RADIANT FIBER BURNERS FOR GAS-FIRED APPLIANCES AND EQUIPMENT

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ABSTRACT

Many existing residential, commercial, and industrial gas burner systems are based on designs developed when fuel costs were low. Today, gas users are seeking cost-effective burner improvements and new burner designs that can increase fuel efficiency, comply with environmental regulations, and (for industrial systems) improve productivity and product quality. One such system is the gas-fired fiber burner.

The fiber burner is a radiant burner using a ceramic fiber matrix as the combustion surface. Premixed gaseous fuel and air enter the burner plenum, pass through the fiber surface, and are ignited. Once the burner is operating steadily, the surface glows without visible flame at 1800^{o}F and typical emissions are 20 ppm CO, 15 ppm NO_x, and 2 ppm HC.

Current applications of the fiber burner have been developed primarily under the sponsorship of the EPA, the Gas Research Institute, and Southern California Gas Company. These applications include residential and commercial warm-air furnaces, residential and commercial water heaters, residential hydronic heaters, firetube boilers, refinery process heaters, and aluminum melters. Field testing of the burner in firetube boilers, commercial warm-air furnaces, and refinery process heaters has verified the laboratory test results, and commercialization of the technology is now beginning.

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INTRODUCTION

Alzeta Corporation manufactures and markets advanced proprietary combustion products, performing the research, development, design, and tooling necessary to convert them into commercialized systems. One such product is the radiant ceramic fiber burner, and the advanced heating systems currently being developed for this burner promise performance improvements over the conventional systems now used in buildings.

The subject burner is a premixed, power burner that uses a radiant ceramic surface as the heat source rather than a conventional suspended flame. Its major attractions are its very low NO_x emissions -- 15 ppm -- and its enhancement to the efficiency of the radiant section of the heat exchanger.

Commercially-available ceramic fiber burners are currently being used by industry mainly for continuous drying operations. Alzeta Corporation is focusing the use of its fiber burner for other residential, commercial, and industrial applications, especially those that can benefit from the burner's low NO_x characteristics. Specific applications of the burner that would be of interest in this ACEEE Summer Study include the following:

- Commercial warm air furnace
- Firetube boiler
- Residential warm air furnace

All of these equipment types would be candidates for inclusion in the planning and design of energy efficient buildings. These and other applications of the burner are described in this paper.

DESCRIPTION OF BURNER

The burner used in the applications described in this paper belongs to the class of combustion devices known generically as infrared, or radiant, burners. A radiant burner is distinguished from a conventional burner by its lack of a suspended flame and its incandescent, hot surface. This surface transfers most of the burner's heat input directly to the opposing heat sink by thermal radiation.

The ceramic fiber burner, shown in Figure 1, is a subtype of infrared burner. It consists of a porous layer of ceramic fibers through which premixed gaseous fuel and air are passed and ignited on the outer surface. The surface glows flamelessly and uniformly at about 1800^{O}F. Both the low conductivity of the fibers and the convective cooling by the incoming reactants allow the burner to operate safely and with no flashback tendencies at surface velocities below the mixture flame speed.

The ceramic fiber materials currently used in commercially available radiant burners are basically vacuum-formed insulation products and were not originally designed or intended for use as a burner. They have a relatively high pressure drop when operating as a burner, are usually limited to a flat plate geometry, and require relatively elaborate mounting and edge sealing techniques.

By contrast, the Alzeta burner is a patented combination of ceramic fibers and a special binder system and was originally formulated to function as a burner. It operates at very low excess air and pressure drop, turns on and off instantly, is noiseless, and is not susceptible to thermal shock. Its NO_x emissions are less than 15 ppm with simultaneous low CO and hydrocarbon emissions. The low NO_x level is due to the low combustion temperature which suppresses thermal NO_x formation.

The fiber burner operates at a heat release rate per unit area of burner surface of 100,000 Btu/hr-ft^2. Because the heat input is based on surface area, the burner is easily scalable. Burners ranging in size from 12,000 Btu/hr up to 10^6 Btu/hr are commonly made using the same type of support structure and forming techniques. Also, the burner can be made in a variety of geometric shapes, notably flat plates and cylinders. This versatility makes the Alzeta burner appropriate for a wide range of uses, including the applications described in this paper.

APPLICATION 1. COMMERCIAL WARM AIR FURNACE

In 1982, Alzeta began a project to incorporate a radiant ceramic fiber burner into a warm air furnace used for heating commercial and industrial buildings. We are working with a furnace manufacturer, York-Shipley Inc., of York, PA. The project is sponsored by the Gas Research Institute.

During this project, the furnace will be developed in a progression from a retrofit in an existing heater to an entirely

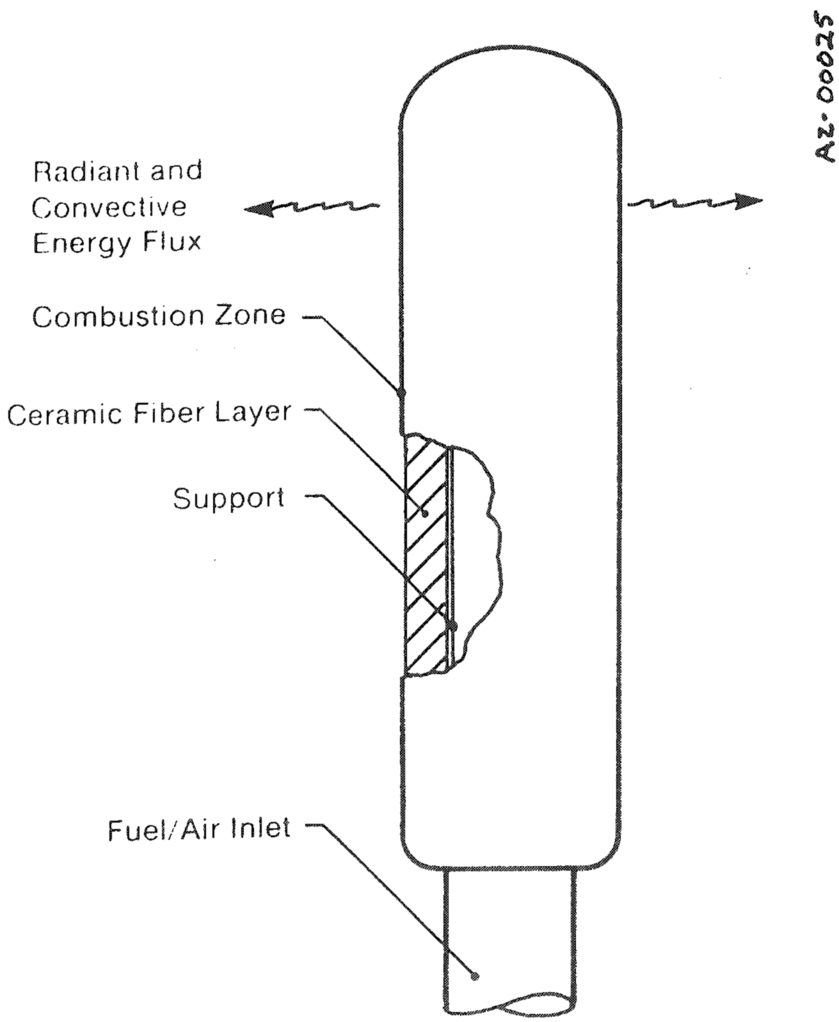

Figure 1. The fiber burner's components are simple and inexpensive.

new heater design with an optimized heat exchanger. Prototypes of the advanced heater will be field-tested for one heating season at various U.S. sites.

The type of commercial warm air furnace being focused on is a rugged device designed about 30 years ago. It consists of primary and secondary heat exchangers and a pair of room air fans. The upflowing cool air passes over the two heat exchangers, picking up heat and exiting from the top of the heater and into the building's duct system.

Thus far, the retrofit task has been completed and the first advanced prototype furnace is being built. The retrofit tasks consisted of installing a fiber burner and a condensing heat exchanger into a conventional furnace and comparing its performance with the conventional set-up (Figure 2). The new burner greatly reduced noise and NO_x emissions without adversely affecting the heater's thermal performance, but the benefit of this retrofit was not considered to be cost-effective. However, the results suggested that more significant improvement could be achieved by modifying the furnace's design specifically for use with the fiber burner.

The re-designed furnace is shown in Figure 3. The main features of this new furnace include the following:

- The positions of the primary and secondary heat exchangers have been reversed to create a counterflow situation, which improves heat transfer rates.
- The secondary heat exchanger has been augmented with more area and different flow patterns to achieve condensing operation.
- Custom-designed mounting flanges and a pilot/flame safety system for the fiber burner have been installed.

These features will combine with the improved performance in the primary heat exchanger to give a predicted 93 percent efficiency, which is a 20 percent gain over conventional furnaces.

An early version of this heater was installed in an industrial building in Ohio for the 1983-84 heating season. Although the final results of this field test are not yet quantified, early indications are that the higher efficiency furnace has reduced the user's gas bill by a significant amount.

Currently, a prototype of the advanced heater is being fabricated and readied for lab testing. This prototype incorporates all of the features and improvements suggested by past lab and field testing. The heat exchanger surface and rotating

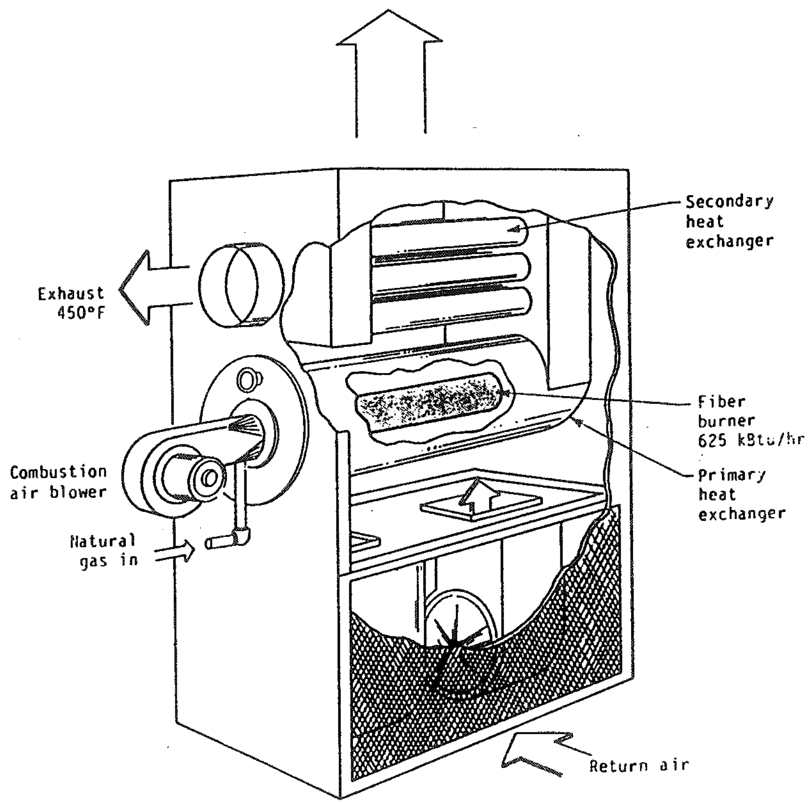

Figure 2. Phase 1 unit heater.

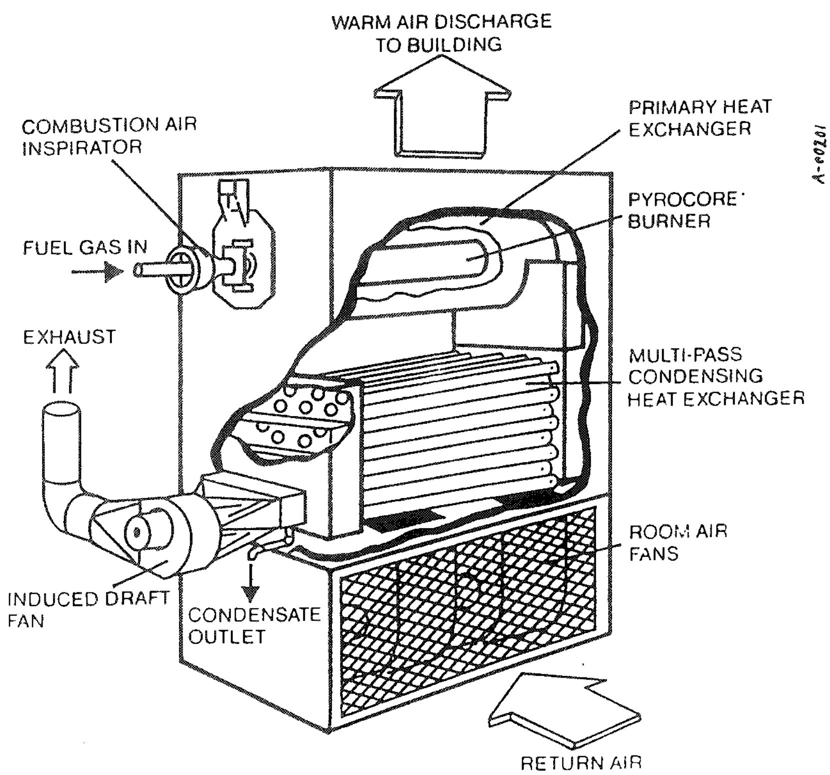

Figure 3. Advanced commercial warm air furnace

equipment are designed to handle the corrosive condensate on a long-term basis.

After completion of a laboratory evaluation of this prototype, two to three more units will be built and field tested during the 1984-85 heating season. The furnace will be ready for commercialization following these field tests.

APPLICATION 2. FIRETUBE BOILER

Firetube boilers are devices used to supply steam or hot water in large commercial and industrial buildings. There are currently more than 150,000 gas-fired firetube boilers in the U.S., with an additional 3,000 new boilers installed annually.

The firetube boiler was the first application of the fiber burner to commercial and industrial equipment. The fiber burner is especially attractive for application to these boilers because its heat release rate per unit area is well matched to that of the boiler's radiant section, and because of its noiseless and low NO_x characteristics.

For this application, the burner is manufactured in several cylindrical segments to facilitate shipping and installation. These segments are connected together to form a larger cylinder that fits inside the boiler's combustion chamber.

Figure 4 illustrates how the burner installation compares with the conventional arrangement. In most cases, fiber burner retrofit is a straightforward process. The cylindrical burner fills the same volume as the conventional flame and uses the existing blower, ignition and control systems.

The application of the fiber burner was initially supported by the U.S. Environmental Protection Agency in the interest of improving air quality through lower NO_x emissions. This project took the burner through laboratory tests to evaluate performance, scaleup to 1,000,000 Btu/hr, and demonstration in a 25 hp low-pressure steam boiler. Retrofit and field testing of larger boilers (40 to 100 hp) is currently being supported by the Gas Research Institute, York-Shipley, Inc., and Alzeta Corporation. This program focuses on 1-year durability testing at three field sites.

This field testing began in the Spring of 1983. The sites included a military facility in California, a chemical company in Cleveland, Ohio, and a food processor in York, Pennsylvania. Site arrangements were made with the assistance and cooperation of the local gas utilities.

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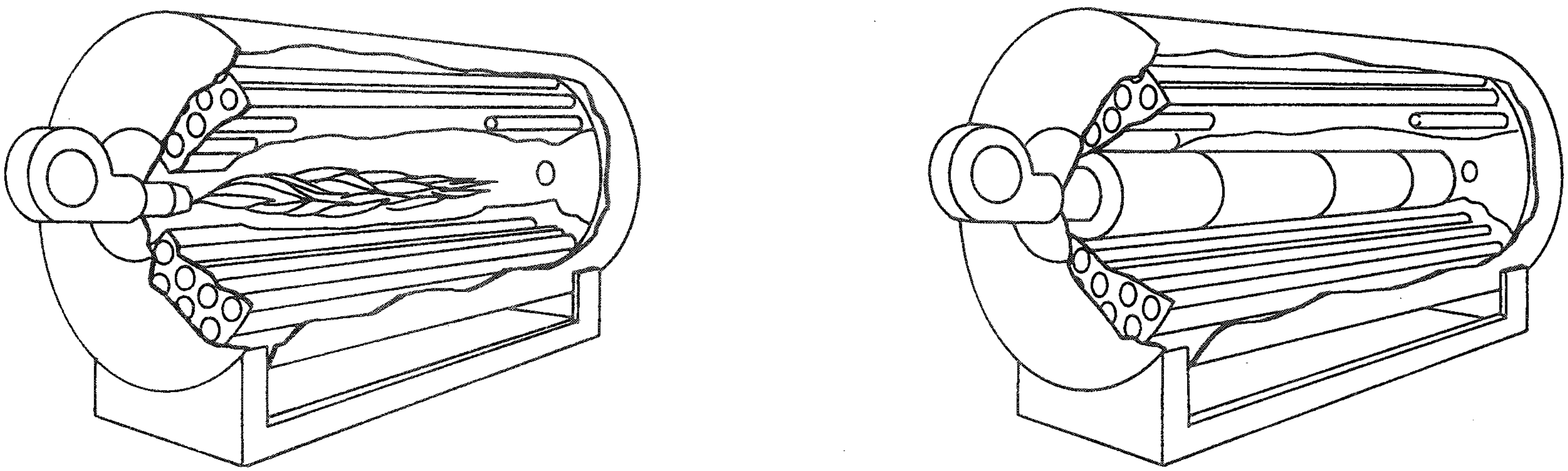

CONVENTIONAL

RETROFIT WITH FIBER BURNER

Figure 4. The uniform radiant surface of the fiber burner replaces the conventional flame.

Thus far, the burners have been operating for a cumulative time greater than 8,000 hours. The thermal efficiency of the boilers has gone up an average of 1-2 percent and NO_x emissions have been reduced by 80 percent (to 10 ppm).

From the user's standpoint, however, the most important benefit of the fiber burner has been the increase in steam capacity. This amounts to up to 25 percent over the conventional burner when the fiber burner system is adjusted back to its pre-retrofit efficiency conditions. This means that the user has a heating or process expansion available to him without the need to purchase new capital equipment (e.g., a new boiler).

Based on these successful field tests, this application of the fiber burner is now entering the commercialization phase. York-Shipley, Inc., has been given exclusive rights to market the burner for retrofit and new boiler applications.

APPLICATION 3. RESIDENTIAL WARM AIR FURNACE

In response to energy conservation concerns, market conditions, and impending NO_x regulations, residential furnaces currently are undergoing significant design changes. These changes include new and modified burners, condensing heat exchangers, and new control systems. Alzeta has developed an advanced furnace that combines these features with the low NO_x burner.

Alzeta developed this furnace under the sponsorship of the Southern California Gas Company. Three prototype furnaces were built and tested, culimating in a fourth and final prototype that incorporated all of the best design features from the previous units. This furnace is shown in Figure 5.

The furnace is based on the upflow, clam shell design found in standard central warm air furnaces. Two burners, 30,000 Btu/hr each, are placed in two heat exchanger cells in the middle of the furnace to eliminate jacket loss and to assure that these hottest sections are in the region of greatest flow from the room air fan.

Exhaust from each burner rises to the top of the heat exchanger and out an opening in the upper back. This opening is manifolded with an opening in the first condensing heat exchanger. Exhaust gas enters this section and is distributed along its length by an internal baffle. The gas then flows down and counter to the room air. It leaves through an opening in the lower back and is piped back up to the top of the second, identical, condensing heat exchanger for one more pass. The flue gas is finally sent out the lower back of this section, and

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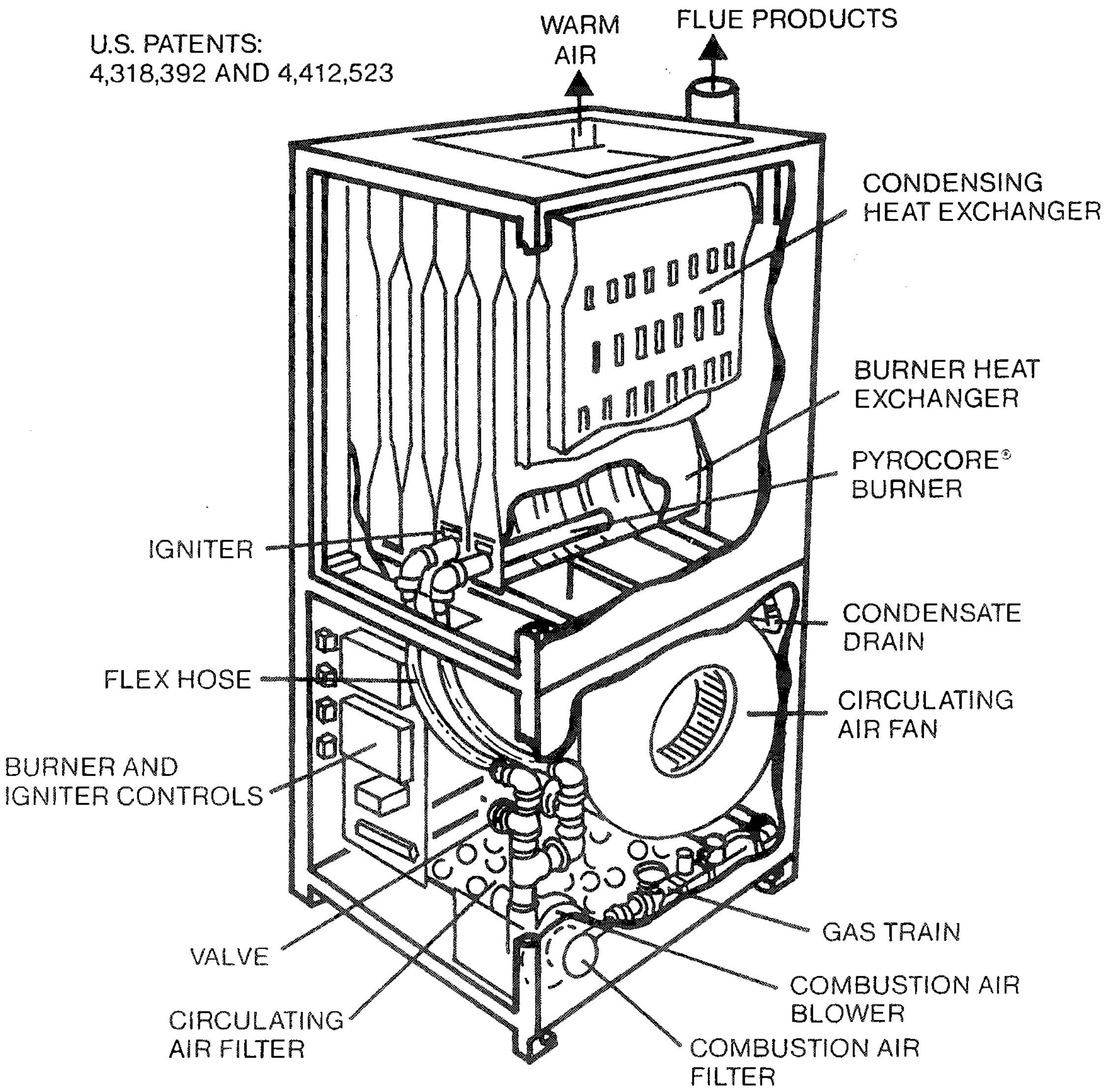

Figure 5. The advanced residential furnace combines the fiber burner with condensing heat exchangers.

brought together with the exhaust from the other burner for passage into the flue duct.

These condensing heat exchanger sections comprise sufficient area to cause some of the moisture in the flue gas to condense on the inside walls of the exchangers. The flue gas is routed in counterflow to the circulating air to maximize heat transfer efficiency (by maintaining a constant temperature gradient) and to allow the condensate to drop into the cool zone and avoid re-evaporation. The condensate is collected in the bottoms of the condensing heat exchangers and is drained out.

The series, rather than parallel, arrangement for the condensing heat exchangers was chosen to maximize the exhaust gas velocity, thus increasing the internal convective heat transfer coefficient (which is the controlling coefficient). Tests on the previous prototype furnaces showed that this approach produced a sufficiently high efficiency at a low pressure drop.

The condensing heat exchangers have internal fins to increase heat transfer rates. These fins are bar dimples pressed into the sheet metal. The rows of fins are staggered and oriented parallel with the exhaust gas flow to minimize form drag and pressure drop. Their key function is to break up the laminar boundary layer, which contributes to thermal resistance. Also, the fins increase the exchanger surface area by about 15 percent.

Burner control components include a silicon carbide glow igniter/flame sensor and control module for each burner, a 24 vac transformer, and a gas solenoid valve. The control module is designed to energize the igniter, open the gas solenoid valve, ignite the burner, de-energize the igniter, and then monitor the presence of the flame. The absence of a proper flame current through the SiC element causes the control module to close the solenoid and lock out the furnace until it is manually reset.

The performance of this furnace in terms of emissions and efficiency is very impressive. At the nominal heat rate of 60,000 Btu/hr, the flue temperature is only about 30^{o}F above ambient, giving a steady state efficiency of 95 percent. The seasonal efficiency (AFUE), although not measured on this prototype, will be higher than a conventional furnace because the presence of the power burner prevents gas flow through the heat exchangers during the off cycle. This minimizes heat loss due to natural convection.

In terms of emissions, the furnace's NO_x emissions are only 13 ppm (based on zero percent O_2). This translates to an emission factor of 6.2 ng NO_x/JUH at the condensing efficiency (95 percent) and 7.4 ng/JUH at the noncondensing efficiency (80 percent). These figures are much lower than the new California

(L.A. and S.F. Bay Area) regulation of 40 ng/JUH, and are by far the lowest emission factors of all new furnaces currently being brought to market. Unlike furnaces with conventional blue flame burners, which must trade off between NO_x and combustible emissions, the fiber burner-equipped furnace simultaneously reduces NO_x, CO and unburned hydrocarbons.

A commercialization partner is currently being sought for this furnace. The fiber burner is also available separately to manufacturers for use in their existing line of equipment.

OTHER APPLICATIONS

Other applications of the fiber burner that relate to energy use in buildings are in an early stage of development. These include a hydronic heater, a commercial water heater, and commercial cooking equipment. In all of these applications, the radiant property of the burner translates into hardware cost savings. In one case, the burner is firing in the downward mode (not possible with conventional burners) which has reduced ducting length. In another application, the burner has allowed reduced heat transfer area for the same efficiency. More details on these applications of the burner will be available after the field tests begin.

The burner is being used in other applications not related to energy use in buildings. These include immersion tube heaters for oil refinery storage tanks and burners for refinery heaters. In the former application, the burner has increased thermal efficiency, eliminated hot spots, and reduced NO_x and noise emissions from the immersion heaters, all of which are significant benefits from the refinery's point of view. For refinery heaters, the burners soon will be used in a GRI-sponsored project to field-test a pilot scale advanced heater in the Los Angeles area. This heater will be the prototype of a new line of heaters that will help refineries meet the increasingly strict local NO_x regulations.