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Topical Report

Advanced IR Products and Services

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Advanced IR Products and Services

Topical Report

by

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13. ABSTRACT ***(Maximum 200 words)***

IR heating has important applications in drying, curing, and baking operations in the plastics thermoforming, pulp and paper, metal finishing, food processing, and textiles industries. In addition, a significant market exists in the commercial area for applications such as space heating, cooking, and packaging. Technical information and specifications for IR heaters are deficient because of non standard test protocols and due to the fact that comprehensive and modern test equipment are not available to all the users, manufacturers, and suppliers. GTI addressed this shortfall by developing an IR Test Facility using a standardized test protocol and providing product development collaboration. GTI test protocol focused on the systematic and proper determination of important thermal and combustion characteristics of infrared radiant heaters, viz., radiant and combined heat flux distributions, spectral intensity, thermal response times, and emissions indices. In addition GTI supports product development, application evaluation, and benefit analysis of IR heaters. This project discusses IR market study, major applications of IR heating currently used with future potential markets, introduction to IR heating with different types of IR heaters and GTI IR Test Facility development

RESEARCH SUMMARY

Title Advanced IR Products and Services

Objective Main objectives of this project included: IR burner market study, applications of infrared heating technology, classification of different IR heaters, typical results on thermal and combustion characteristics of gas and electric heaters, and the development of Test Facility at GTI .

Technical Perspective In-spite of diversified uses of IR heating in thermoforming, powder coating, pulp and paper, and annealing industries for drying, heating, and curing operations, the thermal and combustion characteristics of IR heaters have not been consistently reported. The reason is that there has not been standardized testing procedures or standard test protocols developed.

Technical Approach This report summarizes the background of IR heating, a market survey of infrared heating industries, a summary of test results available for typical gas fired and electrical heaters, and the establishment of an IR test Facility at the GTI Combustion Laboratory complete with test and evaluation hardware and software.

Results A survey of the existing and projected IR markets shows that IR heaters have great promise for a variety of applications. The results available on different types of IR heaters with respect to their radiant and combined radiant and convective efficiency, spectral intensity, heat-up and cool-down times, and emission analyses show considerable disagreement. The Test Facility developed at GTI is expected to bridge the gap of these anomalies with its standardized test procedures and test protocol.

Project Implications GTI IR Test Facility is available to support IR R&D and product development projects on behalf of manufacturers, end users, testing agencies, and utilities for independent testing.

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Introduction

The efficient use of natural gas to minimize environmental impact has been the major source for the development of gas fired infrared heaters. With the recent introduction of metal fiber heaters in the IR market, the surface combustion has received phenomenal increased interest. Surface combustion of premixed gas and air can occur in two modes depending on the intensity:

- Radiant with red-orange flame- where combustion occurs inside a porous structure, which heats to incandescence and releases a portion of energy input as thermal radiation
- Convective with blue flame-the flame is attached with the porous structure

Gaz de France has recently developed a unique burner with a high power output of 1.3 million Btu/ft^2. It is expected that development of such a technology will rule out a misconception on one hand that the IR heaters are limited by low intensity while dramatically reducing the NO_x on the other.

Currently, there are two major classes of gas IR heaters-catalytic and open flame. Catalytic heaters generate heat by oxidizing natural gas with the aid of a catalyst on a porous flame support pad. They are characterized by flameless operation, relatively low operating temperatures (400-1000^{o}F) and relatively low radiant flux densities (up to 8000 Btu/hr ft^2). They are being widely used in plastic sheet thermoforming and powder coat finishing lines. Open-flame IR burners (ported metal and ceramic, reticulated ceramic, and fiber matrix) operate in a temperature range of 1200 to 1700^{o}F with heat flux densities from 20,000 to 100,000Btu/hr ft^2. At present, there is immediate need of a class of burners for the intermediate range, i. e., between the maximum performance of catalytic units and the minimum of the open flame type high flux heaters.

GTI has developed vigorous programs designed to better understand the performance of IR heaters and their application in various processes. Work is ongoing to map radiant and combined efficiencies, spectral intensities, thermal response times, and pollutants emissions indices. Some work has been done on the development of a variable temperature, low cost, catalytic heaters for thermoforming. Radiant structures and modeling of IR heater's performance is also being done. Predictive models for heating in curing, drying, and thermoforming are under development. Alliances have been formed with organizations targeting support services for powder coating, food processing, plastics thermoforming, and paper drying applications. These service organizations will help in:

- Evaluation of infrared and convective heating options
- Independent evaluation of various infrared heating options
- Establishment of heating and/or curing times
- Oven retrofit options
- Productivity or heating quality improvement options
- New oven designs
- Process efficiency improvements
- Emissions data

Overall Objectives

The main objectives of the proposed project included:

- Evaluation of an infrared market study
- Major applications of IR heating currently used
- Potential future IR heating markets
- Infrared heating technology
- Classification of IR heaters
- A comparative study of different IR heaters
- GTI IR Test Facility development

Evaluation of an IR market study

Natural gas IR heating has important applications in drying, curing, and baking operations in the plastics thermoforming, pulp and paper, metal finishing, food processing, and textiles industries. In addition, a significant market exists in the commercial area for applications such as space heating, cooking, and packaging. According to a recent survey by The Martec Group gas fired IR represents approximately 25% of all IR installations in the US market (Figure 1).

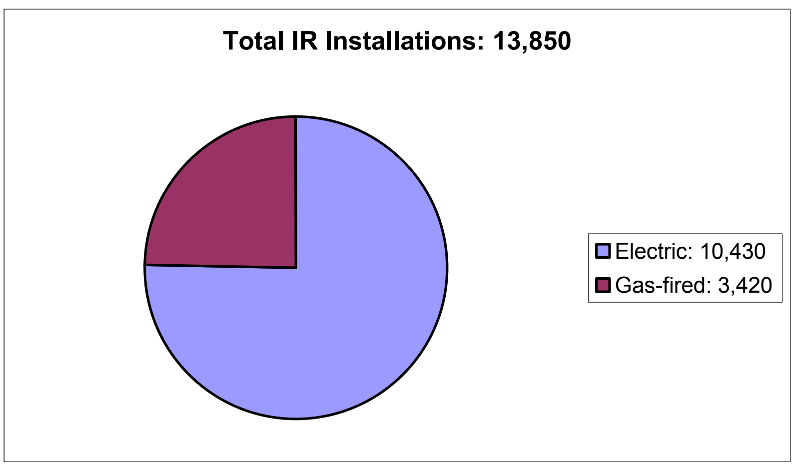


Figure 1. Electric versus gas-fired IR units

Major Applications of IR heating and Potential Future IR Markets

Gas fired IR represents approximately 31 billion cubic feet or about 17% of the cumulative gas load in the thermoforming, paints and coatings, paper, and textiles industries. Figure 2 shows current IR heating applications in representative industries. Figure 3 shows potential, new gas IR heating applications. Based solely on capturing all current IR installations (taking share from electric IR) the potential for gas fired IR is approximately 83 BCF per year.

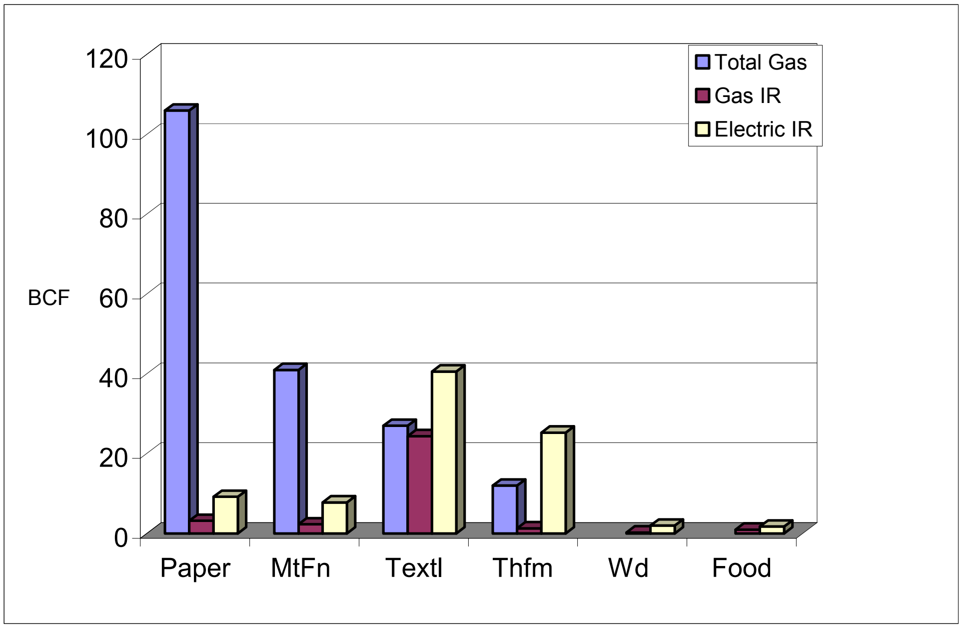


Figure 2. Current IR Heating Applications

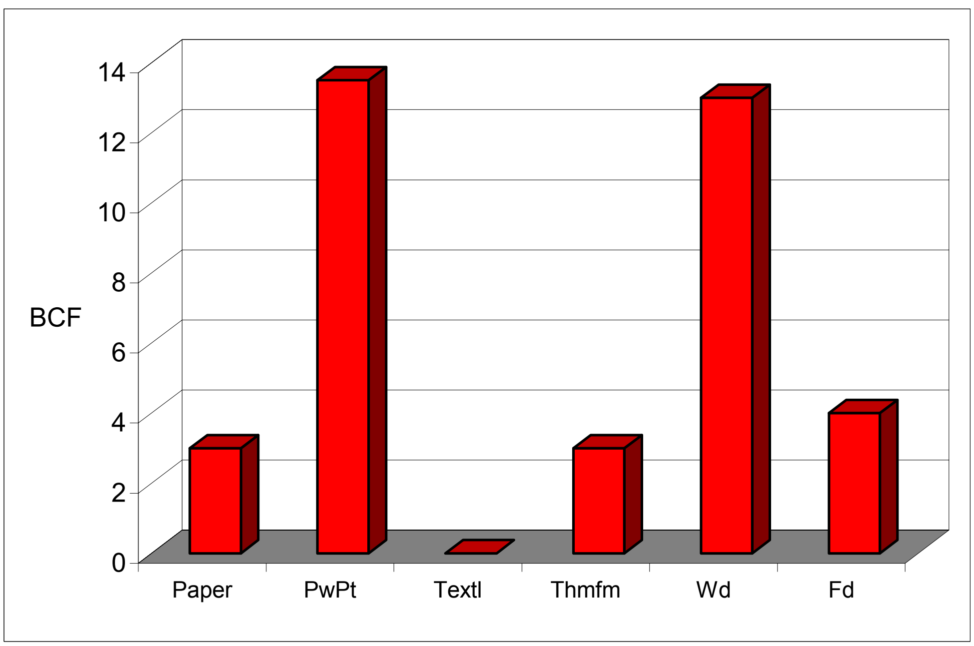


Figure 3. Potential, New Gas IR Heating Applications

IR Heating

Figure 4 shows the spectrum of electromagnetic radiation. The radiation emitted in the wavelength range of about 0.7 micrometers to 100 micrometers is termed as infrared radiation. All the gas fired and electric IR heaters emit their radiant energy within a window of approximately 0.7 to 10 micrometers. High flux radiant heaters emit most of their energy between 0.7 to 6 micrometers while the low flux catalytic heaters emit most of their energy in a wider band of 0.7 micrometers to about 10 micrometers.

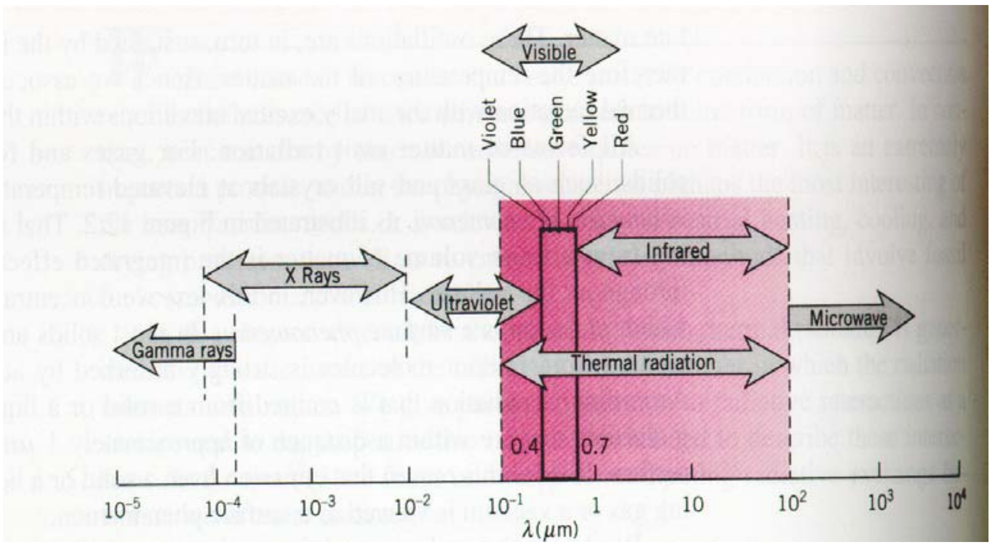


Figure 4. Spectrum of electromagnetic radiation

Types of Heaters

Infrared heaters can be broadly categorized into low (4.5 to 7.0 kBtu/hr ft^2) and high (30-150 kBtu/hr ft^2) radiant flux heaters (Figure 5). Low radiant flux heaters are catalytic heaters which may be diffusion type or partial premix types. These heaters are known for negligible NOx, low CO (5-30 ppm), and high unburned hydrocarbons (500-4000 ppm). High radiant flux heaters are homogeneous (since they offer a homogeneous reaction between fuel gas and air as against catalytic heaters where fuel gas reacts with air at the catalyst surface, making it a heterogeneous reaction). These heaters can be further categorized as submerged, surface, and flame impingement types. Submerged combustion takes place in reticulated ceramic heaters. The flame is called in-situ if the ceramic surface has no support. The flame is called externally submerged if it is sandwiched between the ceramic surface and the support grid. Surface combustion takes place in ported metal, ported ceramic, sintered metal fiber, and similar heaters. Special ported ceramic heaters with slots are especially built for flame impingement. The flame thus gives radiant and convective heat to the ceramic surface, which in turn, radiates back to the load. All these homogeneous heaters are pre-mixed type and typically show NOx concentration 5-20 ppm, CO less than 50 ppm, and negligible unburned hydrocarbons.

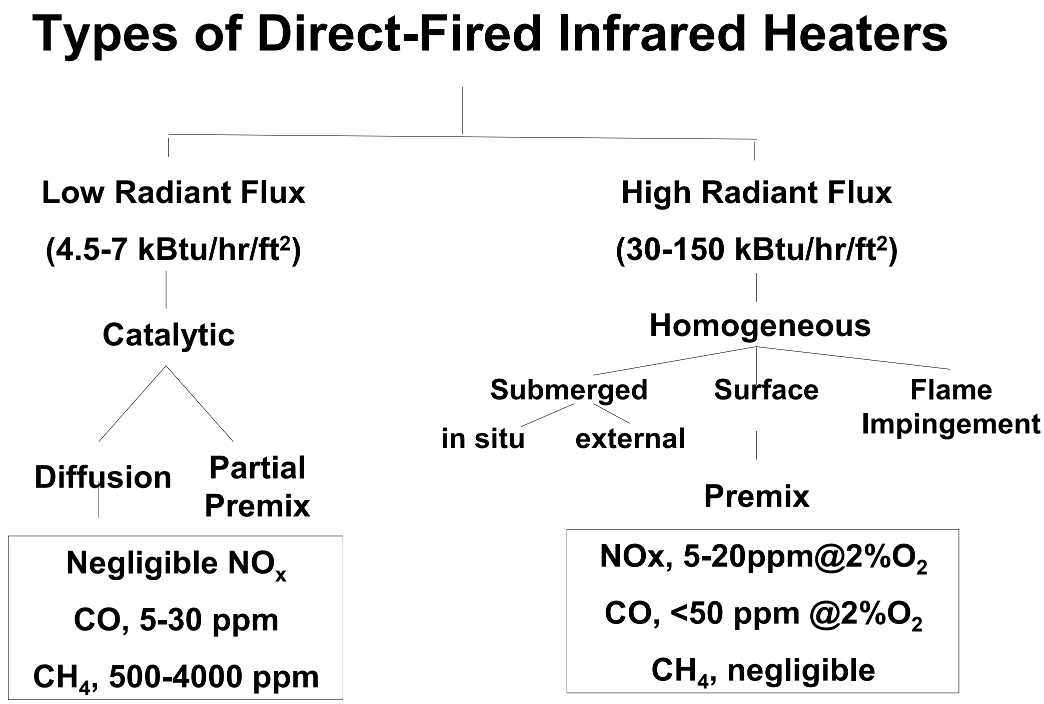


Figure 5. Types of Gas Fired Heaters

Comparative Study of Different Heaters

Figure 6 shows a comparison of radiation efficiency of different high flux radiant heaters as a function of firing rate. The data clearly show that the externally submerged heaters have the highest radiant efficiency and the impingement type heaters have the lowest radiant efficiency. Insitu submerged and surface combustion type heaters have intermediate efficiencies. The topmost curve corresponds to an ideal situation when the equivalence ratio is 0.9 and emissivity is 1.0.

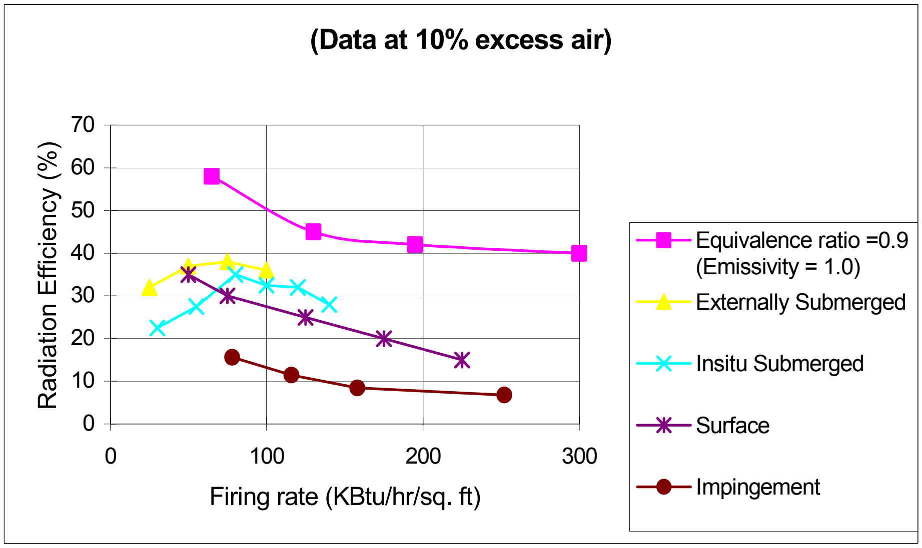


Figure 6. Radiant Efficiencies of High Flux Gas Heaters

Figure 7 shows a comparison of radiation efficiency of different electrical heaters as a function of input power. It shows that out of 11 different types of heaters studied, only three showed efficiency above 70%, all others showed maximum efficiency of about 60%.

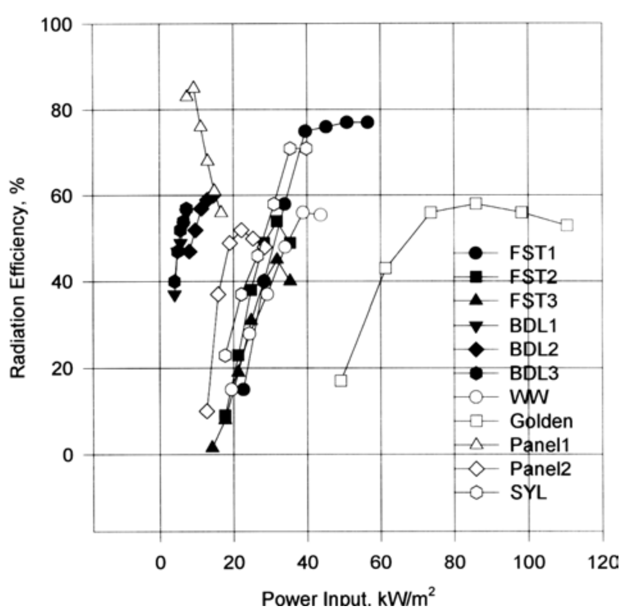


Figure 7. Radiant Efficiencies of Electrical Heaters

Figure 8 shows a comparison of high and low flux gas fired radiant heaters and electrical heaters. An important point to note is that the electrical heaters have maximum input energy of about 20 kBtu/hr ft^2 and the gas heaters have the maximum input of up to about 200 kBtu/hr ft^2.

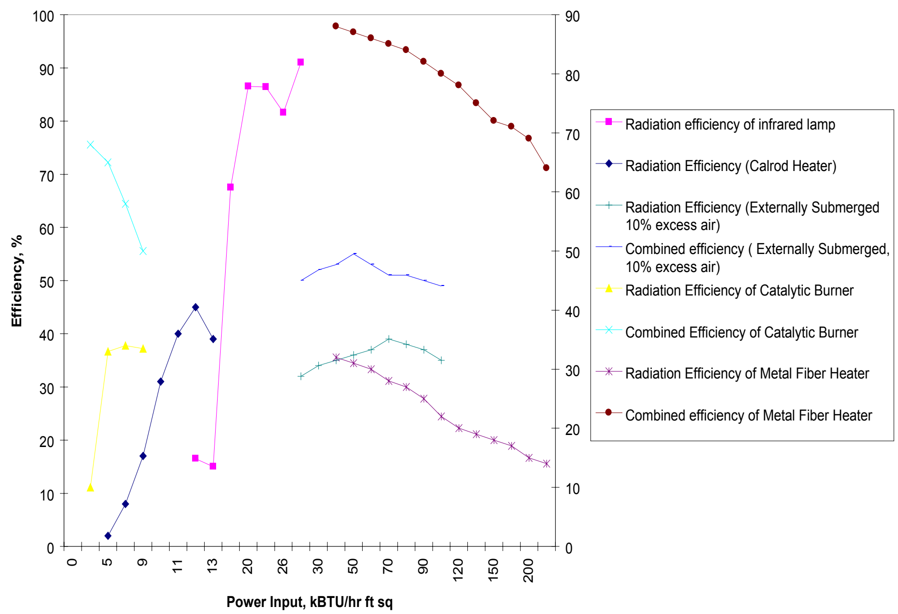


Figure 8. Comparison of High and Low Flux Gas and Electrical Heaters

Figure 9 shows a comparison of spectral intensities of typical electric and gas heaters. The figure shows that electric heater receives only 9 kBtu/hr ft^2 power input while the gas heater receives 75 kBtu/hr ft^2 power input. Note that the temperature of both the heaters are comparable (1700 versus 1868^{o}F). The spectral intensity of gas heater is a 3.5 order of magnitude higher than the electric heater.

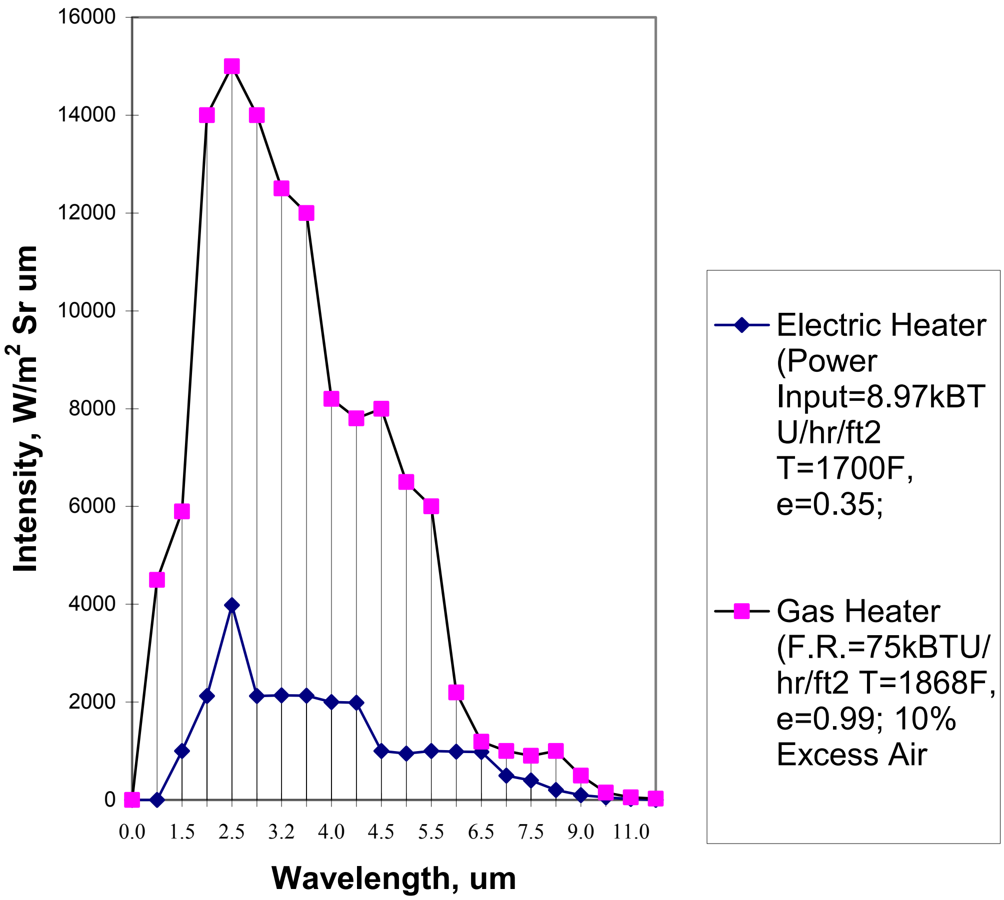


Figure 9. Comparison of Spectral Intensities of Typical High Flux Gas and Electrical Heaters

Figure 10 shows thermal response times for surface combustion type gas heaters. Five different types of ported ceramic heaters from different manufacturers were compared. It can be seen that the heating time for heaters varies from 4 to 15 minutes and similarly, cooling time varies from 4 to 20 minutes. This range of heating and cooling times is typical of all the gas fired heaters. Catalytic heaters take at least 15 more minutes to preheat their catalyst before firing the heater.

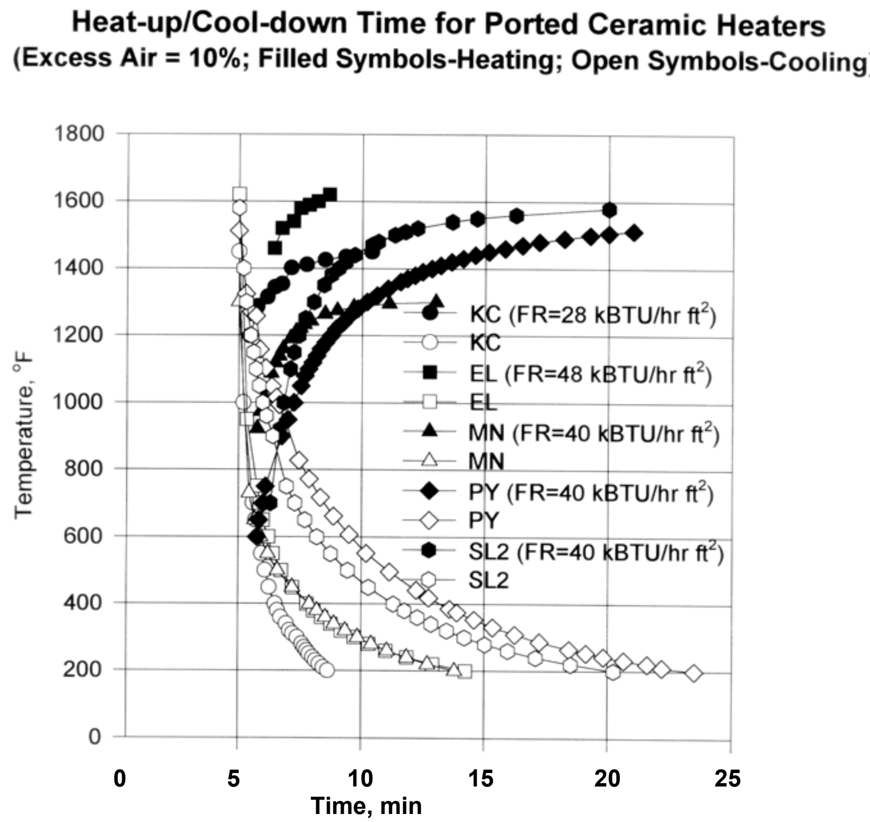


Figure 10. Thermal Response Times for Typical Surface Combustion Gas Heaters.

Figure 11 shows thermal response times for typical electric heaters. A comparative study was done with metal rods/coils type heaters from three different manufacturers. The heaters take 5 to 10 minutes to reach their highest temperatures and 10 to 25 minutes to cool to about 200°F. This thermal response is typical of most electrical heaters.

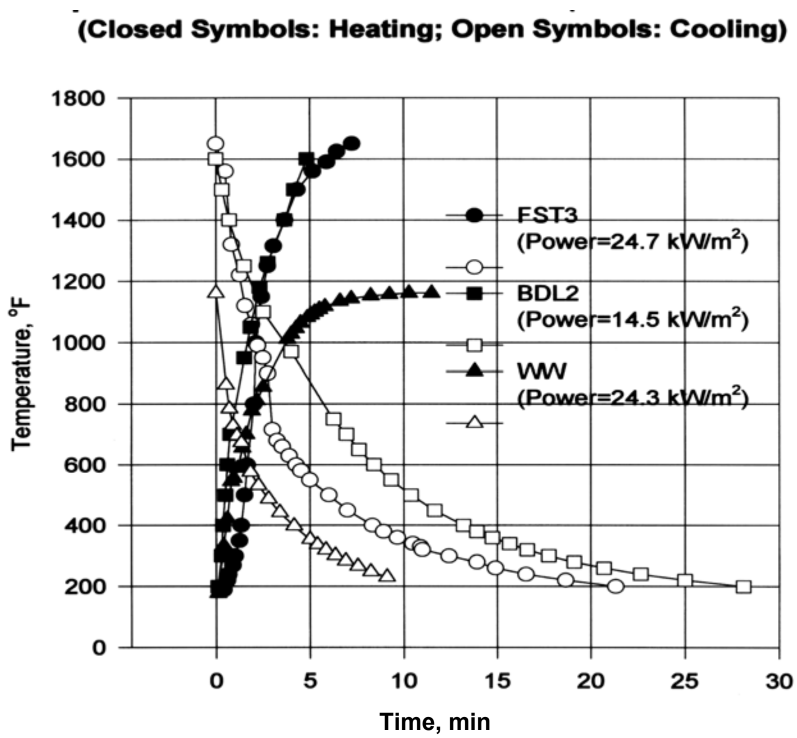


Figure 11. Thermal Response Times for Electrical (Metal Rods/Coils) Heaters.

Figure 12 shows emissions analysis from 3 typical catalytic heaters supplied from two different manufacturers. It may be noted that the Heater #3 had been in service for more than a year, while Heaters #1 and 2 were new. CO emission in the three heaters was less than 25 ppm. In case of Heater #3 very high unburned hydrocarbons was produced because of excessive methane slippage which may be attributed to the catalyst degradation with time.

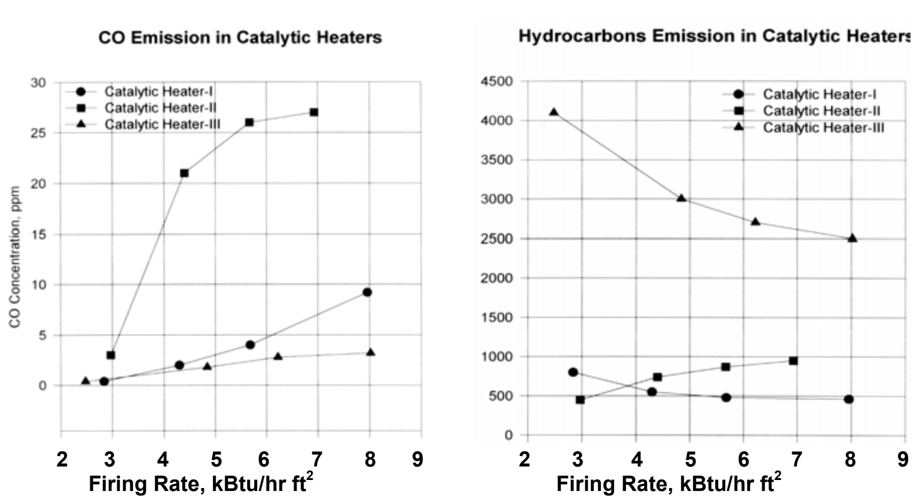


Figure 12. Emissions Analysis of Typical Catalytic Heaters.

GTI IR Test Facility Development

The thermal and combustion characteristics of IR heaters available in the market provided by manufacturers are based on non-standardized test protocols conducted by individual laboratories using non-standard instrumentation and equipment. The reason for this deficiency is primarily because individual laboratories do not have expensive instrumentation to meet the desired accuracy and precision of the measurements. As an example, radiation efficiency of these heaters reported by different suppliers/vendors varies from 20% to 55%. Although the major contributing factor for the difference in efficiency is because of different categories of heaters (ported metal, fiber metal, ported ceramic, reticulated ceramic, catalytic, etc.) an equally important reason is that the results are not standardized due to non-availability of a standard protocol for the tests. Similarly, other performance characteristics of these heaters vary widely from laboratory to laboratory and from one vendor to the other. The technical information and specifications for IR heaters are deficient because:

- Non standard test protocols are used
- Comprehensive and modern test equipment is not available
- Product development, application evaluation, and benefit analysis is not supported

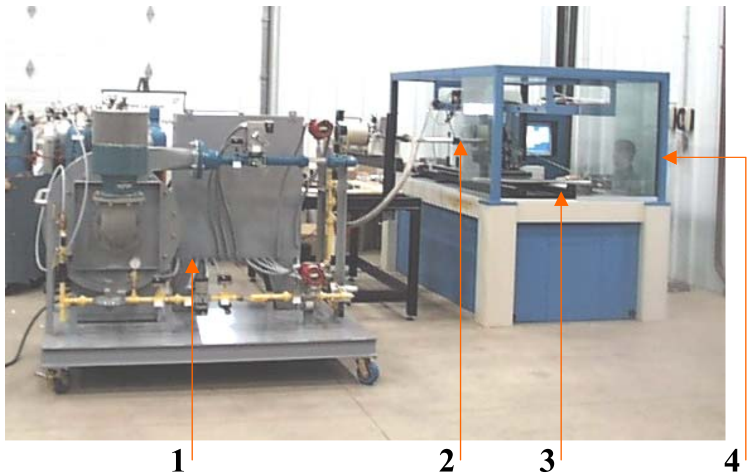
GTI addressed this shortfall by developing an IR Test Facility using a standardized test protocol. GTI test protocol focused on the systematic and proper determination of important thermal and combustion characteristics of infrared radiant heaters as mentioned below:

- Max and Min Power density (kW/m^2) ($Btu/sec\text{-}ft^2$)
- Heat Flux Density and uniformity (kW/m^2) ($Btu/ft^2\text{-}sec$)
- Average surface temperature
- Radiant efficiency (fraction of fuel heating value converted to thermal radiation)
- Combined efficiency (sum of combined radiant and convective energy generated from fuel)
- Spectral intensity ($W/m^2.sr.\mu m$) as a function of wavelength (μm)
- Emissivity of emitter
- Thermal response (heat-up and cool-down times) and
- Emissions indices (concentration of CO, NO_x, and unburned hydrocarbons)

GTI Test Facility is equipped with:

- Fully automatic measurement and determination of radiant energy distribution as opposed to manual and time-consuming procedures
- Automatic measurement and determination of combined radiant and convective energy distribution (conventional calorimetric method suffers with heat losses and is time-consuming)
- Spectral intensity determination in a very short time by automatically changing filters, gratings, and detectors
- Emissions measurement through a custom-built hood attached to the heater avoiding ambient air being drawn in and diluting the sample
- Automatic determination of heat-up and cool-down times, isolating human errors.

Figure 13 shows an overall view of the state-of-the-art Test Facility at GTI. (1) Combustion rig consists of blower, natural gas valve train, air valve train, a venturi mixing device and a control panel. (2) Sensor tube assembly houses water cooled total heat flux sensor or water-cooled and nitrogen-purged radiant heat flux sensor. (3) Optical table has monochromator assembly fixed on it. (4) Enclosure system helps housing the entire optics and enhances performance by avoiding dust, air current, and thermal variations.

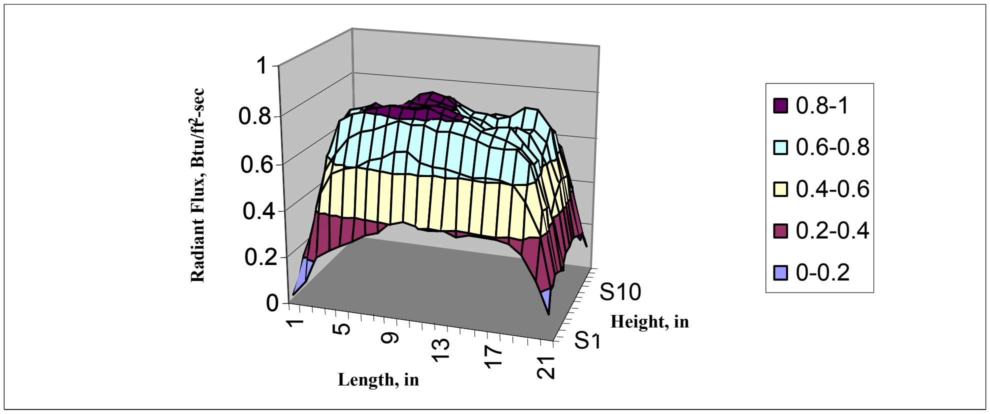


1. Combustion Rig; 2. Sensor Tube Assembly; 3. Optical Table; 4. Enclosure System

Figure 13. GTI IR Test Facility.

In addition, the Test Facility is equipped with the Burner Stand Assembly, Horizontal and Vertical Positioning System with Controller, Monochromator, UV and IR Detection Instrument, Heat Flux Sensors and Heat Flux Meter, Blackbody Source and Controller, and Emissions Analyzers. The Facility also has a computer system for data acquisition, storage, and processing.

Figure 14 shows typical results on the distribution of radiant heat flux and combined radiant and convective heat flux of a catalytic heater measured by GTI's heat flux sensor assembly. The figure shows that the catalytic heater has a fairly good distribution of radiant and combined heat flux over the entire surface of the heater.



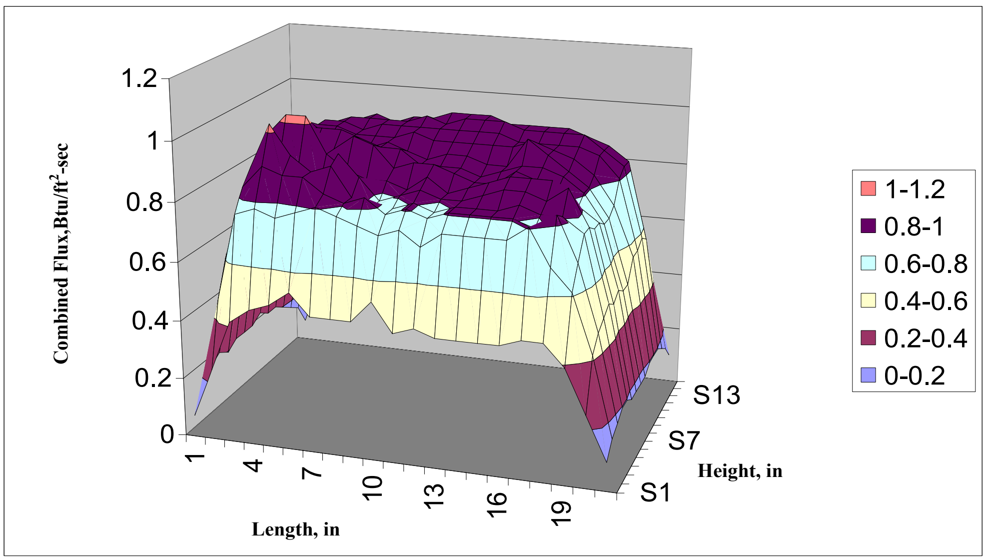


Figure 14. Radiant and Combined Heat Flux Distributions of a Typical Catalytic Heater.

Spectral intensity of a typical metal fiber heater measured by GTI's Test Facility is as shown in Figure 15. Close agreement between the measurements and the theoretical Planck Distribution Equation shows the accuracy of the test instruments.

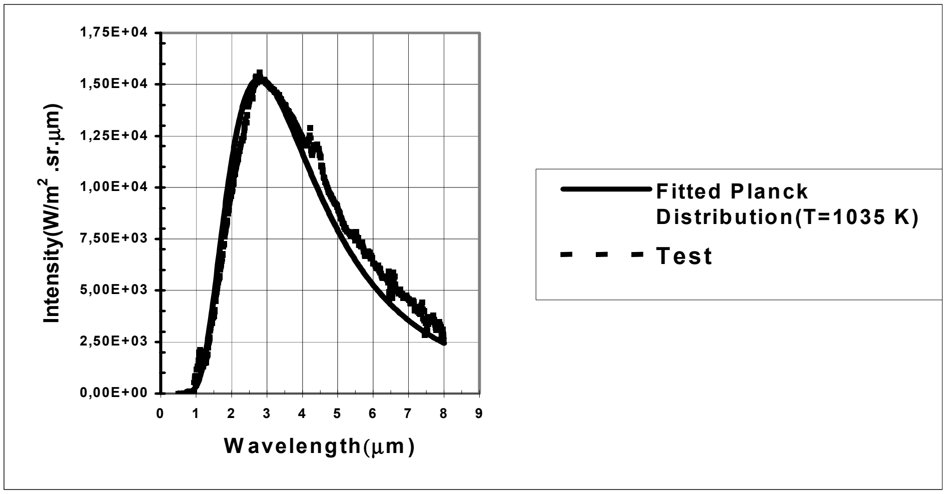


Figure 15. Spectral Intensity of a Typical Metal Fiber Heater (10 kBtu/hr.ft^2, 10% Excess Air)

Figure 16 shows typical heat-up and cool-down curves for an electric heater obtained by GTI's automatic thermal response measurement unit.

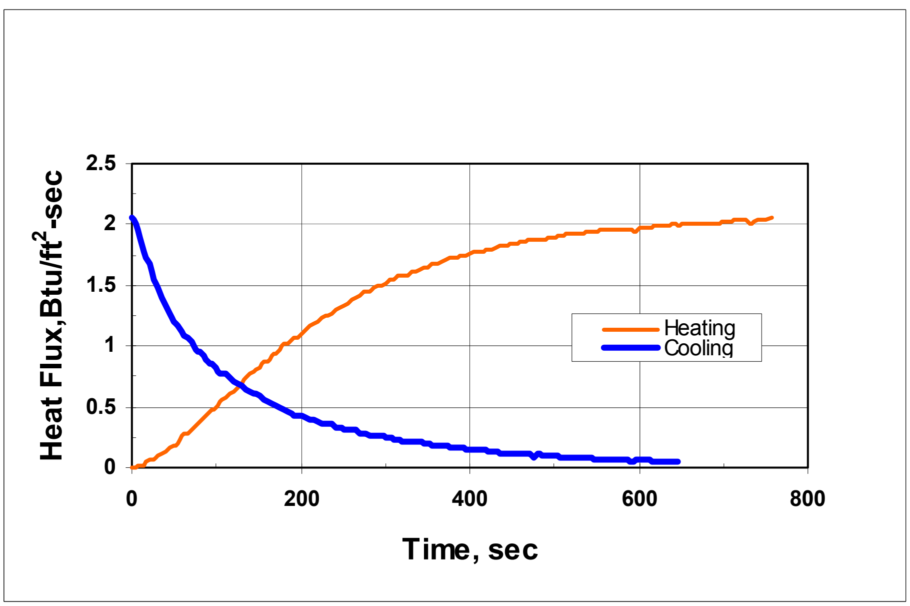


Figure 16. Heat-up and Cool-down Times of a Typical Electric Heater (1000 Watts)

Figure 17 shows results obtained for emissions analysis while firing a typical metal fiber heater at 10 kBtu/hr ft^2 with 10% excess air. It shows that the heater is not a good choice for heat release rates beyond 7.5 kBtu/hr ft^2 due to high CO emissions.

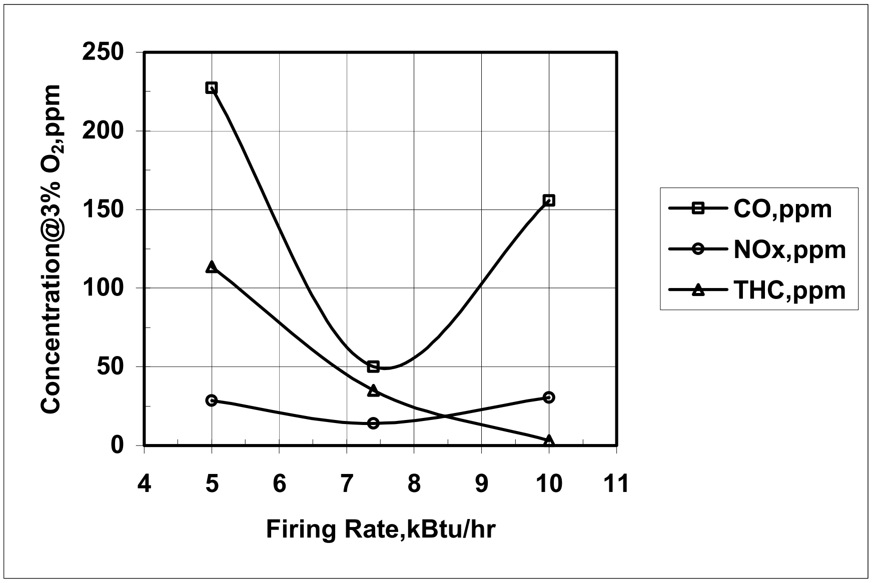


Figure 17. Emissions Analysis of a Typical Metal Fiber Heater

It can thus be summarized that:

- GTI's IR test facility is suitable to evaluate small lab scale heaters as well as large industrial scale heaters
- The facility can be used for both gas fired heaters and electric heaters
- The GTI methodology is a systematic approach for evaluation of thermal and combustion characteristics of infrared heaters
- The results obtained show the accuracy and precision of the equipment, software, and the test protocol, all of which are critical for repeatable, uniform, and standardized test results
- The facility is available to support IR R&D and product development projects on behalf of manufacturers, end users, testing agencies, and utilities for independent testing

Major Achievements of the Project

Information available on the characterization of IR heaters is in bits and pieces. There has not been a unified approach to develop standard test methods and test protocols. The present project has been able to test and characterize a variety of IR heaters, both gas fired and electric. All the reported tests were conducted under controlled laboratory conditions using standardized test procedures. The data base on IR heaters created under this project is very useful for researchers, developers, manufacturers, and end users. The Test Facility developed by GTI is a state-of-the-art facility with modern automatic instrumentation and control. Now it is possible to test and characterize IR heaters, both laboratory size and industrial size, with these instruments and equipment in a very short time with more accuracy and reliability.

Major Technical Problem Areas Encountered

During the course of the project it was realized that since there were no systematic studies available, there was hardly any data to be used for comparison. The radiation efficiency, combined efficiency, spectral intensity, thermal response times, and emissions analysis data available in the literature were widely different and inconclusive and could not be used as guidelines. There were some problems with the monochromator setup. The data acquisition system could not respond with the monochromator. But this problem was later on solved and the setup started working.

Conclusions

The data base on IR heaters developed under the project are extremely useful for the researchers, manufacturers, and end users. Thermal and combustion characteristics of these heaters are now available as guidelines for future developers and users. Classification of these IR heaters into low radiant and high radiant flux heaters, and further sub-dividing low flux catalytic into diffusion and partial premix, and high radiant homogeneous heaters into submerged, surface, and impingement types have not only brought different heaters on one scale, it has also changed the “Art” of IR heaters into “Science”. GTI’s IR test facility is suitable to evaluate small lab scale heaters as well as large industrial scale heaters. It can be used for both gas fired heaters and electric heaters. The GTI methodology is a systematic approach for evaluation of thermal and combustion characteristics of infrared heaters. The results obtained show the accuracy and precision of the equipment, software, and the test protocol, all of which are critical for repeatable, uniform, and standardized test results. The facility is available to support IR R&D and product development projects on behalf of manufacturers, end users, testing agencies, and utilities for independent testing.

Recommendations

There is an immediate need for a heater which can bridge the gap between low flux catalytic heaters and high flux radiant gas heaters. Gas heaters have cost advantage over electric heaters, still they have not been able to capture the IR market as expected. The catalytic heaters suffer due to two major problems: low heat flux and excessive methane slippage at their normal and maximum firing rates. In addition, the catalyst degradation with time causes loss in efficiency and poor performance. Thus, the replacement of the catalyst pad adds to the already high price of these heaters. Development of a catalytic heater which can operate at heat fluxes higher than 8000 Btu/hr ft^2 and temperatures more than 1000^oF, is needed.

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Glossary

CO	Carbon monoxide
Fd	Food
IR	Infrared
kBtu/hr	kilo British Thermal Units per hour
MMBtu/hr	Million British Thermal Units per hour
MtFn	Metal Finishing
NOx	Nitrogen oxides (NO, NO_2, and N_2O)
O_2	Oxygen
ppm	Parts per million
PwPt	Powder Paint
sr	Steradian (unit of solid angle)
THC	Total hydrocarbons
Thfm	Thermoforming
Txtl	Textile
Wd	Wood
μm	micrometer (10^{-6} meter)

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