BNL-63135

CONF-9606183--2

Development of an Air-Atomized Oil Burner

Dr. Thomas A. Butcher and Yusuf Celebi
Brookhaven National Laboratory

Leonard Fisher, P.E.
Consultant

and

Dr. Bola Kamath
Heat Wise, Inc.

Abstract

A new concept for the design of a residential oil burner is presented involving a low pressure, air atomizing nozzle. Advantages of this approach, relative to conventional, pressure atomized burners include: ability to operate at very low excess air levels without smoke, ability to operate at low (and possibly variable) rates, reduced boiler fouling, and low NO_x.

The nozzle used is a low pressure, airblast atomizer which can achieve fuel spray drop sizes similar to conventional nozzles and very good combustion performance with air pressure as low as 5 inches of water (1.24 kPa). A burner head has been developed for this nozzle and combustion test results are presented in a wide variety of equipment including cast iron and steel boilers, warm air furnaces, and water heaters over the firing rate range 0.25 gph to 1.0 gph (10 to 41 kW).

Beyond the nozzle and combustion head the burner system must be developed and two approaches have been taken. The first involves a small, brushless DC motor/fan combination which uses high fan speed to achieve air pressures from 7 to 9 inches of water (1.74 to 2.24 kPa). Fuel is delivered to the atomizer at less than 1 psig (6.9 kPa) using a solenoid pump and flow metering orifice. At 0.35 gph (14 kW) the electric power draw of this burner is less than 100 watts. In a second configuration a conventional motor is used with a single stage fan which develops 5 to 6 inches of water pressure (1.24 to 1.50 kPa) at similar firing rates. This burner uses a conventional type fuel pump and metering orifice to deliver fuel. The fuel pump is driven by the fan motor, very much like a conventional burner. This second configuration is seen as more attractive to the heating industry and is now being commercialized.

Field tests with this burner have been conducted at 0.35 gph (14 kW) with a side-wall vented boiler/ water storage tank combination. At this firing rate steady state flue gas temperature leaving the boiler is 275 F (135 C) and the system met the space heating and hot water load under all conditions tested. At the test site instrumentation was installed to measure fuel and energy flows and record trends in system temperatures. Efficiency of the test system with several variations are compared to the existing boiler system.

This report was prepared under the auspices of the U.S. Department of Energy under Contract No. DE-AC02-76CH00016.

Introduction

The residential oil burner market is currently dominated by the pressure-atomized, retention head burner. In these burners oil is delivered to a fuel nozzle at pressures from 100 to 150 psi (690 to 1000 kPa). In addition to atomizing the fuel, the small, carefully controlled size of the nozzle exit orifice serves to control burner firing rate. Burners of this type are currently available at firing rates over 0.5 gph (21 kW). Nozzles have been made for lower firing rates but experience has shown that such nozzles suffer rapid fouling of the small passages required, leading to bad spray patterns and poor combustion performance. Two factors contribute to this fouling. The first is fuel system dirt which might be controlled through better filtration. The second is coke formation on internal passages occurring after normal burner shutdowns when the nozzle is heated by radiation from the combustion chamber. This period after shutdown is more severe than the time when the burner is actually firing. Because of the cooling effect of the combustion air flow over the nozzle at shutdown oil remaining in the nozzle line during the off-period becomes dry (cokes).

The pressure-atomized, retention head burner has an excellent reputation for reliability and efficiency. While it is only correct to discuss the efficiency of complete heating systems rather than the efficiency of the burner alone, the burner has a very strong influence on system efficiency in several important ways. To achieve high efficiency, the burner should be capable of operating with a minimum of excess air. Smoke production during warm-up and in steady state are the factors which set the lower limit on excess air. Most modern pressure-atomized burners can operate at excess air levels as low as 15% at a firing rate of 1 gph (41 kW), under good conditions [1]. At low firing rates, higher excess air levels are required. A second way in which burners can influence system efficiency relates to fouling of heat exchanger surfaces and degradation of efficiency over time. Burners which are operating very badly, possibly because of a fouled nozzle for example, may produce high smoke levels leading to rapid coating of heat exchanger surfaces with carbonaceous soot. In more normal cases, where the burner continues to operate smoke-free the fouling rates will be lower. One field study concluded that the average efficiency degradation rate is 2% per year [2]. Studies at Brookhaven National Laboratory (BNL) have shown that a very important part of the normal fouling deposit is iron sulfate scale resulting from the deposition of sulfuric acid from the flue gas onto the heat exchanger surfaces. The amount of sulfuric acid which is produced in a flame is dependent upon the burner excess air level. Acid production and scaling rate can be controlled by using burners which can operate at very low excess air levels [3,4,5].

Another way in which burners can influence heating system efficiency is through off-cycle losses. After the burner has shut off, the system continues to lose heat up the chimney. This heat loss rate depends upon the rate of air flow through the unit which, in turn, depends upon the burner design. A burner which has has high fan pressure also has small open passages will allow lower off cycle air flow rates.

The objective of the development effort described in this paper is an advanced, air-atomized burner which can provide new capabilities not currently available with pressure atomized, retention head burners. Specifically this includes:

- ability to operate at firing rates as low as 0.25 gph;
- ability to operate with very low (5%) excess air levels (14%+ CO_2) for high steady state efficiency and to minimize formation of sulfuric acid and iron sulfate fouling;
- low emissions of smoke, CO and NOx at these excess air levels;
- potential for modulation - either stage firing or continuous modulation.

In addition, of course, any such advanced burner must have production costs which would be sufficiently attractive to allow commercialization.

In the past a number of very interesting designs for achieving some or all of the objectives listed above have been developed to varying degrees, some as part of the DOE/BNL program. Air atomization, blue flame (recirculating), and prevaporizing burners have received attention. In 1980, a review of prior work in this area was completed by Battelle Colombus Laboratories for BNL [6]. Some of the more recent work in advanced burners has been described in the proceedings of the annual BNL Oil Heat Conferences. In 1990, BNL completed a study in which the emissions performance of conventional and advanced burners were compared [1]. This study included air atomization and prevaporizing burners. General options for atomizers for advanced burners were reviewed by Krishna et.al. in 1987 [7]. Reasons why none of these advanced burners are currently available commercially vary but generally include: high cost, poor reliability, excessive complexity (difficult to service), and others.

In all residential air-atomized burner concepts which have been developed, a small compressor was used to provide a small flow of air at 5 to 20 psi (34 to 138 kPa) to the nozzle for atomization. A conventional fan was also included to provide the remainder of the air needed to complete combustion. This secondary air is delivered at much lower pressure, about 1 inch of water (.25 kPa).

The atomizer used in the burner described below is a low-pressure, high volume nozzle. It can achieve good atomization with very low air pressures ranging from 6 to 12 inches of water (1.5 to 3. kPa). The volume of air used for atomization is considerably greater than with high pressure atomizers. Depending upon firing rate from 15 to 40% of the total combustion air is used for atomization. From a burner design perspective this approach carries an inherent advantage - all of the air required for both atomization and combustion can be provided from a single fan.

The atomizer used in this burner is based on a nozzle originally developed by Parker Hannifin Corporation in a joint project with the General Motors Corporation to heat air and clean a catalytic filter used to reduce particulate concentration in diesel engine exhaust [8]. Figure 1 provides a simple illustration of the nozzle (side cross section). Air at pressures of 6 to 12 inches of water (1.5 to 3. kPa) enters the back. Most of the air passes through the outer swirler and spins out through the main exit orifice. A smaller amount passes radially inward through four, small offset holes ("A" in Figure 1.) providing co-swirling air around the pintle. Fuel entering at the centerline flows radially out through three small holes near the pintle tip where the swirling air distributes and swirls the oil, filming it as it leaves the inner orifice (B in Figure 1). The two swirling air flows accelerate as they converge at the exit orifice, shearing the sheets and ligaments of fuel into a conical spray.

Prototype Burner Development

Figure 2 is a very simple illustration of the way in which the burner head has been developed for the nozzle. While not correct in detail, this sketch shows how all of the air from a single plenum at the back of the burner is divided into three parts: atomizing air entering the set of holes in the back end of the nozzle body and exiting the nozzle at point 1; secondary air which passes through a set of small holes in a metering plate (which surrounds the nozzle body) and then enters the flame zone through slots, 2, in the retention plate; and tertiary air which enters the flame zone through a small annular passage, 3. The head can be moved back and forward, increasing and decreasing the tertiary air flow for adjustments in the excess air level. The flame is surrounded by a metal flame tube (not shown in Fig. 2, see Fig. 3) which improves flame retention and cold start performance, improves combustion in some cold-wall applications, and controls gas recirculation rates. Figure 3 is a photograph showing actual burner head components.

The complete system developed for the first burner prototype is illustrated in Figure 4. Air at the required pressure is provided by a 5 inch (12.7 cm) diameter plastic blower driven by a brushless DC motor at high speed. At the nozzle the required fuel pressure is less than 1 psig (6.9 kPa). An electric solenoid fuel pump is used in combination with a bypass type pressure regulator (typically set at 7.5 psig (53 kPa)) and a metering orifice to deliver the required amount of fuel to the nozzle. The control being used has interrupted ignition and provides programmable pre- and post purge periods.

Combustion tests with the prototype burner have been done in a wide variety of equipment in the BNL lab including furnaces, water heaters, cast iron boilers, and steel boilers [9]. While this testing has been done over the firing rate range 0.25 to 1.0 gph (10.3 to 41 kW), most of the emphasis has been on rates less than 0.5 gph (21 kW). For example Figures 5 and 6 provide a comparison of the smoke and CO / excess air relationship with a conventional retention head burner and the Fan-Atomized Burner. These tests were done in a steel boiler with a horizontal, cylindrical combustion chamber.

NO_X emissions with the Fan-Atomized Burner tend to be somewhat lower than with a retention head burner at the same firing rate. When operated at lower firing rates, the Fan-Atomized Burner will produce much lower NO_X emissions. Figure 7 shows the effect of firing rate on NO_X in the same steel boiler discussed above. These tests were all conducted with the Fan-Atomized Burner prototype operating at 12% excess air.

Field Tests

Field trials with the Fan-Atomized Burner prototype have been conducted during the 1994/1995 and 1995/1996 heating seasons in one home on Long Island. At this site the existing boiler is a steel, dry base boiler fired with a conventional retention head burner running at a firing rate of 0.7 gph (28.7 kW). Hot water is provided by a coil in the boiler. For the field test, a new boiler was added at the site temporarily and the piping and controls configured such that either boiler could be operated. Instrumentation was installed to monitor system temperatures, fuel use, and heat delivered to both the baseboards and domestic hot water. The new boiler was planned to take full advantage of the capabilities of the Fan-Atomized burner. It is a steel, positive pressure boiler, side wall vented without a draft inducer. The control on the Fan-Atomized Burner was programmed for a 15 second pre-purge and 10 second post-purge. After completion of a heat call, extra heat stored in the boiler is purged into the heated space and the boiler may go fully cold between cycles. A separate, well insulated, 40 gallon (.15 m^3) hot water tank is used with the test system and this is treated as a priority zone.

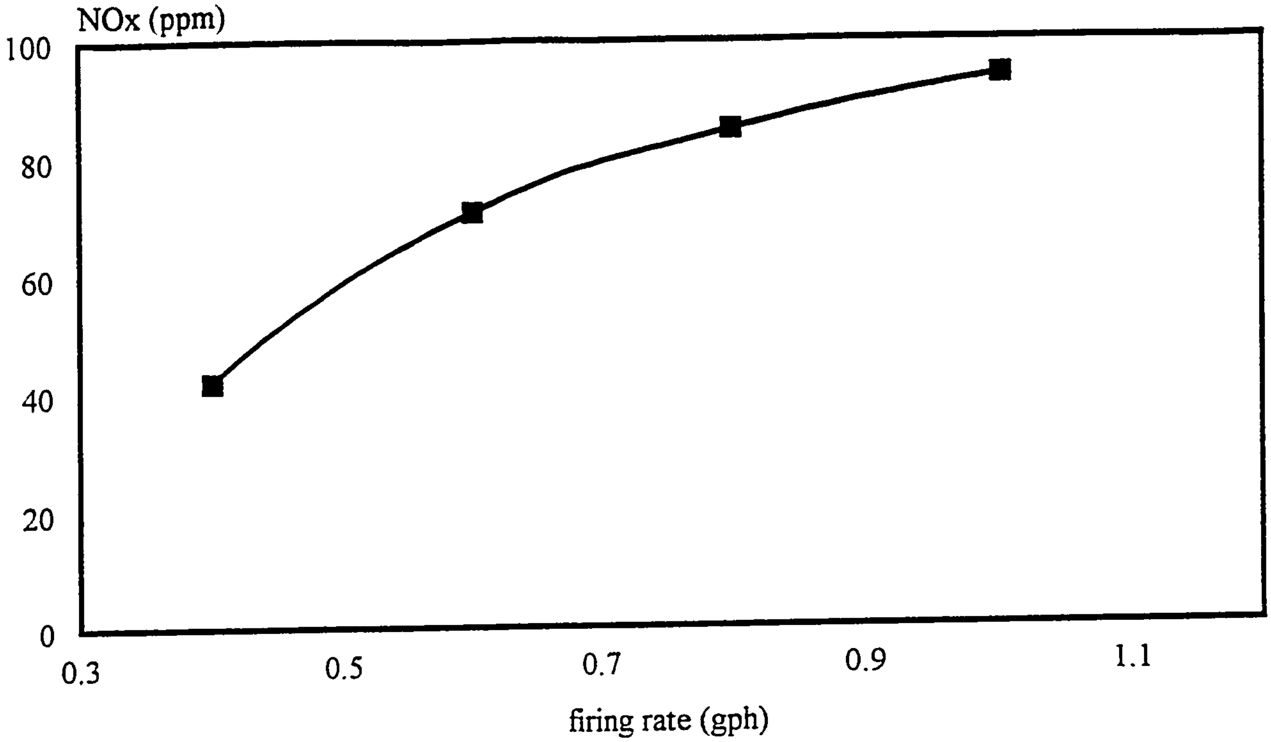

Figure 7. Results of Fan Atomized Burner tests in steel boiler. NOx as a function of firing rate. All tests at 12% excess air (13.7% CO_2)

Testing was done at several different firing rates although the most extensive testing was done at 0.35 gph (14.4 kW). At this input rate the test system had no difficulty in meeting the heating and domestic hot water demand with outdoor temperatures as low as 7 F (-14 C). This is the lowest observed outdoor temperature during the test period and is the 99% design point for the location. At the lowest outdoor temperature conditions for which field testing was done, the burner was on about 90% of the time. At 0.35 gph (14.4 kW), and 13.5% CO_2, the steady state gas temperature leaving the boiler is about 300 F (150 C), giving a steady state efficiency (based on stack loss) of 88%. Figure 8 provides a comparison of the efficiency/load curves of the old system and the test system with the Fan-Atomized Burner. Burner noise, which was a concern early in the development program; was not found to be objectionable in the field. Based on occupant observations the test burner system was quieter than the older, retention head burner system.

Burner Commercialization

The Fan Atomized Burner concept is currently being developed for commercialization by Heat Wise, Inc. of New York. The Heat Wise goal is to make this technology complimentary to (not competitive with) existing technology by extending the range of appliances which can use oil heat. The

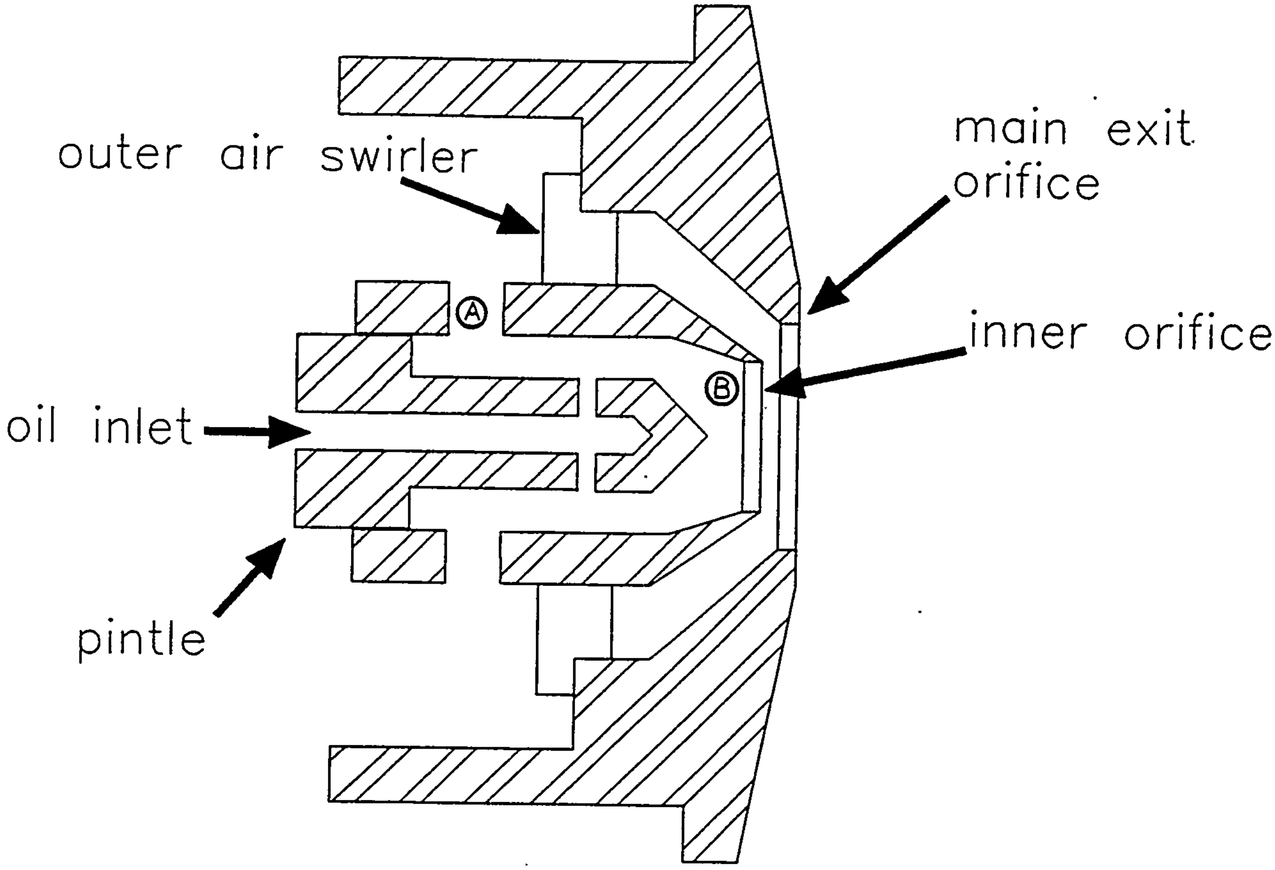

Figure 1. General illustration of the low-pressure, air atomizing nozzle showing air and fuel flow passages

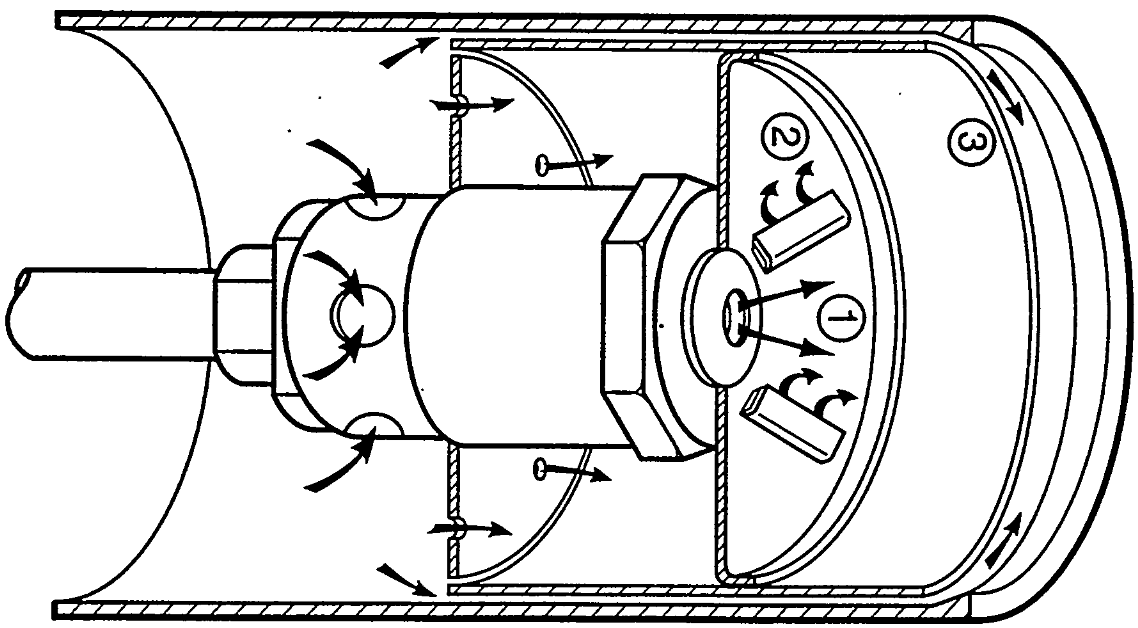

Figure 2. Illustration of burner head showing air flow distribution.

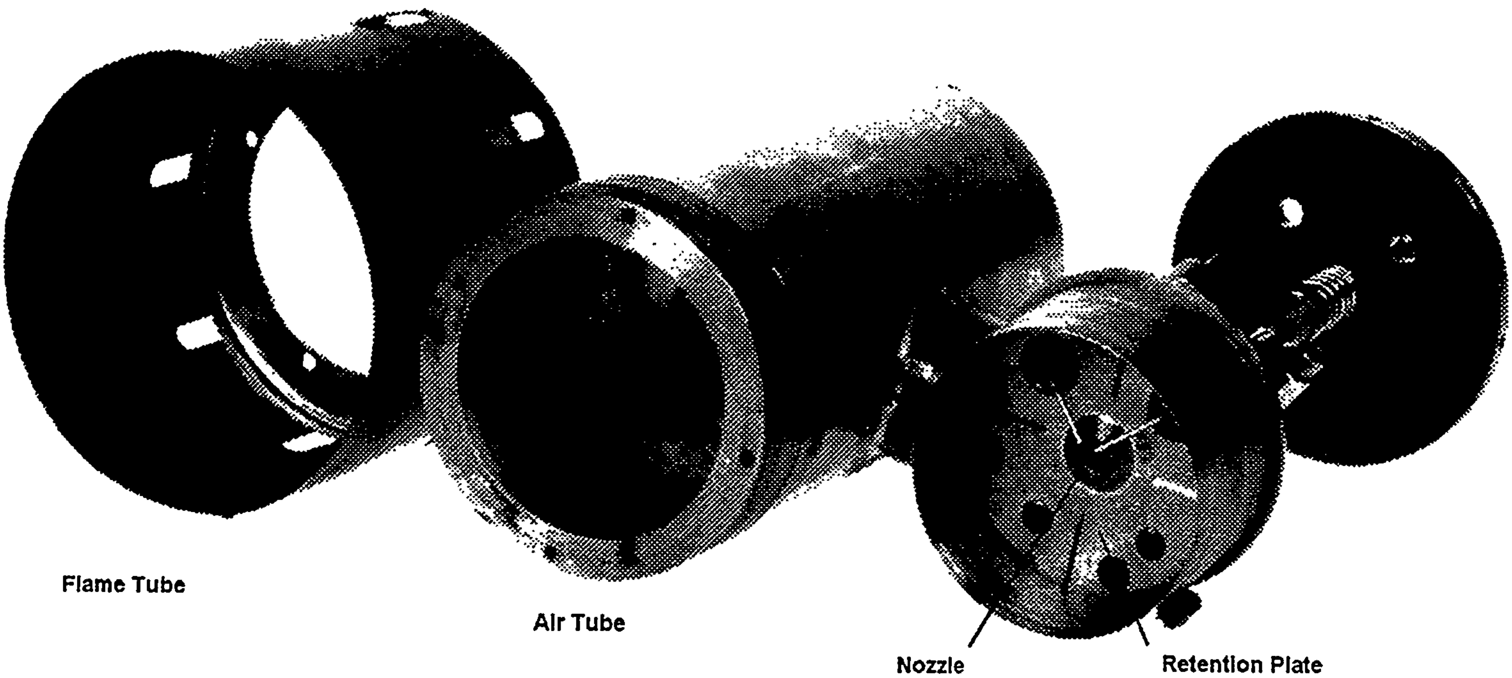

Figure 3. Photograph of burner head components

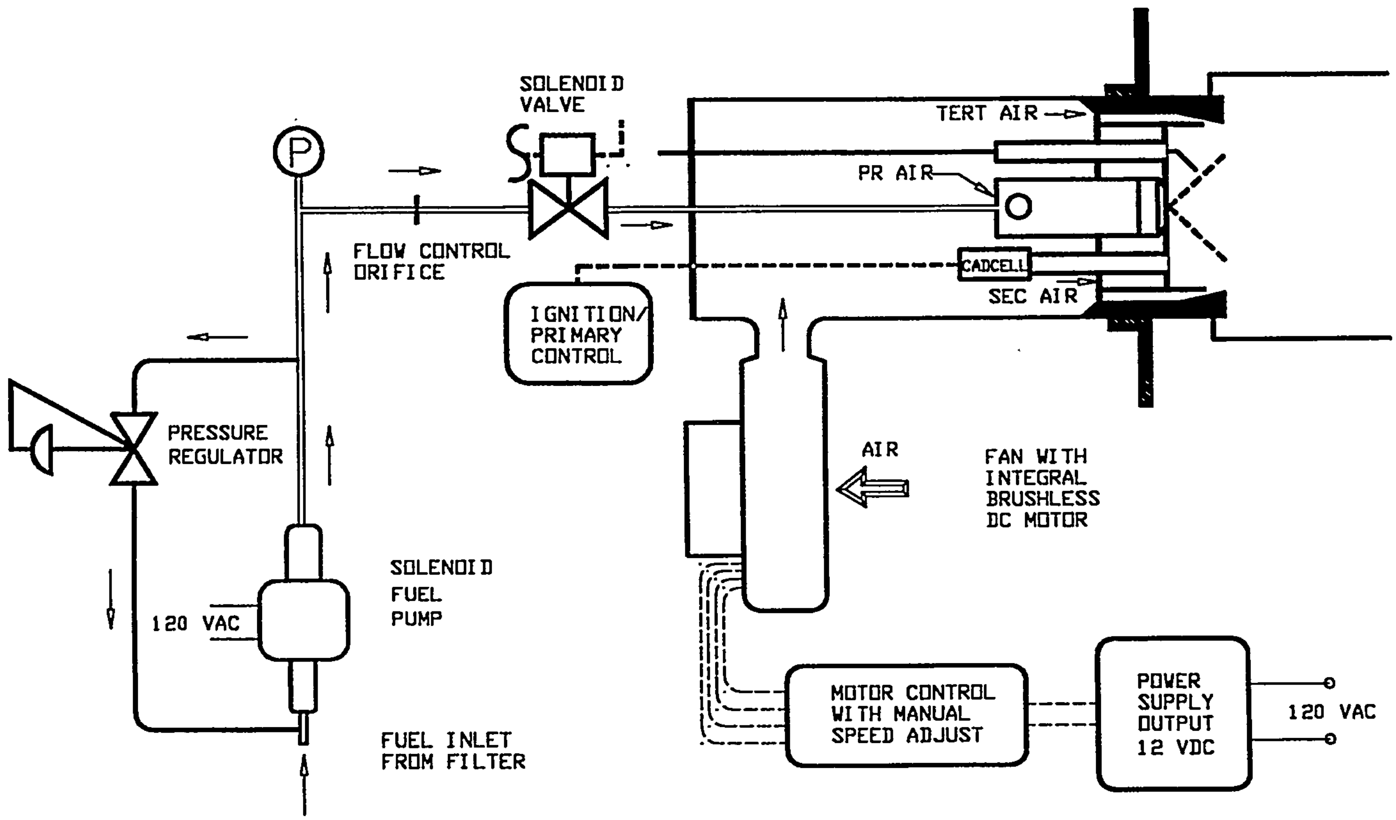

Figure 4. Schematic of prototype burner system

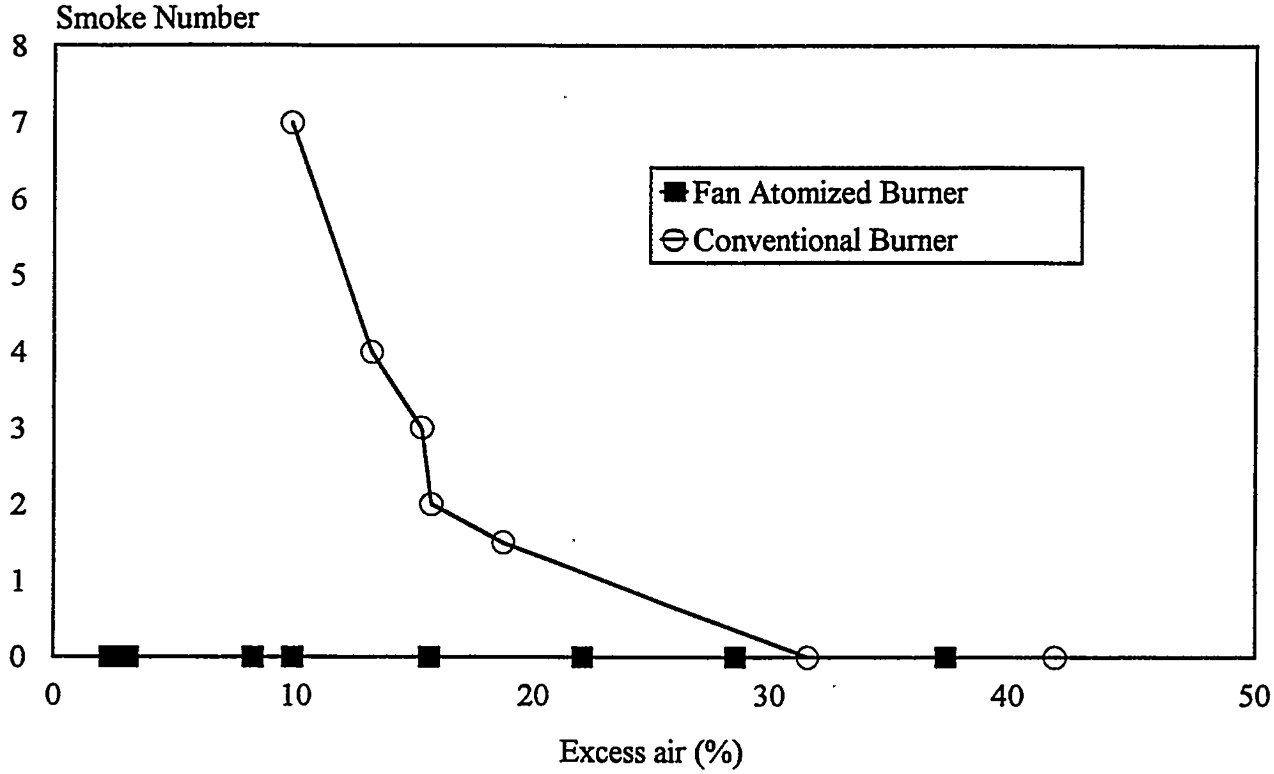

Figure 5. Combustion performance comparison-smoke number. Fan-Atomized Burner at 0.35 gph and conventional retention head burner at 0.65 gph. Steel boiler.

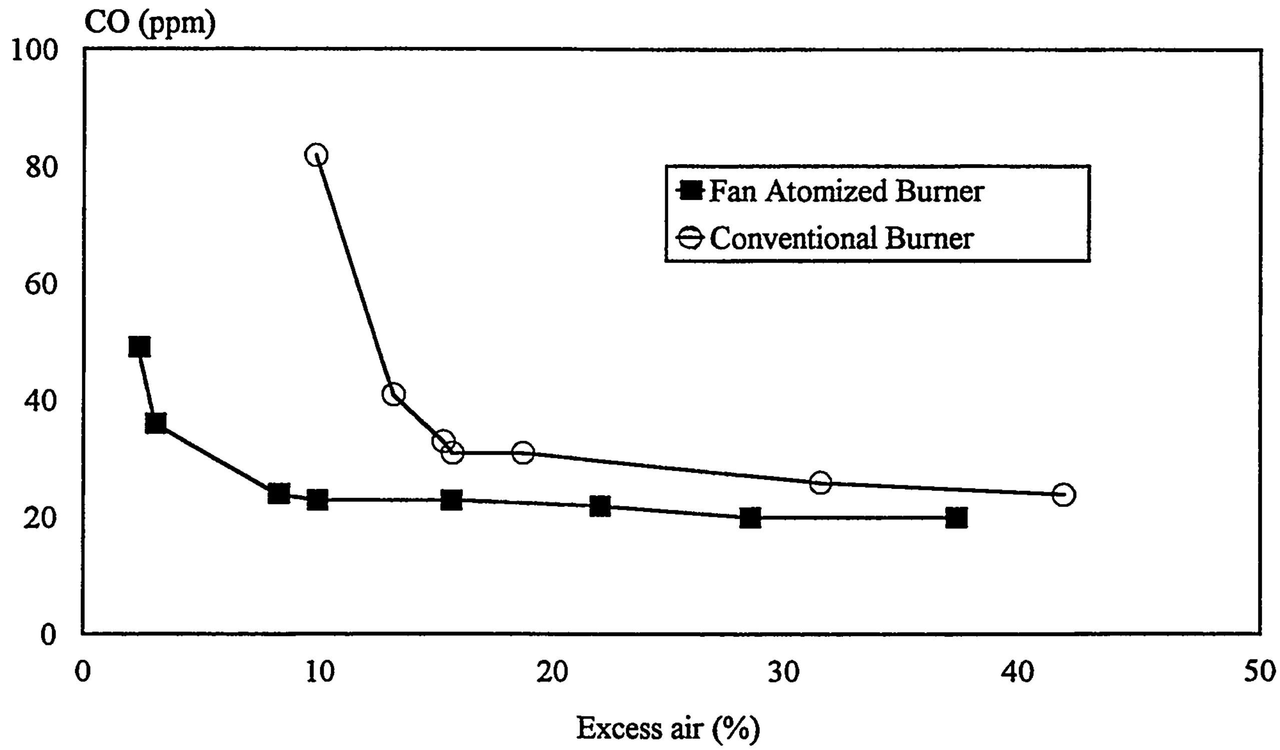

Figure 6. Combustion performance comparison -CO. Fan-Atomized Burner at 0.35 gph and conventional retention head burner at 0.65 gph. Steel boiler.

without a draft inducer. The control on the Fan-Atomized Burner was programmed for a 15 second pre-purge and 10 second post-purge. After completion of a heat call, extra heat stored in the boiler is purged into the heated space and the boiler may go fully cold between cycles. A separate, well insulated, 40 gallon (.15 m^3) hot water tank is used with the test system and this is treated as a priority zone.

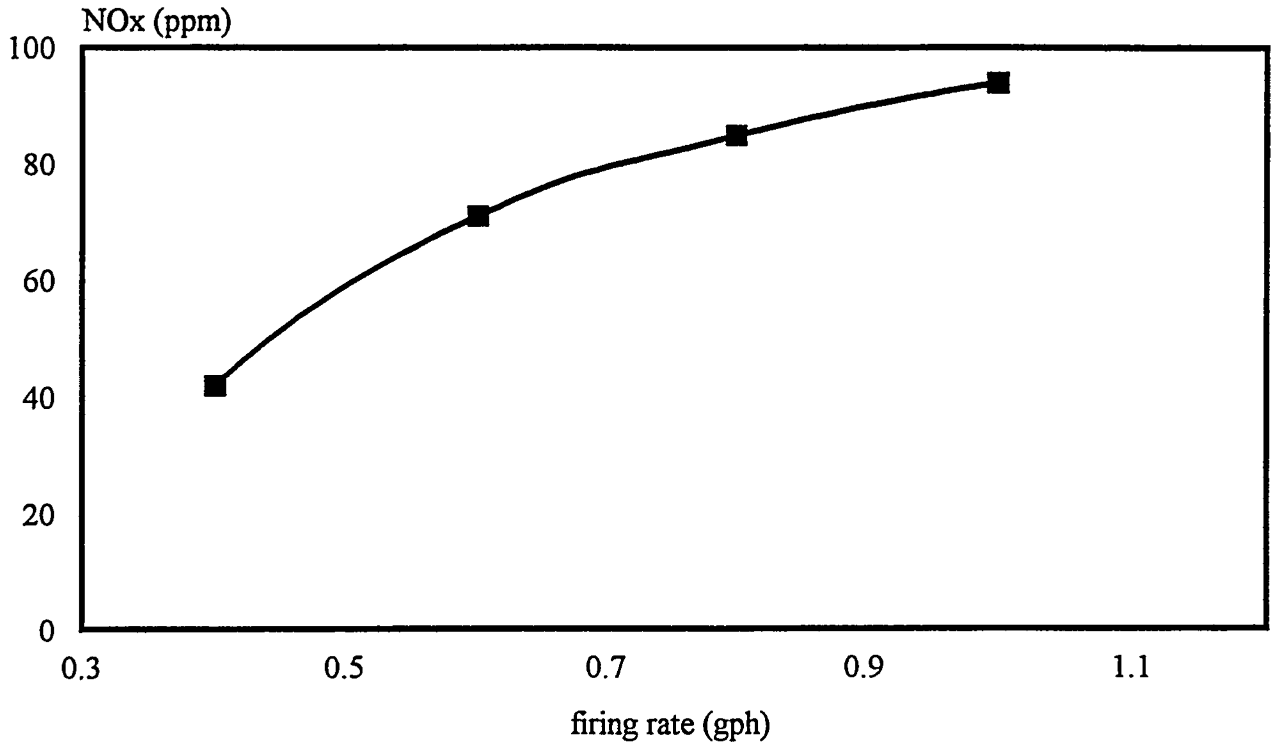

Figure 7. Results of Fan Atomized Burner tests in steel boiler. NOx as a function of firing rate. All tests at 12% excess air (13.7% CO_2)

Testing was done at several different firing rates although the most extensive testing was done at 0.35 gph (14.4 kW). At this input rate the test system had no difficulty in meeting the heating and domestic hot water demand with outdoor temperatures as low as 7 F (-14 C). This is the lowest observed outdoor temperature during the test period and is the 99% design point for the location. At the lowest outdoor temperature conditions for which field testing was done, the burner was on about 90% of the time. At 0.35 gph (14.4 kW), and 13.5% CO_2, the steady state gas temperature leaving the boiler is about 300 F (150 C), giving a steady state efficiency (based on stack loss) of 88%. Figure 8 provides a comparison of the efficiency/load curves of the old system and the test system with the Fan-Atomized Burner. Burner noise, which was a concern early in the development program; was not found to be objectionable in the field. Based on occupant observations the test burner system was quieter than the older, retention head burner system.

Burner Commercialization

The Fan Atomized Burner concept is currently being developed for commercialization by Heat Wise, Inc of New York. The Heat Wise goal is to make this technology complimentary to (not competitive with) existing technology by extending the range of appliances which can use oil heat. The conventional pressure atomized burners listed with Underwriters Laboratories start at a firing rate of 0.4 gph (16.4 kW). They are, however, very seldom installed in the field at rates lower than 0.6 gph (25 kW). There is a clear cut need to use #2 oil in the field below 0.6 gph (25 kW) reliably. For this reason, the Heat Wise goal is to span the range 0.25 gph to 0.65 gph (10 to 25 kW).

The commercial version of this burner is being developed to be as similar as possible to a conventional burner. Initial testing by Heat Wise indicated that good combustion performance could be achieved with lower air pressures (as low as 4 inches of water (1 kPa)) than were being used in the prototype and the pressure levels required could be achieved with careful modifications of conventional burner fans. This provided the opportunity for the development of a very practical commercial burner. The brushless DC, high speed motor and solenoid fuel pump in the prototype have been replaced by a conventional AC motor driving a single stage fan and a conventional type fuel pump, as with a conventional retention head burner. The fan has a somewhat larger diameter than a conventional burner and a high performance housing, which enables it to deliver pressures of 6 inches of water (1.5 kPa) or higher under firing conditions. This is much higher than conventional burner fans, which normally operate with about 1 inch of water (.25 kPa) and have maximum static pressures of about 3 inches of water (.75 kPa). The fuel pump is a modified version of a conventional burner fuel pump, which has a low discharge pressure matching the needs of the air atomized nozzle. This provides the same dry lift and reliability characteristics expected by the industry. The burner uses conventional safety controls and interrupted ignition.

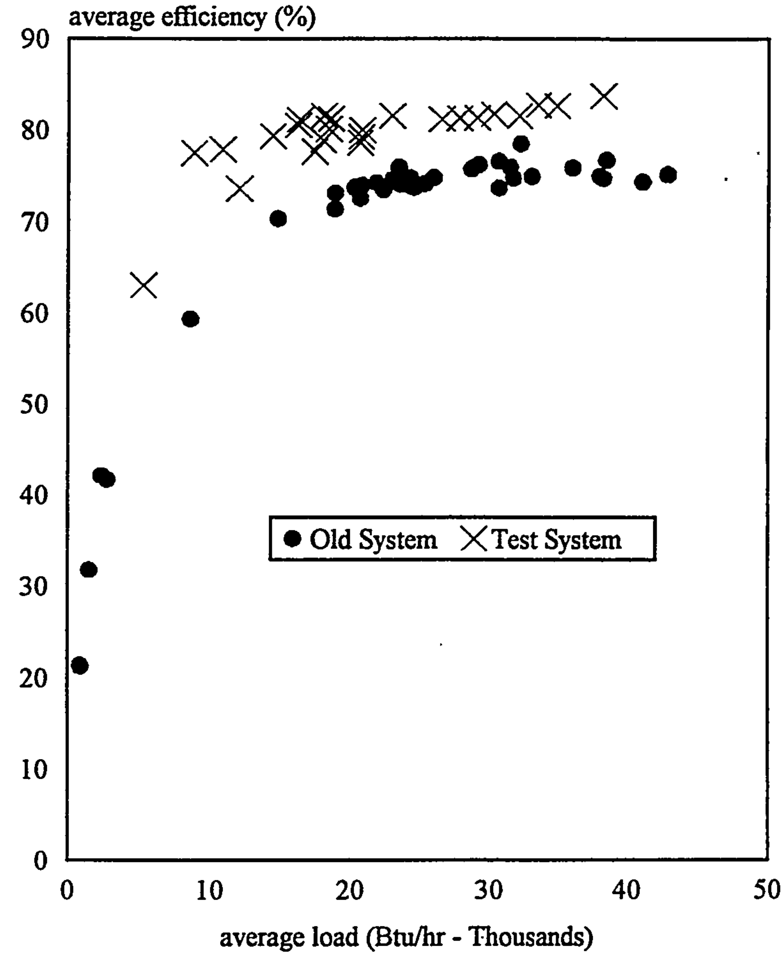

Figure 8. Field test results. Efficiency/load curves for baseline and test systems

Performance testing has been done with the burner over the firing rate range 0.25 to 1.0 gph (10.3 to 41 kW)and excellent performance at CO_2 levels over 14% are achieved.

Conclusions

The Fan-Atomized Burner concept offers the heating industry a new combustion alternative which gives improved efficiency and can operate at lower firing rates than conventional burners. The development work presented in this paper has shown that the burner has strong commercial potential.

An important advantage of this technology is the low firing rates which may create new oil-heat product opportunities including: very low input boilers, furnaces, and water heaters for new construction and electric conversions, wall hung direct vent boilers, and small zone heaters.

Acknowledgements

The basic development of the Fan-Atomized Burner has been sponsored by the U.S. Department of Energy, Office of Building Energy Research. Commercialization is being supported under a cooperative agreement between New York State Energy Research and Development Authority and the U.S. Department of Energy.

References

1. Krajewski, R. Celebi,Y., Coughlan, R., Butcher, T., McDonald, R. Emissions characteristics of modern oil heating equipment. BNL 52249, July 1990.

2. Kelly, G.E., Didion, D.A., Quigley, D., and Collins, B. Potential energy savings in residential oil-fired heating systems in the U.S., NBS Building Science Series 163, National Bureau of Standards, December 1984.

3. Celebi, Y., Butcher, T., Gang, W. Research in oil burner design and emissions control. Proc. of the 1990 Oil Heat Technology Conf. and Workshop, Upton, N.Y., May 21-22, 1990.BNL 52284, November 1990.

4. Butcher, T., Celebi, Y., Wei, G. Fouling of heat exchanger surfaces. Proc. of the 1991 Oil Heat Technology Conf. and Workshop, Upton, N.Y., Sept. 30- Oct 1, 1991.BNL 52340, July 1992.

5. Butcher, T., Celebi, Y. Fouling of oil-fired boilers and furnaces. Proc. of the 1993 Oil Heat Technology Conf. and Workshop, Upton, N.Y., March 25-26, 1993.BNL 52392, September 1993.

6. Locklin, D.W., Hazard, H.R. Technology for the development of high-efficiency oil-fired residential heating equipment, Battelle Colombus Laboratories for BNL, BNL 51325, June 1980.

7. Krishna, C.R., Butcher, T., and McDonald, R. Review of atomization and soot formation for advanced residential oil burner systems. BNL 52173, December 1987.

8. Tuteja, A.D., Hoffman, M.B., Lopez-Crevillen, J.M., Singh, S., Stomber, R.R., and Wallace, G.C. Selection and development of a particulate trap system for a light duty diesel engine. Society of Automotive Engineers SAE 920142, 1992.

9. Butcher, T., Celebi, Y. and Fisher, L. The Fan-Atomized Burner - status and application testing. Proceeding of the 1994 Oil Heat Technology Conference and Workshop, Upton, N.Y., March 24-25, 1994. BNL 52430, April 1994.