NOx – How Low is Achievable with Oilheating Combustion Systems?

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Abstract
In the recently completed Oilheat Industry Roadmap – Towards a Sustainable Energy Future, nitrogen oxide emissions (NOx) were identified as an issue of concern in the competition between oil and other fuels. Research leading to low NOx emissions was identified as one of the high priorities for future oilheat research. This year Brookhaven National Laboratory (BNL) has been exploring the technical feasibility of achieving NOx emission under 10 ppm, a factor of 10 lower than current, yellow flame oil burners. Main technical routes to achieving this goal include ultra-low nitrogen content fuel, recirculating burners with special provision for startup, and vaporizing systems with porous media radiant burners. Technical issues and results of work at BNL are discussed. The goal has been achieved in laboratory systems. The experimental burner concepts are described in terms of the recent experience gained in the laboratory and how this might translate to practical burner designs. The next steps in developing these technologies will also be discussed.

Introduction

Nitrogen oxides (NOx) includes both NO and NO2 and are a pollutant emissions from all combustion sources. NOx is a concern nationally, mainly because it combines with hydrocarbons in the atmosphere and, under the influence of sunlight, forms ozone – a strong health concern. The East Coast has, on average, high levels of ozone and so there is a particular emphasis on controlling NOx emissions. Up to the present time the Eastern States have not imposed NOx emission limits on small boilers and furnaces. It can be argued that the emissions from these sources are only a small fraction of the contributions from other sources and also, ozone is mostly a summer problem, not impacted directly by winter fuel use for heating. In some other parts of the U.S. – notably the Los Angeles region of California and the State of Texas, ozone concerns are even more severe and emission regulations which affect small boilers and furnaces have been put in place. In many parts of Europe, NOx emission limits have been placed on small sources for many years and low-NOx burners are common on the market place.

Gas-fired boilers are currently available with reported NOx emissions under 10 ppm and, even where fuel selection is not driven by NOx regulations, the lack of oil-fired options in this range supports arguments about the relative cleanliness of oil. Considering this, the region-specific regulations, the trends in Europe, and recognition that the future may bring NOx regulations in more U.S regions, there is a growing consensus that the oilheat industry should be proactive in developing U.S. options for low NOx appliances.

In 2002, the U.S. Department of Energy and many other organizations collaborated to prepare a roadmap for the future of oilheat development [1]. One goal set during that process was the introduction of clean oil burners with emissions under 20 ppm, based on a nitrogen-free fuel. In the current R&D program at BNL a goal has been set of establishing the technical feasibility of achieving emissions even lower – under 10 ppm.

This paper provides a brief summary of NOx emissions with burners which are currently available on the market and describes the approaches being explored in the BNL program and the results-to-date.

Emission Levels for Current Burners

All burners currently on the market in the U.S. are of the retention head, yellow flame type. In prior work, NOx emissions from these burners have been discussed [2,3]. During the 2002 NORA Technology Symposium several papers presented new data on NOx emissions from conventional and advanced systems [4,5,6].

With conventional yellow flame systems the NOx emissions depend upon the firing rate and the combustion chamber. Higher firing rates and increased refractory lining in the combustion chamber (hotter chamber) tend to produce higher flame temperatures and higher NOx. Current U.S. systems range from roughly 75 ppm to 180 ppm. Arguably, 110 ppm is about the average for oil combustion with yellow flame burners.

A great deal of effort (largely in Europe) has been put into the development of low-NOx residential oil burners based on high rates of recirculation of combustion products within the combustion chamber. These burners have higher air velocity, more of the air introduced to the flame zone along the burner centerline, flame tubes to control recirculation, and flame tube slots or holes which control the amount and location of the recirculated flue gas. With these burners achievable NOx emissions range from 40 to 65 ppm.

Routes to Sub-10 ppm

One key aspect of achieving the goals of sub 20 or sub 10 ppm NOx is the nitrogen content of the fuel. Currently, heating oil has a nitrogen content of 150 mg/kg (.015wt%). At this level of nitrogen content essentially all of the fuel nitrogen is converted into NOx and this contribution is about 23 ppm. In the BNL lab, combustion tests with a nitrogen free fuel, and a high performance, low-NOx, blue flame burner firing into a cool-wall combustion chamber have yielded NOx emissions of about 18 ppm with very low CO emissions.

Nitrogen-free Number 2 heating oil is not available on the market. The primary purpose of setting the goal based on a nitrogen-free fuel was to eliminate nitrogen as a variable in comparing different technologies and to demonstrate what might be achievable in the future. Ultra-low sulfur diesel fuels which are being introduced mostly for test and limited use purposes tend to approach nitrogen-free, as does kerosene.

From these results it is clear that a nitrogen-free fuel and very high quality recirculating burners can be used to achieve the sub-20 ppm goal but not the sub 10 ppm. One of the technical approaches under consideration involves increasing the recirculation rate with low-NOx burners currently in a ***commercial*** status. The recirculation rate could be increased for example by increasing the area of the recirculation slots in the flame tube. In combustion tests at BNL a burner was fired with an externally adjustable recirculation area. These steady state tests with a nitrogen-free fuel resulted in NOx emissions under 10 ppm, below the target goal. Figure 1 shows the burner operating under the highest recirculation condition. Figure 2 shows the trend in NOx emissions as a function of the recirculation area, expressed as a fraction of the flame tube exit area.

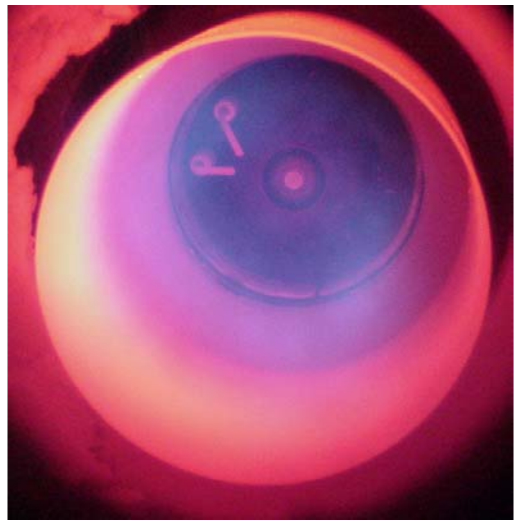

Figure 1. Photo of a low NOx burner operating recirculation rates with very high

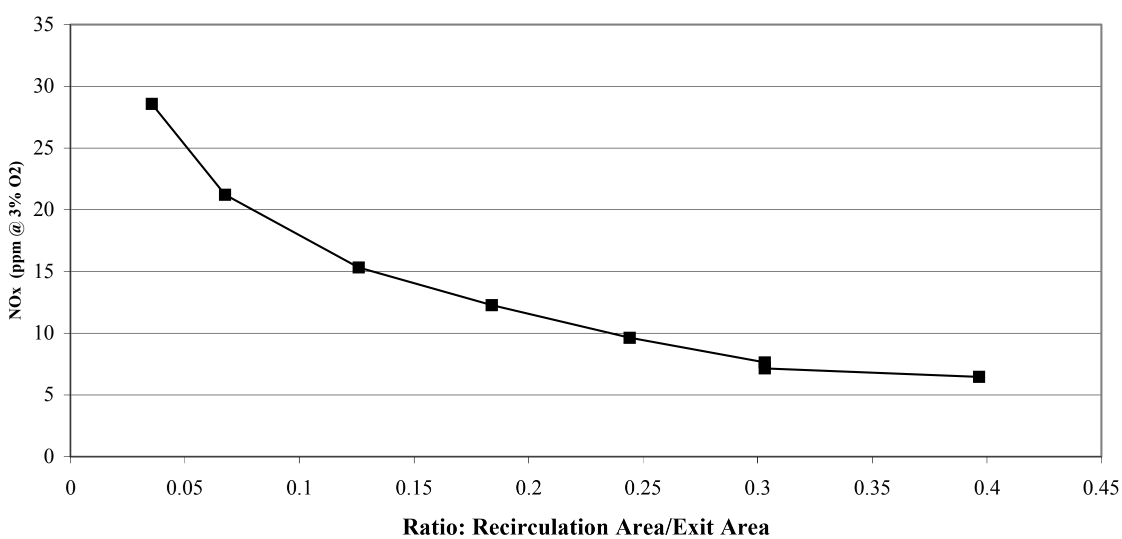

Figure 2 NOx emissions measured as the recirculation area is manually adjusted in a low-NOx burner

At the lowest NOx points measured the burner was pulsing slightly, indicating that a stability limit was being approached. For all points except the one with the highest recirculation area, the

CO emissions were under 25 ppm. At the highest recirculation level (lowest NOx) CO was 63 ppm.

In practice a recirculating burner configured this way could not be started cold. Under cold conditions the rate of gas recirculation is considerably higher than when the burner is warm because of gas density differences. To achieve sub-10 ppm NOx in this way would require a special provision for starting, for example to reduce the recirculation rate only during the warm-up period. This might be achieved with a positional recirculation slide valve or aerodynamic valve closing off of the recirculation flow. An aerodynamic valve could be an air flow over the recirculation slots which prevents recirculated gas from entering the flame tube.

Another approach which could be taken is to combine internal gas recirculation with external gas recirculation and a condensing boiler might be a suitable platform for this. BNL is currently testing three different configurations of oil-fired condensing boilers. These have exhaust gas temperatures which are low – in the 120 F range and in some cases are intended only for use with low sulfur heating oil. This provides an exhaust gas which is relatively cool and which will have low potential for corrosion in the burner air housing. In this case, the advantage of external exhaust gas recirculation is that it might be easier to turn the recirculation gas flow off during the cold start period than with an internal recirculation burner. Prior tests at BNL and Carlin Combustion Technologies have shown the very strong impact that external recirculation can have on thermal NOx emissions in a residential system [3,5].

Burner head designs, which will never stop evolving, may provide an alternative route to achieving sub-10 ppm NOx emissions. One example which has been receiving considerable attention recently involves introduction of part of the combustion air through a circumferential array of ports concentric with the fuel nozzle. This approach is appearing in several European burners, particularly larger commercial burners. This approach allows dilution of the inner and outer parts of the combustion air with combustion products before these two parts mix to complete combustion [7]. In recent tests done cooperatively between BNL and Heat Wise, Inc. a low pressure, air atomizing nozzle was tested in a burner head with this configuration. Over firing rates ranging from 1.5 to 3.0 gallons per hour, NOx emissions in the 10 ppm range were achieved.

Another route which could be considered although with a greater level of complexity, is the combustion of a mixture of vaporized oil and air, within a porous ceramic matrix. Combustion within a ceramic body which can radiate heat away to relatively cooled surfaces has been well developed for ultra-low NOx gas burners. With oil the fuel must first be vaporized and mixed with heated air (and possibly recirculated combustion products). Currently, some very interesting development work is ongoing in the development of practical burners based on vaporizing oil in combination with radiant burners and very low NOx emissions have been demonstrated [8]. BNL has been conducting some tests of this approach for achieving the goals of this project in combination with ongoing studies of cool flames for fuel vaporization. Figure 3 shows a test burner flame inside of a reticulated ceramic burner. Measured NOx produced by this ***flame*** with a nitrogen-free fuel were roughly 6 ppm and CO was under 50 ppm.

Figure 3 Oil flame inside of a ceramic radiant burner at BNL

Conclusions

This work has been focused on exploring the technical feasibility of achieving NOx emissions under 10 ppm with a nitrogen free fuel. The work to date has shown that this goal may be achievable, at least in the lab. Routes which have been developed towards achieving this goal include: 1) increased recirculation rates with current low-NOx burner designs with special provisions for startup, 2) new burner head designs and 3) oil vaporization followed by combustion in radiant, porous media.

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