United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

Research and Development

EPA-600/S7-81-137 Oct 1981

EPA

Project Summary

Pilot-Scale Development of a Low-NO_x Coal-Fired Tangential System

J. T. Kelly, R. A. Brown, E. K. Chu, J. B. Wightman, R. L. Pam, E. L. Swenson, E. B. Merrick, and C. F. Busch

A 293 kW_t (1 x 10^6 Btu/hr) pilot-scale facility was used to develop a low-NO_x pulverized-coal-fired tangential system. Conventional tangential system burner and vortex characterization tests defined the major system design requirements for a low-NO_x system. Given these requirements, a burner concept was developed which achieves low NO_x by directing the fuel and a fraction of the secondary combustion air into the center of the furnace, with the remaining secondary combustion air directed horizontally and parallel to the furnace walls. The separation of secondary combustion air in this manner creates a fuel-rich zone in the center of the furnace where NO_x production is minimized. This combustion modification technique has lowered NO_x 64 percent, relative to conventional tangential firing, by injecting 85 percent of the secondary air along the furnace walls. Under these conditions, NO emissions were 180 ppm corrected to 0 percent oxygen. In addition, at these conditions, CO, UHC, and unburned carbon emissions were less than 40 ppm, 3 ppm, and 2.4 percent, respectively. These levels are comparable to conventional tangentially fired pilot-scale results. Also, the modification places a blanket of air on the furnace walls which is beneficial from a wall corrosion and slagging point of view. With the modification, oxygen concentrations above the burner level near the furnace wall were 12 percent. This is nearly three times conventional tangential pilot-scale system wall oxygen concentrations. Finally, in some configurations, the modification shows a decrease in NO_x emissions as firebox gas temperature is increased. This characteristic might be beneficially applied in a large-scale system to reduce furnace volume, and thereby capital cost, for a given combustion heat release.

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).

Introduction

Maintenance of ambient air quality in the United States requires the restriction of NO_x emissions from stationary combustion sources. Presently, tangential coal-fired boilers produce approximately 10 percent of all stationary source NO_x and consume, in kW-hr, approximately 9 percent of all fuel used in stationary sources.[1] The significant NO_x emissions from these boilers and the projected increase in the number of these boilers make them candidates for emission control development both in terms of retrofit and new boiler designs.

During the combustion of pulverized coal in tangential boilers, NO_x is generated from the nitrogen chemically bound in the fuel as well as from the *oxidation of atmospheric nitrogen*. For typical bituminous coals, NO_x emissions from the fuel bound nitrogen can be a significant fraction of the total.[2] NO_x emissions have been shown to respond to combustion modification techniques which alter oxygen concentration, residence time, and temperature during combustion.[3] Lowering the oxygen concentration surrounding the fuel, either locally by fuel/air stratification or globally by limiting the air flow in the combustion volume, shifts the fuel and atmospheric nitrogen emission reactions from predominantly NO_x formation to a balance between NO_x and molecular nitrogen formation.[3] In addition, given sufficient residence time at oxygen deficient conditions, previously formed NO_x can be reduced to molecular nitrogen by homogeneous[4] and heterogeneous[5] catalyzed and noncatalyzed reactions.

Lowering peak temperature under excess air conditions decreases atmospheric nitrogen NO_x formation.[6] However, under very fuel-rich staged combustion conditions, lowering first-stage temperature can increase NO_x.[6] This is due to less fuel nitrogen being volatilized in the first stage and carrying over and being converted into NO_x in the oxygen-rich second stage.

Even though imperfectly understood, these basic relationships between system parameters and NO_x emissions have been employed to moderately reduce NO_x emissions from tangential as well as other types of utility boilers.[7] Significant further reductions in NO_x from tangentially fired boilers require a better understanding of the combustion processes which control NO_x formation/reduction. Therefore, this study was separated into two phases. The objective of the first phase was to develop an understanding of the processes which control NO_x formation/reduction in pulverized-coal-fired tangential boilers. Utilizing the results of the first phase, the objective of the second phase was to develop and demonstrate, in pilot-scale, low-NO_x combustion modification techniques that can be retrofitted in old or incorporated into new tangential boiler designs.

Definition of Coal-Fired Tangential Systems

Figure 1 illustrates the main features and flow patterns of a tangentially fired

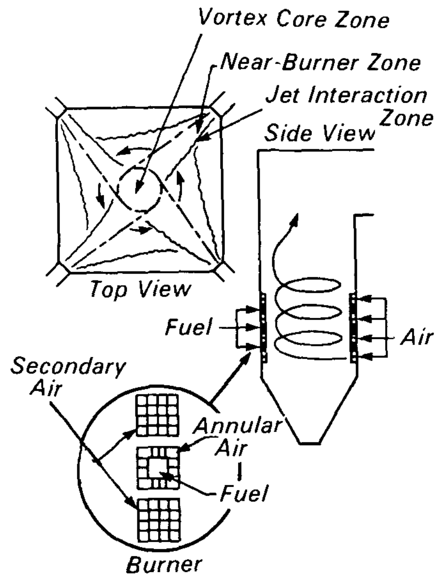

Figure 1. *Tangential boiler schematic.*

boiler. Fuel and air are introduced into the furnace through rectangular registers located in the four corners. The bulk of the combustion air enters above and below the fuel jet as shown in Figure 1. The jets are nonswirling and fuel/air mixing is slow relative to front-wall-fired boilers.

The tangential alignment of the centerlines of the corner jets to the circumference of a circle in the center of the furnace promotes the formation of a large-scale vortex within the furnace. Ignition of the fuel is provided by impingement of hot burnt gases from laterally adjacent burners and large scale internal recirculation of combusted gases. Because ignition occurs primarily on the vortex core side of the fuel jet (see Figure 1), combustion is asymmetric in the horizontal plane.

Pilot-Scale Combustion Facility

To simulate properly full-scale system combustion environments, the pilot-scale facility volumetric heat release, overall residence time, and furnace exit gas temperature were matched to typical full-scale values. Also, burners and their placement in the firebox were patterned after full-scale tangential systems.

The simulation of full-scale firebox flow patterns and mixing by the pilot-scale facility was evaluated by comparing pilot-scale flow and flame patterns to corresponding full-sc results. In the comparison, similarit were found for (1) ignition standoff a character, (2) flame spreading an from burners, (3) apparent jet centerli angle from corners, and (4) vortex si

Baseline Test Results

As shown in Figure 2, NO* emissi levels achieved by the pilot-scale facil at various excess air levels on seve coal types correspond well with fu scale results. The matching of the N trend with excess air is encouraging that this, as well as the abovemention comparison of flame patterns, may l an indication of the matching of mixi processes between the full- and pil scale systems.

During baseline testing, the CO, UH and carbon loss emissions were lo indicating that complete combustion occurring in the pilot-scale facility.

Jet and Vortex Characterization Test Results

To assist in the definition of N emission control strategies, conve tional tangentially fired tests we carried out to characterize the importa processes to NO formation/reduction this system and establish the effect design variables on these processes.

During the characterization tests, th facility was operated at baseline cond tions. The fuel chosen for all combustio system definition and modificatio testing was a Utah bituminous coal. Ir flame gas and solid samples were take by a water-quenched sampling probe a a variety of firebox locations to determin the relative importance of near-burne jet interaction, and vortex zones (se Figure 1 for zone definitions) on N(processes. A limited number of samplin locations (0.076 m below, at, and 0.2 m above the burner centerline) wer chosen to characterize these zones.

Staged combustion probing tests were also run at a lower firebo stoichiometric ratio of 0.85 with ar overall stack excess air level of 1 percent. These tests provided under standing of the impact of fuel-ric combustion on NO_x formation/reductior processes in the firebox.

Once the important zones to NO formation were defined, NO was injecte

*NO is the dominant form of nitrogen oxid emissions from furnaces and only NO was mea sured during this test program

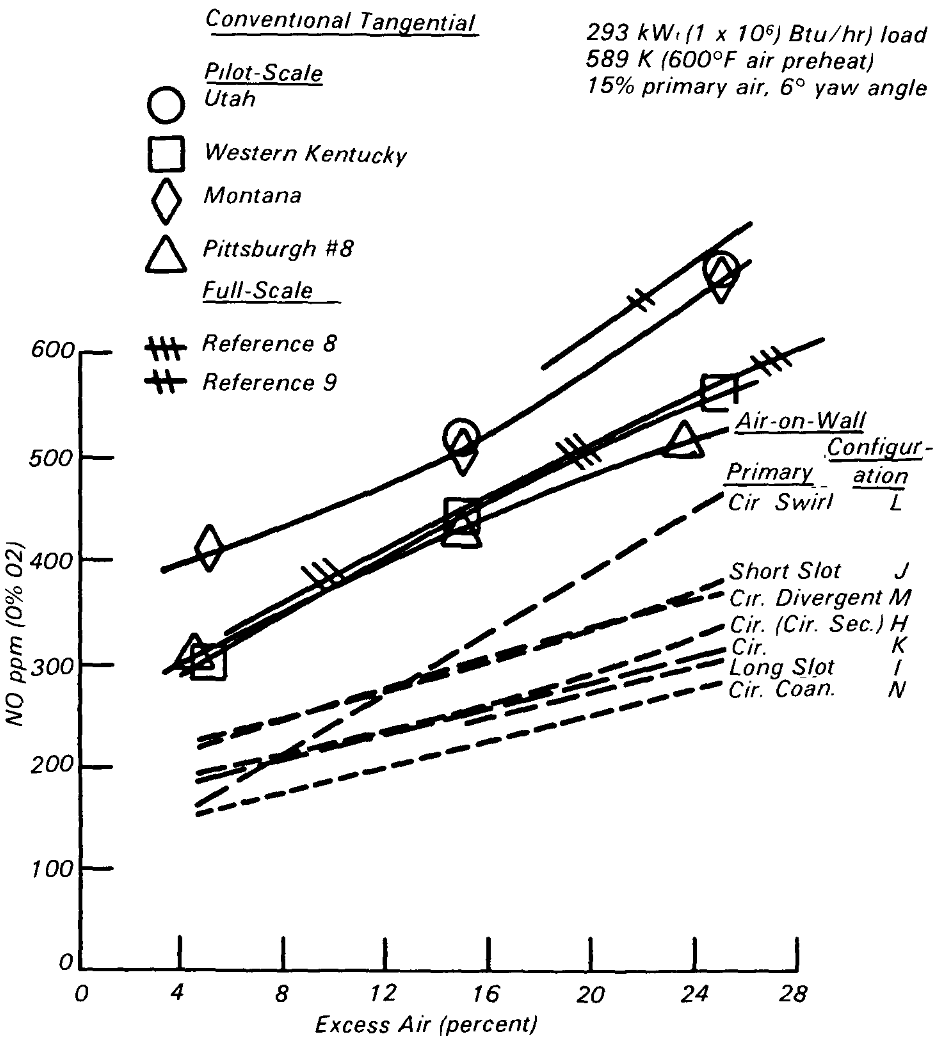

Figure 2. *Effect of excess air on pilot-, full-scale, and air-on-wall system NO emissions.*

into these zones, and others, to determine the NO reduction potential of these zones. The amount of injected NO remaining in the stack gases quantified the NO reduction potential of these zones.

Tangential Burner Characterization Test Results

Different burner designs were tested to assess their impact on NO and to determine the relationship between burner design parameters and NO. Burner designs tested were limited to nonswirling slow-mix designs, such as those presently used in tangential systems. Compact intense flames produced by swirl burners are not compatible with tangential firing due to potential corner slagging and deposition problems

Based on the probing test results and the known importance of O_2 availability in the fuel jet to NO,[6] burner designs were tested where the exposure of the fuel jet to combustion air, and the hot combustion gases which provide ignition, was varied. Also, in some of these tests the relative position between the fuel and air was varied to operate the vortex side of the flame more fuel-rich. For the burner design tests, three conventional baseline burners firing on gas and one experimental burner firing on coal were used to generate a conventional tangential system vortex.

Firebox Mixing Tests

Several burner configurations were tested for the effect of firebox mixing intensity and jet breakup on NO by varying the gas burner firing rates while maintaining the coal burner at a constant 73 kW_t (250 x 10^3 Btu/hr). Varying the gas firing rate changes the vortex strength and the turbulence intensity in the firebox, which alters the coal burner mixing processes.

Discussion of Results from Conventional Tangential Design Tests

Probing tests showed that near the burner face, where the bulk of the total NO is formed, combustion is asymmetric with ignition, intense burning and peak NO production occurring on the vortex core side of the fuel jet in the jet interaction zone. At this location approximately 60 percent of the fuel has been burned and this fraction can be associated primarily with the fuel volatiles. Fuel/air mixing in this zone is enhanced by the crossflow of hot combustion gases over the fuel and air jets. Since the initial fuel nitrogen volatiles see an abundance of oxygen in this zone, NO formation is very high. Lifted flame and dispersed fuel jet burner test results were extreme examples of how high O_2 concentrations at the fuel ignition point can lead to high NO. In addition, this zone has a high gas temperature, due to reduced wall heat transfer and high entrained combustion gas temperature. High temperature under O_2 rich conditions generates significant atmospheric nitrogen NO.[6]

As shown by the staged probing and burner configuration tests, the high NO production rate of the jet interaction zone can be reduced by operating this zone fuel-rich through limits on fuel/air mixing. Under these conditions the volatilized fuel nitrogen will be in a more oxygen-deficient environment and the fuel nitrogen NO formation reaction will shift to a balance between NO and molecular nitrogen formation.[3] Also, atmospheric nitrogen NO formation will be reduced under oxygen-deficient conditions.[3]

Downstream of the near-burner zone, beyond roughly half the firebox length, the vortex interacts with the burner jets and causes the fuel and air to mix rapidly. Combustion and NO production in this zone and beyond are dominated by char burning and the net NO production is small relative to the near-burner region. In this zone, the fuel nitrogen in the char matrix reacts in an environment which has a much lower O_2 concentration than the near-burner region where the volatiles react. Also, previously formed NO concentrations in this zone are high. In this environment, NO reduction of the fuel nitrogen to molecular nitrogen can occur.[3] In addition, previously formed NO can be reduced by homogeneous reactions with fuel components[4] or by catalytic and noncatalytic reactions on fuel particle surfaces.[5] These processes together account for the small net NO production observed for this zone. Similar comments also apply to the above burner elevation zone.

Staged probing tests showed that operating the downstream burner zone fuel-rich causes decay of previously formed NO. In this environment the homogeneous and heterogeneous NO decay reactions discussed above overwhelm any NO production yielding low stack NO levels.

The effectiveness of the various combustion zones in decaying previously formed NO is also clearly demonstrated by the NO dopant tests. For conventional combustion conditions, injecting NO on the fuel jet centerline near the burner gives NO reduction efficiencies of 70 to 80 percent. Away from the burner and in the vortex, reduction efficiency is about 50 percent. In the active zone on the vortex core side of the fuel jet, explored in the probing tests, reduction is 94 percent. Below the burner level, NO reductions of 80 percent were measured, whereas above the burner level reductions were small, being less than 13 percent.

Under staged combustion conditions, at a first-stage SR of 0.85, NO reductions at the burner elevation were a factor of two better than the unstaged results, except at a single point for which no explanation can be given. Below the burner level, reductions observed were about the same as conventional unstaged reductions. Above the burners, the reductions were significantly better for the staged conditions.

These results show that NO is most effectively reduced if the NO is injected into the active combustion and peak NO production zone formed by the interaction of hot burnt gases and the fuel jet. In this zone, reaction is probably fast and addition of NO can drive the reactions from NO_x production toward a balancing of NO_x production and reduction. Another effective reduction zone is near the burner face at the burner elevation. In this zone, oxygen is not abundant and NO is reduced. Below the burner level, NO reduction is effective for both staged and unstaged conditions.

Based on burner flame observation and probing tests, the lower NO found for reduced firebox mixing is primarily due to the maintenance of locally rich zones downstream of the burner face where NO production from the char is minimized and previously formed NO decay is maximized. The same NO reduction processes which occur under globally rich conditions for staged combustion are active in the locally fuel-rich zones created by burner fuel/air stratification. Burner tests also showed that too low a mixing level can result in loss of ignition and lifted flames. These flames have high O_2 availability at the fuel ignition and volatile reaction point, and thereby high NO.

Low-NO_x System

Based on the above observations, the requirements for a low-NO_x tangential system were identified. These are: (1) initiate burning sooner to minimize O_2 availability at the ignition point, (2) operate the jet interaction zone fuel-rich, (3) protect the fuel jet from dispersion by vortex flow, (4) lower firebox mixing with the constraint of positive ignition, and (5) operate portion of the char burnout zo oxygen-deficient to get NO decay. addition to these low-NO_x requiremen constraints must be applied on t system relative to boiler size a efficiency, wall corrosion and slaggin and heat transfer. These constrain dictate that, to minimize corrosion a slagging problems, oxygen-deficie combustion gases should not conta the walls. Also, sufficient time a oxygen must be available to fully bu out the fuel and minimize carbon los CO, and UHC emissions. Finally, furna volume and exit gas temperatures mu be constrained to those typical presently operating units.

Figure 3 presents a top and side vie schematic of the low-NO_x system wit rich and lean zones identified. Th major system features are: (1) fu directed at conventional tangential ya angle into the center of the furnace; (2 some secondary air, either displace toward the wall side of the firebox o surrounding the fuel jet, directe parallel to the fuel jet; and (3) the bulk o the secondary air directed along th wall at and above the fuel jet elevation

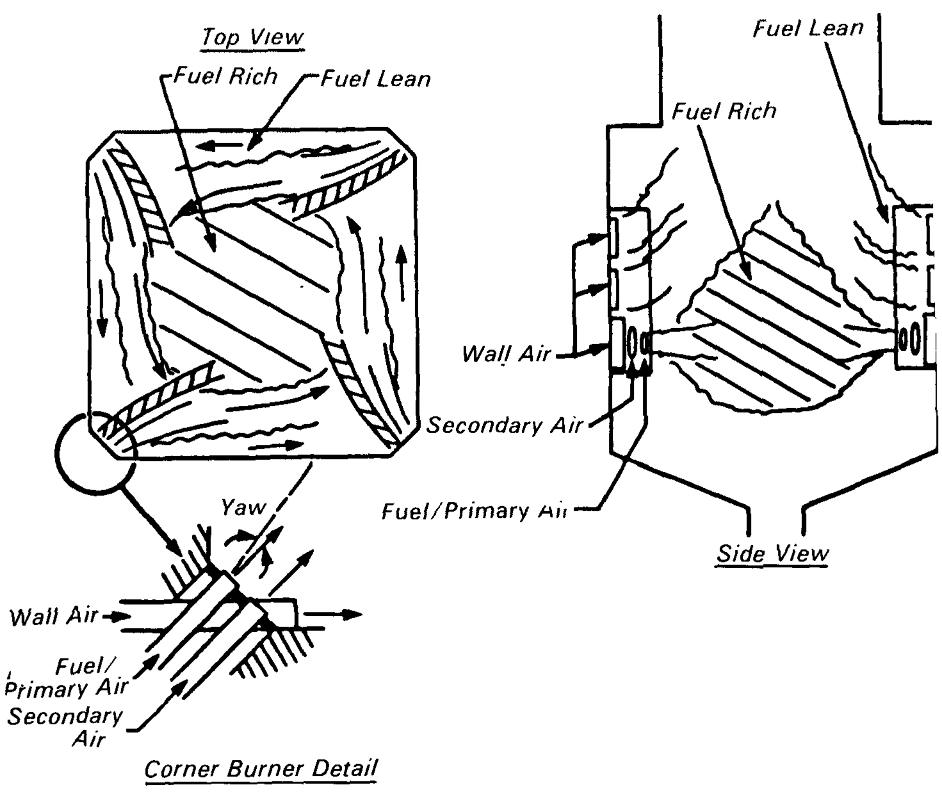

Figure 3. *Low-NO_x air-on-wall system schematic.*

These major system features create oxygen-deficient conditions in the active near burner and the char burnout zone and fuel-lean conditions on the furnace walls at and above the fuel jet elevation. These system characteristics address both the low NO requirements and operational constraints noted above.

The corner burners in the pilot-scale facility were modified to simulate the low-NO_x system illustrated in Figure 3. Figure 4 schematicizes the three burner designs tested. The System 1 burner was partially constructed of high temperature refractory and had variable-angle-wall air jets which exited roughly one third the distance along the firebox side wall. The System 2 burner consolidated the wall air jets into the corner refractory burner block and added two more levels of wall air jets to distribute the wall air vertically in the firebox. The System 3 burner was designed to represent how the low NO_x system would be retrofitted into a modern large-scale utility boiler.

System 1 Test Results

For System 1 testing, the corner burners in the pilot-scale facility were modified as shown in Figure 4 to simulate the low-NO_x system illustrated in Figure 3. Tests were then initiated to optimize the primary fuel, secondary and wall jet configuration, placement, direction, and velocity. As shown in Figure 5, tests varying the primary fuel and secondary jet configurations showed that directing approximately 20 percent of the secondary combustion air into the center of the furnace and 80 percent along the walls, at the fuel jet elevation, gave the lowest NO for most of the System 1 primary configurations tested.

At 80 percent air on the wall, probing results showed that the center of the furnace is oxygen-deficient with this zone typically occupying 40 percent of the firebox at 0 20 m (8 in.) above the burner level for most configurations tested. As the wall air mixes into this oxygen-deficient zone, it typically shrinks to 20 percent at 0.46 m (18 in.) above the burner centerline. At this location, NO formation/reduction processes are essentially complete and NO levels are comparable to stack values.

Vicinity of wall oxygen concentrations are 10 percent at 0.20 m (8 in.) above the burner elevation for the low-NO_x system versus 4 percent typical of conventional tangential firing in the pilot-scale facility.

Figure 2 shows the effect of excess air at the optimal 80 percent air on the wall for several primary configurations. As shown in Figure 2, the best configuration was a coannular primary/secondary air configuration. In this configuration the circular primary is surrounded by an annular passage that contains 20 percent of the secondary combustion air. Flame observation showed that this configuration had the smallest amount of fuel dispersion prior to entering the fuel-rich core zone. Various length slot primaries, although initially burning much sooner than the other configurations, had fuel dispersion problems. The dispersed fuel would burn in fuel-lean zones and yield high NO. Circular

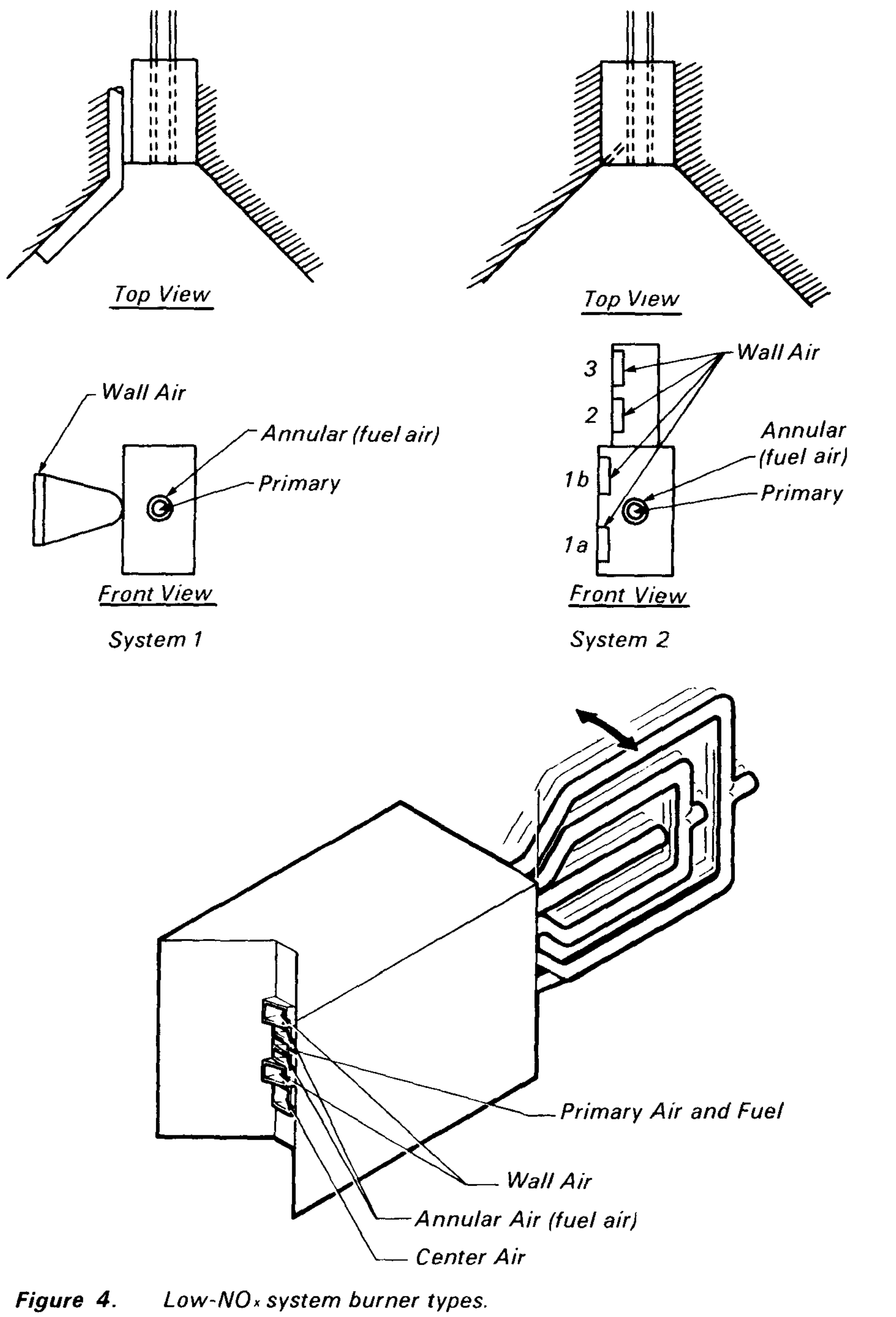

Figure 4. *Low-NO_x system burner types.*

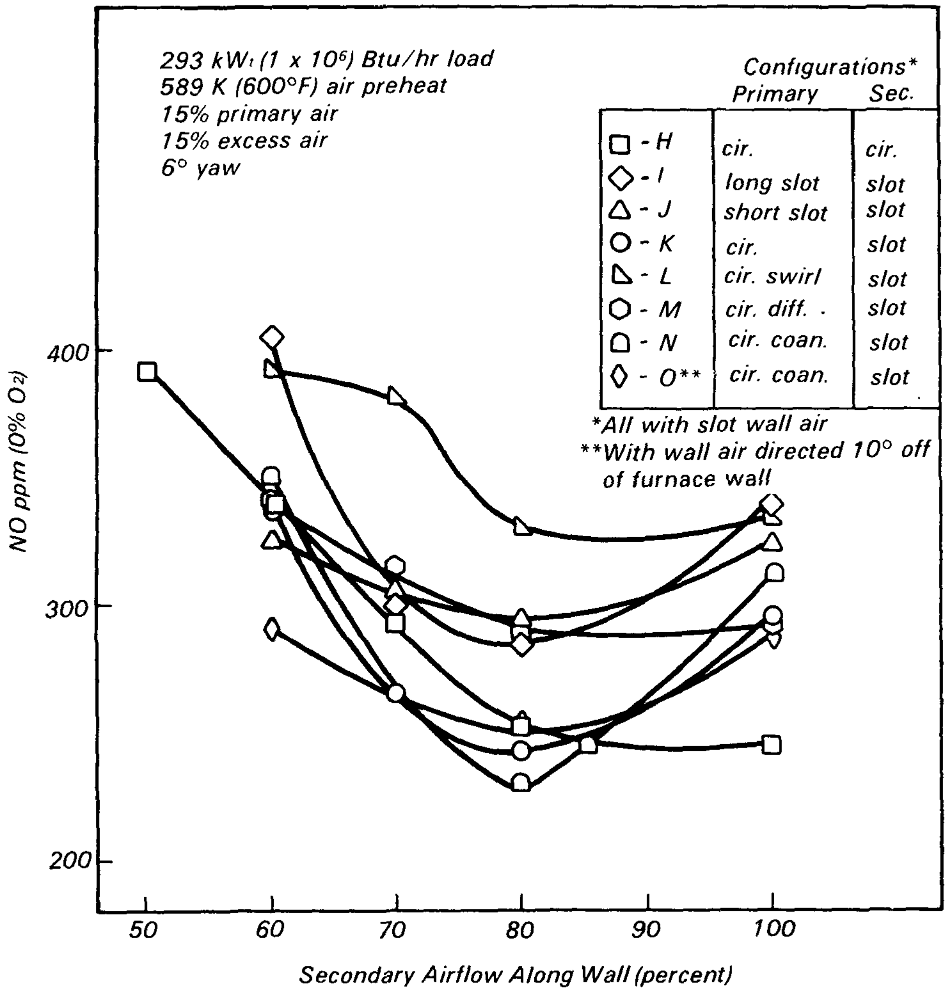

Figure 5. *Configurations H through O NO results with percent wall air.*

primaries having swirling or diverging flow also yielded higher NO at 15 percent excess air.

System 1 tests with a variety of wall jet inclination angles showed that the lowest NO levels are achieved when the wall jet flow is horizontal. As the wall jet inclination angle is varied from the horizontal, the wall jet is directed out from behind the fuel jet which, due to the lack of fuel jet shielding, might be more easily entrained and mixed into the fuel-rich core. The decrease in fuel/air separation caused by this mixing might be the reason for the observed NO increase when the wall jet is inclined with respect to the horizontal.

Besides yielding minimum NO, directing the wall air jet horizontally is desirable for multiburner level firing. For a system with several burner levels, directing the wall air upward or downward with respect to the fuel jet might result in undesirable burner-to-burner air jet interactions.

In addition to varying the inclination angle of the wall jets, one test considered the effect of directing the wall air at 10° away from the furnace wall. As shown in Figure 5, directing the wall air 10° off of the wall (configuration O) increased the minimum NO approximately 25 ppm over the 0° (configuration N) wall jet angle results. In addition, firebox probing tests showed that O_2 concentrations near the wall 0.20 m (8 in.) and 0.46 m (18 in.) above the fuel tube elevation were decreased for the 10° off the wall angle case. The higher wall O_2 concentrations and the lower minimum NO levels for the case where the air is directed along the wall make this the optimal jet orientation.

Comparison of the best low-NO_x concepts results with conventional pilot- and full-scale tangential firing results in Figure 2 shows that t[h]
System 1 concept reduces NO emissio[n]
by roughly 60 percent and lowers t[he]
sensitivity of NO to excess air. Th[e]
reduced sensitivity may be a result [of]
the more diffusive burning nature of t[he]
fuel-rich core.

Combustion characteristics for th[e] low-NO_x System 1 are not marked[ly] different from conventional pilot-sca[le] tangential firing. Carbon monoxid[e,] UHC, and percent carbon in flyash leve[ls] for this system are <36 ppm, <9 ppm and <3 percent, respectively, versu[s] conventional pilot-scale tangenti[al] firing results of <22 ppm, <1 ppm, an[d] <7 percent. These NO reductions an[d] good combustion efficiency are achieve[d] while increasing vicinity of wall oxyge[n] concentrations to 10 percent near th[e] burner elevation. This oxygen blanket[-] ing of the wall is beneficial from a wa[ll] corrosion and slagging point of view.

An additional feature of the low-NO[x] System 1 configuration is the improve[-] ment in NO emissions as temperatur[e] rises. Figure 6 shows that as ga[s] temperature is increased for tw[o] different air-on-wall system burne[r] configurations, NO decreases. Thi[s] attractive emission behavior wit[h] temperature might be used beneficiall[y] to reduce boiler size and capital cost fo[r] a given heat release.

Also shown in Figure 6 is the NO reduction caused by decreasing load at a fixed gas temperature. As discussed previously, reducing load decreases firebox mixing thereby maintaining rich zones in which NO is minimized.

System 2 Test Results

The burner configuration used in System 2 testing is shown schematically in Figure 4. This system differs from the initial configuration in that four wall jets, instead of two, are used and these jets are confined to the corner burner blocks. Operating the four levels of wall air in this configuration defines the emissions and efficiency benefits of distributing the wall air vertically.

Figure 7 presents the variation of NO levels with percent of secondary combustion air on the wall for the System 2 configuration. Each curve represents a different vertical distribution of air flow between wall air ports 1a, 1b, 2, and 3 as defined in Figure 4. The SRs achieved at each wall air level as a result of the vertical distribution of air are given in Figure 7. Configurations 1b and 1ab denote tests where air was flowing only

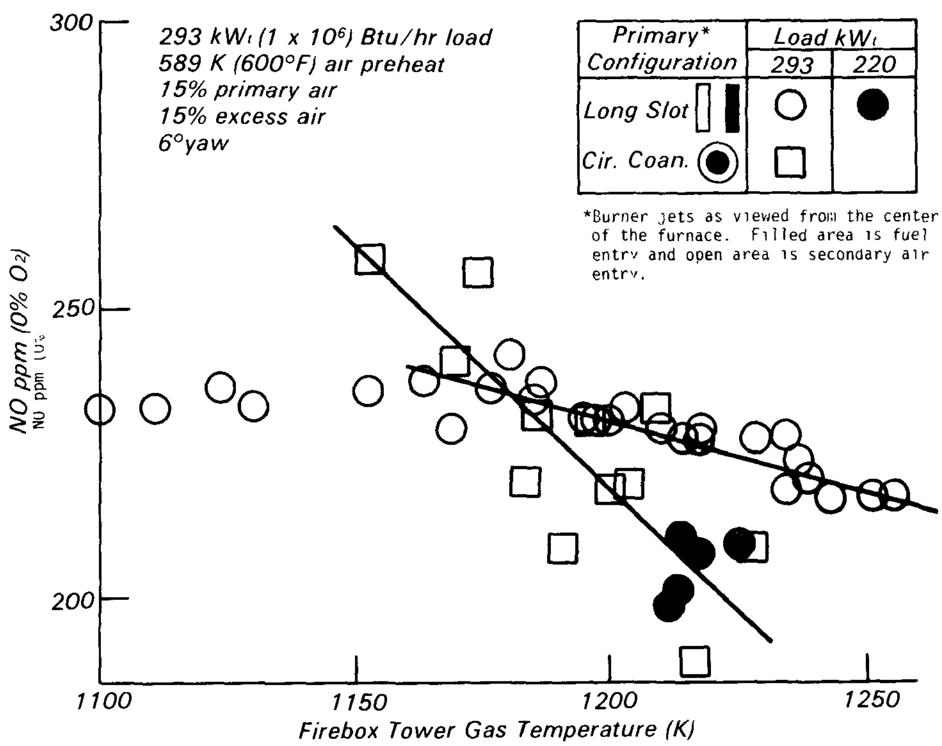

Figure 6. NO versus gas stream temperature for air-on-wall low NO_x system.

in port 1b or air flow was equally split between ports 1a and 1b, respectively. Also included in Figure 7 are the optimal results from System 1 testing.

The cases where SR_1, SR_2, and SR_3 are 1.15 do not have wall air flowing in ports 2 and 3. Therefore, these cases are comparable to System 1 configurations where wall air ports 2 and 3 are absent. As shown in Figure 7, System 1 gives the lowest NO results and System 2, with only the 1b jet operational, gives the highest levels. The percent air on the wall at minimum NO falls between 80 and 85 percent for these cases.

Differences in wall jet configurations and the separation between the fuel and wall air jets probably account for the differences in NO between these cases.

Even though System 2 NO results are marginally higher under these conditions, this configuration is preferred, since the wall air jets are confined to the corners and this approach would be easier to retrofit into a full-scale boiler than the System 1 burner.

For both configurations 1a and 1ab, the Figure 7 results show that when wall air is distributed vertically to ports 2 and 3, NO levels decrease with the minimum NO point shifting to higher levels of percent air on the wall. In these cases, the vertical separation of the fuel and air is creating a larger and more fuel-rich zone at the fuel entry elevation where NO production is minimized.

The minimum NO achieved with System 2 is lower than System 1 levels and represents a 65 percent reduction from baseline tangential system levels. Combustion efficiency during these tests was excellent with CO, UHC, and percent carbon in flyash emissions being less than 40 ppm, 3 ppm, and 2.4 percent, respectively. These levels are comparable to System 1 and conventional tangential system results.

Probing tests at the wall for $SR_1 = 0.88$ showed 15, 12, and 12 percent oxygen at 0.20 m (8 in.) and 0.46 m (18 in.) above the fuel tube elevation, respectively. As indicated previously, maintaining a high oxygen concentration on the wall is beneficial from a wall corrosion and slagging point of view.

System 3 Results

The System 3 burner design represents how the low-NO_x concept might be retrofitted into an existing modern large-scale tangentially fired boiler. Both high and normal primary and center air velocity cases were tested at wall air angles from 31° to 45° and at primary/center air angles of 0° and 8° with respect to the diagonal. The high velocities were produced by inserts in the primary and center air ports.

Figure 8 compares the System 3 burner results with and without inserts to System 1 and 2 results as a function of percent wall air. The System 3 burner results were taken over a range of primary and wall air yaw angles. System 3 burner NO levels decrease with increasing percent wall air as observed for System 1 and 2 burner results. The System 3 results with inserts correspond most closely with System 2 results and System 1 (configurations I, N, and K) results. (See Figure 2 for primary configuration designations.) The System 3 results without inserts correspond most closely with System 1 (configurations H and G) results. Correspondence of NO results were achieved for cases which had similar primary to wall air velocity ratios.

As in System 1 and 2 testing, System 3 CO, UHC, and carbon loss emissions were very low. Carbon burnup was above 99.9 percent for all the System 3 tests.

The System 3 tests showed that the parameters dominating NO formation were percent wall air and primary/center versus wall air velocity ratio. These parameters, as well as wall air angle, determined whether the burner flames would scrape the furnace walls. At high percent wall air and wall air angle, and low primary/center to wall air velocity ratio, flames were observed to scrape the furnace walls. This condition is undesirable because of potential tube wastage and carbon loss problems in full-scale systems. Lowering percent wall air and wall air angle, and increasing primary/center versus wall air velocity ratio alleviated this problem to some extent. It should be noted that System 1 and 2 burners had much lower wall air jet velocities than the System 3 burner and did not experience any wall flame scraping problems.

System 1, 2, and 3 test results show that the low-NO_x system can significantly reduce NO_x while maintaining good combustion efficiency and wall oxygen conditions. With the System 3 burners, some test conditions resulted in flames scraping the furnace walls, which can be alleviated to some extent by reducing wall jet velocity and thereby the angular momentum of the vortex to levels characteristic of System 1 and 2 results.

Conclusions

Through extensive pilot-scale testing, considerable progress has been made in

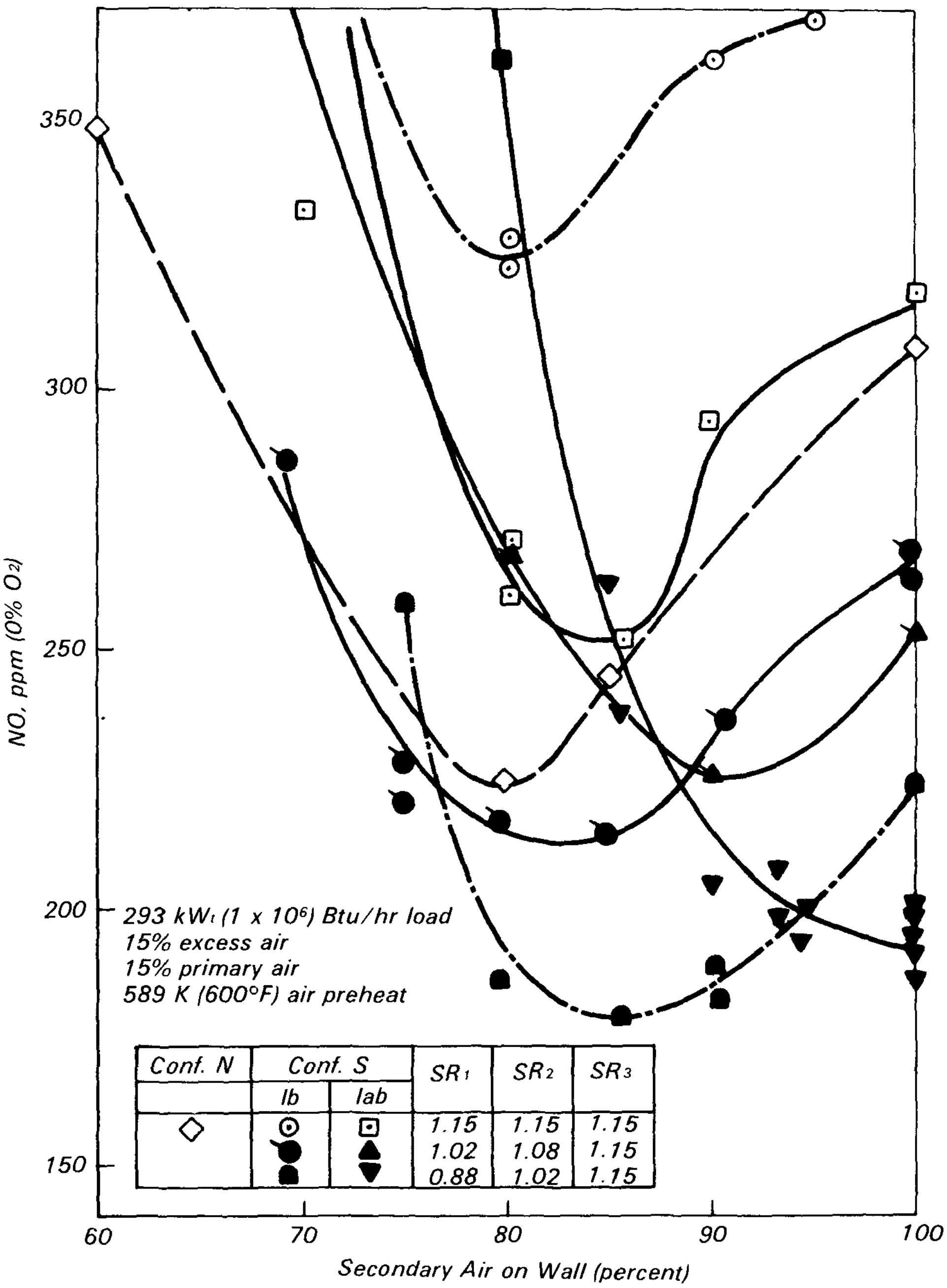

Figure 7. *NO variation with percent air-on-wall for vertical wall air configuration.*

the development of a low-NO_x coal-fired tangential system. Based on coal-fired pilot-scale tangential system burner and vortex characterization tests, the requirements for a low-NO_x tangential system were identified. These are: (1) initiate burning sooner to minimize O_2 availability at the ignition point, (2) operate the fuel/jet vortex interaction zone fuel-rich, (3) protect the fuel jet from dispersion by vortex flow, (4) lower firebox mixing with the constraint of positive ignition, and (5) operate a portion of the char burnout zone oxygen-deficient to get NO decay. In addition to these low-NO_x requirements, constraints must be applied on the system relative to boiler size and efficiency, wall corrosion and slagging, and heat transfer. These constraints dictate that, to minimize corrosion and slagging problems, oxygen-deficient combustion gases should not contact the walls. Also, sufficient time and oxygen must be available to fully bu out the fuel and minimize carbon lo CO, and UHC emissions. Finally, furna volume and exit gas temperatures mu be constrained to those typical currently operating units.

Given the above requirements, a lo NO_x system was defined. The ma system feature is the dividing of t secondary combustion air betwe injection into the center of the furna and injection along the furnace wal The delayed mixing of wall air into t vortex causes a fuel-rich combusti zone to develop in the center of t furnace, minimizing fuel and atm spheric NO_x formation. Primary, se ondary, and wall jet configurations a flowrates strongly influence the effe tiveness of the system to lower N emissions. Testing showed that the be results are achieved with (1) wall a directed horizontally and along tl furnace wall, (2) wall air flow equal to greater than 80 percent of seconda combustion air flow, (3) primary/se ondary air coannular configuration, ai (4) wall air vertically distributed at ar above the fuel entry location. At optim parameter settings, NO reductions of 6 percent from conventional tangenti system levels can be achieved comparable combustion efficiency. addition, wall oxygen concentration the burner level is significantly in creased over conventional tangenti firing. This increase is beneficial fro wall corrosion and slagging points view. Also, in some configurations, th system shows a decrease in NO emissions as temperature is increase This characteristic could be beneficial applied to reduce furnace volume for given heat release.

Recommendations

In preparation and in parallel to demonstration of the low-NO_x system i a modern coal-fired tangential boile additional pilot-scale testing is require This pilot-scale testing is needed to (1 help define burner design and tes conditions to be explored in full-scal testing; (2) define emissions an efficiency performance for a range c burner design parameters, as well a the demonstration burner design condi tions; (3) define emissions and efficienc performance for a range of character istic boiler coals and alternate fuels, a well as the demonstration boiler fue type; and (4) define additional concept which have a high potential to furthe

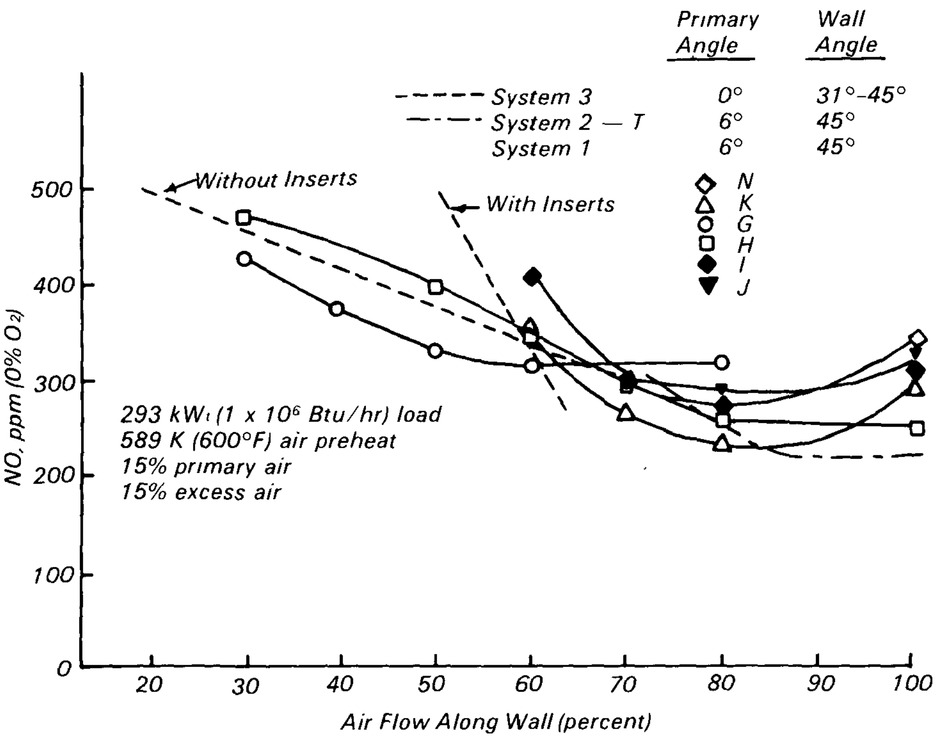

Figure 8. *Comparison of System 1, 2, and 3 burner NO variation with percent total wall air.*

reduce NO_x under good combustion conditions.

These pilot-scale results will significantly broaden the full-scale low-NO_x data base obtained in the demonstration tests. The pilot-scale results will provide information on how the system will perform for other boiler designs and different fuels, which is useful in assessing the retrofit potential of the system to a range of boilers. It will also aid full-scale demonstration program burner design and test condition selection, thus maximizing the value of the demonstration test data. Lastly, it will provide additional low-NO_x concepts and understanding of the low-NO_x system. This information will be useful in upgrading the low-NO_x system for future applications to full-scale boilers.

To maximize the usefulness of the pilot-scale data, testing conditions must closely simulate combustion conditions in the large-scale demonstration boiler. Parameters such as firing intensity, gas temperatures, residence time, and burner and firebox mixing must be properly scaled between the pilot- and full-scale facilities for proper simulation of full-scale performance. Presently, the pilot-scale facility simulates these parameters with a single burner level firebox arrangement. However, modern large-scale boilers have multiple burner levels. The interaction of the burner levels influences emission and combustion performance. To properly simulate large-scale boiler performance in the pilot-scale facility, the system must be modified to incorporate at least two burner levels. With the two burner levels, the effect of multiburner level interactions could be simulated and its impact on emission and combustion performance assessed. In addition, the multiple burner level interactions could be optimized to yield minimum NO_x under good combustion conditions. Therefore, to ensure proper full-scale boiler simulation and to increase the flexibility of the pilot-scale facility, two burner levels must be incorporated into the facility for the recommended pilot-scale test program.

References

1. Lim, K.J., L.R. Waterland, C. Castaldini, Z. Chiba, and E.B. Higginbotham. Environmental Assessment of Utility Boiler Combustion Modification NO_x Controls. EPA-600/7-80-075a (NTIS PB80-220957), April 1980.
2. Habelt, W.W. The Influence of the Coal Oxygen to Nitrogen Ratio on NO_x Formation, presented at 70th Annual AIChE Meeting, November 1977, New York, NY.
3. Macek, A. Seventeenth Symposium (International) on Combustion, The Combustion Institute, 1978, p. 65.
4. Wendt, J.O.L., C.V. Sternling, and M.A. Matlovich. Fourteenth Symposium (International) on Combustion, The Combustion Institute, 1973, p. 897.
5. Gibbs, B.M., F J. Pereira, and J.M. Beer. Sixteenth Symposium (International) on Combustion, p. 461, The Combustion Institute, 1976.
6. Brown, R.A., J.T. Kelly, and P. Neubauer. Pilot Scale Evaluation of NO_x Combustion Control for Pulverized Coal: Phase II Final Report. EPA-600/7-79-132 (NTIS PB 299325), June 1979.
7. Breen, B.P. Sixteenth Symposium (International) on Combustion, The Combustion Institute, 1976, p. 19.
8. Selker, A.P. Program for Reduction of NO_x from Tangential Coal-Fired Boilers, Phases II and IIa EPA-650/2-73-005a and b (NTIS PB 245162 and 246889), June and August 1975.
9. Crawford, A.R., E.H. Manny, M.W. Gregory, and W. Bartok. The Effect of Combustion Modification on Pollutants and Equipment Performance of Power Generation Equipment. In Proceedings of the Stationary Source Combustion Symposium, Volume III. Field Testing and Surveys, EPA-600/2-76-152c (NTIS PB 257146), p. IV-3, June 1976.

J. T. Kelly, R. A. Brown, E K. Chu, J B. Wightman, R. L. Pam, E. L. Swenson, and E B. Merrick are with Acurex Corporation, Mountain View, CA 94042, C F. Busch is presently with Utah Power and Light, Huntington, UT 84528.
***David G. Lachapelle** is the EPA Project Officer (see below).*
The complete report, entitled "Pilot-Scale Development of a Low-NO_x Coal-Fired Tangential System," (Order No. PB 81-242 513, Cost: $18.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

☆U. S. GOVERNMENT PRINTING OFFICE: 1981/559-092/3309

Protection
Agency
EPA-335

iness
Private Use, $300

PS 0000329
U S ENVIR PROTECTION AGENCY
REGION 5 LIBRARY
230 S DEARBORN STREET
CHICAGO IL 60604