x	x	x	x	x	x	x	x	x									
83	3.27	x	x	x	x	x	x	x	x	x	x	x	x							
98	3.86	x	x	x	x	x	x	x	x	x	x	x	x	x						
140	5.51	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
200	7.87	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
245	9.65	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
375	14.76								x	x	x	x	x	x	x	x	x	x	x	x

A: Diameters presently available

B: Active combustion length on the cylinder

5. What applications do we specialize in?

This Metal Fiber burner technology has become these past 10 years the industry standard in the fan assist premix residential and commercial gas fired boilers and water-heater market, both in Europe and North America.

Most recently, Bekaert Combustion Technology has acquired **CEB technologies** (for: Clean Enclosed Burner) which specializes in the flaring industry for petrochemical applications. This break-through approach makes flaring (both for up-stream and down-stream applications) more environmental friendly and even more cost efficient for some application (ex: CEB can combust gases with calorific value lower than 500 BTU/ft2, which limits the amount of supplementary gas needed for combustion of waste gas), plus reduces light & noise nuisance. Bekaert CEB Canada is conveniently located in Calgary and Red Deer, Alberta.

BCT is also focused in non contact IR drying for the paper industry after the acquisition of Solaronics.

6. How do we typically approach burner projects?

We do not just sell burner as a commodity item, but work closely with the OEMs to develop together the optimal burner solution for the application. Every application requires a custom-made approach in the burner design (pressure drop, noise, emission). Market managers / sales engineer are assisting customers in there development and are relating project requirements to the Bekaert's R&D facility in Europe. Once a satisfying prototype is approved, we then enter the field-test and production phases. Support is provided to our customer all along the life of the burner once installed in the field, as any abnormal premature deterioration of the burner would trigger investigation to determine the cause of any eventual mal-function or application issue.

Regarding installation and maintenance, we have a case by case approach and network in place, which varies for every business segment we are in. For example, CEB do install and "baby-sit" the unit 24/7, which in operation, Solaronics provides maintenance and service to paper-mills. For this particular oil treater application, we anticipate that MCI would provide the required service and installation. If need be, we can discuss the details case by case of what would be required for maintenance and installation in a 3-party agreement between BCT, MCI and the end-users.

7. What other products/services do we offer with the burners

Application engineering, R&D development and testing, burner assembly.

8. Some words about your company (corporate profile)

BCT is a joint venture between Bekaert (75%) and Shell (25%), operating under the Bekaert Advanced Material and Coating division. Shell and Bekaert have jointly patented the use of metal fiber for premix gas burners, combining the expertise of Shell in the gas industry and Bekaert in the metal fiber manufacturing.

Bekaert is a $4 billion company employing over 18.400 people worldwide. Bekaert was established in 1880 in Belgium and was the inventor of barbwire. Since then, Bekaert has developed into becoming the world leader in metal transformation and coating technologies. With these 2 competencies, a wide variety of applications have been developed commercially, from Metal fiber burners to champagne cork wire, UV protection window films, concrete reinforcement and metal fiber strips to control air-bag expansion; the main one being steel cord for radial tire reinforcement.

Bekaert Group - Advanced metal transformation and advanced materials and coatings Page 1 of 1

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Building the future. Together. Worldwide.

Bekaert seeks sustainable profitable growth based on its two core competences: advanced metal transformation and advanced materials and coatings. Based in Europe with its headquarters in Belgium, Bekaert generates sales of € 2.7 billion, employing 16 400 people in 120 countries

Bekaert in the news

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Products: Dylyn® Plus coatings on automotive engine parts
Where: Stuttgart, Germany

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About us

Company profile

Bekaert seeks sustainable profitable growth based on its two core competences: advanced me transformation and advanced materials and coatings.

Advanced metal transformation: Bekaert possesses the technological expertise required to convert the raw material, wire rod, into a broad spectrum of specialised wire products. Bekaert's extensive product range covers wires with a wide diversity of applications and attributes, from ve high tensile reinforcing wires to ultra-thin metal fibres with a diameter of just one micron.

Advanced materials and coatings: Bekaert is able to produce advanc materials based on metal fibres and glass fibres and possesses unique technologies for applying specialised, ultra-thin coatings.

Bekaert aims to consolidate its position as both market leader and technological leader in selected segments around the world. With its broad range of high technological products, systems and services, Bekaert offers high added value for its worldwide clientele.

Bekaert is an European based company, headquartererd in Belgium, employing 16 400 people Bekaert, present in 120 countries, generates sales of € 2.7 billion.

Last reviewed on 13-apr-2005

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BCT

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Pre-mix burners

Furipat refractory steel
Flat pre-mix
Round pre-mix

Our solution: Pre-mix burners

Low CO/NOx - High modulation 1/10

3. Round pre-mix using Metal Fibre Media

This round shaped pre-mix burner is equipped with refractory Metal Fibre Media. It is designed to operate specifically in high efficiency / condensing boiler appliances with circular heat exchangers. These burners are used in residential (<100kW), commercial (100-600kW) and industrial appliances (>600kW). A large variation in shape and size is possible due to the flexible use of the knitted Metal Fibre Media.

Your applian

Condensing boilers <100 residential market

Condensing boilers 100-600kW commercial market

Condensing boilers >600 industrial ma

Heaters

It allows to have flames on only a part of the circumference or to have the flames directed inward in stead of outward. This burner ensures extremely low emission levels (following Gaskeur SV / Blue Angel standards) and a very high modulation level (>1/10)! The knitted Metal Fibre Media is welded on to a metallic tube which ensures a closed burner structure without the use of complex fittings. The metallic nature of this burner enhances the flame detection signal and makes it far more robust over traditional ceramic types. This Round Pre-mix burner is 100% recyclable

Last reviewed on 14-apr-2003

C4 Eclipse Literature

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Eclipse, Inc. Corporate Mission Statement

"Innovative Thermal Solutions.... Worldwide"

ECLIPSE
Innovative Thermal Solutions

Our Aim
The Innovative Application of Clean Heat for Industrial Processes.

Our Business
Eclipse, Inc. is a worldwide manufacturer of products and systems for industrial heating and drying applications. We design and manufacture a wide variety of gas and oil burners, recuperators and heat exchangers, complete combustion systems, and accessories for combustion systems. Eclipse Inc. offers its customers an excellent single source for design, installation, and service for total combustion needs, supported by expert application engineering services.... anywhere in the world.

Our Vision
We will be a quality-driven company, treating our employees with respect, while expecting them to continually improve their knowledge and skills; we will continuously improve our processes, delegating decision-making to the most knowledgeable people; we will work to improve our communities, and create an enjoyable work environment; we will become the global, technical, and market leader in the industrial heating industry while focusing on our primary products and customers; we will pursue safety in all our product designs; and we will be ethical corporate citizens.

Our Values
At Eclipse, we know that things work better when we work together toward a common goal. That's why we forge working partnerships with our employees, our suppliers, our communities, and most importantly, our customers. All our business units operate under this same principle.... always working together to bring you the optimal solution to your most challenging opportunities.

The Brands of Eclipse, Inc.

Eclipse Combustion	Combustion Tec	EXO Exothermics	Algas-SDI
Combustion Burners & Equipment	Oxygen-Fuel Burners & Equipment	Heat Exchangers & Recuperators	Liquid Vaporizing & Gas Mixing

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Eclipse Combustion Brand Info

Eclipse Combustion designs and manufactures a wide variety of gas and oil burners, recuperators and heat exchangers, complete combustion systems, as well as accessories for combustion systems.

Eclipse Combustion is widely recognized as the world leader in low emission burner technology. Our Minnox, Winnox and ThermJet burners set new global standards for NOx, CO and aldehyde levels.

Our global structure enables us to help our customers compete in the international marketplace, everyday, in every industrialized country. To facilitate that effort, we have established and staffed over 80 sales and engineering offices in major cities and countries around the world. The resources of these facilities are available to you around the clock. They exist to provide you with the best products and services possible.

Eclipse Combustion
Combustion Burners & Equipment

Eclipse Combustion
1665 Elmwood Rd.
Rockford, IL 61103
USA

Tel: 815-877-3031
Fax:815-877-3336

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Canada

Your Eclipse Combustion representative in Ontario is....

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Doug Henry
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E-Mail:
Harry Sutton
Harry Ajamian
Denis Cloutier

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Calgary, Alberta T2E 6M7
Phone (403) 291-9211
Fax (403) 291-9214
E-Mail:
rforbes@eclipsenet.com

You can reach Eclipse Inc. headquarters in Rockford, Illinois by phone at (815) 877-3031.

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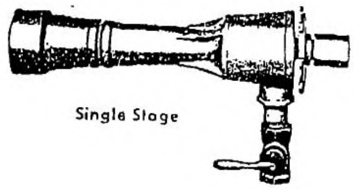
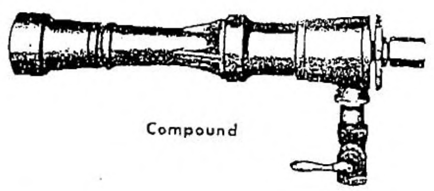
ECLIPSE ATMOSPHERIC INJECTORS

LOW PRESSURE INJECTORS

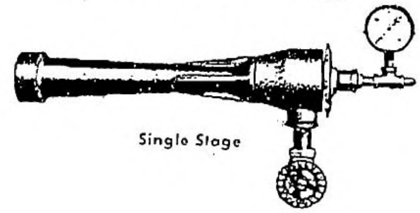


Single Stage

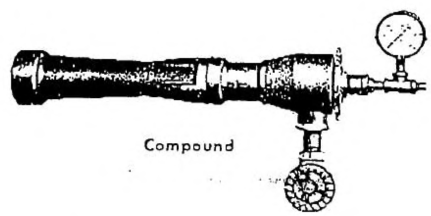


Compound

HIGH PRESSURE INJECTORS



Single Stage



Compound

Eclipse Atmospheric Injectors are simple, low cost, adjustable mixers designed to provide an air/gas mixture to one or more burners. Atmospheric injectors use the kinetic energy of a stream of gas to entrain part or all of the air required for combustion.

Two series of injectors are available; "Low Pressure," for use with gases up to 28" w.c. and "High Pressure," for gases from 1 psig to 30 psig. Both High and Low Pressure Injectors are available as either "Single Stage" or "Compound" units. Single Stage Injectors are designed for use with lower Btu gases, (up to 1200 Btu for Low Pressure Injectors and up to 1100 Btu for High Pressure Injectors). Compound Injectors employ an additional sleeve which assists in entrainment for higher Btu gases.

Standard orifice spuds are made of brass, but steel or other material can also be furnished for use with gases containing sulphur or other corrosive gases. The orifices listed are standard sizes, however, they can be drilled to any desired size or furnished blank. To prevent delays in shipment, the customer should either specify orifice size desired, or the type and pressure of the gas to be used, when ordering. Orifice size will be determined by the factory if no size is specified by the customer.

Capacities range from 15 cfh to 5500 cfh depending upon model selected and the Btu content and pressure of the gas used. Eclipse Injectors are available in sizes from ½" to 6".

LOW PRESSURE INJECTORS (Up to 28" w.c.)

Low Pressure Injectors entrain 30 to 50% of the combustion air required (depending upon the type of system) but sufficient secondary air should be provided around the burner outlet to complete combustion. Low pressure, single stage injectors are suggested for use with low and medium Btu gases up to 1200 Btu. For gases from 1200 Btu to 3300 Btu, a compound injector should be used.

These mixers feature an adjustable air shutter and an integral gas flow adjusting needle. They can be purchased with or without a gas shut-off cock. Single stage injectors are available in sizes from ½" to 6". Compound injectors can be purchased in sizes from 1" to 6".

HIGH PRESSURE INJECTORS (1 to 30 psig)

Eclipse High Pressure Injectors are designed to entrain all or part of the air required for combustion and deliver the mixture to the burner or burner manifold at a high enough pressure to prevent backfiring. These mixers can maintain a constant air/gas ratio throughout a range of turndown. High pressure, single stage injectors can be used for low and medium Btu gases up to 1100 Btu. Either a single stage or compound injector can be used for gases from 750 to 1100 Btu. For gases above 1100 Btu, a compound injector should be used.

Gas flow adjustment is provided by an external needle valve at the gas inlet. Air flow is adjusted by an integral air shutter. These mixers can be purchased with or without the gas adjusting valve and gas pressure gauge. Single stage injectors are available in sizes from ¾" to 6". Compound injectors are available in sizes from 1" to 6".

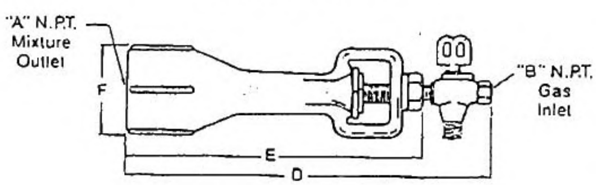
ECLIPSE COMBUSTION
A DIVISION OF ECLIPSE, INC.
ROCKFORD, ILLINOIS 61103 (815) 877-3031
IN CANADA: ECLIPSE FUEL ENGINEERING CO. OF CANADA, LTD. DON MILLS, ONTARIO

LOW PRESSURE INJECTORS
CAPACITIES—CFH

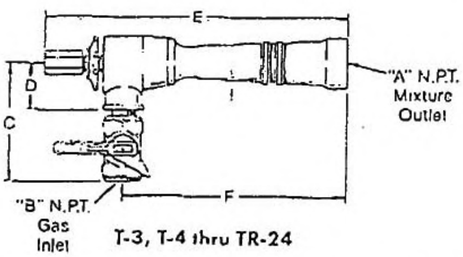
Single Stage Injectors				Compound Injectors			
Catalog Number	Mixture Outlet	Nat. Gas* BTU/Hr.	Std. Orifice Size	Catalog Number	BTU/Hr.** Propane & Butane	Std. Orifice Size Propane	Std. Orifice Size Butane
TR-2 TR-3A T-3	1/2" 3/4" 3/4"	10,000 12,000 16,000	#55 #54 #38	— — —	— — —	— — —	— — —
T-4A T-4 T-5 TR-6	1" 1" 1-1/4" 1-1/2"	20,000 25,000 40,000 55,000	#49 7/64" 9/64" 5/32"	— T-40 T-50 TR-60	— 27,000 45,000 62,000	— #50 #42 #31	— #53 #47 #37
TR-8 TR-10 TR-12	2" 2-1/2" 3"	90,000 140,000 200,000	13/64" 9/32" 3/8"	TR-80 TR-100 TR-120	100,000 155,000 220,000	#29 #18 #9	#30 #27 #18
TR-16 TR-20 TR-24	4" 5" 6"	340,000 540,000 750,000	7/16" 9/16" 5/8"	TR-160 TR-200 TR-240	375,000 590,000 825,000	1/4" #1 21/64"	#3 15/64" 9/32"

*1040 BTU natural gas, .65 sp. gr., 7" w.c. inlet pressure.
**1.52 sp. gr. propane at 11" w.c. inlet pressure or 1.95 sp. gr. butane at 15" w.c. inlet pressure.

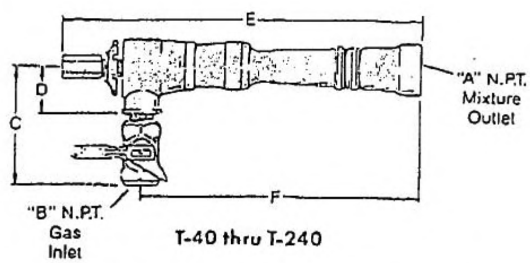
DIMENSIONS



TR-2, TR-3A, TR-4A



T-3, T-4 thru TR-24



T-40 thru T-240

Catalog Number	Assy. No. W/ Gas Cock	Assy. No. W/O Gas Cock	A	B	C	D	E	F
Single Stage Injectors								
TR-2	300262	300266	1/2	1/8	—	6-9/16	5-1/4	—
TR-3A	300263	300267	3/4	1/4	—	8-1/4	6-3/4	1-7/8
T-3	300202	300228	3/4	3/8	3-1/2	1-3/8	8-15/16	7-3/8
TR-4A	300257	300258	1	1/4	—	8-1/4	6-3/4	1-7/8
T-4	300203	300229	1	3/4	4-15/16	1-13/16	11-1/8	8-3/4
T-5	300205	300231	1-1/4	3/4	5-1/8	2	12-1/2	10-3/16
TR-6	300043	300003	1-1/2	3/4	5-1/8	2	11-9/16	9-1/4
TR-8	300044	300004	2	1	6-1/4	2-5/8	13-1/4	10-3/4
TR-10	300045	300005	2-1/2	1	6-3/16	2-5/8	16-1/4	13-3/4
TR-12	300046	300006	3	1-1/4	6-1/8	2-3/4	18-1/2	15-13/16
TR-16	300047	300007	4	1-1/4	7	3-1/2	22-11/16	19-3/16
TR-20	300048	300008	5	1-1/4	7-7/8	4-1/8	31-5/16	27-7/8
TR-24	300049	300009	6	1-1/4	8-1/2	4-1/2	33-1/8	29-9/16
Compound Injector								
T-40	300204	300230	1	3/4	5-7/16	1-13/16	13-1/8	10-3/4
T-50	300206	300232	1-1/4	3/4	5-5/8	2	14-7/8	12-9/16
TR-60	300063	300023	1-1/2	3/4	5-5/8	2	14-7/16	12-1/8
TR-80	300054	300024	2	1	7	2-5/8	16-1/4	13-3/4
TR-100	300065	300025	2-1/2	1	6-15/16	2-5/8	20-5/16	17-13/16
TR-120	300066	300026	3	1-1/4	6-5/8	2-3/4	23-5/16	20-5/8
TR-160	300067	300027	4	1-1/4	7	3-1/2	27-5/8	24-1/8
TR-200	300068	300028	5	1-1/4	7-7/8	4-1/8	38-13/16	34-3/4
TR-240	300069	300029	6	1-1/4	8-1/2	4-1/2	42-5/16	39

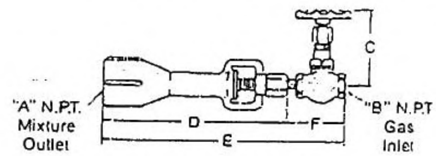
NOTE: All dimensions are in inches.

HIGH PRESSURE INJECTORS
CAPACITIES—CFH

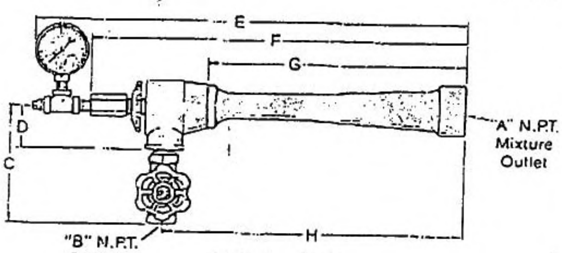
Single Stage Injectors				Compound Injectors		
Catalog Number	Mixture Outlet	CFH: Coke Oven Gas*	CFH: Nat. Gas**	Catalog Number	CFH: Nat. Gas**	CFH: Propane***
TR-3HA	3/4	6.2	8.4	—	—	—
H-3	3/4	50	17	—	—	—
TR-4HA	1	6.2	8.4	—	—	—
H-4	1	100	22.5	H-40	25	—
H-5	1-1/4	175	90	H-50	100	25
H-6	1-1/2	250	135	H-60	150	50
H-8	2	550	225	H-80	250	100
H-10	2-1/2	850	405	H-100	450	150
H-12	3	1300	585	H-120	650	200
H-16	4	2500	1080	H-160	1200	400
H-20	5	3500	1620	H-200	1800	600
H-24	6	5500	3600	H-240	4000	1000

NOTE: All dimensions are in inches.
*595 BTU Coke Oven Gas, .42 sp. gr. at 10 psig inlet pressure.
**1040 BTU Natural Gas, .65 sp. gr. at 25 psig inlet pressure.
***2500 BTU Propane Gas, 1.55 sp. gr. at 25 psig inlet pressure.

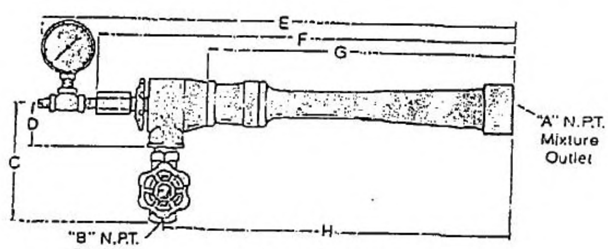
DIMENSIONS



TR-3HA, TR-4HA



H-3 thru H-24



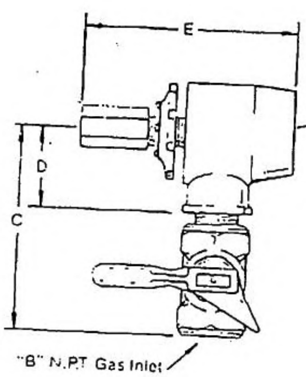
H-40 thru H-240

Catalog Number	Assembly Number: With Valve & Gauge*	Assembly Number: Less Valve & Gauge	A	B	C	D	E	F	G	H
Single Stage Injectors										
H-3	300401	300420	3/4	3/8	4-3/4	1-3/8	11-3/8	8-5/16	6	7-3/8
TR-3HA	300269	300267	3/4	1/8	2-3/8	6-3/4	9	2-1/4	—	—
TR-4HA	300259	300258	1	1/8	2-3/8	6-3/4	9	2-1/4	—	—
H-4	300402	300421	1	3/4	4-7/8	1-13/16	14-3/4	11-1/4	7	7-7/8
H-5	300404	300423	1-1/4	3/4	5	2	17-7/8	14-1/4	10	11-15/16
H-6	300406	300425	1-1/2	3/4	5	2	20-1/4	16-3/4	12-1/4	14-7/16
H-8	300408	300427	2	3/4	5	2-5/8	21-1/4	18-1/8	13-1/4	15-5/8
H-10	300410	300429	2-1/2	1	5-5/8	2-5/8	26	22-1/2	17-1/4	20
H-12	300412	300431	3	1	5-5/8	2-3/4	31	28-1/2	22-3/8	26-13/16
H-16	300414	300433	4	1-1/4	5-3/4	3-1/2	35-3/4	32-11/16	26-1/4	29-3/16
H-20	300416	300435	5	1-1/4	6-1/2	4-1/8	42	38-7/8	31-1/2	34-13/16
H-24	300418	300437	6	1-1/4	7-1/8	4-1/2	47-7/16	43-15/16	35-1/2	40-5/16
Compound Injectors										
H-40	300403	300422	1	3/4	4-13/16	1-13/16	16-1/4	13-3/32	8-7/8	10-3/4
H-50	300405	300424	1-1/4	3/4	5	2	19-1/2	15-7/8	11-5/8	13-9/16
H-60	300407	300426	1-1/2	3/4	5	2	20-3/8	16-7/8	12-3/8	14-9/16
H-80	300409	300428	2	3/4	5	2-5/8	21-3/8	17-29/32	13-1/16	15-7/16
H-100	300411	300430	2-1/2	1	5-5/8	2-5/8	25-15/16	22-7/16	17-3/16	19-15/16
H-120	300413	300432	3	1	5-5/8	2-3/4	32-1/8	30	23-7/8	27-5/16
H-160	300415	300434	4	1-1/4	5-3/4	3-1/2	35-9/16	32-9/16	26-1/8	29-1/16
H-200	300417	300436	5	1-1/4	6-1/2	4-1/8	42-9/16	39-3/16	31-13/16	35-1/8
H-240	300419	300438	6	1-1/4	7-1/8	4-1/2	46-3/4	43-1/4	25-13/16	39-5/8

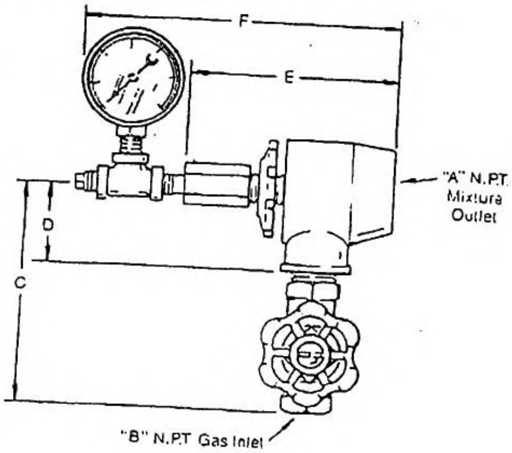
NOTE: All dimensions are in inches.
*No gauge on TR-3HA & TR-4HA.

MIXER HEADS

DIMENSIONS



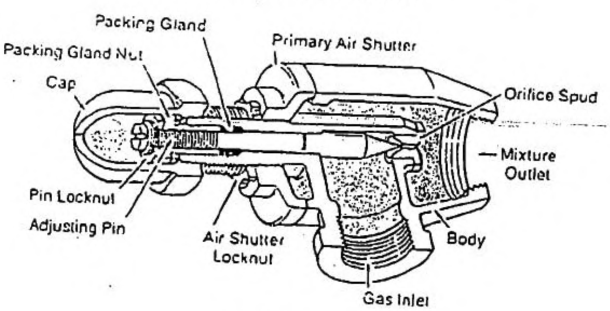
Low Pressure



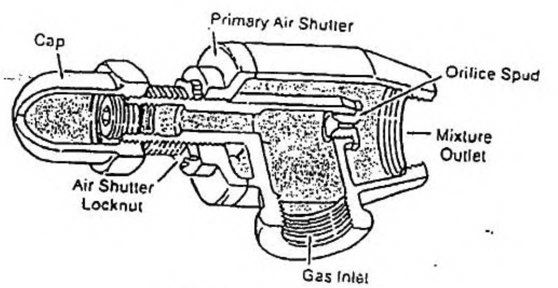
High Pressure

Low Pressure								
Catalog Number	Assembly Number		Dimensions					
	With Gas Cock	Less Gas Cock	A	B	C	D	E	F
NS-3	300101	300116	3/4	3/8	3-1/2	1-3/8	4	—
NS-4	300103	300118	1	3/4	4-15/16	1-13/16	5-13/16	—
NS-5	300105	300120	1-1/4	3/4	5-1/8	2	5-5/8	—
NS-6	300107	300122	1-1/2	3/4	5-1/8	2	6	—
NS-8	300109	300124	2	1	6-1/4	2-5/8	6-3/8	—
NS-10	300111	300126	2-1/2	1	6-3/16	2-9/16	6-1/4	—
NS-120	300112	300127	3	1-1/4	6-1/8	2-1/2	7-7/16	—
NS-160	300113	300128	4	1-1/4	7	3-3/8	8-3/16	—
NS-200	300114	300129	5	1-1/4	7-7/8	4-1/4	9-1/8	—
NS-240	300115	300130	6	1-1/4	8-1/2	4-3/4	9-5/16	—
High Pressure								
Catalog Number	With Valve & Gauge	Less Valve & Gauge	A	B	C	D	E	F
HO-3	300311	300301	3/4	3/8	4-3/4	1-7/8	3-3/8	5-3/8
HO-4	300312	300302	1	3/4	4-7/8	1-7/8	5-1/4	8-3/4
HO-5	300313	300303	1-1/4	3/4	5	2	5-1/4	8-7/8
HO-6	300314	300304	1-1/2	3/4	5	2	4-7/8	7-3/4
HO-8	300315	300305	2	1	5	2	5-3/4	9-1/4
HO-10	300316	300305	2-1/2	1-1/4	5-5/8	2-5/8	6	9-1/2
HO-120	300317	300307	3	1-1/4	5-5/8	2-5/8	6-1/4	8-3/4
HO-160	300318	300308	4	1-1/4	5-3/4	2-3/4	7-3/8	10-7/8
HO-200	300319	300309	5	1-1/4	6-1/2	3-1/2	7	10-1/4
HO-240	300321	300310	6	1-1/4	7-1/8	4-1/8	7-3/4	11-1/4

NOTE: All dimensions are in inches.



Low Pressure



High Pressure

ECLIPSE COMBUSTION
A DIVISION OF ECLIPSE, INC.
ROCKFORD, ILLINOIS 61103 (815) 877-3031
IN CANADA: ECLIPSE FUEL ENGINEERING CO. OF CANADA, LTD. DON MILLS, ONTARIO

Litho in U.S.A.

P.22

Eclipse Combustion, Inc.

Eclipse

September 26, 2000

P.O. Box 5970
Shreveport, LA 71135-5970
Phone: 318/797-8800
Fax: 318/797-8877

SUBJECT: Emissions for Atmospheric Burners

Please note that it is difficult to provide specific data pertaining to Subject as same is effected by the following factors:

-Flue Gas Temperatures
-Type of Nozzle
-Amount of primary air versus secondary air
-Amount of excess air
-Chamber Temperature

In light of these factors, we generally state these Burners will emit a maximum of the following, and in many cases less. Please be advised that these numbers are corrected for 3% O2 in the Stack..

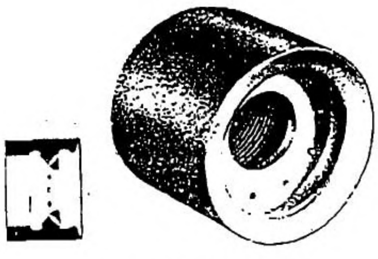
-<100 PPM NOx (0.1197 lb. per million Btu)
-<100 PPM CO (0.0722 lb. per million Btu)

If you have any questions or comments please do not hesitate to contact me. We thank you for using ECLIPSE Products.

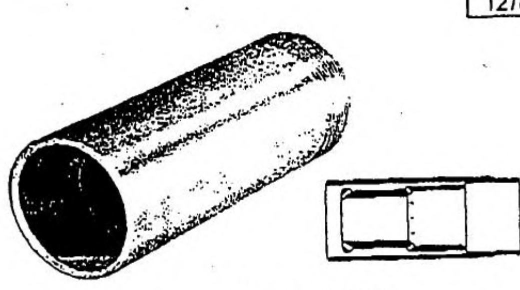
Chuck Carroll
Sr. Sales Representative

ECLIPSE OPEN BURNER NOZZLES

Bulletin 12/87



STICKTITE NOZZLE



FERROFIX NOZZLE

Eclipse Sticktite, Ferrofix, and Unitite Nozzles are for use wherever an open-type nozzle can be applied. Combustion chambers must have balanced or negative pressure. Typical applications include boiler conversion, kilns, ovens, air heaters, furnaces, immersion heating, and other applications where the slight excess air introduced into the combustion chamber around the burner is acceptable.

All Eclipse open burner nozzles are flame retention type nozzles which ensure satisfactory operation over a wide range of mixture pressures and draft conditions. No combustion block is required for proper operation; however, for adapting to a furnace, kiln, or other refractory-lined combustion chamber, combustion blocks are available. See Bulletin P-5. Also, mounting cages are available for supporting the nozzles, with provision for adapting pilots and flame safety to them. See Bulletin P-10.

CAUTION: It is dangerous to use any fuel burning equipment unless it is equipped with suitable flame sensing device(s) and automatic fuel shut-off valve(s). Thermocouple flame monitoring must not be used on burners with capacities greater than 150,000 Btu/Hr. Eclipse can supply flame monitoring systems or information on alternate sources.

Sticktite and Ferrofix nozzles are normally used with any air/gas mixing device capable of delivering a combustible mixture at the pressure required to give desired maximum capacity and turndown range. Typical mixers are: Low and High Pressure Injectors (Bulletin L-150), Proportional Mixers (Bulletin L-300), Variset® Mixers (Bulletin L-310) and Variport® Mixers (Bulletin L-400).

Air/gas mixture for the Eclipse Unitite Nozzle should be supplied by a mixer capable of delivering low pressure air through the nozzle for proper pilot operation when operating on pilot only. Proportional Mixers (Bulletin L-300), Variset Mixers (Bulletin L-310), and Variport Mixers (Bulletin L-400) can be used.

STICKTITE NOZZLES

Eclipse Sticktite Nozzles are available in both cast iron and heat-resisting alloy and all have female threads. Exceptional flame stability is achieved by the Sticktite due to a built-in flame retention feature.

Sticktite nozzles provide a slightly shorter, bushier flame than the Ferrofix nozzle with flames ranging in length from 8" to 10½' depending on size of nozzle and mixture pressure. They are available in ten different pipe sizes ranging from ½" through 6". With 6" w.c. mixture pressure, capacities range from 37,000 Btu/hr. through 5,250,000 Btu/hr. (For complete listing of sizes and capacities, see page 2.)

FERROFIX NOZZLES

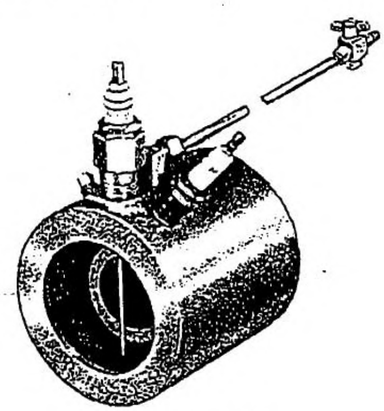
Eclipse Ferrofix Nozzles have a steel shell with male threads and either steel or cast iron spools. They are also available in heat-resisting alloy. As in the Sticktite Nozzle, maximum flame retention is achieved by use of the built-in flame retention feature.

Ferrofix Nozzles are available in three types: Type 1 has a short thread; Type 2, a long thread; Type 3, threaded at both ends. Ferrofix nozzles are furnished in thirteen different pipe sizes ranging from ¼" through 6". Alloy nozzles, however, are available in ½" through 2½" sizes, type 1 only. With 6" w.c. mixture pressure, capacities range from 6,090 Btu/hr. through 5,700,000 Btu/hr. For complete listing of sizes, types, and capacities, see page 3.

UNITITE® NOZZLES

Eclipse Unitite Nozzles are packaged, flame retention type nozzles incorporating pilot, ignition plug and flame rod as integral parts of the nozzle. Also included is 24" of pilot gas tubing and a pilot shut-off cock with adjustable orifice. Stripped nozzles can be supplied if required.

Unitites are available in four different sizes ranging from 2" through 6" with capacities of 73,500 Btu/hr. up to 5,000,000 Btu/hr. at 6" w.c. mixture pressure. For complete listing of sizes and capacities, see page 4.



UNITITE® NOZZLE

ECLIPSE COMBUSTION
A DIVISION OF ECLIPSE, INC.
ROCKFORD, ILLINOIS 61103 (815) 877-3031
IN CANADA, ECLIPSE FUEL ENGINEERING CO. OF CANADA, LTD. DON MILLS, ONTARIO

STICKTITE NOZZLES

CAPACITIES—CFH

(Natural Gas—0.6 Sp. Gr.—8:1 Air/Gas Ratio)*

STEEL

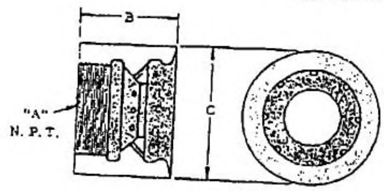
CATALOG NUMBER	MIXTURE PRESSURE - INCHES W.C.																	
	.2	.3	.4	.5	.6	.7	.8	.9	1	2	3	4	5	6	7	8	9	10
ST-102-10	---	---	---	10.5	11.5	12.5	13.3	14.2	15	21.2	26	30	33.8	37	40	43	45	48
ST-103-14	10.7	13	15	17	18.5	20	21.5	22.8	24	34	42	48	54	59	64	68	72	76
ST-204-12	23.5	29.9	33.2	37	41	44	47	50	52.5	75	91	105	118	130	140	150	160	188
ST-205-28	51	62.5	72	80	88	95	102	108	114	162	198	230	255	280	302	325	345	362
ST-206-36	81	100	115	130	142	153	164	174	184	250	330	370	410	450	468	520	550	580
ST-208-42	109	132	154	172	188	203	218	230	243	345	420	490	545	600	645	690	735	770
ST-208-46	130	160	182	205	225	243	260	275	290	410	502	580	655	718	770	830	875	920
ST-210-56	192	235	272	305	332	360	385	410	430	610	750	865	965	1,050	1,130	1,220	1,300	1,360
ST-212-68	290	340	395	440	482	525	560	595	625	890	1,090	1,250	1,400	1,540	1,670	1,780	1,890	2,000
ST-216-84	422	520	600	670	740	795	850	900	950	1,350	1,650	1,900	2,120	2,330	2,520	2,700	2,850	3,000
ST-224-128	960	1,190	1,350	1,510	1,650	1,800	1,910	2,030	2,150	3,050	3,700	4,300	4,800	5,250	5,700	6,100	6,400	6,800

ALLOY

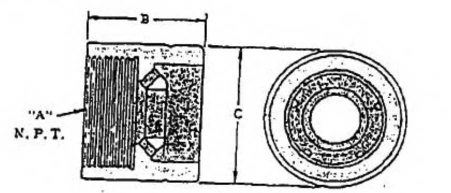
CATALOG NUMBER	MIXTURE PRESSURE - INCHES W.C																	
	.2	.3	.4	.5	.6	.7	.8	.9	1	2	3	4	5	6	7	8	9	10
ST-102-A18-8-7	4	5	5.7	6.4	7	7.6	8.1	8.6	9	12.8	15.3	18	20	22	24	25.5	27	29
ST-102-A18-8-10	5.9	7.1	8.2	9.2	10	10.9	11.7	12.4	13	18.3	22.5	26	29	32	34	36.5	39	41
ST-102-A18-8-12	7.6	9.3	10.8	12	13	14.2	15.2	16	17	24	29.5	34	38	42	45	48	51	54
ST-103-A18-8-12	8.5	10.3	12	13.4	14.8	16	17	18	19	27	33	38	42	46	50	54	57	60
ST-103-A18-8-14	10.2	12.5	14.5	16	17.8	19	20.5	21.6	23	32.3	39.5	46	51	56	60	64.5	68	72
ST-104-A18-8-18	19	23	26.5	30	32.5	35	37.5	40	42	59.5	73	84	84	102	110	120	125	132
ST-105-A18-8-22	27	33	38	42	46	50	53.8	57	60	84	104	120	134	146	160	170	180	190
ST-105-A18-8-28	44.2	54	63	70	77	84	90	95	100	140	172	200	222	245	263	280	300	310
ST-106-A18-8-36	73	59	102	115	125	135	146	155	162	230	280	322	360	395	430	455	485	505
ST-108-A18-8-46	125	153	179	198	213	235	250	267	280	390	480	558	620	680	730	775	830	870

*For air/gas ratios other than 8:1 see multifactor chart on page 3.

DIMENSIONS & SPECIFICATIONS



STEEL



ALLOY

CATALOG NUMBER	PART NUMBER	ACTUAL PORT AREA SQ. INCHES	DIMENSIONS		
			A	B	C
T 102-10	19902-1	.114	1/2	1-1/4	1-1/16
T 103-14	19903-1	.199	3/4	1-3/8	1-5/16
T 204-12	03612	.309	1	1-3/4	2-1/8
T 205-28	03663	.669	1-1/4	2-3/16	2-7/16
T 206-36	03619	1.069	1-1/2	2-1/4	2-3/4
T 208-42	03620-1	1.443	2	2-5/16	3-1/4
T 208-46	03620-2	1.713	2	2-5/16	3-1/4
T 210-56	03665	2.525	2-1/2	2-3/4	4
T 212-68	03684	3.652	3	3-1/16	4-3/8
216-84	03677	5.59	4	3-3/16	5-1/2
224-128	03679	12.8	6	3-5/8	7-11/16

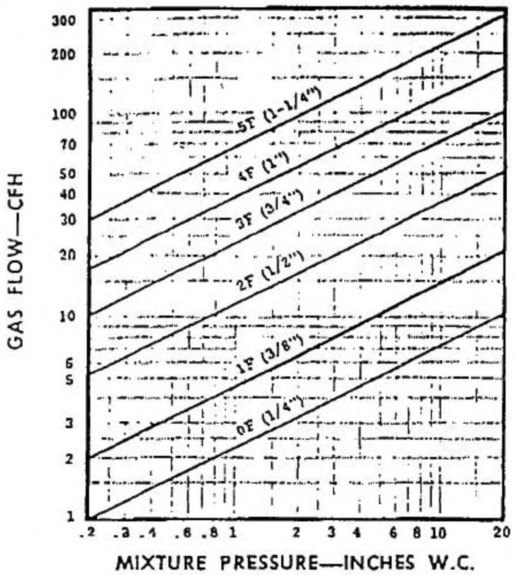
*: All dimensions are in inches.

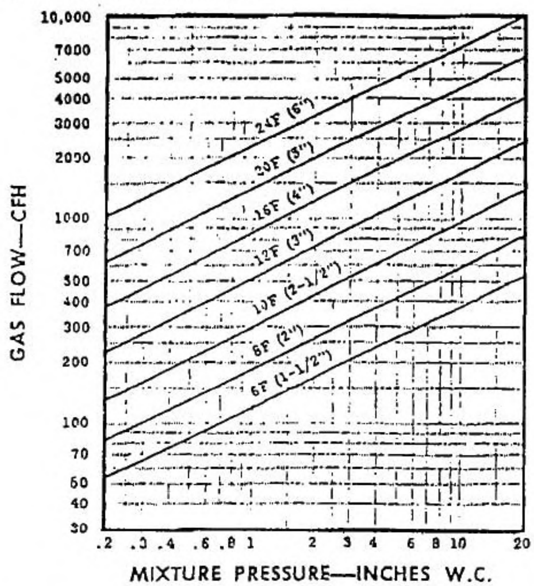
CATALOG NUMBER	PART NUMBER	ACTUAL PORT AREA SQ. INCHES	DIMENSIONS		
			A	B	C
ST 102-A18-8-7	10097-2	.0745	1/2	1-1/4	1-1/16
ST 102-A18-8-10	18902-2	.114	1/2	1-1/4	1-1/16
ST 102-A18-8-12	18902-6	.148	1/2	1-1/4	1-1/16
ST 103-A18-8-12	11995-2	.159	3/4	1-3/8	1-5/16
ST 103-A18-8-14	18903-2	.199	3/4	1-3/8	1-5/16
ST 104-A18-8-19	19174-2	.310	1	1-11/16	1-3/4
ST 105-A18-8-22	19231	.433	1-1/4	2	2
ST 105-A18-8-28	19404	.675	1-1/4	2	2
ST 106-A18-8-36	18974	1.09	1-1/2	2-1/4	2-1/2
ST 106-A18-8-46	18875	1.75	2	2-1/2	3

NOTE: All dimensions are in inches.

CAPACITIES

(Natural Gas—0.6 Sp. Gr.—8:1 Air/Gas Ratio)



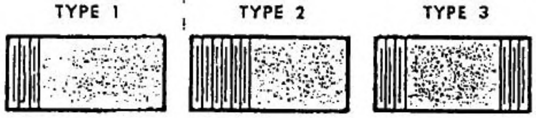


FOR AIR/GAS RATIOS OTHER THAN 8:1 APPLY CFH x MULTIFACTOR BELOW

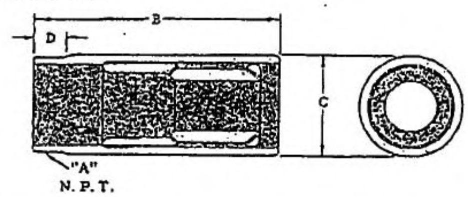
AIR/GAS RATIO	7:1	8:1	9:1	10:1	11:1
MULTIFACTOR	1.12	1.0	.91	.82	.75

DIMENSIONS & SPECIFICATIONS

TYPE 1 TYPE 2 TYPE 3



SHORT THREAD ONE END — LONG THREAD ONE END — THREADED BOTH ENDS



CATALOG NUMBER	TYPE NUMBER	ASSEMBLY NUMBERS STEEL	ASSEMBLY NUMBERS ALLOY	ACTUAL BURNER AREA SQ. INCHES	DIMENSIONS A	B	C	D	SHIP. WT. LBS.
0 F-1	1	103201	---	.018	1/4	1-3/4	17/32	11/32	1/4
1 F-1	1	103202	103227	.037	3/8	3	11/16	3/8	1/4
2 F-1	1	103204	103228	.0896	1/2	3	27/32	1/2	1/4
2 F-3	3	103240	---	.0896	1/2	3	27/32	1/2 TBE*	1/4
3 F-1	1	103206	103229	.1657	3/4	3	1-1/16	9/16	1/3
3 F-2	2	103207	---	.1657	3/4	4-1/2	1-1/16	2	1/2
3 F-3	3	103241	---	.1657	3/4	3	1-1/16	9/16 TBE*	1/3
4 F-1	1	103208	103230	.3021	1	3-1/2	1-5/16	11/16	2/3
4 F-2	2	103209	---	.3021	1	5	1-5/16	2	1
4 F-3	3	103255	---	.3021	1	3-1/2	1-5/16	11/16 TBE*	2/3
5 F-1	1	103210	103231	.5169	1-1/4	3-1/2	1-11/16	11/16	1
5 F-2	2	103211	---	.5169	1-1/4	5	1-11/16	2	2
6 F-1	1	103212	103232	.8266	1-1/2	3-1/2	1-15/16	11/16	1-1/2
6 F-2	2	103213	---	.8266	1-1/2	5	1-15/16	2	2-1/2
8 F-1	1	103214	103233	1.2736	2	6-1/2	2-3/8	3/4	3
8 F-2	2	103216	---	1.2736	2	5	2-3/8	3-3/4	4
10 F-1	1	103217	103234	2.128	2-1/2	6-1/2	2-7/8	15/16	4-1/2
10 F-2	2	103218	---	2.128	2-1/2	8	2-7/8	3-3/4	5-1/2
12 F-1	1	103219	103235	3.62	3	6-1/2	3-1/2	1	6
12 F-2	2	103220	---	3.62	3	8	3-1/2	3-3/4	7-1/2
16 F-1	1	103251	---	6.0244	4	8	4-1/2	1-1/8	15
16 F-2	2	103222	---	6.0244	4	12-1/2	4-1/2	3-3/4	20
20 F-1	1	103252	---	9.751	5	8	5-9/16	1-1/4	17
20 F-2	2	103224	---	9.751	5	12-1/2	5-9/16	3-3/4	23
24 F-1	1	103225	103238	16.093	6	11	6-5/8	1-5/16	24

NOTE: All dimensions are in inches.

*Threaded both ends.

ECLIPSE™

Innovative Thermal Solutions

Eclipse Combustion

- Air Heating Burners
- Furnace Burners
- Immersion Burners
- Infrared Burners
- Air and Fuel Supply Components
- Flame Monitoring Systems

Combustion Tec

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- Air to Air Plate Heat Exchangers in Aluminum, Stainless Steel and Special Alloy
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Algas-SDI

- Diversified Vaporizer Line
- LPG/Air Venturi Mixers
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- Proportional Mixing Systems
- Accessories and Control Systems
- Ammonia Vaporizers and Accessories

With just one call to any of the Eclipse family of brands, you can start discovering new ways to make your heat processes more reliable and efficient. No matter what your finished product, or where you're located, Eclipse has the global resources to react quickly with time-and money-saving thermal solutions and equipment.

By combining our resources, we have created a global powerhouse of proven products supported by sound technologies and problem solving technical service.

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Strategic Alliances

Riello and Eclipse are joined in a strategic alliance to provide the most comprehensive range of combustion solutions from any single source in North America.

RED-RAY

The Eclipse-Red Ray alliance combines the complete line of infra-red burners from Red Ray with the application experience and global sales network of Eclipse.

C5 Hauck Literature

Combustion products, engineering, and software since 1888 Page 1 of 1

Hauck Manufacturing

The people and products behind combustion.

HAUCK

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Hauck Manufacturing Company designs, builds, and markets a wide range of combustion products. Hauck burners, blowers, and controls products are key components in industrial heat processing equipment used by most industries utilizing thermal energy. In business for over a century, Hauck has earned an outstanding reputation for its products and the loyalty of customers nationally and in world markets.

AIG

High Pressure Gas-Air Inspirators

Features

- Single valve control for manual or automatic operation
- Venturi mixer with adjustable air shutter
- Easily removable spud holder and spud

Benefits

- Heavy duty construction
- Maximum air entrainment
- Easy to adjust
- Requires no blower or compressor
- Automatically maintains gas-air ratio

HAUCK MANUFACTURING COMPANY

P.O. Box 90
Lebanon, PA 17042
Phone: 717-272-3051
Fax: 717-273-9882
www.hauckburner.com

Hauck AIG high pressure inspirators make it possible to utilize the energy of the gas to inspirate the necessary air for combustion. The AIG inspirators may be used wherever high pressure gas from 1 to 30 psig is available. The AIG automatically maintains the gas-air ratio. No blower or compressor is necessary for combustion air. A single control valve is used for manual or automatic operation.

Combustion Excellence Since 1888

AIG-1

Hauck Manufacturing Company

AIG

HIGH PRESSURE GAS-AIR INSPIRATORS

HAUCK®

ADVANTAGES OF THE AIG

Heavy Duty Construction

Maximum Air Entrainment

Easy to Adjust

Automatically Maintains Gas-Air Ratio

AIG high pressure inspirator, with Hauck patented 'Retain-a-Flame' gas burner nozzle.

Where high pressure gas from 1 to 30 psig is available, Hauck AIG inspirators make it possible to utilize the energy of the gas to inspirate the necessary air for combustion. The high pressure gas stream passing through the Venturi throat draws in the air, mixes it thoroughly with the gas and delivers the desired mixture at the inspirator outlet. In the Venturi mixer design, the air induced by the gas varies directly with the volume of gas flowing; thus the mixture or gas-air ratio is maintained over a wide range of gas capacities. The mixture is adjusted to give the desired flame by setting the air shutter. Control is maintained with the single valve increasing or decreasing the gas pressure to the mixer, the air varying automatically with the gas.

Hauck AIG inspirators consist of the Venturi mixer with an adjustable air shutter and locking screw and easily removable spud holder and spud. The complete unit is efficient, easily adjustable, and ruggedly constructed.

The mixer air openings and shutter are streamlined to secure greater air entrainment and to reduce turbulence. The air shutter for adjusting the induced air ratio can be rotated for forward or backward movement on the outer threaded part of the spud holder. All parts are made with extreme accuracy to ensure correct alignment.

Optional accessories for air-gas regulation are available for these inspirators. The system consists of a globe needle regulating valve and a gas pressure gauge with connecting tee. The relative quantity of fuel being used is indicated by the pressure gauge.

These inspirators will operate with Hauck Retain-a-Flame gas burner nozzles, sealed-in nozzles, tunnel burner assemblies and any other burner nozzles having the correct gas burner capacity.

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HAUCK®

CAPACITIES

AIG HIGH PRESSURE GAS-AIR INSPIRATORS

TABLE A – For Manufactured Gas – 530 Btu per Cubic Foot – Gravity 0.56

Mixer Discharge Pipe Size	1/2"	3/4"	1"	1-1/4"	1-1/2"	2"	3"	4"
Spud Size No.	55	50	46	1/8	24	7	D	11/32
Gas Pressure In lbs. per Sq. In.	CUBIC FEET OF GAS PER HOUR							
1	21	36	52	127	202	340	517	1028
2	29	51	73	180	286	482	733	1453
3	36	63	90	220	349	590	895	1778
4	41	73	104	246	405	683	1038	2059
5	46	81	116	285	452	763	1160	2300
6	50	89	127	312	495	835	1270	2520
7	54	96	137	337	534	901	1380	2719
8	58	103	147	360	570	963	1463	2900
9	62	109	155	381	605	1020	1550	3078
10	65	115	164	403	640	1079	1639	3250
12	71	126	179	441	700	1180	1793	3660
14	77	136	194	477	756	1276	1939	3847
16	82	146	208	510	810	1365	2075	4115
18	87	154	220	541	858	1448	2200	4360
20	92	162	231	568	900	1520	2305	4580
25	103	182	260	640	1013	1710	2600	5150
30	112	199	283	696	1104	1862	2830	5620

TABLE B – For Natural Gas – 1000 Btu per Cubic Foot – Specific Gravity 0.56

Mixer Discharge Pipe Size	1/2"	3/4"	1"	1-1/4"	1-1/2"	2"	3"	4"
Spud Size No.	71	65	57	50	45	38	30	14
Gas Pressure In lbs. per Sq. In.	CUBIC FEET OF GAS PER HOUR							
5	13	21	33	81	121	209	332	639
6	14	23	36	89	132	229	364	700
7	15	24	39	96	143	248	394	758
8	16	26	41	103	153	264	420	808
9	17	28	44	109	162	281	446	858
10	18	29	46	115	171	296	469	903
12	20	32	51	126	187	324	515	990
14	22	34	55	136	202	350	555	1070
16	23	37	58	146	216	374	595	1145
18	25	39	62	155	230	398	632	1216
20	26	41	65	163	242	419	665	1280
25	29	46	73	182	270	468	744	1430
30	32	50	80	199	296	512	813	1564

(OVER)

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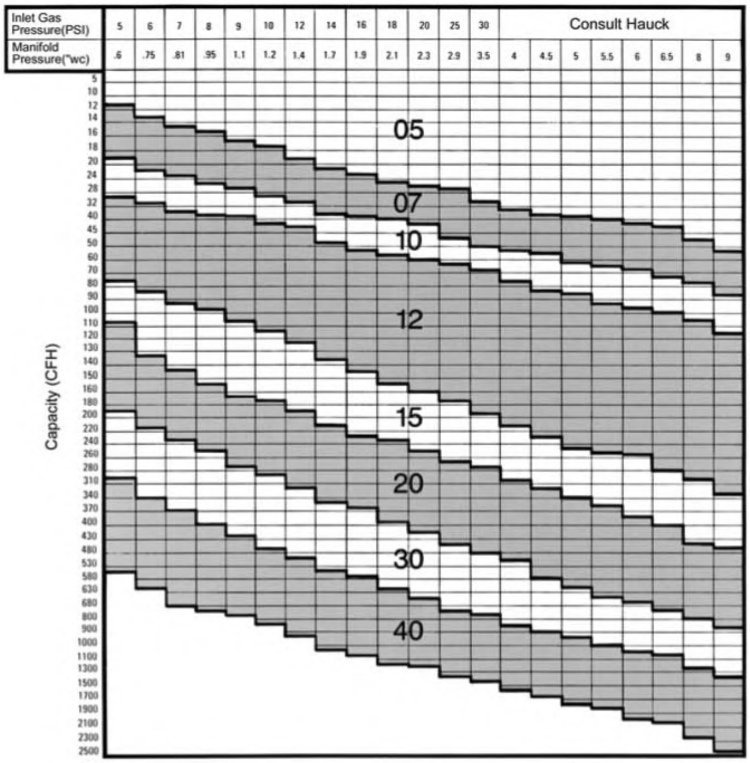
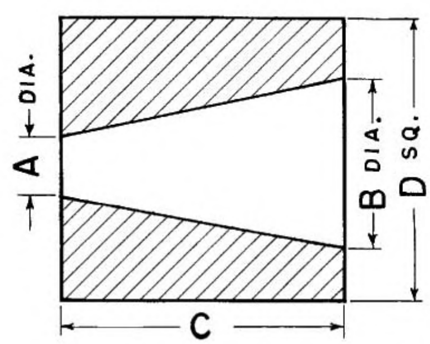


Notes:
1. Capacities based on natural gas with HHV of 1000 Btu/ft^3, 0.60 S.G., and stoichiometric air/gas ratio of 10:1 with nozzle firing under no back pressure.
2. Inlet Gas Pressure refers to use only with Hauck High Pressure Gas-Air Inspirators (AIG).

Table 1. Nozzle Selection – Capacity vs. Pressure

REFRACTORY BURNER TILES

Refractory tiles are recommended when firing into furnaces, oven, or kilns. These tiles protect the burner nozzle from furnace heat, reduce heat loss at the firing port inlet, and control secondary air. They are cube shaped with a conical firing opening sized for the best operating results. They may be placed directly into a firing wall and still maintain the wall's strength. Actual operating conditions determine the tile selected. Consult Hauck for recommendations.



GV37

Nozzle Size	Tile Dimensions (Inches)			
	A	B	C	D
05	1 ¼	3	5	5
07	1 ¼	3	7 ½	7 ½
10	1 ½	4	9	9
12	2	4	9	9
15	2 ½	5	9	9
20	3 ½	7	9	9
30	4	8	13 ½	13 ½
40	5	10	13 ½	13 ½

TABLE C – For Propane Gas – 2500 Btu per Cubic Foot – Specific Gravity 1.52

Mixer Discharge Pipe Size	1/2"	3/4"	1"	1-1/4"	1-1/2"	2"	3"	4"
Spud Size No.	77	74	69	56	53	48	44	31
Gas Pressure In lbs. per Sq. In.	CUBIC FEET OF GAS PER HOUR							
5	3.3	5.3	8.9	21	33	60	82	166
6	3.6	5.8	9.7	23	36	66	80	182
7	3.9	6.3	10.5	25	39	71	97	197
8	4.2	6.7	11	27	42	76	103	210
9	4.4	7.1	12	28	44	80	110	223
10	4.7	7.5	12.5	30	46	85	115	235
12	5	8.2	13.5	33	50	93	126	258
14	5.5	9	15	35	55	100	137	280
16	6	9.5	16	38	60	107	146	300
18	6.3	10	17	40	62	114	155	315
20	6.7	11	18	42	66	120	165	335
25	7.4	12	20	48	75	135	188	375
30	8.1	13	23	52	80	150	200	432

All of the above capacities are based upon the mixer supplying a burner of the proper size which is operated without back pressure or draft. Back pressure will decrease the capacity of the mixer and burner as much as 50%, and draft will increase the capacity to 150% and more.

For gases of any other specific gravity than 0.56 multiply the capacities given in Tables A or B by the correction factors shown below. (Do not apply these factors to Table C.)

Specific Gravity	Factor
.44	1.13
.46	1.10
.48	1.08
.50	1.06

Specific Gravity	Factor
.52	1.04
.54	1.02
.56	1.00
.58	.98

Specific Gravity	Factor
.60	.96
.62	.95
.64	.93
.66	.92

Specific Gravity	Factor
.68	.90
.70	.89
.75	.86
.80	.83

Specific Gravity	Factor
.90	.79
1.00	.74
1.52 p	.603
2.07 b	.52

p=propane b=butane

Given on this sheet are the capacities of Hauck High Pressure Inspirators for various gases under pressures of from 1 to 30lbs. per square inch. Intermediate capacities can be supplied or unusual operation conditions can be overcome by replacing the easily interchangeable gas spud with one of the proper drill size opening.

Constant gas pressure should be supplied to these inspirators to eliminate the necessity of readjusting the gas valve to compensate for the fluctuation in pressure.

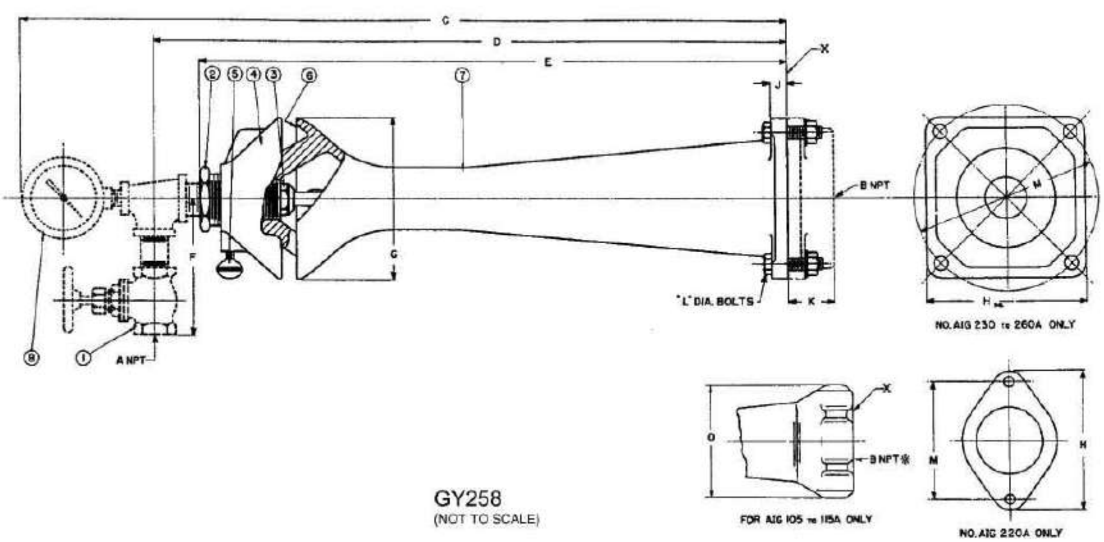
To obtain a minimum loss in mixture pressure, use as few elbows as possible in the mixture piping from the outlet of the mixer. Where multiple burners are to be served by one inspirator, the mixing piping should be large enough (usually one pipe size larger than the mixer outlet) to avoid undesirable pressure loss.

In accordance with Hauck's commitment to Total Quality Improvement, Hauck reserves the right to change the specifications of products without prior notice.

HAUCK®

DIMENSIONS

AIG HIGH PRESSURE GAS-AIR INSPIRATORS



GY258
(NOT TO SCALE)

INSPIRATOR NUMBER	GAS INLET CONN. A NPT	MIXTURE OUTLET B NPT	DIMENSIONS IN INCHES									
			C	D	E	F	G	H	J	K	L	M
AIG 105A	3/8	1/2 *	14 1/4	10	8	5	2 5/16	1 9/16	-	-	-	-
AIG 107A	3/8	3/4 *	14 1/4	10	8	5	2 5/16	1 9/16	-	-	-	-
AIG 110A	1/2	1 *	16 1/4	12	10	5 1/2	2 13/16	2 1/4	-	-	-	-
AIG 112A	1/2	1 1/4 *	17	12 3/4	10 3/4	5 1/2	3 5/16	2 9/16	-	-	-	-
AIG 115A	1/2	1 1/2 *	17 3/4	13 1/2	11 1/2	5 1/2	3 5/16	2 7/8	-	-	-	-
AIG 220A	3/4	2	20 5/8	16	13 3/8	6 3/8	4 1/2	4 3/16	7/16	7/8	5/16	3 9/16
AIG 230A	3/4	3	25 1/8	20 1/2	17 7/8	6 3/8	4 9/16	4 7/8	7/16	1 3/8	3/8	5 5/8
AIG 240A	1	4	29 1/4	24 1/8	21 3/4	6 7/8	5 15/16	5 1/2	9/16	1 1/2	3/8	6 3/8
AIG 250A	1	5	34 1/4	29 1/8	26 3/4	6 7/8	7 3/4	6 3/4	5/8	1 5/8	1/2	7 7/8
AIG 260A	1 1/4	6	38 3/4	33 1/4	30 3/4	7 1/4	10 5/8	8	11/16	1 3/4	1/2	9 3/8

FLANGE TO THREAD ADAPTERS AVAILABLE B NPT
* THREADED CONNECTION ONLY IN THESE SIZES

OPERATION

Referring to GY258, high pressure gas is admitted thru the gas valve (1) to the inside of the spud holder (2); it then passes thru the spud (3) into the Venturi throat of the mixer (7) where, due to its high velocity, it draws air thru the large air inlet (6) of the mixer. The air shutter (4) which can be rotated around the spud holder for increasing or decreasing the air inlet opening to secure the desired gas-air ratio, is locked at the proper position by locking the screw (5) and the fiber pad. The pressure gauge (8) indicates the operating gas pressure.
If ever necessary, the spud orifice can be easily cleaned by removing the pressure gauge and running a wire into the tee opening and thru the spud.

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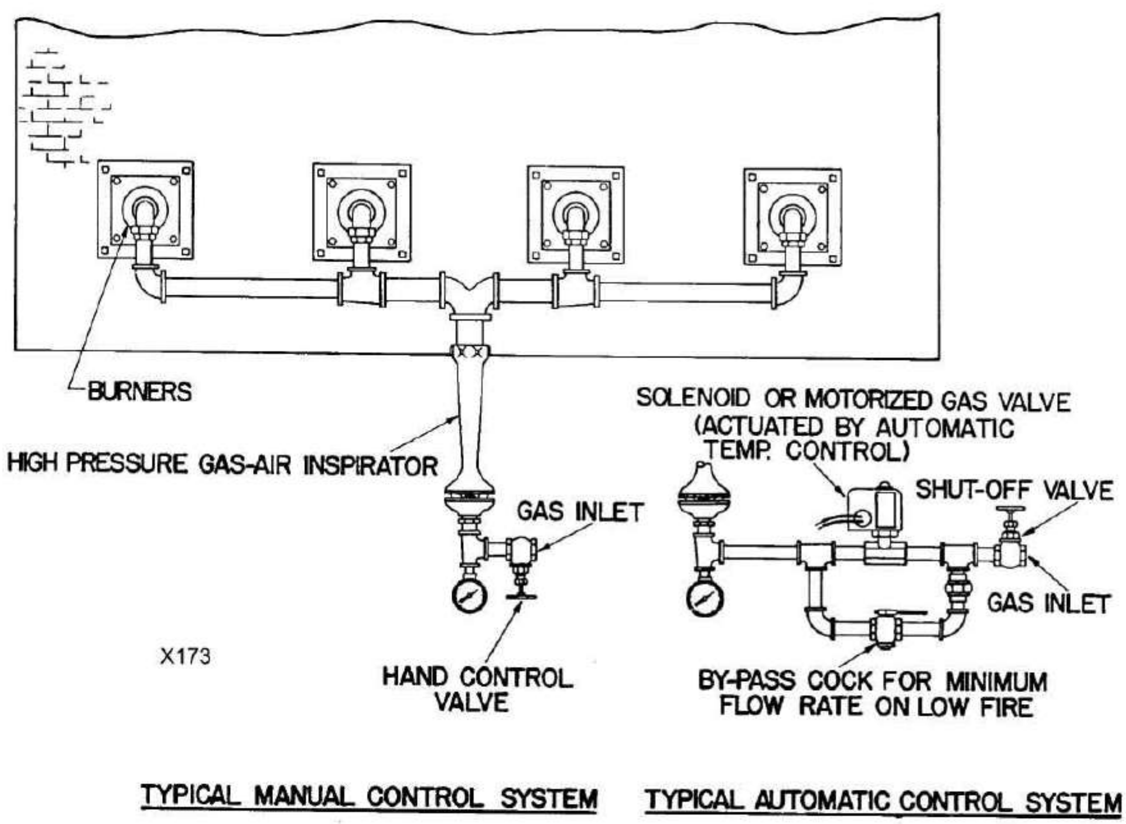
SUPPLEMENTAL DATA

AIG HIGH PRESSURE GAS-AIR INSPIRATORS

Typical Application of a Hauck High Pressure Gas-Air Inspirator for Multiple Burners



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8/92 AIG-4

RETAIN-A-FLAME

Gas Burner Nozzles

HAUCK®

Features

- Designed to produce long cylindrical blast flame
- Manual or spark ignition option
- Available with threaded or flanged connections
- Available in straight or elbow options

Benefits

- Produces long flame for greater heat distribution
- Excellent flame stability and retention
- Minimizes possibility of flashback on low fire

Hauck's 'Retain-a-Flame' burner nozzles are recommended for firing of gas–air mixtures where a small amount of excess air induced around the nozzle is allowable. These nozzles are ideal for firing either into the open ports of furnaces, or into the open without a combustion chamber. They have been successfully used for firing kilns, heat treating and melting furnaces, ovens, air heaters, boilers, kettles, immersion tubes and for ladle heating or drying.

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RAF-1

Hauck Manufacturing Company

RETAIN-A-FLAME

GAS BURNER NOZZLES

ADVANTAGES OF THE RETAIN-A-FLAME GAS BURNER NOZZLE

Series 1100 RFS Straight Retain–A–Flame Nozzles (top).
Nozzle attached to High Pressure Gas–Air Inspirator (bottom).

Produces Long Flame for Greater Heat Distribution

Excellent Flame Stability and Retention

Minimizes Possibility of Flashback on Low Fire

Retain-a-Flame nozzles are available in two versions: the Series 1100 RFS straight nozzle and the Series 1200 RFE elbow nozzle. They are available in sizes ranging from 40,000 to 2 million Btu/hr (12 to 586 kW).

These nozzles will retain the flame at their tips under usual operating conditions. Flame retention is achieved by removing part of the air-gas supply and burning it in a recess around the main burner opening. The nozzle design permits a wider range of mixture pressures without blowing the flame off the burner tip or backfiring. Little turbulence is caused in the main stream of gas mixture, with a resulting long, cylindrical flame of good stability.

All RFS straight nozzles are designed to produce a long cylindrical, torch type blast flame of unusually good stability. These flame characteristics provide heat distribution over a greater distance. These nozzles may be ignited manually and, if properly equipped, by a spark ignition system.

Series 1200 RFE Elbow Retain–A–Flame Nozzle (top).
Nozzle attached to High Pressure Gas–Air Inspirator (bottom).

The RFE elbow and straight nozzles combine, in one unit, an excellent flame retention capability and the ease of mounting associated with flanged units. These highly functional units have many advantages. Their unique design not only permits a wider range of operation but also ensures the proper delivery of the mixture to the nozzle, thus minimizing the possibility of flashback on low fire.

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Printed in U.S.A. 10/01

HAUCK®

CAPACITIES

RAF RETAIN-A-FLAME GAS BURNER NOZZLES

RFS STRAIGHT AND RFE ELBOW NOZZLES

Nozzle Size	Pipe Size NPT (See Note 3)	Discharge Area (In^2)	Capacity @ 6"wc Mixture Press. (1000 Btu/hr)
05	½	.11	40
07	¾	.18	65
10	1	.27	100
12	1 ¼	.7	250
15	1 ½	1.1	390
20	2	1.8	670
30	3	2.8	1000
40	4	5.2	2000

NOTES:

1. Capacities based on 80% combustion air in the mixture, natural gas with HHV of 1000 Btu/ft^3, 0.60 S.G. and stoichiometric air/gas ratio of 10:1 with nozzle firing under no backpressure.
2. Nozzle will ignite with as little as 50% combustion air in the mixture, however, the remaining air must be induced.
3. Nozzle sizes 20, 30, and 40 are also available with a square flanged connection; flanged to NPT adapters are also available.

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10/01

RAF-2

HAUCK®

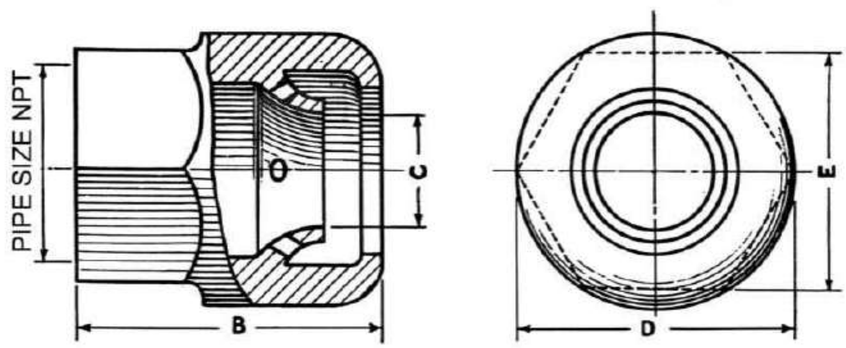
DIMENSIONS

RAF RETAIN-A-FLAME GAS BURNER NOZZLES

Series 1100 Retain-A-Flame Straight Nozzles

	Dimensions (Inches)				
Nozzle No.	Pipe Size NPT	B	C	D	E
RFS 1105A	½	1 ¾	5/16	1 ½	1 ½*
RFS 1107A	¾	1 ¾	7/16	1 ½	1 ½*
RFS 1110A	1	2 1/8	9/16	1 7/8	1 5/8
RFS 1112A	1¼	2 3/8	7/8	2 ½	2 3/16
RFS 1115A	1½	2 7/8	1 1/8	3 1/8	2 11/16
RFS 1120A	2	3 7/8	1 ½	3 7/8	3 3/8
RFS 1130A	3	4 5/8	1 7/8	4 5/8	4 ¼
RFS 1140A	4	5 ½	2 9/16	5 ½	5 1/8

Note: *Nozzles for 1105A and 1107A are round.



GW174

RFS 1105A – 1140A

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HAUCK®

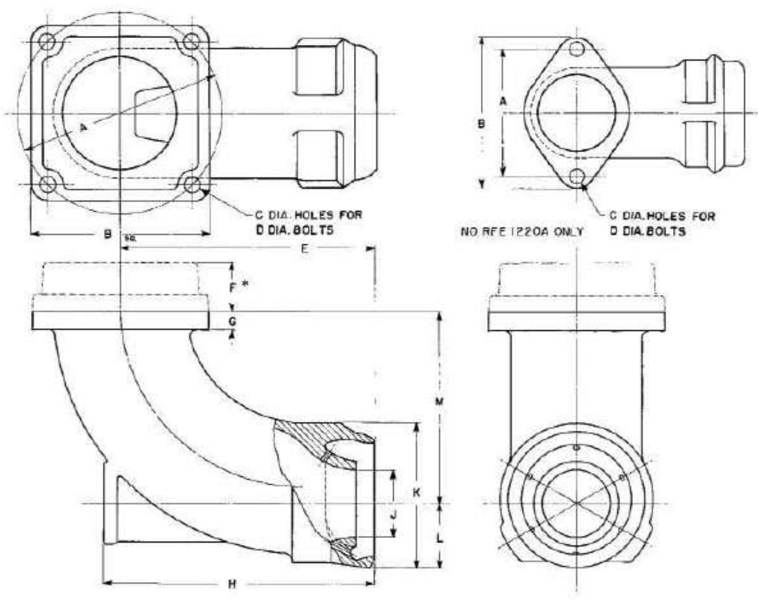
DIMENSIONS

RAF RETAIN-A-FLAME GAS BURNER NOZZLES

Series 1200 Retain-A-Flame Flanged Elbow Nozzles

Nozzle No.	Dimensions (Inches)											
	A	B	C	D	E	F*	G	H	J	K	L	M
RFE 1220A	3 9/16	4 3/16	11/32	5/16	4 5/8	13/16	7/16	5 5/16	1 ½	3 3/16	1 ½	3 3/8
RFE 1230A	5 5/8	4 7/8	7/16	3/8	7	1 5/16	7/16	7 ½	1 7/8	4	1 25/32	5 1/4
RFE 1240A	6 3/8	5 ½	7/16	3/8	8	1 ½	½	8 7/16	2 9/16	5 9/16	2 5/8	6

Note: * Flange to threaded adapters available.



GY257

RFE 1220A – 1240A

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10/01

RAF-3.1

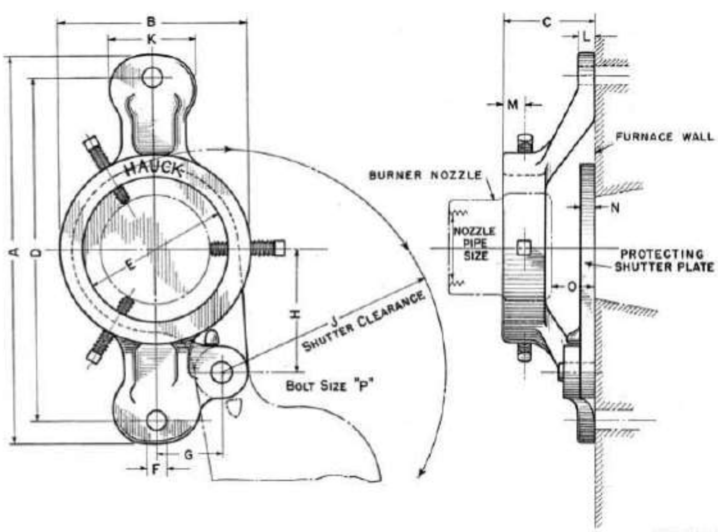
HAUCK®

DIMENSIONS

RAF RETAIN-A-FLAME GAS BURNER NOZZLES

Mounting Brackets

Bracket No.	Retain-A-Flame Nozzle RFS & RFE	Dimensions (Inches) A	B	C	D	E	F	G	H	J	K	L	M	N	O
BMB 2253A	1105,1107 & 1110	7	2 ¾	1 7/16	6	2 1/8	7/16	1 ¼	2 3/8	4 1/8	1 ½	5/16	3/8	¼	½
BMB 2254A	1112	9	5	2 1/8	8	4	7/16	1 ½	2 7/8	5 3/8	2	3/8	½	5/16	5/8
BMB2254A	1115,1120 & 1220	9	5	2 1/8	8	4	7/16	1 ½	2 7/8	5 3/8	2	3/8	½	5/16	¾
BMB 2255A	1130, 1140, 1230 & 1240	13 ¾	7	3 ¾	12	5 7/8	5/8	2 ¼	4 ¾	8 ½	2 ½	½	¾	½	¾



GX142

Mounting Bracket BMB 2253A – BMB 2255A

In accordance with Hauck's commitment to Total Quality Improvement, Hauck reserves the right to change the specifications of products without prior notice.

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10/01

RAF-3.2

SUPPLEMENTAL DATA

RAF RETAIN-A-FLAME GAS BURNER NOZZLES

SPARK IGNITION APPLICATION

All straight nozzles can be ordered equipped with a spark plug ignition system. RFS nozzle No.'s 3100 - 3115 are equipped with a spark plug mounted vertically on the side (see Figure 1); this arrangement prohibits the use of nozzles with nozzle mounting brackets. RFS nozzle No.'s 3120 – 3140 are equipped with a spark plug mounted at an angle of approximately 45° (see Figure 1) which enables the use of nozzle mounting brackets. RFE nozzle No.'s 3420 – 3440 have the spark plug and adapter bushing mounted parallel to the nozzle tip and can also be used with nozzle mounting brackets.

Each nozzle equipped with a spark plug will require a 5000 volt standard coil ignition transformer with a high voltage lead wire, connectors, and momentary pushbutton.

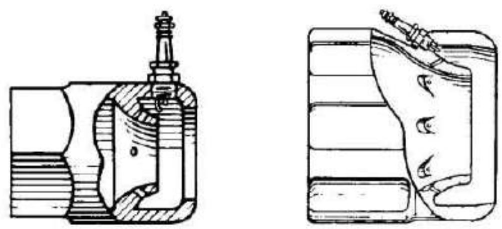

Figure 1. Spark Plug Ignition of Straight Nozzles

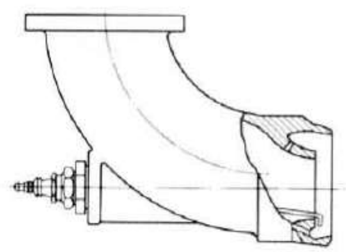

Figure 2. Spark Plug Ignition of Elbow Nozzles

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HAUCK®

SUPPLEMENTAL DATA

RAF RETAIN-A-FLAME GAS BURNER NOZZLES

NOZZLE SELECTION

When selecting a nozzle, the nozzle size is critical. The unit chosen must meet the maximum capacity requirements of the application but not be oversized. An oversized nozzle may reduce the degree of turndown available as well as increase the probability of a flashback.

To determine the appropriate nozzle size for your application:

Determine the mixture manifold pressure ("wc) for the mixer being used. Appropriate manifold pressures appear along the top of Table 1 (opposite page). When the mixer services two or more nozzles, divide the manifold pressure by the number of nozzles used. Next subtract from each pressure the pressure losses associated with the piping to each burner. The result approximates the pressure at each nozzle. For assistance, contact Hauck.

Determine the CFH required for each nozzle. If one nozzle is used, this will be the CFH of the mixer. If two or more nozzles are used with one mixer, divide the mixer CFH by the number of nozzles it supplies.

Using the values obtained above, find the point on Table 1 (opposite page) which satisfies both of these values.

Read the nozzle size number directly from the graph.

Using the charts given below, determine the nozzle no. for the nozzle size and configuration you require. When ordering a Retain-A-Flame nozzle, include the complete no. as listed below.

Nozzle Size	Nozzle No. Threaded Straight Manual	Nozzle No. Threaded Straight Spark
05	RFS 1105A	RFS 3105A
07	RFS 1107A	RFS 3107A
10	RFS 1110A	RFS 3110A
12	RFS 1112A	RFS 3112A
15	RFS 1115A	RFS 3115A
20	RFS 1120A	RFS 3120A
30	RFS 1130A	RFS 3130A
40	RFS 1140A	RFS 3140A
Nozzle Size	**Flanged Elbow Manual**	**Flanged Elbow Spark**
20	RFE 1220A	RFE 3420A
30	RFE 1230A	RFE 3430A
40	RFE 1240A	RFE 3440A

(OVER)

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C6 Kenilworth Literature

WHY CHOOSE KENILWORTH

An Established Technology Leader

Kenilworth was established in 1981 to pursue the development, production and marketing of direct fired natural draft process heaters. Since its inception, Kenilworth has helped the oil and gas industry meet the ever increasing emphasis on fuel efficiency, reliability, emissions reductions and safety. Kenilworth developed and markets a patented, reliable, low pressure burner that operates on solution gas or tank farm vapors that would other wise be vented or flared. This burner fully utilizes fire tube capacity as set out in the following table. Kenilworth's **Back Pressure System** enables the customer to utilize low pressure solution gas volumes and to ensure oil production is not sacrificed when capturing solution gas.

Kenilworth has refined this remarkable low pressure burner to be able to automatically shift between low pressure solution gas and higher pressure propane or line gas or to **burn two fuels simultaneously**. The **Flame Scavenger** heat systems have been added to prevent freeze up, enhance combustion and further add to reliability, minimizing the need for operator intervention.

The **Exhaust Recycle** burner is a milestone in natural draft combustion technology for treaters, fwko, line heaters, dehy's, amine reboilers, salt bath heaters and storage vessels. Utilizing the **Exhaust Recycle** technology provides a significant reduction in fuel consumption, emissions, noise pollution and a great improvement in combustion efficiency and thermal performance.

Reliability

Kenilworth's objective is to provide its customers with an extremely reliable system in all weather conditions. The **Flame Scavenger** heat systems are incorporated in the design to prevent burner freeze up. **Dual fuel** systems can automatically shift between line gas or propane and low pressure solution gas without operator intervention. The system also operates simultaneously and trouble free on either fuel for situations where low pressure solution gas alone is not sufficient to maintain vessel heat.

KENILWORTH COMBUSTION
ADVANCED THERMAL SOLUTIONS

www.kenilworth.ca

Box 12118, Lloydminster, Alberta, Canada T9V 3C4
Phone: 780/744-3974 • Fax: 780/744-2242
Direct Dispatch Only: 1-866-744-3974

Rapid Paybacks

Kenilworth installed products have provided customers with paybacks within 13 to 31 days through replacing purchased fuel with free solution gas.

Service and Quality

Kenilworth new installations and upgrades of existing burner systems are aimed at customer satisfaction with reduced fuel usage, increased heating capacity, reduced emissions, minimal operator intervention and increased operator safety. Kenilworth does not just sell a burner over the counter, we sell and install a quality burner system. A pre and post assessment is recorded to ensure that the customer is aware of the value added. Kenilworth has a strong commitment to preventive maintenance and offers its customers a scheduled maintenance service program. Our growing fleet of owner operated field service units ensures rapid response time and quality service. Fully equipped service units ensure that once on site, the job can be completed.

Corporate Objectives

Kenilworth's product development and service process is focused on:

- working with cost conscious, progressive producers with environmental foresight in developing and installing high energy efficiency combustion products
- providing customer service through growing its network of customer oriented locally owned field service units backed up by a specialized technical support team
- ensuring the highest quality products and the best fit burner system delivered and installed where needed in the shortest time possible to minimize customer down time and enhance production reliability
- providing environmentally responsible products and customer use of those products, and
- safety in the manufacture, installation and operation of its products.

Contacts

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heine@kenilworth.ca

Troy Donovan
Ph. (306) 893-7258
sales.service@kenilworth.ca

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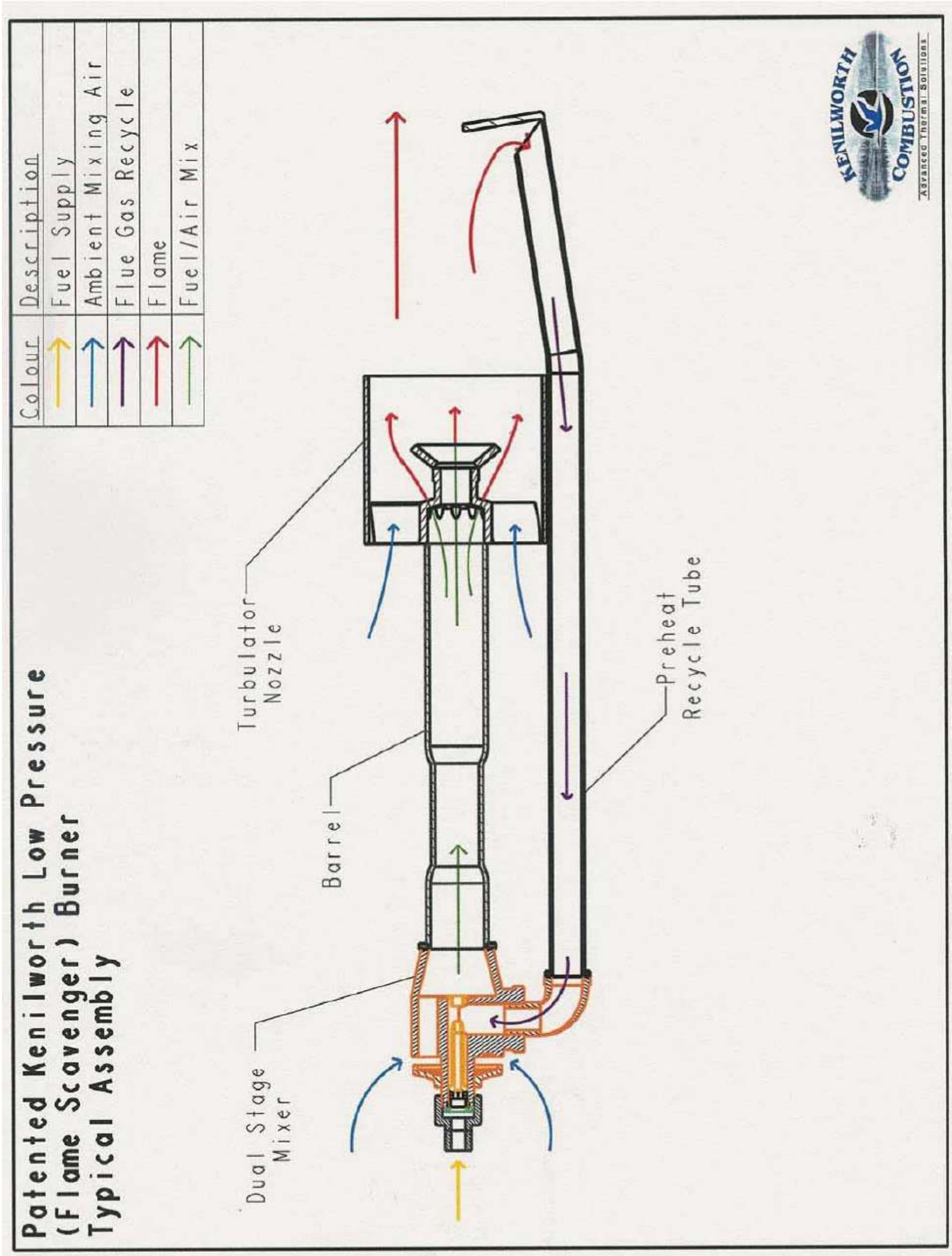
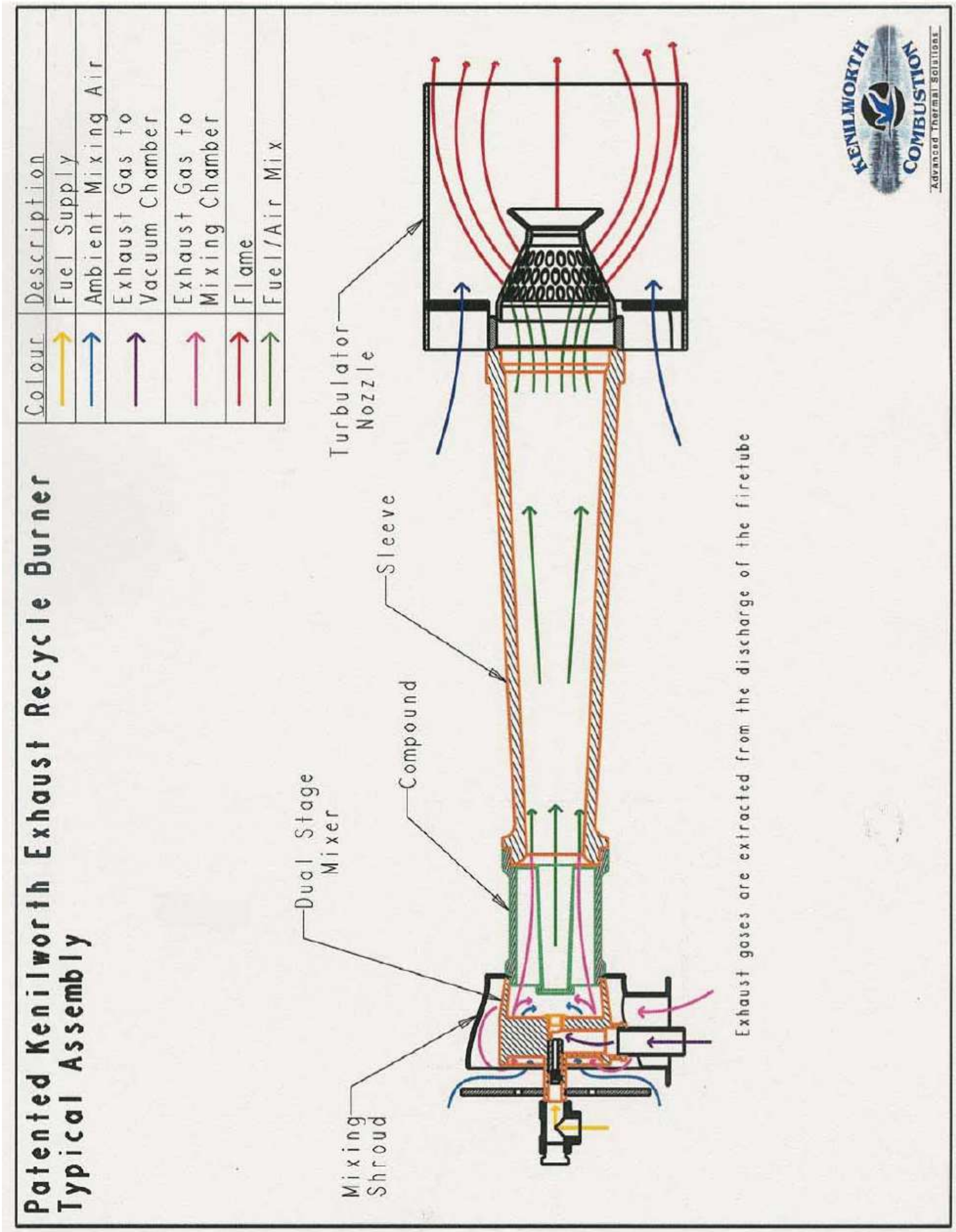
Kenilworth Burner Reference Sheet

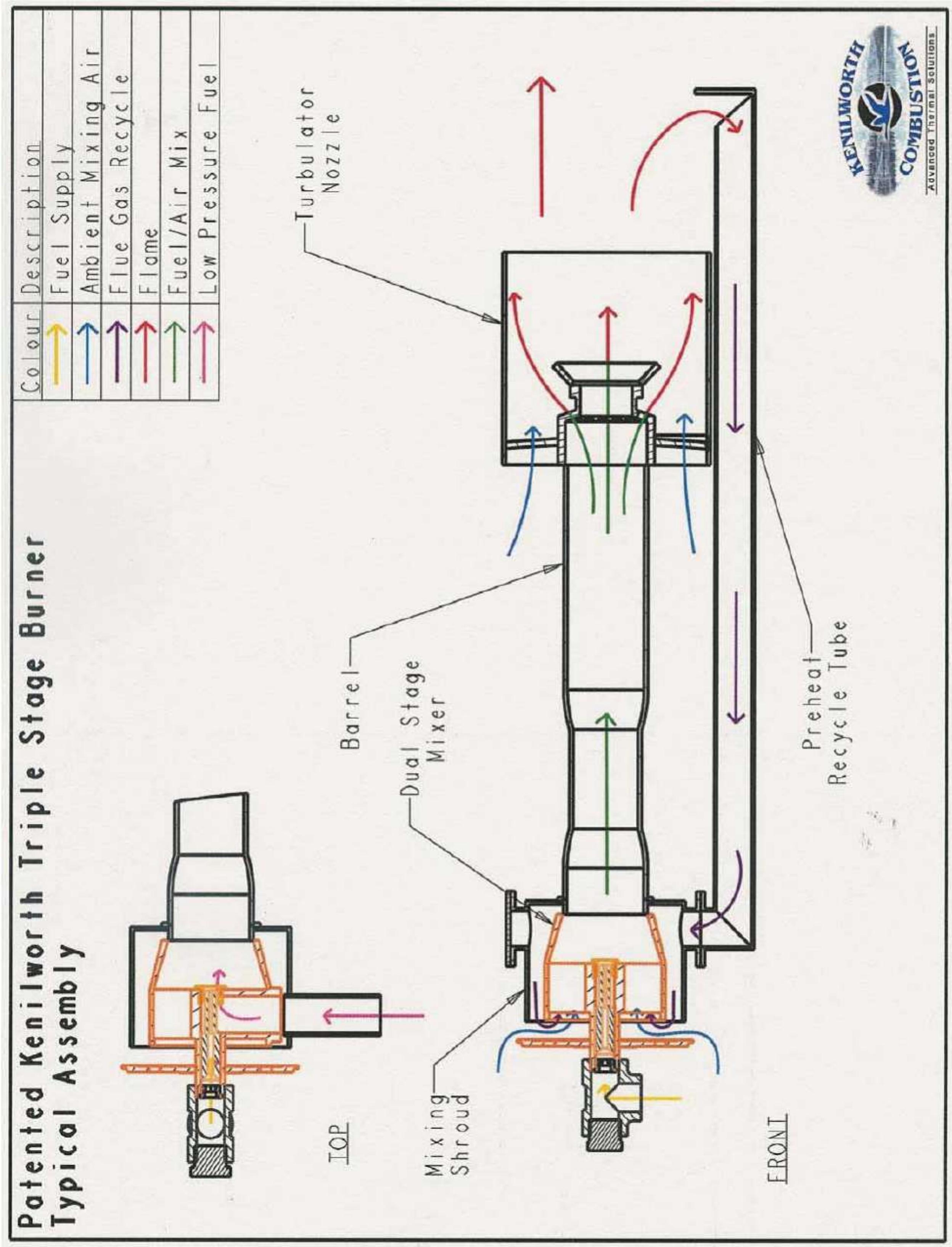
	Low Pressure		Low Pressure	
	Flame Scavenger Dual Stage Burner	Exhaust Recycle Dual Stage Burner	Flame Scavenger Triple Stage Burner	Conventional Burner
Fire tube sizes	6", 8", 10" ,12"	12" (see note)	12"	6", 8", 10", 12"
Burner Mix Size Available	1", 1 1/2", 2", 3"	3" (see note)	3"	1", 1 1/2", 2", 3"
Turbulator Nozzle for Increased Flame Stability with nozzle and flame diameter of:	4", 5", 6", 8"	8"	8"	4", 5", 6", 8"
Suggested Pressure Range	4 oz to 10 psi	4oz to 10 psi	4 oz to 10 psi	4 to 14 psi
Burner BTUs ranging from	60,000 btu 1,600,000 btu	250,000 btu 1,600,000 btu	100,000 btu 1,600,000 but	60,000 btu 1,600,000 btu
Pilot Burner Required	Optional	Optional	Optional	Optional
14" - 44" Fire Tube	all	all	all	all
Burner Size Available	3", 4", 5"	3", 4", 5"	3", 4", 5"	3", 4", 5"
Turbulator Nozzle for Increased Flame Stability with nozzle and flame diameter of:	10", 12", 16"	10", 12", 16"	10", 12", 16"	10", 12", 16"
Suggested Pressure Range	3 - 14 psi	8 - 30 psi	4 oz to 14 psi	6 - 15 psi
Burner BTUs ranging from	300,000 btu 14,000,000 btu	500,000 btu 9,000,000 btu	300,000 btu 9,000,000 btu	500,000 btu 14,000,000 btu
Pilot Burner Required	yes	yes	yes	yes
Net Achievable Combustion Efficiency	75 - 80%	75 - 88%	75 - 80%	68 - 76%
Achievable NOx	45 - 65 ppm	16 - 32 ppm	45 - 65 ppm	60 - 85 ppm
Achievable O_2	2 - 9%	2 - 6%	5 - 9%	7 - 11%
Achievable CO	0 - 10 ppm	0 - 10 ppm	0 - 20 ppm	0 - 20 ppm
Gas Applications				
Solution Gas	yes	yes	yes	yes
Prevents Freezing on wet solution gas	yes	yes	yes	no
Line Gas	yes	yes	yes	yes
Propane	yes	yes	yes	yes
3 Fuels: different pressure at same time w/o intervention	no	no	yes	no
2 Fuels; different BTU value, w/o intervention	yes	yes	yes	yes

* Note: Exhaust Recycle systems for **6", 8" and 10"** tubes are currently being tested.

Burner noise pollution can be greatly reduced by: Increasing orifice size reducing the input pressure, avoiding aggressive burner assemblies where not required, avoid over sizing the flame arrestor, using a firebox constructed of steel with an external secondary air damper rather than aluminum and use the Kenilworth Exhaust Recycle System.


Patented Kenilworth Low Pressure
(Flame Scavenger) Burner
Typical Assembly
Colour
Description
Fuel Supply
Ambient Mixing Air
Flue Gas Recycle
Flame
Fuel/Air Mix
Dual Stage
Mixer
Barrel
Turbulator
Nozzle
Preheat
Recycle Tube
KENILWORTH
COMBUSTION
Advanced Thermal Solutions


Patented Kenilworth Exhaust Recycle Burner
Typical Assembly
Colour
Description
Fuel Supply
Ambient Mixing Air
Exhaust Gas to Vacuum Chamber
Exhaust Gas to Mixing Chamber
Flame
Fuel/Air Mix
Turbulator Nozzle
Sleeve
Compound
Dual Stage Mixer
Mixing Shroud
Exhaust gases are extracted from the discharge of the firetube
KENILWORTH COMBUSTION
Advanced Thermal Solutions


Patented Kenilworth Triple Stage Burner
Typical Assembly
Colour
Description
Fuel Supply
Ambient Mixing Air
Flue Gas Recycle
Flame
Fuel/Air Mix
Low Pressure Fuel
Turbulator Nozzle
Barrel
Dual Stage Mixer
Preheat Recycle Tube
Mixing Shroud
TOP
FRONT
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CORPORATE PROFILE

Service

We pride ourselves in having the necessary experience, knowledge and products to provide our customers with solutions for their heating system. All of Kenilworth's products and services are available from depots across Western Canada. Fully trained personnel, accredited by Kenilworth, are available to provide product information, installation and maintenance for all types of heating systems. We also provide training for our customers so they may fully utilize the potential of their heating systems.

Manufacturing

All of our manufacturing is carried out in a controlled environment by trained personnel. Only the highest quality of materials and parts are used to construct our products. Once assembled, all products are thoroughly tested to meet or exceed industry standards before they leave our facilities.

Research and Development

At Kenilworth, we are constantly setting new boundaries and goals in the development of our products. By combining research with Oil and Gas Industry leaders, new standards for safety, guidelines on emissions, and the need for greater product versatility and reliability, we have developed products to satisfy customer expectations.

KENILWORTH PROGRAM GOALS & OBJECTIVES
FOR
HEATING SYSTEM SOLUTIONS

IN THIS PROGRAM WE WILL ADDRESS THE PROBLEMS RELATED TO THE HEATING OF FLUIDS IN THE OIL AND GAS INDUSTRY WHETHER IT IS ON NEW OR EXISTING SYSTEMS AND PROVIDE ADDED VALUE FOR THE CUSTOMER.

1. Provide a safe and viable work environment.

2. First recognize a heating systems fixed and variable limitations or deficiencies rather than continually replacing the burner and it's supplier.

3. To provide an understanding of the combustion process in a firetube, and the travel of the flue gas until it leaves the stack.

4. To provide an understanding of how heat is transferred from the firetube to the fluid by conduction, then throughout the tank or vessel by convection.

5. Accommodate various production ranges without mechanical change.

6. Eliminate fire tube failures by;
   - eliminating flame impingement
   - allowing the flue gas to flow unrestricted providing an even distribution of heat throughout the fire tube.

7. Reduce fuel consumption and lower harmful emissions.

8. Utilize waste casing and solution gas to reduce venting and flaring.

9. Provide products and economical alterations to an existing system to achieve our goals and objectives.

10. Always ensure added value for the customer.

11. Follow the API RP 12N code of practice for Fireboxes and Flame Arresters. Further develop this procedure to provide greater safety and accuracy during this test to the extent that we, and the end user, feel safe carrying out this practice in the field at all times.

Kenilworth Combustion

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New Technology

Low Pressure Burner

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Burners

Burners

- Mixer and Air Assist Barrel w/ Turbulator Nozzle
- Mixer and Air Assist Barrel w/ Turbulator Nozzle 4 and 5inch
- Mixer and Pipe Sleeve w/ Turbulator Nozzle
  - Turbulator Nozzles
  - Mixer Heads
  - Burner Barrels
  - Air Assist Barrel
  - Orifice Spud
  - Mixer Head Air Dampner
  - Acorn Mixer Cap
  - Mixer Backup Nut
- Mixer w/Compound Barrel / Sleeve and Turbulator Nozzle
  - Sleeve
  - Compound Barrel
- KFS Turbulator Burner
  - KFS Orifices
  - KFS Turbulator Burner Run
  - KFS Uniformed Turbulator Burner Head
- VRU Scavenger System
- Kenilworth Single Stage Low Pressure Burner Assembly - **New Technology**
- Ultimate Ounce Burner - **New Technology**

Mixer and Air Assist Barrel w/ Turbulator Nozzle

- 1 1/2 inch
- 2 inch
- 3 inch
- mixer head
- turbulator nozzle
- barrel with adjustable support brackets
- quick coupler attachment to firebox for burners up to 2 inch
- flue gas thermometer 100 - 550 degree C
- flame fail thermocoupler mount for burners up to 3 inch

Click for larger image.

- no pilot burner required for burners 3 inch and under

Mixer and Air Assist Barrel w/ Turbulator Nozzle: 4 and 5 inch

- 4 inch
- 5 inch
- mixer head
- turbulator nozzle
- air assist barrel
- adjustable support bracket

Click for larger image.

Mixer and Pipe Sleeve w/ Turbulator Nozzle

- 1 inch
- 1 1/2 inch
- 2 inch
- 3 inch
- 4 inch
- 5 inch
- mixer head
- turbulator nozzle
- barrel with adjustable support brackets
- quick coupler attachment to firebox for burners up to 2 inch
- flue gas thermometer 100 - 550 degree C
- flame fail thermocoupler mount for burners up to 3 inch
- no pilot burner required for burners 3 inch and under

Click for larger image.

TURBULATOR BURNER NOZZLES

Turbulator Nozzles

- stainless steel construction
- nozzles will fit all makes of stick type burners
- flame fail thermocoupler mount for burners up to 3"
- no pilot burner required for 3" and under

- 1 1/2 inch Turbulator nozzle #4
- 1 1/2 inch Turbulator nozzle #5
- 2 inch Turbulator nozzle #6
- 3 inch Turbulator nozzle #8
- 4 inch Turbulator nozzle #10
- 5 inch Turbulator nozzle #12
- 6 inch Turbulator nozzle #16

Click for larger image.

Mixer Head

Click for larger image.

- 1 inch Mixer Head
- 1 1/4 inch Mixer Head
- 1 1/2 inch Mixer Head 300122
- 2 inch Mixer Head 300124
- 2 1/2 inch Mixer Head 300126
- 3 inch Mixer Head
- 4 inch Mixer Head
- 5 inch Mixer Head

Burner Barrels (support legs sold separately)
Standard length (or specify) 14 inch long, 16 inch long, 18 inch long

Click for larger image.

- 1 1/4 inch x 12 inch Barrel
- 1 1/2 inch x 12 inch Barrel
- 2 inch x 12 inch Barrel
- 3 inch x 12 inch Barrel
- 4 inch x 12 inch Barrel
- 5 inch x 12 inch Barrel

Air Assist Barrel (support legs sold separately)
Standard length (or specify) 14 inch long, 16 inch long, 18 inch long

Click for larger image.

- 1 1/2 inch x 12 inch Air Assist Barrel
- 2 inch x 12 inch Air Assist Barrel
- 3 inch x 12 inch Air Assist Barrel

Air Assist Barrel (support legs sold separately)
Standard length (or specify) 30 inch long, 36 inch long

Click for larger image.

- 4 inch x 24 inch Air Assist Barrel
- 5 inch x 24 inch Air Assist Barrel

Orifice Spud

Click for larger image.

- 1 1/4 inch Mixer Head
- 1 1/2 inch Mixer head
- 2 inch Mixer Head
- 2 1/2 inch Mixer head
- 3 inch Mixer head

Primary Air Dampner

- 1 inch Mixer
- 1 1/4 inch Mixer
- 1 1/2 inch Mixer
- 2 inch Mixer
- 2 1/2 inch Mixer
- 3 inch Mixer
- 4 inch Mixer
- 5 inch Mixer

Click for larger image.

Acorn mixer cap

- 1 inch
- 1 1/4 inch
- 1 1/2 inch
- 2 inch
- 2 1/2 inch
- Larger cap available for 3 inch , 4 inch , 5 inch

Click for larger image.

Mixer backup nut

- 3/4 inch
- 1 inch

Click for larger image.

Mixer w/Compound/Sleeve and Turbulator Nozzle

- 1 inch
- 1 1/2 inch
- 2 inch
- 2 1/2 inch
- 3 inch
- 4 inch
- 5 inch

Click for larger image.

- mixer head
- turbulator nozzle
- compound with sleeve and adjustable support brackets
- quick coupler attachment to housing for burners up to 2 inch
- flue gas thermometer
- flame fail thermocoupler mount for burners up to 3 inch
- no pilot burner required for burners 3 inch and under

Sleeve

- 1 1/2 inch x 2 inch Sleeve
- 2 inch x 2 1/2 inch Sleeve
- 2 1/2inch x 3 inch Sleeve
- 3 inch x 4 inch Sleeve
- 4 inch x 5 inch Sleeve
- 5 inch x 6 inch Sleeve

Click for larger image.

Compound Barrel

- 1 1/2 inch Barrel
- 2 inch Barrel
- 2 1/2 inch Barrel
- 3 inch Barrel
- 4 inch Barrel
- 5 inch Barrel

Click for larger image.

KFS Turbulator Burner

- stainless steel Turbulator burner head
- 3-low pressure, 3 hole orifices
- internal burner supply run
- quick coupler attachment to firebox
- flue gas thermometer 100 - 550 degree C
- flame fail thermocoupler mount
- no pilot burner required

Click for larger image.

KFS Orifices (P, M, G or CG)

- Price per orifice
- P- for propane
- M- for propane and gas
- G- for line gas
- CG- for lean casing gas

Click for larger image.

KFS Turbulator Burner Run

- includes quick couplers
- burner barrel w/adjustable support leg
- 3/8 inch Burner Barrel leg

KFS Uniformed Turbulator Burner Head

- flame fail thermocoupler mount
- no pilot required
- stainless steel construction

Click for larger image.

Click for larger image.

VRU Scavenger System

Dual Stage

Port # 1 VRU inlet or Exhaust inlet or Flame Scavenger

- To serve as a positive pressure supply port
- To serve as a vacuum supply port

Port #1 function will only accommodate 1 of the above capabilities at any time.

Patent Pending

Port # 2 User fuel inlet

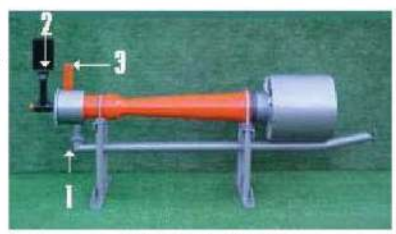
- Low or high pressure function
- Wellhead gas/line gas/solution gas or propane.

*This burner is available for all sizes of firetubes.

Triple Stage

Port # 1 Flame Scavenger
This inlet is to be used for Flame Scavenging to

- To serve as a vacuum supply port



Patent Pending

Port # 2 User fuel inlet

- Low or high pressure function
- Wellhead gas/line gas/solution gas or propane.

Port # 3 VRU or Waste gas inlet

- To serve as a positive pressure supply port
- To serve as a vaccum supply port .

Port #3 function will only accommodate 1 of the above capabilities at any time.

*This burner is available for all sizes of firetubes.

Triple Stage

Port # 1 VRU inlet

- To serve as a positive pressure supply port
- To serve as a vacuum supply port

Port # 2 User fuel inlet

- Low or high pressure function
- Wellhead gas/line gas/solution gas or propane.

Port # 3 Exhaust scavenger

- To serve as a vacuum supply port

Patent Pending

Port #1 function will only accommodate 1 of the above capabilities at any time.

*This burner is available for all sizes of firetubes.

Kenilworth Single Stage Low Pressure Burner Assembly

- 1 inch for 6 inch firetubes
- 1 and a half inch for 8 inch firetubes
- 2 inch for 10 inch firetubes
- 3 inch for 12 inch firetubes
- 3 inch for 14 inch firetubes

includes the following :

- 6 inch Stack Thermometer
- 0 -15 PSI Dry Gauge
- Burner Run with Quick Connect
- **no pilot burner required for burners 3 inch and under**

***It is recommended that all Low Pressure Burner initial installation and settings are to be carried out by a Certified Burner Service Technician.**

****Kenilworth****
780-744-3974

Date: 05-23-02
Time: 16:23:36

NATURAL GAS			
O2	%		0.1
CO	PPM		1
Prs	NOT FITTED		
EFF	%	(N)	90.5
XAIR	%		0
CO2	%		11.8
CO/CO2	R		0.0000
PI			0.00
NO	PPM		69
NO2	PPM		0
NOX	PPM		69

****Kenilworth****
780-744-3974

Date: 05-23-02
Time: 16:29:41

NATURAL GAS			
O2	%		8.4
CO	PPM		0
Prs	NOT FITTED		
EFF	%	(N)	83.2
XAIR	%		67
CO2	%		7.1
CO/CO2	R		0.0000
PI			0.00
NO	PPM		49
NO2	PPM		0
NOX	PPM		49

****Kenilworth****
780-744-3974

Date: 05-23-02
Time: 16:31:58

NATURAL GAS			
O2	%		13.3
CO	PPM		1
Prs	NOT FITTED		
EFF	%	(N)	73.4
XAIR	%		177
CO2	%		4.3
CO/CO2	R		0.0000
PI			0.00
NO	PPM		29
NO2	PPM		0
NOX	PPM		29

SO2	NOT FITTED		SO2	NOT FITTED		SO2	NOT FITTED	
CxHy	NOT FITTED		CxHy	NOT FITTED		CxHy	NOT FITTED	
NETT	C	271.3	NETT	C	304.8	NETT	C	292.3
FLUE	C	281.4	FLUE	C	314.9	FLUE	C	302.4
INLT	C	10.1	INLT	C	10.1	INLT	C	10.1
AMBIENT	C	22.9	AMBIENT	C	22.7	AMBIENT	C	22.7

These efficiencies can easily be achieved with the use of The Kenilworth® Returnside Turbulator®, Turbulator Nozzel®, Secondary Air Intake Dampner and Low Pressure Burner Assembly patent pending.

Kenilworth Combustion

Box 12118, Lloydminster, AB Canada T9V 3C4
Tel: (780) 808-2247 Fax: (780) 808-2967
Email: info@kenilworth.ca

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C7 Maxon Literature

Maxon Corporate Profile

Maxon Corporation sets the standard for industrial combustion equipment. A privately held, employee-owned company, Maxon is a worldwide manufacturer of industrial combustion equipment and shut-off valves with manufacturing facilities in the United States and Europe.
· Maxon Corporation - Muncie, Indiana
· Maxon International - Brussels, Belgium

Sales offices, representatives and support services are available worldwide:

- 36 locations in United States, Canada and South America
- 9 locations in Europe
- 8 locations in the Pacific Rim area

Original Maxon facility built in an old piano factory, circa 1916

Quality

The efforts of dedicated employees have earned Maxon the distinction of being the first industrial burner manufacturer to receive **ISO 9001 Certification**.
Maxon is committed to forming long-term partnerships with customers by providing quality products and services. Since ISO certification in 1993, Maxon employees have shipped over 99.3% of customers orders error-free within the Quality Management System.

Innovation

Maxon's objective is to provide practical, real-world solutions to our customers' industrial heating needs. Our solid commitment to research and development has allowed us to offer one of the most comprehensive and advanced product lines available in combustion equipment and valve technology.

- Oven Burners
- Furnace Burners
- Incineration Burners
- Oxy-fuel Burners
- Line Burners
- Immersion Tube Burners
- Control Valves
- Fuel Shut-off Valves
- Vent Valves
- Control Panels, Pipe Trains and Accessories

Versatility

Maxon equipment is used in the manufacturing of products that are a part of our everyday lives. Our customers include the following industries plus others:

- Automotive
- Building Materials
- Chemical
- Container
- Glass

- Petrochemical/Refining
- Plastics
- Printing
- Pulp and Paper
- Food Processing
- Textiles

Some of the heating applications used by these industries include:

- Baking
- Curing
- Drying
- Heat Treating
- Incineration
- Melting

Environmental

Development of products aimed at the control of emissions has continued to be the primary objective of Maxon's Research and Development efforts. This focus on emission control in new product design has brought some very impressive results.

Today's Maxon building, main entrance

- OXY-THERM® Burners reduce emission levels by up to 70% when compared to other oxy-gas burners.
- CYCLOMAX® Burners produce the industry's lowest NOx and CO levels for nozzle-mix burners.

Maxon International

This wholly-owned subsidiary of Maxon Corporation serves customers in Europe and the Middle East and provides the entire range of Maxon products. In addition, they have the capability to package complete systems, including start-up assistance, where turnkey installation is a requirement.

North American Sales Representatives and Distributors

Back to Locations

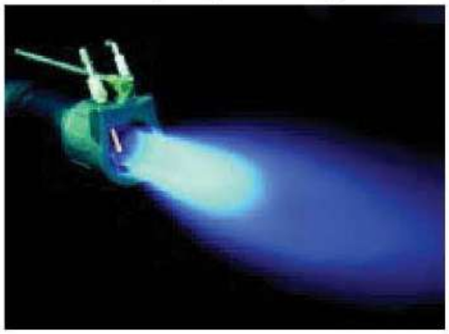
Atlanta	(404) 794-3440 Fax: (404) 794-3521	**Stromquist & Co. Inc.** 4620 Atlanta Road Smyrna, GA 30080-7063 USA
Birmingham	(205) 942-3501 Fax: (205) 942-9025 email: lcollins@mcconnellsales.com	**McConnell Sales & Engineering Corp.** P.O. Box 19098 117 Citation Ct. Birmingham, AL 35219-9098 USA
Buffalo	(716) 759-8348 Fax: (716) 759-2050	**A.C.T. & Associates, Inc.** P.O. Box A-E 10100 Main St. Clarence, NY 14031-0499 USA
California (Distributor - Valves Only)	(661) 833-1902 Fax: (661) 833-4008	**ESYS** 4520 Stine Rd., Suite Bakersfield, CA 93313 USA
California - North	(925) 602-7733 Fax: (925) 798-0127	**Controlco Automation Distributors** 5600 Imhoff Dr. Suite G Concord, CA 94520 USA
Charlotte	(704) 847-9838 Fax: (704) 847-1500	**Weeks-Williams-DeVore Inc.** 1014 Industrial Dr. P.O. Box 987 Matthews, NC 28106-9998 USA
Chicago	(847) 223-7990 Fax: (847) 223-7998	**Maxon Corporation** 997 North Corporate Circle Unit B Grayslake, IL 60030 USA
Cincinnati	(513) 229-0137 Fax: (513) 229-0138	**Maxon Corporation** 7577 Central Park Blvd. Suite 212 Mason, OH 45040 USA
Cleveland	(330) 467-0141 Fax: (330) 467-8547	**Maxon Corporation** 8536 Crow Dr. Suite #255 Macedonia, OH 44056-1986 USA
Cochrane, Alberta	403-255-7794 Fax: 403-255-7798	**C.A.T. Combustion Automation Tech. Inc.** 49 Riverview Circle Cochrane, Alberta T4C 2K3 Canada
Denver	(303) 232-6402 Fax: (303) 237-0959	**Blair-Alexander Engineering Co./Wilson-Mohr** 1109 Harlan St. Denver, CO 80214-2122 USA

Bulletin 1100

Maxon Burner Nozzles

STICKTITE™ & PILOTPAK™ Flame Retention Nozzles

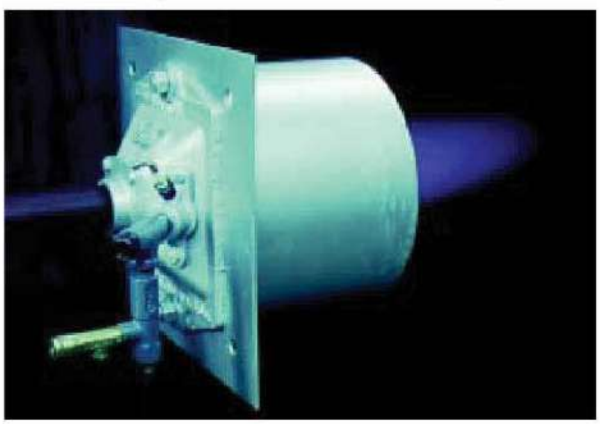
for open-port firing



Provides positive flame retention and stable clean burning, while directing the torch-shaped flame onto or through open ports to your heat processes. *(Photo: "SP" PILOTPAK™ Nozzle with flame rod)*

Series "SN" Sealed Nozzles

with refractory tunnel block for sealed-port firing



Improve higher temperature operating efficiency and atmosphere control by mounting the Sealed Nozzle assembly into your oven or furnace wall, effectively sealing out any secondary air introduction. *(Photo: Series "SNF" Sealed Nozzle with pilot and seal & support housing)*

Air/gas premixing equipment used to provide thorough blending of air/gas mixture to Maxon Burner Nozzles

PREMIX® Blower Mixers
(see catalog bulletin 3100)

MULTI-RATIO® Mixers
(see catalog bulletin 3200)

Series "HG" Mixing Tubes
(see catalog bulletin 3200)

Series "LG" Mixing Tubes
(see catalog bulletin 3200)

ENTITE™ Inspirator Mixers
(see catalog bulletin 3300)

MAXON®
CORPORATION 201 East 18th Street, P.O. Box 2068, Muncie, Indiana, 47307-0068. Phone: (765) 284-3304. FAX (765) 286-8394

Maxon Burner Nozzles

Principle of Operation

STICKTITE™ and PILOTPAK™ Nozzles are designed for direct-fired air heating and/or open-port firing into a furnace, duct, or immersion tube. The single torch-like flame creates a venturi effect that pulls secondary air in around the burner nozzle and provides necessary cooling of the cast metal nozzle.

The burner nozzle is threaded onto the feed manifold from your air/fuel premixing device. This premixture is directed out through the nozzle's main port. A small portion of the premixture is channeled out through the smaller ignitor ports that surround the large main port. The gas/air mixture is ignited by a spark ignitor or separate pilot assembly.

The eddy currents created on the face of the nozzle provide positive flame retention of the torch flame emitted out of the main port. The flames from the tiny ignitor ports are protected from outside air turbulences and surround the base of main flame to continually ignite the premixture being forced out of the nozzle by the mixture pressure from your mixing device.

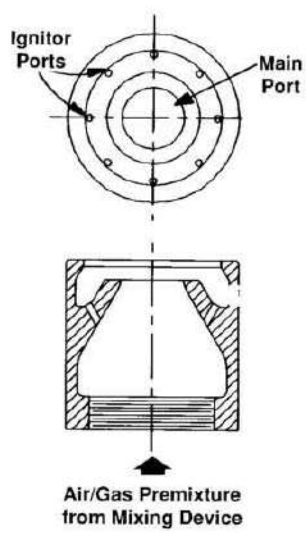
Series "SN" Sealed Nozzles are tunnel-type, refractory block, closed-port burners for firing of air/gas premixtures without secondary air. They are designed to be installed into refractory, thin-wall, or soft-wall combustion chambers and fed by almost any air/gas premixing system.

The air/gas mixture manifold from your premixing system is threaded into the Series "SN" Sealed Nozzle assembly. This premixture is directed out through the nozzle body's main port into the stepped-tunnels of the refractory burner block.

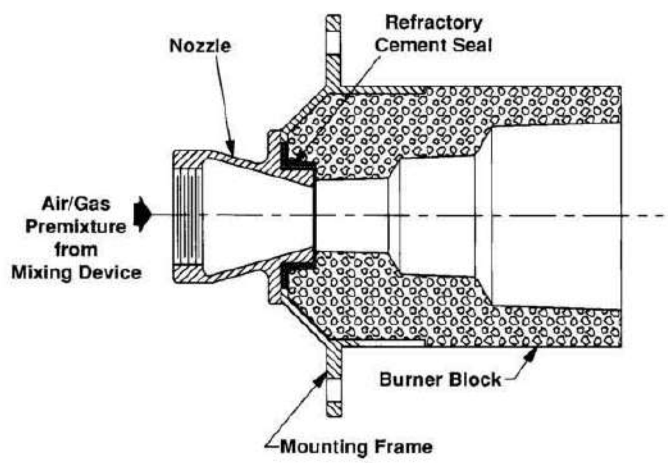
A pilot port tunnel and a flame supervision port (not shown in sketch below) intersect the main tunnel directly in front of the nozzle body's main port. At this three-way tunnel intersection, the flame safeguard (flame rod or UV scanner) monitors the pilot flame and/or main burner flame.

Once the air/gas premixture is ignited by a separate mounted pilot and spark ignitor, the flame front progressively steps out through the burner block's tunnels. The "hot" refractory and the eddy-currents created at each one of the steps within the tunnel serve to provide positive flame retention of the burner flame at all firing rates.

Typical STICKTITE™ Nozzle Construction



Typical Series "SN" Sealed Nozzle Construction



MAXON® CORPORATION

4/92

CORPORATION 201 East 18th Street, P.O. Box 2068, Muncie, Indiana, 47307-0068. Phone: (765) 284-3304. FAX (765) 286-8394

Design and Application Details

Burner nozzle designations

All Maxon burner nozzles are identified with a 3-part designation. This code identifies (1) the type of nozzle, (2) the inlet pipe size, and (3) the main gas port diameter.

Example: **SPA – 2-1/2" – 27**

SP = PILOTPAK™ Nozzle
SPA = PILOTPAK™ Nozzle with adjustable orifice
HD = STICKTITE™ Nozzle (for higher drafts)
BP = STICKTITE™ Nozzle (for back pressures)
HV = STICKTITE™ Nozzle (for radiant temperatures)
SN = Sealed Nozzle
SNF = Sealed Nozzle with provision for flame safeguard device

Inlet pipe size (NPT)

Main gas port diameter (in 16ths of an inch)

Maxon burner nozzles are offered in different types, each type optimized for a specific type of application. All require a full air/gas premixture from a premixing device. The air/gas premixing equipment sections of your Maxon catalog include specific capacities for single and multiple nozzle applications with the various types of premixing equipment:

PREMIX® Blower Mixers – section 3100
Mixing Tubes & MULTI-RATIO® Mixers – section 3200
VENTITE™ Inspirators – section 3300

A complete burner nozzle system will also include gas train, proportioning and mixing equipment, combustion air supply and a combustion control panel. Your Maxon representative can help you select from the broad range available.

STICKTITE™ Nozzles

"HD" STICKTITE™ Nozzles (available in 1/2" through 8" sizes) are cast iron burners used for immersion tubes or for "open-port" furnace operations (with slight "draft", normally less than -0.5" wc static pressure). Nozzle is also used where differential air/gas mixture pressures exceed 7" wc, regardless of the application. The nozzle's eight ignitor ports provide flame retention under higher draft conditions.

"BP" STICKTITE™ Nozzles (available in 1/2" through 4" sizes) are cast iron burners used for "open-port" furnace applications (with "balanced or slightly positive", normally up to +0.25" wc static pressure), providing the differential air/gas mixture pressures do no exceed 7" wc. The nozzle's four ignitor ports provide cooler operation and longer service life.

"HV" STICKTITE™ Nozzles (available in 2" through 8" sizes) are cast iron burner bodies with a stainless steel retention ring. They are used for "open-port" firing of higher temperature applications (up to 2400°F/1316°C) or where the nozzle might be exposed to high radiant heat and/or sting-out from the firing port.

Design and Application Details

PILOTPAK™ Nozzles

Type "SP" PILOTPAK™ Nozzles (available in 1-1/2" through 6" sizes) are special packaged "HD" STICKTITE™ Nozzles. Their cast iron bodies and gray iron ignition rings provide a built-in pilot, 10mm spark ignitor, pilot gas tubing, pilot shut-off cock and provision for mounting a flame sensing device (flame rod or UV scanner).

Type "SPA" PILOTPAK™ Nozzles are the same as "SP" nozzles and include a pilot gas adjustable orifice in lieu of the pilot shut-off cock.

PILOTPAK™ Nozzles may be applied on any application suitable for the "HD" STICKTITE™ Nozzles. They may also be mounted directly in a duct or housing of recirculated air as long as air temperatures do not exceed 600°F (316°C).

Direct spark ignited STICKTITE™ Nozzles (available in 1/2" through 4") are "HD" STICKTITE™ Nozzles drilled and tapped to mount a spark ignitor directly in the outer ignition ring of the "HD" burner nozzle. This provides an economical alternative to those applications when the separate pilot portion of the PILOTPAK™ Nozzle may not be required.

"SP" PILOTPAK™ Nozzle

"SN" Sealed Nozzle with hinged lighter port cover

Series "SN" Sealed Nozzles

Series "SN" Sealed Nozzles (available in 3/4" through 1" sizes) consist of a threaded nozzle, cast iron frame and a refractory burner block. "SN" Sealed Nozzles do not include any provision for mounting a flame safeguard device.

Series "SNF" Sealed Nozzles (available in 1-1/4" through 3" sizes) are the same as "SN" Sealed Nozzles, but incorporate a flame safeguard port through which a flame rod or a UV scanner can be mounted.

All Sealed Nozzle assemblies include a pilot port tunnel and provision for mounting of a broad range of accessory pilots.

NOTE: Every Sealed Nozzle burner must be ordered either with an appropriate pilot assembly or with optional pilot port cover kit. If a pilot assembly is not ordered, a **pilot port cover kit** (see photo below) must be used to prevent the possibility of flame and/or hot combustion gases escaping out of the burner's "open" pilot port tunnel, or to prevent infiltration of secondary air on "un-piloted" installations.

Standard burner block material is suitable for operating temperatures up to 2600°F (1427°C). The maximum operating temperature limit may be downrated to 2400°F (1316°C) if the Sealed Nozzle Burner is operating under the following conditions:

- burner is installed in a furnace with fiber wall construction
- frequent cycling inducing thermal shock and stresses

Optional refractory block materials are available to extend maximum operating temperature limits as follows:

- up to 2800°F (1538°C); or
- up to 3000°F (1649°C)

These higher temperature material options are available at net extra cost and may extend normal delivery schedules.

Burner Nozzles

Page 1105

Capacity/Selection Data

All Maxon Burner Nozzles provide positive flame retention and clean, complete, stable combustion when supplied with a 100% air/gas premixture. Their **heat release is directly related to the differential mixture pressure** developed by that supply system.

Capacities in 1000's Btu/hr are plotted (on the charts on this page and the following page) against the differential mixture pressures for each of the nozzle sizes.

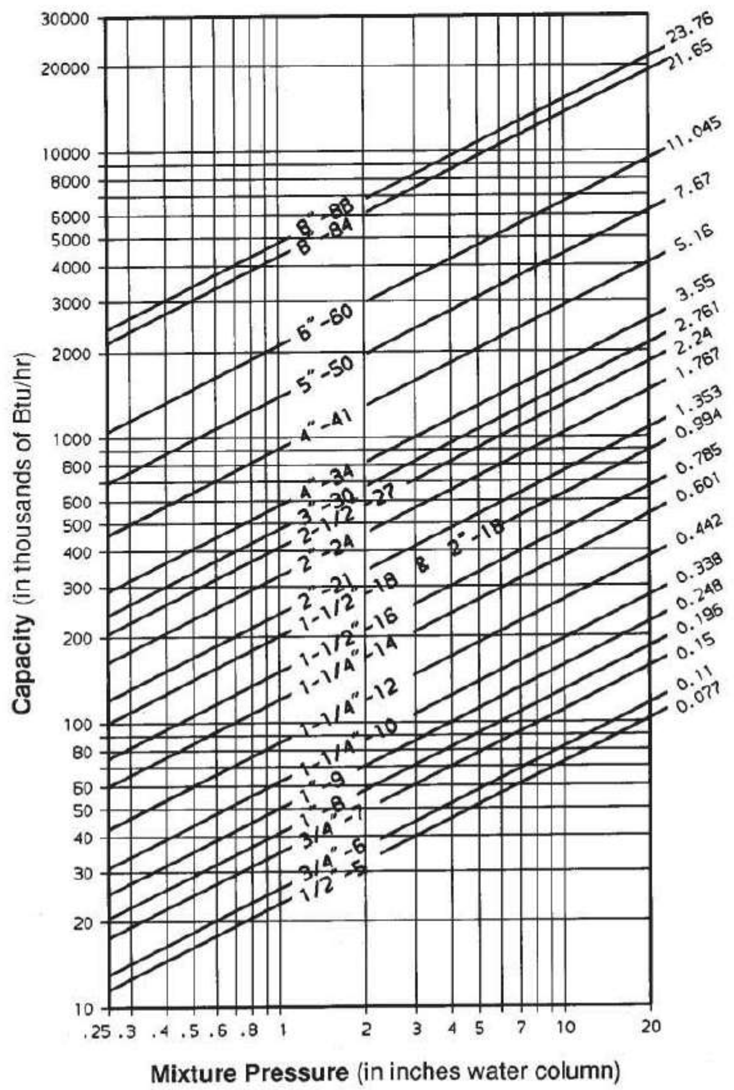
Discharge area for each nozzle size is also shown.

Any reference to a "pressure" must relate to the "effective discharge area" through which the volume of gas or air/gas premixture is passing. When selecting premixing equipment systems, the maximum and minimum mixture pressures must be evaluated relative to the quantity and/or size of the nozzle(s). The ratio between these two factors dictates the turndown capabilities of the overall system.

Multiple nozzle combinations may be considered for a given heat release with a specific premixing device, but the total discharge areas of all the multiple nozzles must not exceed the effective discharge area of the specified single nozzle size.

A minimum differential mixture pressure of +0.25" wc must be maintained to minimize the potential for backfiring.

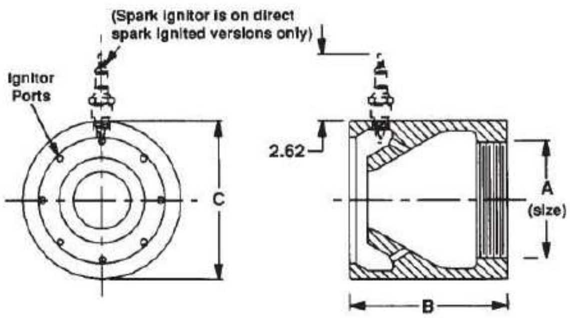
STICKTITE™ Burner Nozzle Capacities



Page 1110 **Burner Nozzles**

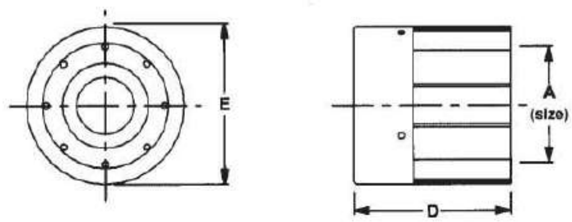
Dimensions (in inches)
STICKTITE™ Nozzles

"HD" and "BP" STICKTITE™ Nozzles
also for direct sparked "HD" Nozzles



NOTE: "BP" Nozzles have (4) ignitor ports; all others have (8) ignitor ports

"HV" STICKTITE™ Nozzles



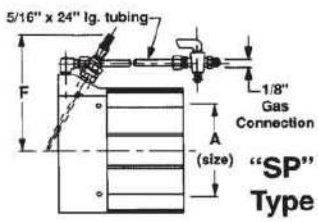
Nozzle dimensions (in inches)

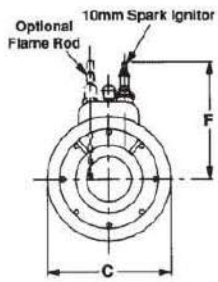
Nozzle Size	Main Port diameter (inches)	Discharge Area (in^2)	A (NPT)	B	C	D	E
1/2"-5	5/16	0.77	1/2	1.44	1.44	---	---
3/4"-6	3/8	.110	3/4	1.56	1.56	---	---
3/4"-7	7/16	.150				---	---
1"-8	1/2	.196	1	2	2	---	---
1"-9	9/16	.248				---	---
1-1/4"-10	21/32	.338	1-1/4	2.38	2.38	---	---
1-1/4"-12	3/4	.442				---	---
1-1/4"-14	7/8	.601				---	---
1-1/2"-16	1	.785	1-1/2	2.69	2.69	---	---
1-1/2"-18	1-1/8	.994				---	---
2"-18			2	3.25	3.25	---	---
2"-21	1-5/16	1.35				3.25	3.25
2"-24	1-1/2	1.77					
2-1/2"-27	1-11/16	2.24	2-1/2	3.88	3.88	3.88	3.88
3"-30	1-7/8	2.76	3	4.56	4.56	4.56	4.56
4"-34	2-18	3.55	4	5.88	5.88	5.88	5.88
4"-41	2-9/16	5.16					
5"-50	3-1/8	7.67	5	5.5	6.62	7.12	7.12
6"-60	3-3/4	11.04	6	8.5	8.5	8.25	8.25
8"-84	5-1/4	21.65	8	---	---	10.75	10.75
8"-88	5-1/2	23.76		11.38	11.38	---	---

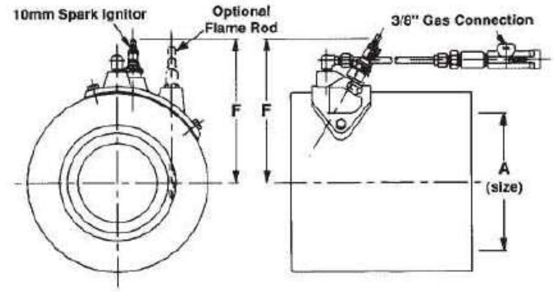
Pipe threads on this page conform to NPT (ANSI Standard B2.1)

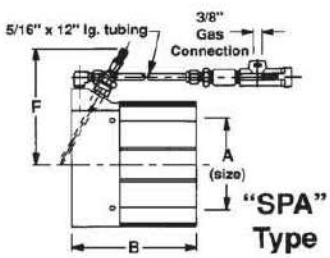
Burner Nozzles **Page 1111**

Dimensions (in inches)
PILOTPAK™ Nozzles









NOTE: Typical of 1-1/2" through 5" PILOTPAK™ Nozzles

NOTE: Typical of **SPA-6-60** PILOTPAK™ Nozzle only

Nozzle dimensions (in inches)

Nozzle Size	Main Port diameter (inches)	Discharge Area (in^2)	A (NPT)	B	C	D	E	F
1/2"-5	5/16	.07	1/2	1.44	1.44	---	---	---
3/4"-6	3/8	.110	3/4	1.56	1.56	---	---	---
3/4"-7	7/16	.150				---	---	---
1"-8	1/2	.196	1	2	2	---	---	---
1"-9	9/16	.248				---	---	---
1-1/4"-10	21/32	.338	1-1/4	2.38	2.38	---	---	---
1-1/4"-12	3/4	.442				---	---	---
1-1/4"-14	7/8	.601				---	---	---
1-1/2"-16	1	.785	1-1/2	2.69	2.69	---	---	4.25
1-1/2"-18	1-1/8	.994				---	---	
2"-18			2	3.25	3.25	---	---	4.62
2"-21	1-5/16	1.35				3.25	3.25	
2"-24	1-1/2	1.77						
2-1/2"-27	1-11/16	2.24	2-1/2	3.88	3.88	3.88	3.88	4.88
3"-30	1-7/8	2.76	3	4.56	4.56	4.56	4.56	5.25
4"-34	2-1/8	3.55	4	5.88	5.88	5.88	5.88	6
4"-41	2-9/16	5.16						
5"-50	3-1/8	7.67	5	5.5	6.62	7.12	7.12	6.38
6"-60	3-3/4	11.04	6	8.5	8.5	8.25	8.25	6.88

Pipe threads on this page conform to NPT (ANSI Standard B2.1)

Bulletin 3300

VENTITE™ Inspirator Mixers

- **Use kinetic energy of higher gas pressures** to provide air/gas mixture for all Maxon premix-type burner systems
- **Uses most clean fuel gases** 500-3200 Btu/ft^3
- **Low initial cost**
- **Maintenance-free design**
- **Easy to adjust and operate**
- **Maximum application flexibility** offered with 10 different sizes
- **Provides for partial premixing** of air/gas ratios to Maxon AIRFLO® type burner systems

Partial Premix Burner Systems

'66' AIRFLO® Burner

Premix Burner Systems

SN Sealed Nozzles

STICKTITE™ Nozzles

Style A & B LINOFLAME® Burners

VFL & VFH LINOFLAME® Burners

MAXON® CORPORATION 201 East 18th Street, P.O. Box 2068, Muncie, Indiana, 47307-0068. Phone: (765) 284-3304. FAX (765) 286-8394

VENTITE™ Inspirator Mixers

Principle of Operation

VENTITE™ Inspirators provide a low-cost means of supplying air/gas mixture to premix-type gas burners.

Gaseous fuel under high pressure is introduced through a drilled spud orifice into the venturi throat, pulling in a proportional amount of combustion air. The air and gas are mixed and may be used to supply most premix-type burner nozzles.

Spud is easily replaceable in the field, so different fuels can be readily accommodated. (Spud orifice drilling varies with gas characteristics and available inlet pressures.)

Air shutter is adjustable to accommodate draft requirements of installation and includes a thumb lock screw.

Control can be **manual**, as by the firing cock; **automatic**, using a control motor to throttle fuel flow through Maxon's Series "CV", "Q", or Synchro Gas Valves; or **on/off firing** using a solenoid valve.

Flow Control Valves

Series "CV" Valve

Series "Q" Valve

SYNCHRO Valve

VENTITE™ Inspirator

A complete VENTITE™ Inspirator system will also include gas train, burner, throttling equipment, and a control panel. Your Maxon representative can help you choose from the broad range available.

Typical applications include air heaters, grain dryers, ceramic kilns, incinerators, solution heating, metal melting, refinery heater/treaters, and many other direct flame applications.

Aluminum hand torches are specialized aluminum VENTITE™ Inspirators with a cast iron HD-2-24 STICKTITE™ Nozzle.

These lightweight units (only 9 pounds) are easy to handle and are totally portable, requiring only flexible gas and/or air connections.

Application flexibility is provided with six different options available for high or low gas pressure installations.

Typical applications include foundry floor mould drying, ladle drying, core drying, die preheating, brazing, preheating for welding and ore car thawing operations.

Aluminum Hand Torch

MAXON®

9/90

CORPORATION 201 East 18th Street, P.O. Box 2068, Muncie, Indiana, 47307-0068. Phone: (765) 284-3304. FAX (765) 286-8394

Capacity/Selection Data

General

Capacity of a burner system incorporating VENTITE™ Inspirators is determined by the size, type and number of burners or nozzles through which it fires, and by the field conditions under which it operates. Select from the following capacity/selection tables for the combination of mixer, burner and operating conditions of your application.

Even slight variations in combustion chamber pressure, draft conditions or the availability of secondary air can affect ratings and performance drastically.

Designations of VENTITE™ Inspirators are based on outlet pipe size. **For example:** A 1-1/2" VENTITE™ Inspirator will discharge the air/gas mixture through a 1-1/2" standard threaded pipe connection. A specific spud orifice drilling must always be designated when ordering a VENTITE™ Inspirator.

Open-port firing with STICKTITE™ Nozzles

VENTITE™ Inspirators may be used as shown at right to supply air/gas mixture to STICKTITE™ Burner Nozzles being fired out in the open, into immersion tubes, or firing through a chamber wall with the use of a Maxon tuyere block.

STICKTITE™ Nozzle may be threaded directly onto VENTITE™ Inspirator outlet or optional 90° elbow arrangement may be specified as shown at right. Support clamp is standard on 3" and larger VENTITE™ Inspirators and available as optional accessory on 2" and 2-1/2" versions.

Capacities and nozzle sizing information are provided on pages 3304-3306 for burner systems utilizing VENTITE™ Inspirators with STICKTITE™ Burner Nozzles. Data is based on the use of a single, full-sized STICKTITE™ Nozzle threaded directly onto the outlet of a VENTITE™ Inspirator or arranged for right-angle firing with a single elbow and close nipple.

Use only the "HD" STICKTITE™ Nozzle size indicated for each VENTITE™ Inspirator.

Your actual choice of an appropriate VENTITE™ Inspirator and STICKTITE™ Nozzle combination will be based on combustion chamber back pressure or draft and the available pressure and heating value of the fuel gas being used.

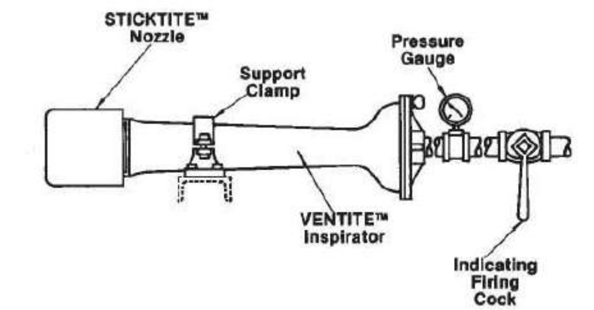
To select the appropriate Inspirator/STICKTITE™ Nozzle combination, determine your expected negative pressure conditions and available gas pressure.

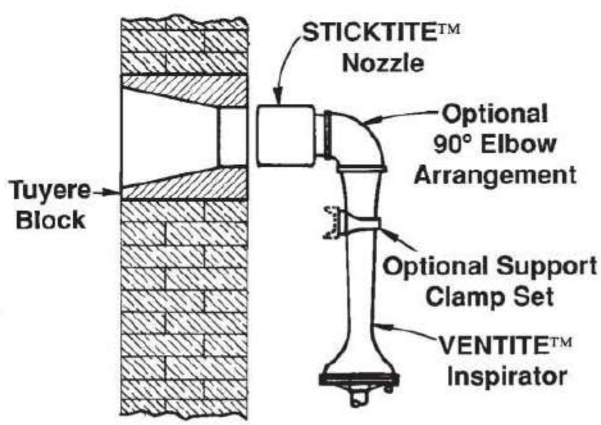
Catalog data extends only to 30 PSIG. Higher pressures are possible, but noise frequently becomes a consideration.

Locate your available gas pressure in the appropriate table and scan downward in that column to the fuel and heat release required. Separate data is provided for 1000 Btu/ft³ natural gas and 2500 Btu/ft³ propane.

Identify VENTITE™ Inspirator size and spud orifice drilling by following across the line showing your desired fuel, pressure and heat release.

Select and order the matching "HD" STICKTITE™ Nozzle from the information given in the STICKTITE™ Nozzle catalog section.





Capacity/Selection Data

VENTITE™ Inspirator and STICKTITE™ Nozzle

SCFH natural gas capacities when firing into balanced combustion chamber pressure

(0 to -0.05" wc static pressure) – Under these firing conditions, approximately 80% primary air inspiration is expected. **Do not fire on propane gas with these conditions.**

VENTITE™ Inspirator Size with single STICKTITE™ Nozzle size	**Inspirator's Spud Orifice Drill Size** area of spud orifice in square inches	**Natural Gas [1] Pressures (PSIG) measured at VENTITE™ Inspirator Inlet**												
		1 Min.	**2**	**3**	**4**	**5**	**6**	**8**	**10**	**12**	**15**	**20**	**25** [2]	**30** [2]
1" HD- 1" -9	**#56** .00169	24	33	39	45	50	54	62	69	74	83	94	104	114
1-1/4" HD- 1-1/4" -14	**#51** .00353	39	54	66	76	86	92	105	119	130	143	165	185	200
1-1/2" HD- 1-1/2" -18	**#36** .0089	85	118	144	167	183	203	235	267	285	320	370	405	425
2" HD- 2" -24	**#33** .01003	114	157	187	213	237	258	299	335	368	416	490	565	638
2-1/2" HD- 2-1/2" -27	**#30** .01297	146	200	241	275	304	333	384	430	470	530	620	720	810
3" HD- 3" -30	**9/64"** .01553	172	238	284	324	360	393	454	508	560	631	743	855	968
4" HD- 4" -41	**13/64"** .03241	360	495	592	673	750	818	945	1060	1170	1317	1550	1780	2020
5" HD- 5" -50	**17/64"** .05542	610	840	1005	1140	1275	1380	1605	1790	1980	2240	2635	3030	3425
6" HD- 6" -60	**19/64"** .06922	765	1055	1260	1435	1590	1740	2005	2250	2500	2800	330	3800	4300
8" HD- 8" -88	**13/32"** .1296	1360	1870	2240	2550	2830	3100	3575	4000	4400	4980	5860	6750	7600

[1] Gross heating value of natural gas assumed to be 1000 Btu/ft^3 and specific gravity 0.60.
[2] Inlet gas pressures above 20 PSIG on a VENTITE™ Inspirator often result in higher noise levels.

Aluminum Hand Torches

These are specialized aluminum VENTITE™ Inspirators with cast iron HD-2"-24 STICKTITE™ Nozzles and provisions for simple air/gas adjustments.

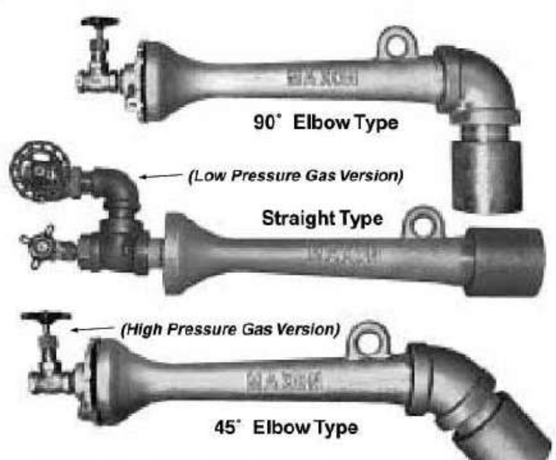
Three styles are offered (as illustrated at right): straight type, 45° elbow type, and 90° elbow type. Each style may also be specified in two (2) versions (based upon available gas pressure).

Low pressure gas version requires 0.2" wc to 8 osi natural gas pressure and a compressed air supply at 5-60 PSIG (2-3 SCFM flow) and is rated at 210,000-475,000 Btu/hr. **High gas pressure** version requires natural gas supply at 5-25 PSIG capacity and is rated at 250,000-500,000 Btu/hr.

These lightweight units (only 9 pounds) are easy to handle, requiring only flexible gas and/or air connections for portability. You need only connect to your gas supply (and compressed air lines for low pressure versions).

Light-off is normally manual in most applications, without flame supervision.

When ordering, specify spud orifice drilled #33 for natural gas firing or #43 spud orifice for propane gas.



Note: Tees and elbows may not be in the orientation shown.

VENTITE™ Inspirators **Page 3305**

Capacity/Selection Data

VENTITE™ Inspirator and STICKTITE™ Nozzle

SCFH gas capacities when firing into slightly negative combustion chamber pressure

(-0.05 to -0.15" wc static pressure) – Under these firing conditions, approximately 65% primary air inspiration is expected.

VENTITE™ Inspirator Size with single STICKTITE™ Nozzle Size	Inspirator's Spud Orifice Drill Size area of spud orifice in square inches	Fuel Gas Type [1] (SCFH)	Gas Pressures (PSIG) measured at VENTITE™ Inspirator Inlet												
			1 Min.	2	3	4	5	6	8	10	12	15	20	25 [2]	30 [2]
1" HD- 1" -9	#55 .00212	Natural	30	41	49	56	62	67	78	87	95	106	123	140	156
	#59 .00132	Propane	12	16	20	22	24	27	31	35	38	42	49	56	62
1-1/4" HD- 1-1/4" -14	#46 .00515	Natural	59	81	98	112	124	135	156	175	192	215	252	287	320
	#52 .00317	Propane	24	32	39	45	50	54	62	70	77	86	101	115	128
1-1/2" HD- 1-1/2" -18	#31 .01131	Natural	122	169	203	232	257	283	327	367	400	450	528	600	660
	#41 .00724	Propane	50	68	81	93	103	113	131	147	160	180	211	240	264
2" HD- 2" -24	#27 .01629	Natural	188	259	309	352	391	425	493	552	607	687	808	930	1050
	#32 .01057	Propane	75	104	124	141	156	170	197	221	243	275	323	372	420
2-1/2" HD- 2-1/2" -27	#19 .02164	Natural	238	325	393	448	497	542	625	700	770	875	1030	1185	1335
	#29 .01453	Propane	95	130	154	180	199	217	250	280	308	350	412	475	534
3" HD- 3" -30	#13 .02688	Natural	294	404	484	552	613	669	772	864	955	1075	1265	1450	1650
	#25 .01755	Propane	118	162	194	221	245	267	310	346	382	430	506	580	660
4" HD- 4" -41	17/64" .05542	Natural	605	835	1000	1135	1265	1375	1595	1780	1965	2220	2610	3000	3400
	#3 .03563	Propane	242	335	400	455	508	550	638	712	790	890	1040	1200	1360
5" HD- 5" 50	#Q .08657	Natural	938	1295	1545	1750	1960	2125	2465	2755	3040	3440	4050	4650	5260
	17/64" .05542	Propane	375	518	620	700	785	850	985	1100	1215	1375	1620	1860	2100
6" HD- 6" -60	3/8" .11045	Natural	1155	1590	1900	2170	2400	2620	3025	3390	3750	4225	4975	5725	6460
	#N .07163	Propane	462	636	760	870	960	1050	1210	1330	1500	1690	1990	2300	2580
8" HD- 8" -88	17/32" .2217	Natural	2130	2935	3500	4000	4440	4850	5600	6260	6900	7800	9180	10600	11900
	27/64" .1398	Propane	850	1170	1400	1600	1780	1940	2240	2500	2760	3120	3670	4240	4760

[1] Gross heating value of natural gas assumed to be 1000 Btu/ft^3 and specific gravity 0.060; propane gas to be 2500 Btu/ft^3 with specific gravity of 1.55

[2] Inlet gas pressures above 20 PSIG on a VENTITE™ Inspirator often result in higher noise levels.

Capacity/Selection Data

VENTITE™ Inspirators and STICKTITE™ Nozzle

SCFH capacities when firing into high negative combustion chamber pressure

(-0.15 to -0.3" wc static pressure) – Under these firing conditions, approximately 50% primary air inspiration is expected.

VENTITE™ Inspirator Size with single STICKTITE™ Nozzle Size	**Inspirator's Spud Orifice Drill Size** area of spud orifice in square inches	**Fuel Gas Type** [1] (SCFH)	**Gas Pressures (PSIG) measured at VENTITE™ Inspirator Inlet**												
			1 Min.	**2**	**3**	**4**	**5**	**6**	**8**	**10**	**12**	**15**	**20**	**25** [2]	**30** [2]
1" HD- 1" -9	**#53** .00278	Natural	35	48	58	66	73	80	93	104	115	129	152	175	198
	3/64" .00173	Propane	14	19	23	26	29	32	37	42	45	51	61	70	79
1-1/4" HD- 1-1/4" -14	**#42** .00687	Natural	78	108	129	147	161	178	206	230	254	286	338	388	440
	#49 .00419	Propane	31	43	52	59	64	71	82	92	101	114	135	155	176
1-1/2" HD- 1-1/2" -18	**#29** .01453	Natural	159	219	262	296	331	362	418	467	516	581	685	790	895
	7/64" .0094	Propane	64	87	105	118	131	145	168	186	206	233	274	316	358
2" HD- 2" -24	**11/64"** .0232	Natural	262	360	430	490	545	592	686	768	846	958	1125	1295	1465
	#29 .01453	Propane	105	144	172	196	218	237	274	306	338	383	450	518	586
2-1/2" HD- 2-1/2" -27	**#10** .02941	Natural	330	450	545	620	690	750	865	970	1070	1220	1440	1650	1860
	#23 .01863	Propane	132	180	217	247	276	300	346	388	428	487	575	660	742
3" HD- 3" -30	**7/32"** .03758	Natural	415	570	683	779	865	945	1090	1220	1350	1520	1790	2050	2325
	#17 .02351	Propane	166	228	274	311	346	378	436	487	540	608	715	820	930
4" HD- 4" -41	**5/16"** .0767	Natural	850	1175	1400	1600	1775	1935	2240	2500	2760	3120	3670	4225	4785
	1/4" .04909	Propane	340	470	560	640	710	770	890	1000	1100	1245	1465	1690	1915
5" HD- 5" -50	**25/64"** .1198	Natural	1265	1745	2085	2365	2640	2875	3325	3720	4100	4640	5465	6275	7100
	5/16" .0767	Propane	508	700	830	950	1050	1150	1330	1495	1640	1850	2180	2500	2840
6" HD- 6" 60	**7/16"** .15033	Natural	1540	2125	2540	2900	3215	3500	4050	4530	5000	5650	6650	7650	8625
	#S .09511	Propane	615	850	1010	1160	1285	1400	1620	1810	2000	2260	2660	3060	3450
8" HD- 8" -88	**5/8"** .3068	Natural	2900	4000	4760	5440	6050	6600	7625	8520	9400	10625	12500	14400	16250
	1/2" .19635	Propane	1160	1600	1910	2170	2420	2640	3050	3410	3760	4250	5000	5760	6600

[1] Gross heating value of natural gas assumed to be 1000 Btu/ft^3 and specific gravity 0.060; propane gas to be 2500 Btu/ft^3 with specific gravity of 1.55

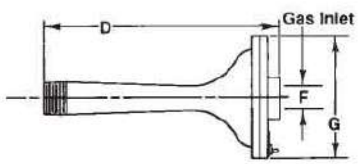
[2] Inlet gas pressures above 30 PSIG on a VENTITE™ Inspirator often result in higher noise levels.

VENTITE™ Inspirators **Page 3317**

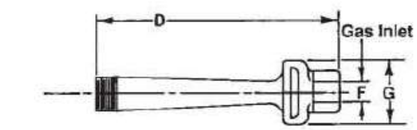
Dimensions (in inches)

Standard VENTITE™ Inspirators

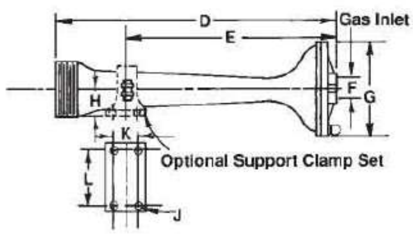
1" – 1-1/2" Sizes (with primary air shutter)



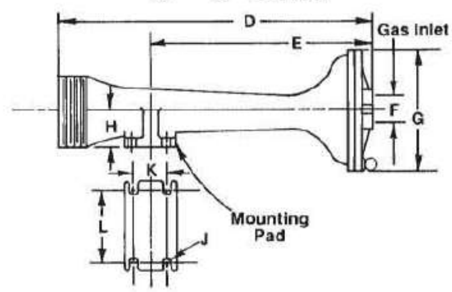
1" Size (without primary air shutter)



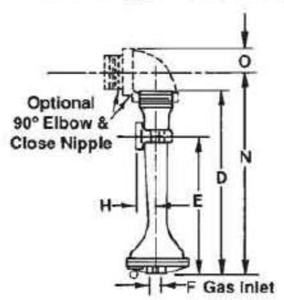
2" – 2-1/2" Sizes



3" – 8" Sizes



Elbow Type (any size)



Accessories

90° firing arrangements are available to reduce space requirements by mounting VENTITE™ Inspirator parallel to chamber wall.

Support clamps are included as part of 3" and larger VENTITE™ Inspirators. They are optional for 2" and 2-1/2" sizes.

VENTITE™ Inspirator Size	D	E	F (gas)	G	H	J	K	L	N [3]	O
1"	8.62	---	1/2	2.25 [1] 4.44 [2]	---	---	---	---	9.69	1.06
1-1/4"	10.56			4.44					11.69	1.31
1-1/2"	12.38								13.75	1.5
2"	17.31	12.81	3/4	6.5	1.69	.44	1.5	3.62	18.88	1.81
2-1/2"	19.56	13							21.38	2.12
3"	16.5	13.56	1	7.88	1.88		1.12	2.88	18.56	2.56
4"	18	14.38			2.12	.56	2	3.38	20.75	3.12
5"	21.06	15.94	1-1/2	11.5	2.38		2.25	4.75	24.38	3.75
6"					2.62				25	4.38
8"	28.5	22		15	3.25	.69	3	5	33.88	5.69

[1] Assembly without primary air shutter. [2] Assembly with primary air shutter
[3] VENTITE™ Inspirator size is outlet pipe size. Dimension "N" is based on typical thread engagement and may vary.

Pipe threads on this page conform to ANSI Standard B2.1.

C8 North American Literature

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• NEW ZEALAND

North American
Manufacturing Company

HIGH PRESSURE INSPIRATORS

Bulletin 3070

April 1992

3070 High Pressure Inspirators use the energy in 5-30 psi gas to induce combustion air and mix the two for proper combustion in open or sealed-in premix burners.

Desired air/gas ratio is set with the air disc at high fire and is maintained reasonably throughout the turndown range, as long as combustion chamber pressure is fairly steady.

A gas orifice in the spud is carefully aligned with the machined throat in the body to ensure proper air inspiration and highest possible mixture pressures.

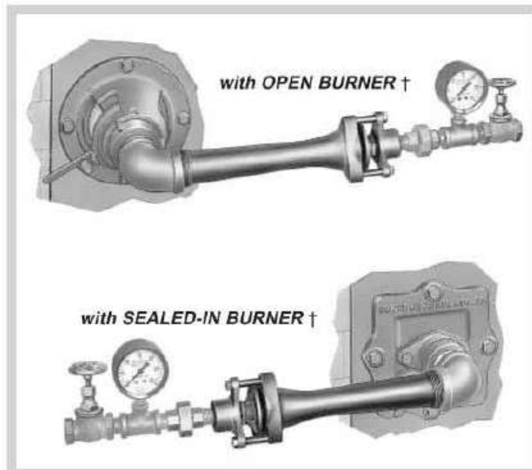
Inspirator capacity is affected significantly by the type of installation and pressure conditions within the combustion chamber:

Negative pressures (draft) increase inspirator capacity and retard flashback.

Positive pressures reduce capacity, and probability of flashback is greater.

At neutral furnace pressures, flashback normally will not occur at mixture pressures above 0.25"wc for natural gas.

Available turndown depends on mixture pressure, which in turn depends on gas and furnace pressures. Inspirators are primarily on-off devices.



† Greater stability can be obtained by inserting pipe nipples, two pipe diameters long, at each end of the pipe elbow.

TABLE 1. Natural Gas capacities and Developed Mixture Pressures
(for 0.6 sp gr, natural gas, 1000 Btu/ft³, 10 ft³ air required/ft³ gas)

Gas Flow (**cfh**) in Bold Type, Mixture Pressures ("wc) in Light Type

Inspirator designation	gas pressure, psi 5	10	15	20	25	30	Burner size
3070-1-68	**17**	**24**	**30**	**34**	**38**	**42**	-1-A
	0.24	0.48	0.72	0.96	1.20	1.44	
3070-1-65	**22**	**32**	**38**	**44**	**49**	**54**	-1-B
	0.25	0.50	0.75	1.00	1.25	1.50	
3070-2-59	**31**	**43**	**53**	**61**	**69**	**75**	-2-A
	0.30	0.60	0.90	1.20	1.50	1.80	
3070-2-57	**36**	**51**	**63**	**72**	**81**	**89**	-2-B
	0.31	0.62	0.93	1.24	1.55	1.86	
3070-2-55	**44**	**62**	**76**	**88**	**99**	**108**	-2-C
	0.32	0.64	0.96	1.28	1.60	1.92	
3070-2-54	**51**	**71**	**88**	**101**	**113**	**124**	-2-D
	0.33	0.66	0.99	1.32	1.65	1.98	
3070-3-53	**60**	**84**	**103**	**119**	**133**	**146**	-3-A
	0.37	0.74	1.11	1.48	1.85	2.22	
3070-3-52	**76**	**108**	**131**	**152**	**170**	**186**	-3-B
	0.40	0.80	1.20	1.60	2.00	2.40	
3070-4-50	**96**	**136**	**166**	**192**	**215**	**235**	-4-A
	0.41	0.82	1.23	1.64	2.05	2.46	
3070-4-46	**125**	**176**	**216**	**249**	**278**	**305**	-4-B
	0.43	0.86	1.29	1.72	2.15	2.58	
3070-4-44	**138**	**195**	**238**	**275**	**308**	**337**	-4-C
	0.45	0.90	1.35	1.80	2.25	2.70	
3070-5-41	**168**	**238**	**291**	**336**	**376**	**412**	-5-A
	0.47	0.94	1.41	1.88	2.35	2.82	

Inspirator designation	gas pressure, psi 5	10	15	20	25	30	Burner size
3070-5-36	**201**	**284**	**348**	**402**	**450**	**492**	-5-B
	0.48	0.96	1.44	1.92	2.40	2.88	
3070-6-34	**226**	**320**	**391**	**451**	**505**	**550**	-6-A
	0.50	1.00	1.50	2.00	2.50	3.00	
3070-6-31	**278**	**393**	**481**	**555**	**621**	**680**	-6-B
	0.52	1.04	1.56	2.08	2.60	3.12	
3070-6-30	**306**	**437**	**536**	**619**	**692**	**757**	-6-C
	0.53	1.06	1.59	2.12	2.65	3.18	
3070-7-29	**352**	**498**	**611**	**705**	**788**	**863**	-7-A
	0.55	1.10	1.65	2.20	2.75	3.30	
3070-7-22	**453**	**640**	**784**	**905**	**1012**	**1100**	-7-B
	0.57	1.14	1.71	2.28	2.85	3.42	
3070-7-11/64	**560**	**766**	**938**	**1082**	**1210**	**1350**	-7-C
	0.59	1.18	1.77	2.36	2.95	3.54	
3070-8-3	**826**	**1178**	**1430**	**1663**	**1847**	**2022**	-8-A
	0.62	1.24	1.86	2.48	3.10	3.72	
3070-8-C	**1038**	**1468**	**1800**	**2075**	**2325**	**2550**	-8-B
	0.64	1.28	1.92	2.56	3.20	3.84	
3070-8-J	**1462**	**2068**	**2535**	**2935**	**3270**	**3585**	-8-C
	0.66	1.32	1.98	2.64	3.30	3.96	
3070-8-5/16	**1788**	**2530**	**3100**	**3575**	**4000**	**4380**	-8-D
	0.69	1.38	2.07	2.76	3.45	4.14	
3070-9-27/64	**3250**	**4580**	**5620**	**6480**	**7260**	**7680**	-9
	0.74	1.48	2.22	2.96	3.70	4.44	

Catalog Number Explanation: **3070-4-50**

- **spud drilling (#50 drill)**
- **pipe code (4 = 2" pipe)**
- **product number**

TABLE 2. Factors for rich operation and for other gases

gas specifications			% air thru Inspirator	gas capacity factor	spud area and mixture press. factor
Btu/ft³	sp gr	ft³ air/ft³			
800	0.54	5.8	100	0.68	1.36
			90	0.56	1.65
			80	0.47	2.00
			70	0.38	2.44
1000	0.6	10.0	90	0.83	1.21
			80	0.67	1.50
			70	0.53	1.90
1200	0.7	11.7	100	1.25	0.85
			90	1.03	1.02
			80	0.83	1.28
			70	0.66	1.60

TABLE 3. Inspirator Size for Multiple Premix Burners

Inspirator Selection. When more than one nozzle is used per inspirator, manifold must be designed for very low pressure drop to obtain listed inspirator ratings. Too much resistance reduces capacity and upsets air/gas ratios.

Burner size	number of burners 1	2	3	4	5	6
-0-A		3070-1-68	3070-1-65	3070-2-57	3070-3-53	3070-3-53
-0-B		3070-1-65	3070-2-57	3070-3-53	3070-3-52	3070-4-50
-0-C		3070-2-57	3070-2-54	3070-3-52	3070-4-50	3070-4-46
-1-A	3070-1-68	3070-2-55	3070-3-53	3070-4-50	3070-4-46	3070-4-44
-1-B	3070-1-65	3070-2-55	3070-3-52	3070-4-46	3070-5-41	3070-5-41
-2-A	3070-2-59	3070-3-53	3070-4-50	3070-4-44	3070-5-36	3070-6-34
-2-B	3070-2-57	3070-3-52	3070-4-44	3070-5-41	3070-6-34	3070-6-31
-2-C	3070-2-55	3070-4-50	3070-5-41	3070-5-36	3070-6-31	3070-6-30
-2-D	3070-2-54	3070-4-46	3070-5-36	3070-6-34	3070-6-30	3070-7-29
-3-A	3070-3-53	3070-4-44	3070-6-34	3070-6-31	3070-7-29	3070-7-22
-3-B	3070-3-52	3070-5-41	3070-6-31	3070-7-29	3070-7-22	3070-7-$^{11}/_{64}$

Burner size	number of burners 1	2	3	4	5
-4-A	3070-4-50	3070-6-34	3070-7-29	3070-7-22	3070-7-$^{11}/_{64}$
-4-B	3070-4-46	3070-6-31	3070-7-22	3070-7-$^{11}/_{64}$	
-4-C	3070-4-44	3070-6-31	3070-7-22		
-5-A	3070-5-41	3070-7-29	3070-7-$^{11}/_{64}$		
-5-B	3070-5-36	3070-7-22			
-6-A	3070-6-34	3070-7-22			
-6-B	3070-6-31	3070-7-$^{11}/_{64}$			
-6-C	3070-6-30				
-7-A	3070-7-29	Multiple burners are not recommended because of flashback hazard in large manifolds.			
-7-B	3070-7-22				
-7-C	3070-7-$^{11}/_{64}$				

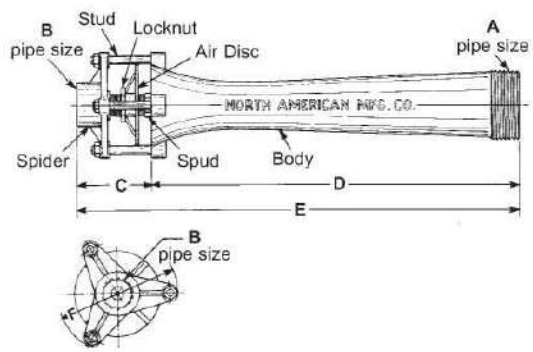
Example: Non-standard selection. Inspirator to supply 80% air for 300 cfh of 20 psi 1000 Btu/ft³ gas.

In Table 2, read a 0.67 capacity factor and a 1.50 spud and mixture pressure factor. The required 300 cfh capacity × 0.67 = 201 cfh equivalent capacity. In the left half of Table 1, look down the 20 psi gas pressure column until you find a gas flow near 201 cfh. 192 cfh corresponds to a 3070-4-50 tentative inspirator designation and 1.64"wc tentative mixture pressure. The last number in the designation means #50 spud drill, which has 0.00385 sq. in. area (from any drill size table). Multiply this by the spud area factor, 0.00385 × 1.50 = 0.00578 sq. in. The next larger standard drill is #44 with 0.00581 sq. in. area. Therefore, specify a 3070-4-44 Inspirator. To find actual mixture pressure, multiply 1.64 × 1.50 = 2.46"wc.

For information on using 3070 Inspirators as high pressure air reducers (compressed air instead of a blower for low pressure air supply), refer to Sheet 3070-1.

For inspirators used with coke oven or producer gas, see Sheet 3080-1.

Inspirator designation	dimensions in inches A	B	C	D	E	F	wt, lb
3070-1	1	$^{3}/_{8}$	$2^{7}/_{16}$	7	$9^{7}/_{16}$	$3^{3}/_{16}$	$2^{1}/_{4}$
3070-2	$1^{1}/_{4}$	$^{1}/_{2}$	$2^{7}/_{16}$	$8^{7}/_{16}$	$10^{7}/_{8}$	$3^{3}/_{16}$	3
3070-3	$1^{1}/_{2}$	$^{1}/_{2}$	$2^{9}/_{16}$	10	$12^{9}/_{16}$	$3^{7}/_{8}$	$5^{1}/_{2}$
3070-4	2	$^{1}/_{2}$	$2^{3}/_{4}$	12	$14^{3}/_{4}$	$4^{5}/_{8}$	8
3070-5	$2^{1}/_{2}$	$^{3}/_{4}$	$2^{3}/_{4}$	$14^{13}/_{16}$	$17^{9}/_{16}$	$4^{7}/_{8}$	11
3070-6	3	$^{3}/_{4}$	$3^{5}/_{16}$	$18^{3}/_{4}$	$22^{1}/_{16}$	$5^{7}/_{16}$	$14^{1}/_{2}$
3070-7	4	1	$3^{9}/_{16}$	$21^{7}/_{16}$	25	$6^{5}/_{16}$	23
3070-8	6	1	$4^{1}/_{4}$	30	$34^{1}/_{4}$	$8^{5}/_{8}$	57
3070-9	8	$1^{1}/_{2}$	$6^{3}/_{16}$	36	$42^{3}/_{16}$	$11^{1}/_{4}$	110



DIMENSIONS SHOWN ARE SUBJECT TO CHANGE. PLEASE OBTAIN CERTIFIED PRINTS FROM NORTH AMERICAN MFG. CO. IF SPACE LIMITATIONS OR OTHER CONSIDERATIONS MAKE EXACT DIMENSION(S) CRITICAL.

WARNING: Situations dangerous to personnel and property can develop from incorrect operation of combustion equipment. North American urges compliance with National Safety Standards and Insurance Underwriters recommendations, and care in operation.

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NA700-B3070

North American Manufacturing Company

FLAME RETENTION GAS BURNER NOZZLES

Bulletin 4682

Ref: Bulletins 3065 and 3070

June 1996

4682 Burners are open fired nozzles fed an air-gas premixture by an aspirator or inspirator mixer. They produce a well defined, medium to high velocity blue flame when at high fire on stoichiometric ratio.

These nozzles are never sealed into a refractory wall, rather they provide stable combustion firing in the open or through a tunnel in the furnace wall.

A 4682 nozzle can have its own air-gas mixer; or a gang of nozzles can be fed by one mixer. Mixture pressures as high as 12"wc and as low as 0.25"wc imply available turndown of about 7:1. However, such is difficult to count on in the "real world:" Certain piping arrangements can cause low pressure pockets in the mixture line that allow flashback long before the 0.25"wc theoretical flashback point is reached at the mixer discharge.

4682 nozzles and a compressed air torch with a nozzle--torch is handy for many spot and preheating jobs.

4682 Burners can be run fuel rich if secondary air is available around the nozzle. This increases capacity and (in some cases) widens turndown available, but flames are longer and usually have less drive.

Combustion Air Capacities
(see note below)

scfh

Burner designation	**Mixture Pressure in inches of water** 1	2	5	6	7	10	12
4682-0-A/BO	200	280	440	480	520	640	670
4682-0-B/BO	250	350	560	610	660	790	860
4682-0-C/BO	280	400	640	700	750	900	990
4682-1-A/BO	350	490	790	860	920	1 120	1 210
4682-1-B/BO	440	620	990	1 070	1 160	1 390	1 520
4682-2-A/BO	560	790	1 260	1 370	1 480	1 770	1 930
4682-2-B/BO	650	920	1 460	1 590	1 720	2 060	2 240
4682-2-C/BO	780	1 100	1 750	1 910	2 060	2 460	2 680
4682-2-D/BO	880	1 240	1 980	2 150	2 320	2 780	3 020
4682-3-A/BO	980	1 380	2 200	2 390	2 590	3 100	3 380
4682-3-B/BO	1 200	1 690	2 690	2 930	3 170	3 800	4 120
4682-4-A/BO	1 500	2 120	3 360	3 660	3 960	4 760	5 150
4682-4-B/BO	1 900	2 680	4 270	4 650	5 000	6 000	6 550
4682-4-C/BO	2 050	2 890	4 610	5 000	5 400	6 500	7 050
4682-5-A/BO	2 450	3 450	5 500	6 000	6 500	7 750	8 450
4682-5-B/BO	2 900	4 100	6 500	7 100	7 650	9 200	10 000
4682-6-A/BO	3 200	4 510	7 200	7 800	8 450	10 100	11 000
4682-6-B/BO	3 850	5 450	8 650	9 400	10 200	12 200	13 200
4682-6-C/BO	4 250	6 000	9 550	10 300	11 200	13 400	14 600
4682-7-A/BO	4 750	6 700	10 600	11 600	12 600	15 000	17 000
4682-7-B/BO	6 000	8 450	13 400	14 700	15 800	19 000	20 600
4682-7-C/BO	7 050	9 950	15 800	17 200	18 600	22 200	24 200
4682-8-A/BO	10 500	14 800	23 500	25 600	27 700	33 200	36 200
4682-8-B/BO	13 000	18 400	29 200	31 800	34 400	41 300	44 900
4682-8-C/BO	18 000	25 500	40 400	44 000	47 600	57 000	62 000
4682-8-D/BO	21 500	30 200	48 100	52 500	57 000	68 000	74 000
4682-9/BO	37 700	53 000	84 500	92 000	99 500	—	—

NOTE: For Btu/hr, multiply air capacity by 100.

If secondary air is available around nozzle, burner can be run fuel rich and Btu/hr capabilities increased by factors in adjoining table.

% Combustion Air Through Burner	**Multiply Capacity by**
90	1.1
80	1.22
70	1.38

CONSTRUCTION / INSTALLATION

Standard 4682 nozzles are heat resistant cast iron that will take 950 F **nozzle temperature** -- since burners normally are surrounded by relatively cool ambient air, they can fire furnaces or kilns as hot as 2000 F without being damaged, as long as tunnel configuration into which they fire protects them from excessive radiation.

For **nozzle temperatures** up to 1350 F, alloy nozzles (N) are available.

For best operation, use at least 4 pipe diameters between nozzle and nearest fitting or mixer.

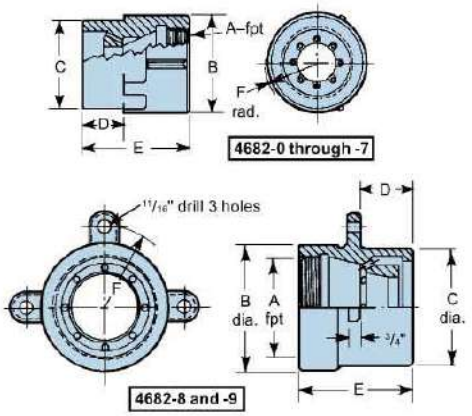
Conical mountings (MP) facilitate proper positioning of pilots and flame detectors, also help assure alignment of nozzle with firing tunnel in furnace wall.

Tiles of 3000 F dense castable material are available; or tunnels can be rammed into the furnace wall (see note below).

For 4682-0 through -7 sizes, order mountings and/or tiles as separate items. 4682-8 and -9 Burners can be ordered as separate pieces -- nozzle, air register (with shutter to control secondary air), mounting plate, tile -- or with all of these in an assembly.

Flame supervision can be accommodated -- consult North American for an arrangement appropriate for your application.

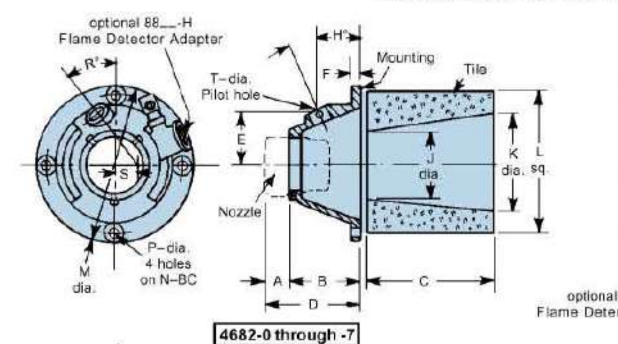
BURNER NOZZLE DIMENSIONS

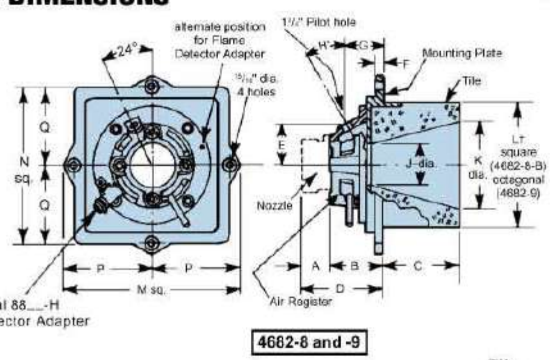


Nozzle designation	A	B	C	D	E	F	Wt, lb
	dimensions in inches						
4682-0-A,-0-B,-0-C/BO	3/4	1 7/8	1 3/4	11/16	2 23/32	1 1/16	2
4682-1-A,-1-B/BO	1	2	1 13/16	13/16	2 23/32	1 1/8	2
4682-2-A,-2-B,-2-C,-2-D/BO	1 1/4	2 7/16	2 1/4	13/16	2 27/32	1 11/32	3
4682-3-A,-3-B/BO	1 1/2	2 3/4	2 9/16	1 1/16	3 1/32	1 1/2	3
4682-4-A,-4-B,-4-C/BO	2	3 1/8	2 15/16	1 3/8	3 9/16	1 11/16	5
4682-5-A,-5-B/BO	2 1/2	3 5/8	3 3/8	1 3/8	4 1/8	1 15/16	6
4682-6-A,-6-B,-6-C/BO	3	4 1/4	4 1/16	1 3/8	5 1/4	2 1/4	11
4682-7-A,-7-B,-7-C/BO	4	5 3/8	5 3/16	1 3/8	6 1/4	2 7/8	22
4682-8-A,-8-B,-8-C,-8-D/BO	6	7 3/4	7 3/8	3 5/16	7 1/8	5	32
4682-9/BO	8	9 7/8	9 7/16	6 1/16	8 5/8	6 1/4	50

For alloy nozzles, place "N" before "/ ", e.g. 4682-1-AN/BO.

MOUNTING & TILE DIMENSIONS





Mounting designation	A	B	C	D	E	F	G	H°	J	K	L†	M	N	P	Q	R°	S	T	Tile part numbers
	dimensions in inches and degrees.																		
4682-0-MP†	2 1/16	2 5/8	5 1/2	4 11/16	2 1/16	1/2	1 15/16	25	1 3/4	3	5	6	5 1/4	7/16	–	40	5/8	1	4-2653-1
4682-1-MP	1 15/16	2 5/8	7	4 9/16	2 1/16	1/2	1 15/16	25	2 5/16	4	6	6	5 1/4	7/16	–	40	5/8	1	4-2653-2
4682-2-MP	2 1/16	2 7/8	7	4 15/16	2 1/4	1/2	2 1/8	25	2 5/16	4	6	6 1/2	5 3/4	7/16	–	45	7/8	1	4-2653-3
4682-3-MP	2	3 9/16	8	5 9/16	2 5/16	1/2	2 13/16	30	2 3/4	4 1/2	7	7 1/2	6 3/4	7/16	–	40	1	1	4-2653-3
4682-4-MP	1 7/16	4	9	5 7/16	3	9/16	2 7/16	30	3 3/8	5 1/2	9	8 3/4	7 3/4	9/16	–	40	1 1/4	1	4-2653-4
4682-5-MP	1 13/16	4 5/16	9	6 1/8	3 3/8	9/16	2 11/16	30	4	6	9	9 3/4	8 3/4	9/16	–	40	1 3/8	1	4-2653-5
4682-6-MP	2 7/16	4 13/16	9	7 1/4	4	5/8	2 7/8	30	4	6	9	11	10	9/16	–	40	1 3/4	1 1/8	4-2653-5
4682-7-MP	2 1/2	5 3/4	10 15/16	8 1/4	4 13/16	11/16	3 1/16	30	6	11 7/16	15 1/8	13 1/2	12 1/4	9/16	–	40	2 5/16	1 1/8	3-0351-6
4682-8-MP	3 13/16	6 9/16	9	10 3/8	6	13/16	3 5/8	30	7 1/2	11 1/4	15 1/8	21 1/2	19 1/2	10 3/4	9 3/4	–	–	–	4-2156-1
4682-9-MP	2 9/16	9 1/16	8 3/4	11 5/8	7 13/16	7/8	4 3/16	26	9 1/2	14	18 5/8	26 1/4	23 3/4	13 1/8	11 7/8	–	–	–	4-2157-1

†4682-0 Nozzle uses 4682-1-MP Mounting.

If tunnels are to be rammed in furnace wall, use dimension "J" at entrance, and taper tunnel at least 15°. Space nozzle about 2" from outer face of wall.

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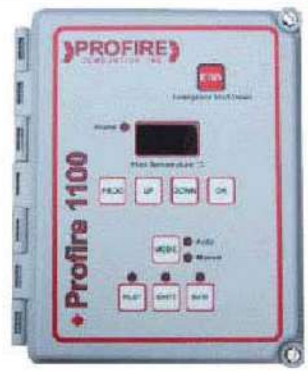

Features

- Dual Flame sensing modes for safety.
  - Ionization and K Thermocouple
- All the electronics in the main case, only the ignition coil is mounted externally to the case.
- Blue LED display.
- Operator information displayed on front panel include: thermocouple temperature, flame status, valve status and operation modes.
- Front panel has buttons for control of Pilot, Main Valve, Spark, Operation Modes, Configuration and an ESD button.
- Manual Mode and Automatic Re-light Mode.
- START/STOP contact input for RTU/PLC control.
- LOCKOUT contact input for connection to safety interlock devices.
- PRESSURE SWITCH contact input for fuel pressure verification.
- ESD contact input for connection to shutdown alarms.
- Flame failure alarm contact output with three alarm/status modes.
- Pilot and Main solenoid outputs can drive multiple solenoids.
- Low power polarity protected 12 volt or 24 volt DC operation, solar powered packages available.
- Temperature rated from -45C to +55C
- Nema 4X fiberglass case with outdoor UV resistant front panel.

Canada

- CSA 213-92 Class 1 Division 2 approved for hazardous areas
- CSA 22.2 #199 burner safety approval
- CSA 14-95 Industrial Process Equipment approval

United States

- FCC Part 15, Class 'A', Subpart B (2000)

European

- 94/9/EC : Equipment and Protective Systems Intended for use in Potentially Explosive Atmospheres (ATEX)
- 89/336/EECV : EMC Directive as amended by 92/31/EC and 93/68/EEC (EMC)

C10 Pyronics Literature

Combustion for Industry

pyronics

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Company

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View our new burners with our 360° Interactive Product Tours!

Pyronics Inc. located in Cleveland, Ohio emerged from Bryant Industrial Products Corporation in the late forties. The Company began with a solid foundation based on the high efficiency Flomixer, burners and accurate air-gas balanced zero-ratio regulators. From these combustion system components, Pyronics has grown into a leading player in the competitive combustion marketplace.

Pyronics promotes a commitment to solving their customers' combustion related quality and productivity problems. Maintaining this commitment to customer service would be ineffective without a dependable product line. Pyronics succeeds here also. "Combustion for Industry" is the company's slogan, and the product line is complete.

Burners, valves, regulators, combustion air blowers, flame safeguards and other combustion systems components are all part of the product line. In addition to the balanced zero-ratio regulators mentioned earlier, the Company also supplies other fuel / air regulators, relief regulators, shut-off regulators, reducing regulators, deadweight zero regulators, flow ratio control regulators, and standard air regulators. Additionally, a full line of burners is available including various types of nozzle mix or premix systems. Flame variations from flat to high velocity are possible. Environmentally conscious low NOx burners, including high velocity low NOx burners also are included.

Forging a close alliance with W B Combustion, located near Milwaukee, Wisconsin, Pyronics was early in the development of a single end, recuperative radiant tube burner. This self-recuperative burner operates to a maximum temperature of 1800° and comes in diameters of up to 6 inches for standard metallic tubes. High performance non-metallic tubes are capable of temperatures over 2000°. The company has been building single-ended recuperative burners since 1979.

Newly developed and introduced the past year is a line of Packaged Burners for all low temperature applications including air heating, immersion tank heating and fume incineration.

Completing the product line is safety equipment including Sens-A-Flame flame safety system and a variety of combustion valve components.

Pyronics serves a wide variety of industries requiring process heating including ferrous and non-ferrous metal processing, glass, ceramics, plastics, food processing, chemical processing, textiles and finishing and coating. Both end users and furnace and equipment builders serving these industries achieve production and product quality with Pyronics combustion systems.

The Company has been a member of Industrial Heating Equipment Association (IHEA) since 1946.

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TORCH BURNERS

LOW, MEDIUM, AND HI-PRESSURE SERIES

MODEL : T,TA,TB,RTA,RTB
ET,ETA,ETB,RETA,RETB

Revision: 0

BULLETIN 3215, 3216, 3217

12 ET

12 RETB

DESCRIPTION

Torches are made up in three series - Low-Pressure, Medium-Pressure, and Hi-Pressure. The chief differences in construction and operation are based on gas pressure requirements and primary air-gas ratios. These factors affect capacity, flame lengths and all other operating characteristics. All series are made up in various assemblies, including mounting cages and combustion blocks to fit almost any job requirement.

The charts on the following pages cover the important operating characteristics of the three Torch Series and show the important physical features of each. For detailed description of each series and capacity tables see Pages 3 and 4.

LOW-PRESSURE SERIES

LOW-PRESSURE SERIES TORCH BURNERS are made up of Lojectors, lever-handled gas cocks, AN Burner nozzles, mounting cages, pilots and blocks in cast iron holders, and assembled as required. They are designed for low pressure gas at normal city pressures. Because they depend mainly on draft for most of the combustion air required, their capacity can only be increased by increasing the draft through the burners.

The Multiplier Table for Capacity Table No. 1 on Pages 4 & 5, shows how much gas can be burned at drafts other than 0.1" W. C. To obtain the increased capacities, the gas orifice must be enlarged or, in some cases, removed altogether. Valves and lead-in pipes may also have to be enlarged.

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TORCH BURNERS

BULLETIN 3215, 3216, 3217
PAGE NO. 2

MEDIUM-PRESSURE SERIES

MEDIUM-PRESSURE SERIES TORCH BURNERS are similar to the Standard Series, except they are for use with gas at pressures from 1 lb. to 10 lbs.

Medium-Pressure Series capacities are based on entrainment, by the gas, of primary air of about 50% of the total air required for combustion. Secondary air is entrained partially by the velocity of the mixture issuing from the burner nozzle and partially by draft. For this reason, draft variations are not so important as for the Standard Series, although some increase in capacity can be secured by using higher drafts as indicated by the Table for Capacity Table No. 2 on Pages 4 & 5. It will, of course, be necessary to increase the orifice size to secure this additional capacity.

Particularly with the slow burning gases like Propane and Natural Gas, the flame tends to blow away from the nozzle at gas pressures above 10 lbs. Also, in some sizes, lack of secondary air space in the cage limits the gas that can be burned. See Capacity Table No. 2.

HI-PRESSURE SERIES

HI-PRESSURE SERIES TORCH BURNERS for use with gases at pressures from 10 lbs. to 60 lbs. are made up of Hijectors, FR Nozzles, high pressure needle valves and necessary cages and blocks, as required by various assembly specifications. The 4800 size uses the 6" Lojector and a lubricated high pressure cock as Hijectors are only made up to 4". HI-PRESSURE TORCHES provide for entrainment through the Hijector of practically all of the air necessary for combustion (80 to 90%) so they are almost independent of draft and can even operate against normal furnace back pressures of several hundreths of an inch W. C.

The Hi-Pressure Series capacity varies according to the kind of gas and gas pressure to be used. By enlarging the orifice, the gas capacity can be increased but the primary air-gas ratio is at once decreased and the additional air required must be drawn in by draft. FR Nozzles used in this series will not hold flames with less than 60% primary air.

Having once established the maximum capacity for a given gas and primary air-gas ratio, the burner capacity will vary with changes in gas pressure was shown by the Multiplier Table, for Capacity Table No. 3 on Pages 4 & 5, with practically no change in flame characteristics.

COMPARISON CHART AND GENERAL SPECIFICATIONS

BULLETIN 3215, 3216, 3217
PAGE NO. 3

LOW, MEDIUM, AND HI-PRESSURE SERIES

TORCH BURNER SERIES COMPARISON CHART

Gas Pressure Range	LOW-PRESSURE SERIES *	MEDIUM PRESSURE SERIES **	HI-PRESSURE SERIES ***
	3" to 15" W. C.	1 to 10 PSIG	10 to 30 PSIG
Percent of Total Combustion Air induced by gas as primary air	20% to 40%	40% to 60%	65% to 100%
Percent of Total Combustion Air pulled in by draft	70% to 90%	40% to 60%	0 to 40%
Effect of draft on capacity	The most important factor.	Required to develop ratings.	Not important but can be utilized.
Btu/hr normally released per cubic foot combustion space	20,000 to 40,000	40,000 to 50,000	60,000 to 100,000

*LOW-PRESSURE SERIES commonly used on air heaters, kilns, dryers, stills and boilers, where ample draft is always available and combustion chambers are large enough for slow combustion.
**MEDIUM PRESSURE SERIES commonly used on large boilers, kilns and furnaces where combustion chambers are suitable for large capacities. Draft must be ample if high capacities required.
***HI-PRESSURE SERIES commonly used on furnaces and kilns operating at high temperatures where high heat releases are required, regardless of draft. Capacity may be increased when ample draft available.

GENERAL SPECIFICATIONS TORCH BURNERS

Burner Numbers		Lojector & AN Nozzle Pipe Size Inches	AN Nozzle Area Sq. Inches	Cage Catalog Number	Block Dimension Inches	Block & Holder Assy. Catalog Number	Gas Cock Pipe Size Inches	Maximum Orifice Diameter Inches
Standard Series	Medium Series							
6	60	3/4	0.55	-	-	-	3/8	ADJ
8	80	1	0.80	-	-	-	3/8	ADJ
10	100	1-1/4	1.35	10 BCA	7 x 7	7 BH	1/2	ADJ
12A	120A	1-1/2	1.75	12 BCA	7 x 7	7 BH	1/2	ADJ
12B	120B	1-1/2	1.75	12 BCB	7 x 7	7 BH	1/2	ADJ
16	160	2	2.90	16 BCB	9 x 9	9 BH	1	5/8
20	200	2-1/2	4.20	20 BCB	11 x 11	11 BH	1	5/8
24	240	3	6.20	24 BCB	11 x 11	11 BH	1	7/8
321	3210	4	8.38	32 BCB	13 x 13	13 BH	1-1/4	7/8
322	3220	4	10.72	32 BCB	13 x 13	13 BH	1-1/4	7/8
323	3230	4	12.19	32 BCB	13 x 13	13 BH	1-1/4	7/8
481	4810	6	14.16	48 BCC	18 x 18	18 BH	1-1/2	1-3/8
482	4820	6	16.93	48 BCC	18 x 18	18 BH	1-1/2	1-3/8
483	4830	6	20.63	48 BCC	18 x 18	18 BH	1-1/2	1-3/8
484	4840	6	23.19	48 BCC	18 x 18	18 BH	1-1/2	1-3/8
485	4850	6	25.35	48 BCC	18 x 18	18 BH	1-1/2	1-3/8

HI-PRESSURE SERIES

Burner Number	Hijector and FR Nozzle Size Inches	FR Burner Area Sq. Inches	Cage Catalog Number	Block Dimension Inches	Block & Holder Assembly Catalog Number	Gas Connection Pipe Size Inches
600	3/4	0.182	-	-	-	3/8
800	1	0.294	-	-	-	3/8
1000	1-1/4	0.666	10 BCA	7 x 7	7 BH	1/2
1200	1-1/2	1.059	12 BCB	7 x 7	7 BH	1/2
1600	2	1.848	16 BCB	7 x 7	7 BH	3/4
2000	2-1/2	2.486	20 BCB	9 x 9	9 BH	3/4
2400	3	3.045	24 BCB	9 x 9	9 BH	1
3200	4	5.533	32 BCB	11 x 11	11 BH	1-1/4
4800	6*	11.191	48 BCB	15 x 15	15 BH	1-1/2

* NOTE: Lojector used in this size only.

CAUTION: Operation of combustion equipment can be hazardous resulting in bodily injury or equipment damage. Each burner should be supervised by a combustion safeguard and only qualified personnel should install, make system adjustments and perform any required service.

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CAPACITY TABLES

BULLETIN 3215, 3216, 3217
PAGE NO. 4

LOW, MEDIUM, AND HI-PRESSURE SERIES TORCH BURNERS

CAPACITY TABLE NO. 1 - LOW PRESSURE SERIES
for all gases - 20% to 40% primary air

Torch Size	1000 BTU/HR 0.1 DRAFT Minimum	Maximum	Approximate Flame Length Inches	Kind of Gas	Btu/cf	Gas Pressure
6	40	65	12 - 18	Manufactured Gas	450/600 Btu/cf	3" - 12" W.C.
8	70	95	14 - 24			
10	100	135	16 - 28	Mixed Gas	650/850 Btu/cf	4" - 12" W.C.
12 (A cage)	140	165	18 - 32			
12 (B cage)	160	175	18 - 36	Natural Gas	900/1150 Btu/cf	5" - 12" W.C.
16	200	280	20 - 40			
20	300	400	22 - 44			
24	450	600	24 - 48	Propane	2500 Btu/cf	11" - 15" W.C.
321	650	800	26 - 52			
322	850	1,000	28 - 56	Butane	3200 Btu/cf	11" - 15" W.C.
323	1,000	1,200	30 - 60			
481	1,300	1,400	32 - 64			
482	1,600	1,700	34 - 68	* Specify gas pressure on order so correctly sized orifice can be supplied.		
483	1,900	2,000	36 - 72			
484	2,200	2,300	38 - 76			
485	2,500	2,600	40 - 80			

CAPACITY TABLE NO. 2 - MEDIUM-PRESSURE SERIES
for all gases - 1000 Btu/hr - 0.1 draft - 40% to 60% primary air

Torch Size	gas pressures - PSIG 1#	2#	3#	4#	5#	6#	8#	10#	Approximate Flame Length in Inches
60	70	100	120	140	155	170	195	210	14 - 28
80	100	140	170	200	220	240	280	300	16 - 32
100	135	190	230	270	300	320	380	400	18 - 36
120	200	280	340	400	440	480	560	600	20 - 40
160	280	390	475	560	610	-	-	-	22 - 44
200	500	700	850	1,000	1,100	1,200	1,400	1,500	24 - 48
240	600	840	1,000	1,200	1,300	1,450	-	-	28 - 56
3210	900	1,250	1,500	1,800	2,000	2,150	2,500	2,700	30 - 60
3220	1,250	1,750	2,100	2,500	2,750	3,000	-	-	34 - 68
3230	1,400	1,950	2,400	2,800	3,000	-	-	-	36 - 72
4810	1,750	2,400	2,900	3,500	3,850	4,200	4,900	5,250	40 - 80
4820	2,100	2,900	3,500	4,200	4,600	5,000	5,800	6,300	44 - 88
4830	2,500	3,500	4,200	5,000	5,500	6,000	7,000	-	48 - 96
4840	2,900	4,000	4,900	5,800	6,300	7,000	-	-	52 - 104
4850	3,000	4,200	5,100	6,000	6,600	-	-	-	56 - 112

CAPACITY TABLE NO. 3 - HI-PRESSURE SERIES

Torch Size	*Mfg. Gas - 450/600 Btu @ 10# PSIG *Mixed Gas - 650/850 Btu @ 15# PSIG *Natural Gas - 900/1200 Btu @ 25# PSIG		*Propane - 2500 Btu/cf @ 25# PSIG *Butane - 3200 Btu/cf @ 25# PSIG		Approximate Flame Length Inches	
	Draft - 0.1" W.C. or more		Draft - 0.1" W.C. or more			
	Sharp Flame	Soft Flame	Sharp Flame	Soft Flame		
	90% Primary Air	60% Primary Air	90% Primary Air	60% Primary Air	Sharp	Soft
600	38,000	57,000	25,000	37,000	8	16
800	66,000	94,000	38,000	57,000	10	18
1000	150,000	210,000	90,000	133,000	12	20
1200	240,000	340,000	144,000	215,000	14	24
1600	400,000	595,000	250,000	370,000	16	28
2000	535,000	800,000	340,000	500,000	18	32
2400	700,000	1,040,000	435,000	640,000	20	36
3200	1,200,000	1,760,000	740,000	1,100,000	22	40
4800	2,200,000	3,300,000	1,440,000	2,100,000	26	48

*Btu/hr

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DRAFT MULTIPLIER TABLES

USE WITH CAPACITY TABLE NO. 1

LOW-PRESSURE SERIES ONLY					
Draft - Inches W.C.	0.01	0.05	0.10	0.20	0.30
Capacity Multiplier	0.40	0.75	1.00	1.40	1.70
Draft - Inches W.C.	0.40	0.50	0.60	0.80	1.00
Capacity Multiplier	2.00	2.20	2.40	2.80	3.20
Allow one cubic foot of combustion space for each 20,000 to 40,000 Btu/hr capacity. Allow forward flame travel at least 1-1/2 times flame length.					

USE WITH CAPACITY TABLE NO. 2

MEDIUM-PRESSURE SERIES ONLY					
Draft - Inches W.C.	0.01	0.05	0.10	0.20	0.30
Capacity Multiplier	0.60	0.90	1.00	1.10	1.20
Draft - Inches W.C.	0.40	0.50	0.60	0.80	1.00
Capacity Multiplier	1.30	1.35	1.40	1.60	1.70
Medium-Pressure Series Torch will be furnished with orifice, to pass capacity indicated by gas pressure, kind of gas, and available draft. Allow one Cubic Foot of combustion space for each 40,000 to 50,000 Btu/hr capacity. Allow forward flame travel at least 1-1/2 times flame length.					

USE WITH CAPACITY TABLE NO. 3

HI-PRESSURE SERIES								
Gas Pressure Listed	For pressures other than listed							
	5#	10#	15#	20#	25#	30#	35#	40#
10#	0.709	1.000	1.220	1.410	1.580	1.730	1.870	2.000
15#	0.578	0.815	1.000	1.150	1.260	1.410	1.530	1.630
25#	0.447	0.631	0.775	0.895	1.000	1.090	1.180	1.260
NOTE: Allow one Cubic Foot of combustion space for each 60,000 to 100,000 Btu/hr. Allow forward flame travel of at least 2 times sharp flame length.								

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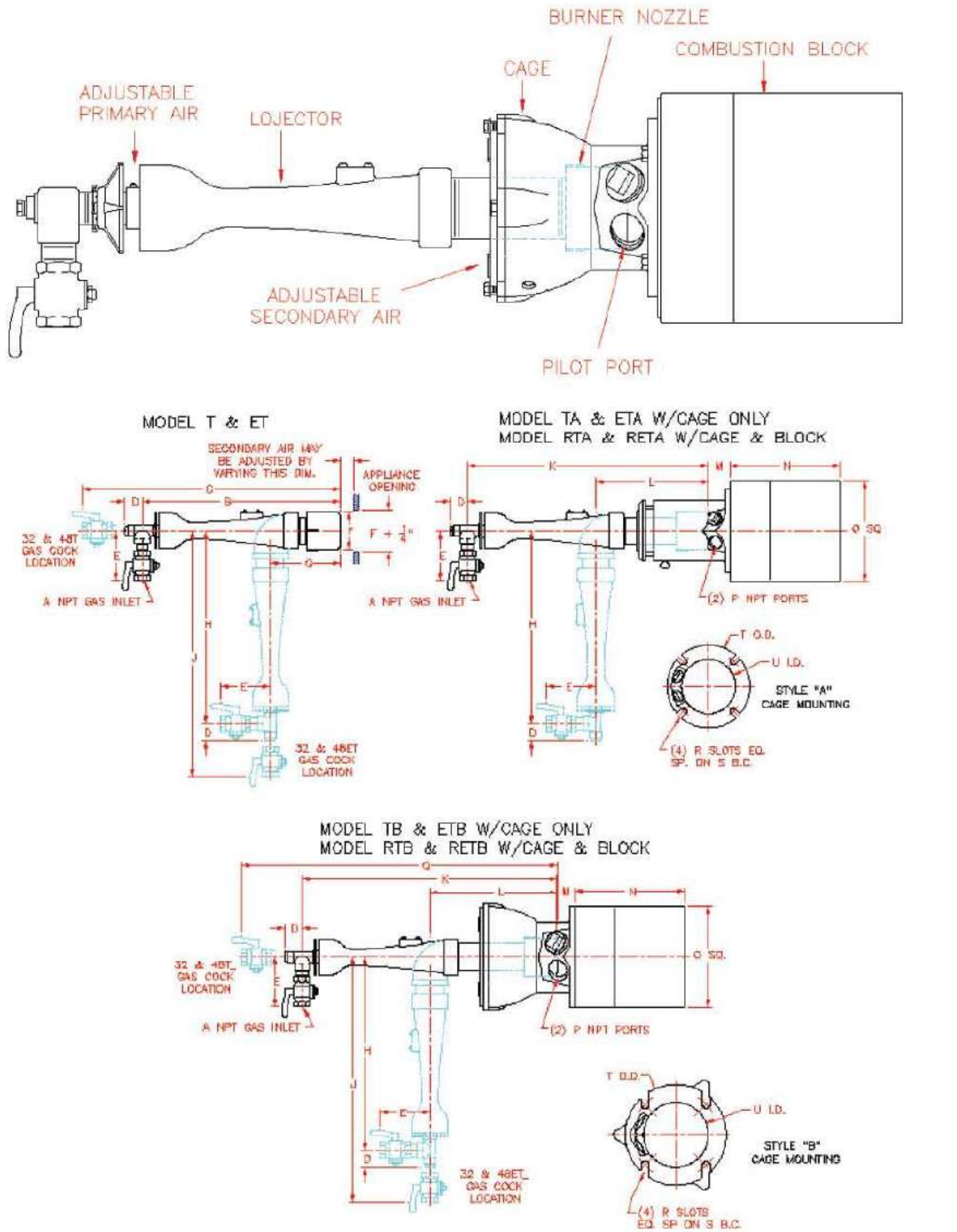
PAGE NO. 6

DIMENSIONS

LOW AND MEDIUM PRESSURE



DIMENSIONS

BULLETIN 3215, 3216, 3217
PAGE NO. 7

ALL LOW & MEDIUM PRESSURE TORCHES

4800 HI-PRESSURE TORCH

All dimensions in inches
All dimensions ± 1/8" unless noted

T & ET SERIES LOW & MEDIUM PRESSURE

Torch Size	A NPT	B ± 1/4	*C ± 1/4	D	*E	F DIA	G	H ± 1/4	*J ± 1/4
6	3/8	10	-	2	2-1/2	1-3/4	3-3/4	9-1/2	-
8	3/8	10	-	2	2-1/2	1-7/8	3-7/8	9-1/2	-
10	1/2	13-1/2	-	1-1/4	3-1/2	2-3/8	4-3/8	13-1/4	-
12	1/2	13-3/4	-	1-1/4	3-1/2	2-5/8	4-7/8	13-1/2	-
16 & 160	1	19	-	1-5/8	4-3/4	3-1/4	5-3/4	18-3/4	-
20 & 200	1	22	-	1-5/8	4-3/4	3-7/8	6-1/2	21-3/4	-
24 & 240	1	25	-	1-5/8	4-3/4	4-1/2	7-1/4	24-3/4	-
32_ & 32_0	1-1/4	-	37-1/2	-	-	5-7/8	9-1/2	-	37-1/2
48_ & 48_0	1-1/2	-	48	-	-	7-1/2	11-1/2	-	48-1/2
4800 **	1-1/2	-	49-1/2	-	-	8-1/4	12	-	49-1/2

TA & ETA, RTA & RETA SERIES ADDITIONS LOW & MEDIUM PRESSURE

Torch Size	K ± 1/4	L	M MAX	N	O SQ	P NPT	R DIA	S B.C.	T O.D.	U I.D.
10	16-1/2	7-3/8	1-3/4	7-5/8	7	3/4	7/16	4-7/8	5-3/4	3-3/4
12	16-3/4	7-7/8	1-1/2	7-5/8	7	3/4	7/16	4-7/8	5-3/4	3-3/4

TB & ETB, RTB & RETB SERIES ADDITIONS LOW & MEDIUM PRESSURE

Torch Size	K ± 1/4	L	M MAX	N	O SQ	P NPT	Q ± 1/4	R DIA	S B.C.	T O.D.	U I.D.
12	17-3/4	9	2	7-5/8	7	1-1/4	-	9/16	6	7	4-1/2
16 & 160	22-12	9-1/4	1-7/8	9-5/8	9	1-1/4	-	9/16	6	7	4-1/2
20 & 200	28	12-5/8	4	11-5/8	11	1-1/4	-	9/16	7-5/8	8-5/8	6-1/8
24 & 240	31	13-1/4	3-1/4	11-5/8	11	1-1/4	-	9/16	7-5/8	8-5/8	6-1/8
32_ & 32_0	-	15	3-1/4	13-5/8	13	1-1/4	43	5/8	9-3/4	11-1/4	8-1/4
48_ & 48_0	-	18	2-1/4	13-1/4	18	1/2 / 1-3/8	54-1/2	5/8	18-1/2	15 SQ	13-3/4
4800 **	-	18-1/2	1-3/4	15-5/8	15	1-1/4	56	5/8	11-3/4	13	9-1/2

* Add 1" for medium pressure series ** 4800 Hi pressure torch dimensions

CATALOG NUMBER EXPLANATION

Torch catalog numbers give complete information on the unit desired, except the orifice size.

The complete catalog number includes the burner number (which automatically specifies the series) and the letters designating the exact assembly required in the following order:

R - Indicates refractory block and holder.
E - Indicates elbow between injector and nozzle.
T - Incicates basic torch (nozzle, nipple, injector and cock or valve).
A - Indicates A style cage (one piece).
B - Indicates B style cage (two piece).

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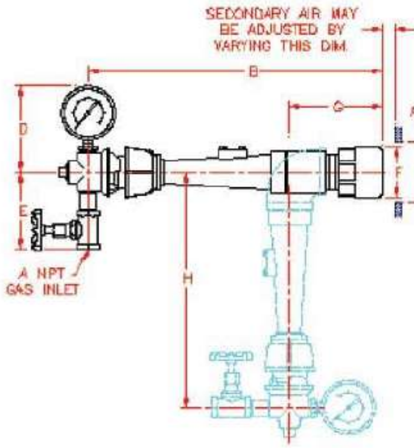
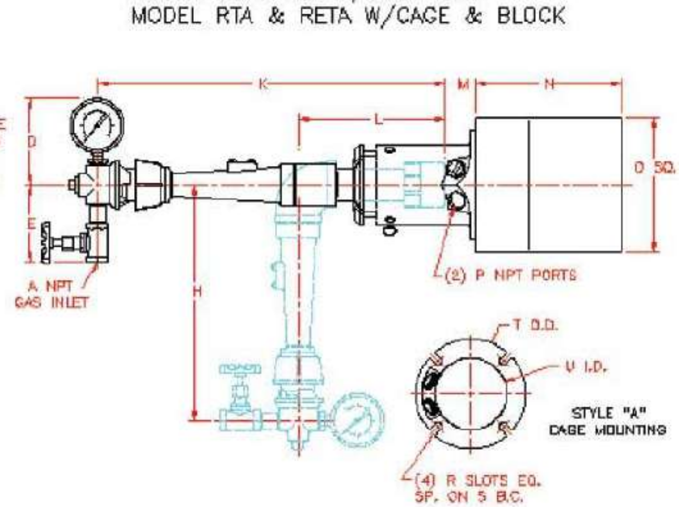
DIMENSIONS
HI-PRESSURE TORCHES

BULLETIN 3215, 3216, 3217
PAGE NO. 8

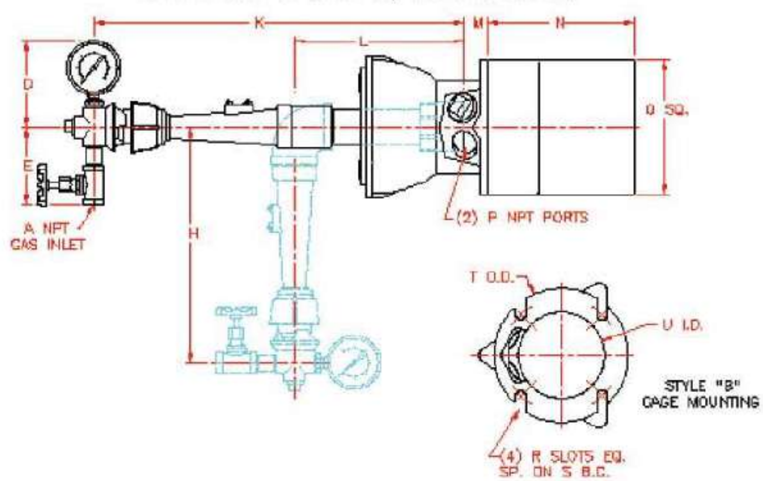
MODEL T & ET



MODEL TA & ETA W/CAGE ONLY
MODEL RTA & RETA W/CAGE & BLOCK



MODEL TB & ETB W/CAGE ONLY
MODEL RTB & RETB W/CAGE & BLOCK



DIMENSIONS
HI-PRESSURE TORCHES

BULLETIN 3215, 3216, 3217
PAGE NO. 9

All dimensions in inches
All dimensions ± 1/8" unless noted

T & ET SERIES

Torch Size	A NPT	B ± 1/4	D	E	F DIA	G	H ± 1/4
600	3/8	8-1/2	4-1/4	3-3/8	1-5/8	3-3/4	6-3/4
800	3/8	11-1/2	4-1/4	3-3/8	1-7/8	3-7/8	8-5/8
1000	1/2	14-1/8	4-1/2	4-1/8	2-3/8	4-1/2	11-1/8
1200	1/2	15-3/8	4-1/2	4-1/8	2-5/8	4-3/4	12-1/4
1600	3/4	19-1/4	5	4-3/4	3-1/4	5-5/8	16
2000	3/4	23-1/2	5	4-3/4	3-7/8	6-1/2	19-1/8
2400	1	27-3/4	5-1/8	5-3/4	4-1/2	7-1/4	23-3/8
3200	1-1/4	35-1/8	5-3/8	6-5/8	5-7/8	9-5/8	29-3/4
4800	See Low & Medium Pressure Dimensions						

TA & ETA, RTA & RETA SERIES

Torch Size	K ± 1/4	L	M MAX	N	O SQ	P NPT	R DIA	S B.C.	T O.D.	U I.D.
1000	17-1/4	7-1/2	1-5/8	7-5/8	7	3/4	7/16	4-7/8	5-3/4	3-3/4

TB & ETB, RTB & RETB SERIES

Torch Size	K ± 1/4	L	M MAX	N	O SQ	P NPT	R DIA	S B.C.	T O.D.	U I.D.
1200	16-3/8	8-7/8	2	7-5/8	7	1-1/4	9/16	6	7	4-1/2
1600	22-3/4	9-1/4	1-7/8	7-5/8	7	1-1/4	9/16	6	7	4-1/2
2000	29-1/2	12-5/8	4	9-5/8	9	1-1/4	9/16	7-5/8	8-5/8	6-1/8
2400	33-3/4	13-1/4	3-1/4	9-5/8	9	1-1/4	9/16	7-5/8	8-5/8	6-1/8
3200	40-5/8	15-1/8	3-1/8	11-5/8	11	1-1/4	5/8	9-3/4	11-1/4	8-1/4
4800	See Low & Medium Pressure Dimensions									

ORDERING INFORMATION

Orders for gas torch assemblies should show:

1. Quantity and catalog number.
2. Kind of gas and Btu/cf.
3. Gas pressure.
4. Btu each torch is to handle.
5. Draft conditions.

Examples:

10-#24 ETB -Nat. Gas (1050 Btu/cf)-6" W.C.
500,000 Btu/hr each - 0.1" - W.C. Draft.

5-#200 RTBP-Mixed Gas (800 Btu/cf)-5 PSI.
1,320,000 Btu/hr each - 0.3" W.C. Draft.

5-#1600 ET -Propane (2500 Btu/cf)-25 PSI.
250,000 Btu/hr each - Balanced Draft.

CAUTION: Operation of combustion equipment can be hazardous resulting in bodily injury or equipment damage. Each burner should be supervised by a combustion safeguard and only qualified personnel should install, make system adjustments and perform any required service.

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LOW-PRESSURE TORCH BURNER SELECTION DATA

TYPE T, ET, TA, ETA, TB, ETB, RTA, RETA, RTB & RETB

*Capacity @ draft

		3" MFD. 450-600		4" MIXED 700-850		5" NAT. 900-1200		10" PROPANE 2500		10" BUTANE 3200	
		0.0"	0.2"	0.0"	0.2"	0.0"	0.2"	0.0"	0.2"	0.0"	0.2"
#6	BTU	35000	83000	30000	61000	22000	50000	16000	40000	16000	40000
	CFH	66	157	38	76	22	50	6.4	16	5	12.5
	ORIFICE	#27	#1	#37	#25	#45	#31	#56	#48	#57	#53
#8	BTU	57000	120000	44000	96000	38000	72000	25000	62000	25000	62000
	CFH	108	226	55	120	38	72	10	25	7.8	19.4
	ORIFICE	#12	"I"	#30	#10	#38	#28	#53	#43	#54	#50
#10	BTU	82000	200000	74000	162000	55000	125000	40000	100000	40000	100000
	CFH	155	378	93	202	55	125	16	40	12.5	31
	ORIFICE	#1	11/32"	#19	1/4"	1/8"	#12	#49	#34	#50	#44
#12	BTU	105000	265000	96000	210000	70000	160000	52000	130000	52000	130000
	CFH	198	500	120	262	70	160	21	52	16	41
	ORIFICE	1/4"	25/64"	#10	9/32"	#28	7/32"	#45	#30	#46	#40
#16	BTU	165000	430000	150000	340000	110000	260000	87000	220000	87000	220000
	CFH	310	790	188	427	110	260	35	88	27	69
	ORIFICE	5/16"	33/64"	15/64"	23/64"	#16	"I"	#38	#19	#41	#22
#20	BTU	250000	630000	220000	500000	175000	380000	125000	310000	125000	310000
	CFH	460	1190	275	625	175	380	50	124	39	97
	ORIFICE	23/64"	41/64"	9/32"	7/16"	#2	21/64"	1/8"	#7	#31	#12
#240	BTU	375000	930000	340000	740000	250000	560000	185000	460000	185000	460000
	CFH	710	1760	425	925	250	560	74	184	58	144
	ORIFICE	15/32"	23/32"	23/64"	35/64"	17/64"	"X"	#24	"C"	#28	#1

CAPACITY MULTIPLIER FOR DRAFTS OTHER THAN 0.0" & 0.2"

DRAFT - INCHES W.C.	0.05	0.1	0.2	0.3	0.4	0.5
MULTIPLIER	0.5	0.7	1.0	1.2	1.4	1.6

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LOW-PRESSURE TORCH BURNER SELECTION DATA

TYPE T, ET, TA, ETA, TB, ETB, RTA, RETA, RTB & RETB

*Capacity @ draft

		3" MFD. 450-600		4" MIXED 700-850		5" NAT. 900-1200		10" PROPANE 2500		10" BUTANE 3200	
		0.0"	0.2"	0.0"	0.2"	0.0"	0.2"	0.0"	0.2"	0.0"	0.2"
#321	BTU	510000	125000	460000	1000000	340000	750000	250000	625000	250000	625000
	CFH	960	2360	575	1250	340	750	100	250	78	195
	ORIFICE	37/64"	59/64"	13/32"	39/64"	5/16"	29/64"	#16	9/32"	#19	17/64"
#322	BTU	650000	1600000	590000	1300000	430000	960000	320000	800000	320000	800000
	CFH	1230	3020	740	1620	430	960	128	320	100	250
	ORIFICE	21/32"	1-1/16"	15/32"	23/32"	"S"	35/64"	#7	"O"	#11	5/16"
#323	BTU	750000	1850000	670000	1500000	500000	110000	375000	940000	375000	940000
	CFH	1420	3500	840	1880	500	1100	150	376	117	294
	ORIFICE	45/64"	1-1/8"	1/2"	25/32"	3/8"	37/64"	7/32"	11/32"	#5	21/64"
#481	BTU	850000	2100000	780000	1700000	570000	1300000	425000	1100000	425000	1100000
	CFH	1600	3960	975	2120	570	1300	170	440	133	344
	ORIFICE	3/4"	1-3/16"	9/16"	13/16"	"X"	5/8"	15/64"	3/8"	#2	23/64"
#482	BTU	1000000	2500000	930000	2000000	680000	1500000	500000	1300000	500000	1300000
	CFH	1890	4720	1160	2500	680	1500	200	520	157	407
	ORIFICE	13/16"	1-5/16"	5/8"	29/32"	7/16"	11/16"	1/4"	"Y"	"B"	25/64"
#483	BTU	1250000	3100000	1100000	2500000	830000	1850000	620000	1600000	620000	1600000
	CFH	2360	5850	1380	3130	830	1850	248	640	194	500
	ORIFICE	29/32"	1-15/32"	21/32"	1"	31/64"	3/4"	9/32"	29/64"	17/64"	27/64"
#484	BTU	1400000	3500000	1280000	2800000	930000	2100000	700000	1800000	700000	1800000
	CFH	2640	6600	1600	3500	930	2100	280	720	219	563
	ORIFICE	31/32"	1-9/16"	927680	1-1/16"	17/32"	13/16"	19/64"	15/32"	9/32"	29/64"
#485	BTU	1550000	3800000	1400000	3000000	1020000	2300000	760000	2000000	760000	2000000
	CFH	2920	7170	1750	3750	1020	2300	304	800	238	625
	ORIFICE	1-1/32"	1-5/8"	3/4"	1-3/32"	9/16"	27/32"	5/16"	1/2"	"L"	15/32"

CAPACITY MULTIPLIER FOR DRAFTS OTHER THAN 0.0" & 0.2"

DRAFT - INCHES W.C.	0.05	0.1	0.2	0.3	0.4	0.5
MULTIPLIER	0.5	0.7	1.0	1.2	1.4	1.6

CAUTION: Operation of combustion equipment can be hazardous resulting in bodily injury or equipment damage. Each burner should be supervised by a combustion safeguard and only qualified personnel should install, make system adjustments and perform any required service.

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HI-LO TORCHES
HIGH TURNDOWN ATMOSPHERIC BURNER

MODEL: 3220, 3221, 3222, 3223, 3224, 3225

REVISON 0

BULLETIN 3220-3225

FEATURES

- 16 to 1 turndown with 10 PSIG gas
- 10 to 1 turndown with standard pressure gas
- No air blower needed
- One valve automatic control
- Low cost proportioning system
- Not afected by variations in draft
- High heat releases
- Simple rugged construction
- Minimum maintenance

USES

- Air heaters
- Boilers
- Chemical stills
- Heat exchangers
- Ovens
- Draft furnaces
- Dryers
- Kilns

DESCRIPTION

Hi-Lo Torches are atmospheric gas burners designed for high turndown ranges on all types of combustion chambers or furnaces operating under a negative pressure.

Combustion chamber draft induces all combustion air. No air blower or mixer is required. Atmospheric type venturi correctly proportions air and gas flows and delivers uniform mixture to burner nozzle.

Exclusive pressure actuator controls burner nozzle stabilizer disc with changes in gas flow to maintain stable flame. A single modulating gas valve controls fuel pressure automatically.

High efficiency Pyronics AN type nozzles used on each assembly provide excellent flame retention at all firing rates and drafts.

Hi-Lo Torches are available in three assembly options. Assemblies "B" and "C" include a burner mounting cage complete with secondary air adjustable shutter and tapped holes for precision mountings of pilots and flame detectors.

The simplicity of an atmospheric torch combined with the high turndown actuator provides an easily adjustable system requiring little if any maintenance.

Novel design minimizes effect of draft variation on burner flame characteristics.

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HI-LO TORCHES

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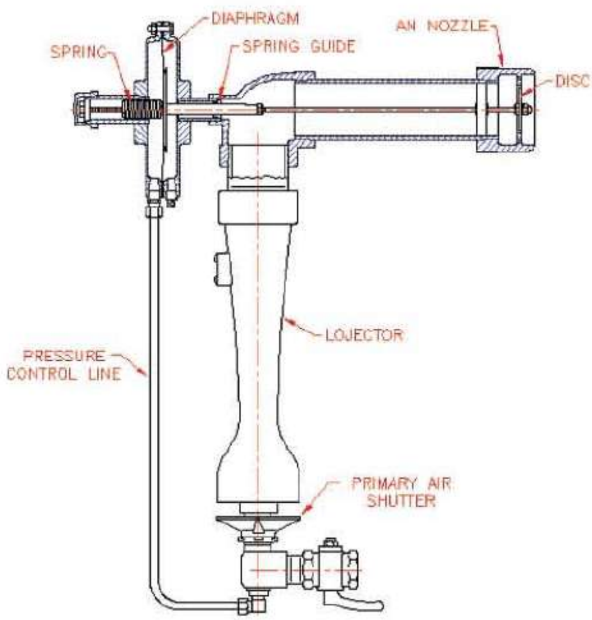
OPERATION

Standard Atmospheric Torches use draft to induce combustion air into the systems. This draft air is independent of gas flow and is constant at all input rates. With reduced gas flow the mixture quality usually becomes leaner and approaches unstable ratios, limiting turndown capacity to less than 2 to 1 on the standard torch.



Hi-Lo Torches use a diaphragm and spring coupled by an operating rod to the port disc. With the modulating valve open, full gas pressure is applied to the diaphragm and gas orifice. The gas pressure force on the diaphragm overrides the spring force and moves the diaphragm assembly towards the nozzle. The operating rod moves the disc to an open position providing full nozzle capacity. The gas orifice size sets the maximum gas flow and the air shutter adjustments control the desired primary air flow.

On turndown both the gas flow through the orifice and the pressure on the diaphragm are reduced. Spring force retracts the nozzle disc closing the burner port area reducing induced draft flow in proportion to gas flow.

Air-Gas mixture ratios remain within stable limits at all input rates.

The spring guide effectively seals the draft from the operating diaphragm even with very high drafts of up to 6" W.C.

CONTROL

The Hi-Lo Torch is designed for automatic control with a single gas flow control valve. Pneumatic, electric or direct actuator drives are coupled to proportioning valves. Recommended minimum travel time from high to low fire is 5 seconds. This time is necessary to coordinate the nozzle disc movement with the gas flow changes.

CAPACITY

Hi-Lo Torch capacities are limited by combustion air induced by operating draft and gas pressures at the orifice. Size selection should be based on both factors.

Table I lists the maximum capacities of Hi-Lo Torches at 0.1 inch W.C. draft and various gas pressures. Multipliers for other drafts are listed in Table II.

Capacities shown in Table I and multipliers in Table II are based on maximum primary air shutter openings and 30% primary aeration on standard pressure gas and 50% on medium pressure gas.

HI-LO TORCHES

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TABLE I - CAPACITY: ALL FUEL GASES
BTU/HR @ 0.1 INCH W.C. DRAFT

Burner Number	Inlet Gas Pressure			
	STD. 6 inch W.C.	2 PSIG	5 PSIG	10 inch PSIG
12 HLT	120,000	280,000	440,000	600,000
16 HLT	200,000	390,000	610,000	860,000*
20 HLT	300,000	700,000	1,100,000	1,500,000
24 HLT	440,000	850,000	1,300,000	1,800,000*
321 HLT	580,000	1,270,000	2,000,000	2,700,000
322 HLT	740,000	1,770,000	2,750,000	3,800,000*
323 HLT	850,000	1,980,000	3,000,000	4,200,000*
481 HLT	1,000,000	2,470,000	3,850,000	5,250,000
482 HLT	1,200,000	2,970,000	4,600,000	6,300,000*
483 HLT	1,420,000	3,540,000	5,500,000	7,700,000*
484 HLT	1,610,000	4,100,000	6,300,000	8,900,000*
485 HLT	1,800,000	4,250,000	6,600,000	9,300,000*

* At these capacities additional secondary air openings are required.

TABLE II
DRAFT vs CAPACITY MULTIPLIER

Draft - Inches W.C.	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1
Multiplier - Low Pressure	.75	1	1.4	1.7	2	2.2	2.4	2.8	3.2
Multiplier - Medium Pressure	0.9	1	1.1	1.2	1.3	1.35	1.4	1.6	1.7

HI-LO TORCH INITIAL ADJUSTMENT

1. Open secondary air cage shutter full and primary air shutter 1/4".

2. Check pilot flame. This should be blue, stable and extend to main nozzle.

3. Slowly open manual gas shut-off valve and verify main burner ignition.

4. At high fire (maximum input), set primary and secondary air shutters for desired flame. Opening primary air shortens flame. Flame color normally should be blue with red to orange tails.

5. Throttle gas flow slowly and observe flame. Set low fire stops on valve at minimum pos ition.

6. The actuator spring is factory set to begin closure at 2 inch W.C. on standard press. models and 1.5 PSIG on medium press. units. These settings normally do not require adjustment.

7. On standard pressure models, if the flame flashes back beyond the burner or be comes unstable during the turndown test, close the primary air shutter slightly or re set the actuator spring (clockwise adjust ment) for faster disc closure or both as re quired.

8. Tighten lock screws on secondary air con trol cage and primary air shutter locknut.

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HI-LO TORCHES

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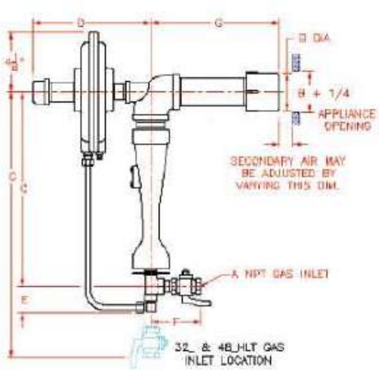
OPTIONS AND DIMENSIONS

"A" ASSEMBLY

Basic burner which includes nozzle, lojector, actuator, port disc, gas cock and tubing.

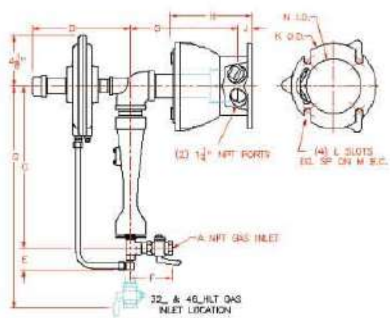
Used for gap firing.



"B" ASSEMBLY

Basic burner with secondary air control mounting cage.

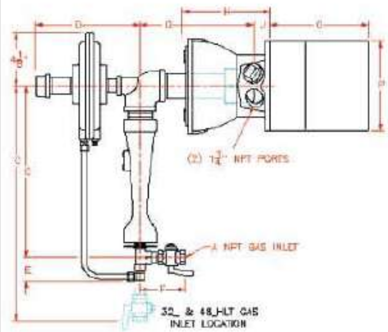
Used on metal lined combustion chambers.



"C" ASSEMBLY

Basic burner with secondary air control mounting cage and pre-fired refactory block.

Used on refractory lined combustion chambers.



DIMENSION TABLE
Inches ± 1/8

Model	A NPT	B	C	D	E	F	G	H	J	K	L	M	N	O	P SQ	Shipping Weight Lbs.		
																A	B	C
12 HLT-	1/2	2-5/8	13- /8	8-1/8	1-7/8	3-1/2*	9	6-3/4	2	7	9/16	6	4-1/2	7-5/8	7	20	30	55
16 HLT-	1	3-1/4	18-3/4	8-3/8	2-1/8	4-3/4*	9-1/4	6-3/4	1-7/8	7	9/16	6	4-1/2	9-5/8	9	28	38	88
20 HLT-	1	3-7/8	21-3/4	8-3/4	2-1/8	4-3/4*	12-5/8	9-5/8	4	8-5/8	9/16	7-5/8	6-1/8	11-5/8	11	42	43	131
24 HLT-	1	4-1/2	24-3/4	9-1/8	2-1/8	4-3/4*	13-1/4	9-5/8	3-1/4	8-5/8	9/16	7-5/8	6-1/8	11-5/8	11	53	54	142
32_HLT-	1-1/4	5-7/8	37-3/8*	10-1/8	-	-	15	10-5/8	3-1/4	11-1/4	5/8	9-3/4	8-1/4	13-5/8	13	74	94	210
48_HLT-	1-1/2	7-1/2	49-3/4*	13-3/8	-	-	17	8-7/8	2-1/4	15 SQ	5/8	18-1/2	13-3/4	13-1/4	18	219	275	570

* Dimensions shown for HLT-L model, for HLT-M add approximately 3/4" to dimensions.

BURNER SELECTION PROCEDURE

1. Determine total HTU/HR input required.
2. Divide total BTU/HR input by number of burners desired to obtain individual burner input.
3. In Table I find capacity equal to desired BTU/HR input in column of available gas pressure and specify basic burner catalog number. Use multi plier Table II for drafts other than 0.1" W.C.
4. If available gas pressure is 6" W.C. to 2 PSIG add suffix "L" to basic catalog number. If the gas pressure is 2 PSIG to 10 PSIG add suffix "M" to basic catalog number.
5. Select burner assembly desired and add suffix "A," "B" or "C."

Example: 16HLT-LB Hi-Lo Torch Natural gas 6" W.C. 0.1" W.C. Draft (200,000 BTU/hr)