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Project Summary

Burner Criteria for NO_x Control: Volume III. Heavy-Oil- and Coal-Fired Furnaces and Further Furnace Investigations

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This report describes the third phase of a research program with the overall objective of specifying burner design criteria for minimum pollutant emissions from both pulverized-coal- and residual-fuel-oil-fired combustors. A distributed mixing burner was developed, and its potential for NO_x control was evaluated for different fuels. The burner produces a fuel-rich zone that reduces the conversion of fuel nitrogen species to NO_x. Injecting additional air from outboard ports completes fuel oxidation. It was postulated that achievable NO_x control depended on nitrogen volatility and local oxygen content. This was confirmed by burning coal, a low volatile petroleum coke, heavy fuel oil, and a heavy fuel oil/water emulsion. A television pyrometer flame diagnostic technique that was evaluated gave promising results.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Program Overview

This report describes the third test series of a research program whose overall objective is the specification of burner design criteria for minimum pollutant emissions from pulverized-coal- and residual-fuel-oil-fired combustors.

The first test series of the program concerned the definition of the effect of various burner design parameters on the formation of nitrogen oxides (NO_x) in both pulverized-coal and natural-gas flames. Furnace trials were carried out which evaluated both input/output investigations and detailed flame mapping in an attempt to establish flow and mixing patterns that yielded the most promise for controlling NO_x emissions by burner redesign. The major accomplishment of the first test series was the finding that, under subscale conditions, NO_x emissions from pulverized coal flames could be varied by a factor of four by changes in furnace design and operating conditions. This variation was achieved mainly by selecting three burner design parameters:

- The method of fuel injection. Rapidly mixing coal with all the combustion air resulted in higher emissions. The lowest emissions were achieved with a high-velocity axial fuel injector which maintained a coherent fuel jet of high coal density.
- Optimum level of swirl to provide a stable ignition source at the fuel injector without mixing the fuel too rapidly with the secondary air. Swirl refers to the fact that the secondary air stream has both a tangential and axial velocity component.
- The amount of primary air. Primary air is air that is mixed with the pulverized coal before delivery into the furnace. NO_x emissions were lowest when the minimum amount of primary air was used consistent with maintaining slow

mixing of the fuel jet with the secondary air.

Although burner conditions had been identified which gave low NO_x emissions, it was readily recognized that such a burner design would be unsuitable for use in existing wall-fired utility boilers.

The second test series was carried out to: (1) provide further information on the formation of NO_x in pulverized coal flames, to aid in interpreting the results; (2) extend the investigation to include residual fuel oil firing, to define parameters that give minimum emissions; and (3) investigate methods of satisfying process requirements and produce minimum emissions (including the definition of the combustion requirements of practical systems, as well as an attempt to reduce emissions by modifying burner design). Results were obtained that defined the emission characteristics of a subscale practical pulverized coal burner and the development of a tertiary air injection system to minimize NO_x formation by using outboard staged air ports. Emissions from dual fuel firing were investigated by firing natural gas and coal simultaneously. Emissions were not additive, and depended on such burner parameters as the type of fuel injector. Emissions from heavy fuel oil were found to be most dependent on the method of atomization; in general, the lowest emissions were produced by the narrowest spray angles. In addition to the furnace investigations, the predictive capabilities of several radiative heat transfer models were evaluated against experimental data and hypothetical test cases.

The third (final) test series included a furnace trial which was planned to answer several questions:

1. What is the potential of tertiary air injection as a method of NO_x control for coal flames?
2. What is the impact of char nitrogen?
3. How are pollutant emissions affected by multiple burner arrays?
4. Is the use of emulsions beneficial?
5. Can a control system be developed for low NO_x burners based on a TV pyrometer?
6. Does an evaluation of detailed flame measurements made in earlier reports indicate the controlling mechanisms of NO formation in flames?

Results

Program results have included: (1) initial development of a delayed mixing burner (DMB), (2) NO_x formation from petroleum coke, (3) the influence of oil/water emulsion on pollutant formation, (4) pollutant measurements in multiburner systems, and (5) using a television pyrometer to control low emission burners.

Initial Development of a Delayed Mixing Burner

In the second test series, a burner design was identified for pulverized coal which produced low NO_x emissions and a flame that was suitable for use in wall-fired boilers. In this burner, used in the third test series, the total combustion air supply was divided into three streams: the fuel-rich primary zone was supplied with primary air (used to transport the coal) and secondary air (through the burner throat); and the third air stream was injected from the periphery of the burner exit to mix the partially oxidized products of the fuel-rich zone some distance downstream, thereby completing combustion. Experiments were conducted to investigate the effect of: air delivery system variables, fuel injector design, air preheat level, and furnace heat extraction.

Figure 1 summarizes the data obtained at different furnace heat extraction rates for two swirl levels (of the secondary air). For both furnace conditions, an increase in burner equivalence ratio (i.e., increasing the flow of air to the outboard staged air ports and therefore decreasing oxygen availability in the primary zone) dramatically reduces NO_x emissions. The level of swirl has a significant impact on emissions close to stoichiometric, but emissions are almost independent of swirl level at high burner equivalence ratios.

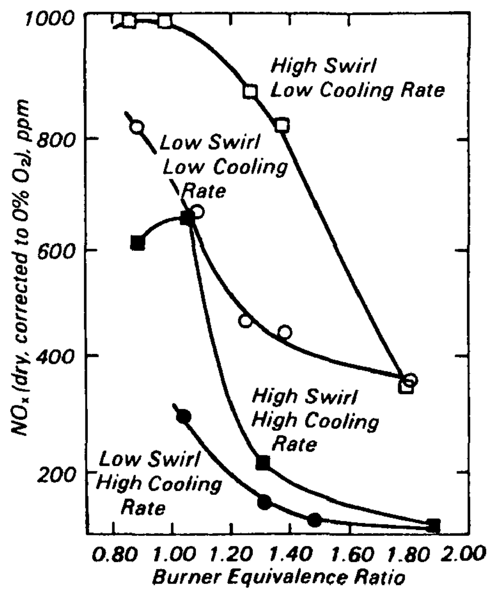

Figure 1. *Effects of swirl, cooling rate, and burner zone stoichiometry on NO_x emissions for a pilot scale DMB.*

NO_x Formation from Petroleum Coke

Petroleum coke is a high-nitrogen low-volatile solid produced by thermally cracking petroleum residuals. Investigations were carried out with pulverized petroleum coke to assess the impact of volatile fuel nitrogen fragments on NO_x formation. Emissions from petroleum coke were found to be relatively insensitive to burner parameters. With fuel injectors that produced rapid mixing between the fuel and air, emissions from pulverized coal were approximately twice those from pulverized petroleum coke. With axial fuel injection at particular swirl levels, emissions were similar for the two fuels. These data suggest that high NO_x emissions from high-turbulent pulverized-coal flames primarily result from the oxidation of volatile fuel nitrogen fractions. Delayed mixing — produced either by the formation of a long thin flame (using axial fuel injection) or with the DMB — reduces emissions because they minimize fuel NO formation from the volatile fuel nitrogen fragment, but they have little impact on char nitrogen oxidation.

The Influence of Oil/Water Emulsions on Pollutant Formation

Attempts to reduce NO_x emissions from fuel-oil-fired combustors are quite often limited by an increase in particulate emissions because of the need to operate with fuel-rich zones. A brief series of tests were conducted with the TOTAL emulsifier to determine if oil/water emulsions would alleviate this problem. Test results indicated that:

- Adding water, in the form of an emulsion, decreased particulate emissions from heavy oil flames.
- When operating under low NO_x conditions, adding water reduced particulate emissions by a factor of three and had only a minor impact (a slight increase) on NO_x emissions.

Pollutant Measurements in Multiburner Systems

All of the previous experimental studies carried out in this program involved single burners. Yet, it is possible that interactions between burners could influence pollutant formation in multiburner arrays. Tests were carried out to compare the characteristics of a three burner system firing natural gas and fuel oil (total heat input of 2.0 MW) with a single burner of equivalent heat input. The burners, scaled geometrically, were operated similarly.

Two basic burners were investigated:

- Type A (high momentum) — the total combustion air was supplied through the throat with a relatively high primary velocity (50 $msec^{-1}$).
- Type B (low momentum) — the air flow through the throat was halved, and the remainder supplied via a secondary duct. A common duct was used for the multiple burners.

An axial fuel gun was used for all cases; natural gas was injected radially and a 90° steam-atomized Y-jet was used for fuel oil. A disc swirler was necessary to stabilize the fuel oil flames. The excess air levels for type A and B flames were 5 and 9 percent of the stoichiometric requirements, respectively.

For natural gas flames, it was found that a decrease in burner momentum increased emissions (i.e., emissions from the single type A burner were less than those measured with the single type B burner). The data presented in Figure 2 indicate that burner spacing does not have a significant influence upon NO_x emissions until the burners are near each other. With the low momentum burners, maximum emissions were observed at intermediate burner separations.

The influence of burner type and spacing on NO_x emissions from fuel oil is shown in Figure 3. In general, emissions increase with reductions in burner spacing. With large single burners, the emissions are reversed from those observed with natural gas. The higher emission from the high momentum burner could be attributed to increase fuel NO formation because of the more rapid fuel/air mixing. Comparison between the small and large burners is difficult because of the problems associated with scaling oil nozzles.

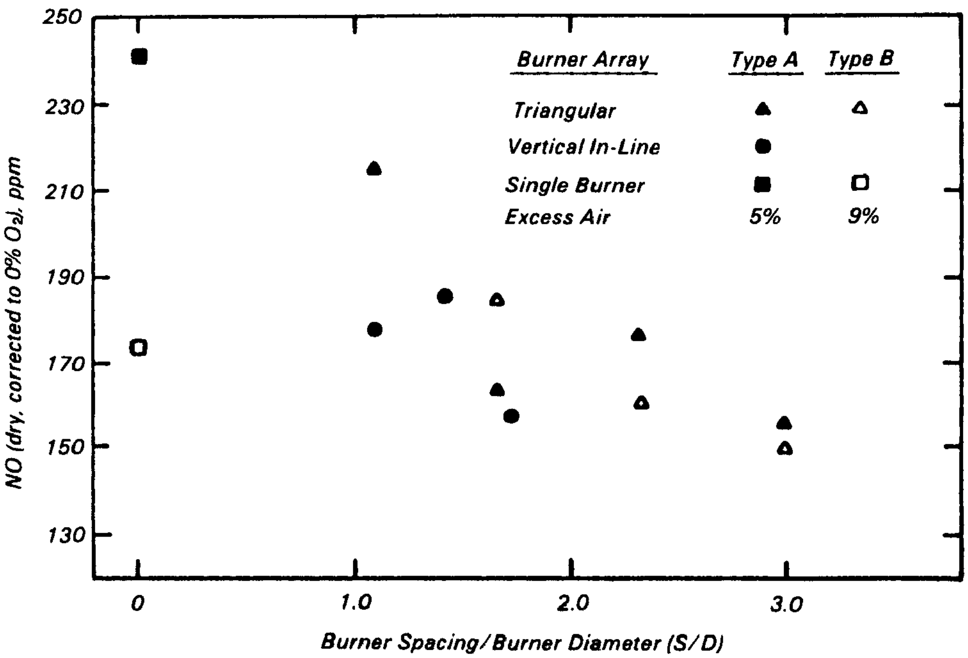

Figure 3. *The influence of burner spacing, type, and configuration on NO formation in fuel oil flames.*

Using a Television Pyrometer to Control Low Emission Burners

Increased complexity and the need to operate low NO_x burners within close limits place stringent demands on control systems. A test was carried out with a television pyrometer (TVP) to determine if this system could be used as a sensor in a burner control system. Figure 4 shows the TVP schematically. The instrument setup consists of five electronic units: a commercial TV camera, an intensity switch, an area integrator, an auxiliary generator, and a commercial black and white (or color) TV monitor. The TV camera views the flame through an optical filter and transforms the flame image into an electrical signal, the video signal. This video signal contains all the optical information from the object that penetrates the optical filter. Entering the intensity switch, the signal is modified by four comparators that subdivide the flame image into areas of four intensity ranges, each of which is displayed on the TV monitor in either four different gray shadings or, when a color TV monitor is used, in four different colors. The threshold value of each comparator can be varied continuously in the full range between 0 and 100 percent; however, during this test series, the intensity distribution was kept constant.

An integration of the number of screen points which lie within each range of equal intensity and the total number of points within the flame image on the screen can be carried out by the area integrator.

The auxiliary generator permits the display of an electronic grid on the TV monitor which gives the observer a visual scale for dimensions, thus avoiding possible paral-

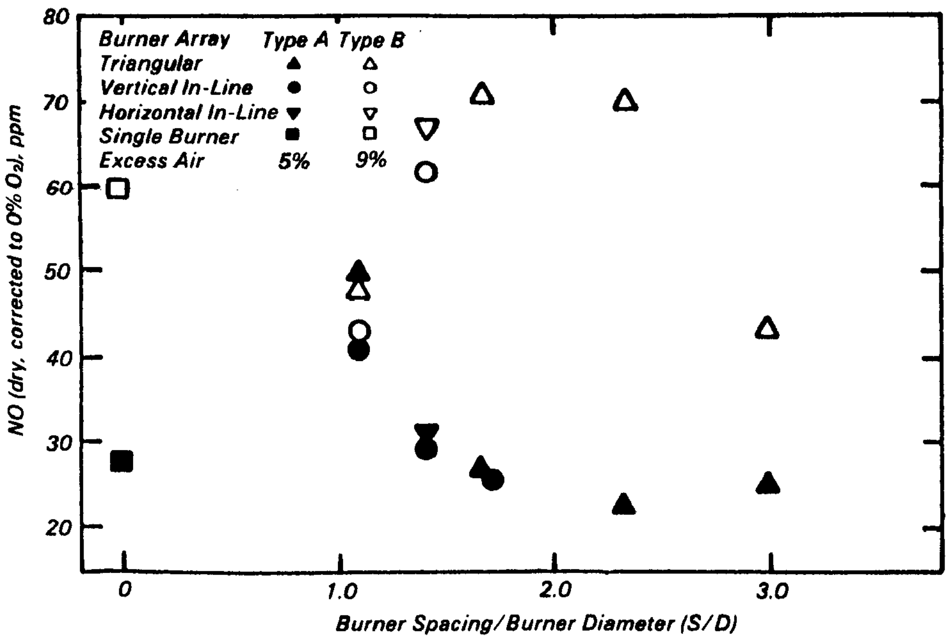

Figure 2. *The influence of burner spacing, type, and configuration on NO formation in natural gas flames.*

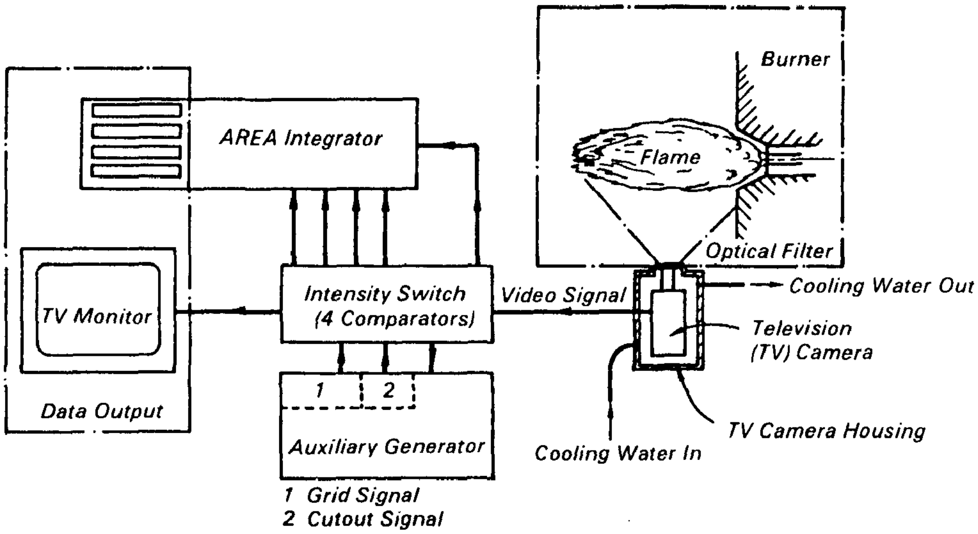

Figure 4. *Composite units of the television pyrometer (TVP).*

lactic aberrations. Furthermore, this generator can cut out (electronically) undesired parts of the monitor screen and thus allow an intensity analysis, for instance, to be confined to only one flame even when more than one flame lies within the angle of vision of the TV camera.

The main objective of testing the TVP was to investigate its potential application as an external burner control for industrial furnaces fired by multiple burner systems. First results of the test indicate that NO_x flue gas concentrations emitted by natural gas flames can be correlated with the data of the intensity distribution obtained by the TVP. However, better controlled experiments would establish correlation data for a wider range of burner and/or flame types.

It has been suggested, that under the conditions considered in this study (nonluminous natural gas flames), the TVP mainly detects the light emission from exited CH and C_2 radicals. It, therefore, offers itself also for the control of other input parameters which influence the radical concentration and temperature; e.g., the excess air level.

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The complete report, entitled "Burner Criteria for NO_x Control: Volume III. Heavy-Oil- and Coal-Fired Furnaces and Further Furnace Investigations." (Order No. PB 84-169 275; Cost: $19.00, subject to change) will be available only from:

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