NO_X CONTROL TECHNOLOGY FOR INDUSTRIAL COMBUSTION SYSTEMS

by

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WORCESTER, MASSACHUSETTS

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Abstract

In a continuing effort to lower NO_X emissions, Riley Stoker is engaged in an ongoing burner development program. The goal of this program is to design a combustion system for wall-fired and TURBO® Furnace boilers capable of achieving 0.2 lb $NO_X/10^6$ Btu (150 ppm at 3% 0_2) or less. Three 100 million Btu/hr burners—high swirl, medium swirl and axial flow—were recently tested in Riley Stoker's Coal Burning Test Facility (CBTF).

All three burner designs incorporate some degree of internal and external staging. This paper discusses results of air staging tests and compares the combustion characteristics of the three burners. Results from the high swirl burner tests are compared to the previous laboratory and field tests and scaling criteria from the test facility to the field are presented.

INTRODUCTION

Since early 1980, Riley Stoker Corporation has been actively involved with the development and testing of advanced low-NO_X burner designs for application to wall-fired and Riley TURBO furnaces. Extensive laboratory and field testing efforts aimed at reducing NO_X emissions in existing wall-fired boilers led to the development of Riley's Controlled Combustion Venturi (CCV™) Burner (*1*). This burner design is presently installed in three full size utility wall-fired boilers and is now being offered on smaller industrial furnaces.

In response to the acid rain issue, more stringent NO_X emission standards may be enacted. The CCV Burner in combination with air staging is capable of meeting anticipated emissions standards in wall-fired furnaces. However, the application of advanced air staging in the TURBO Furnace required the development of a new burner. Our objective was to develop a burner with more stable combustion characteristics at low burner zone stoichiometries for TURBO Furnace operation. The axial flow Directional Flame Burner is utilized in current TURBO Furnace designs.

The Tertiary Staged Venturi (TSV™) Burner therefore was developed to replace the Directional Flame Burner under advanced staged conditions. The TSV Burner was designed to provide flame stability with a medium degree of swirl. Aerodynamic tests were performed on plexiglass models of the TSV and Directional Flame Burners. Aerodynamic model tests of the TSV Burner showed that at medium swirl numbers 0.6-0.7 there was a small amount of recirculation. However, the bulk of the flow was axial, similar to the Directional Flame Burner. The TSV Burner has no expanding quarrel at the burner exit. The amount of recirculation, therefore, for a given swirl number is less than in the conventional circular burners (*2*).

Combustion tests were performed to characterize the NO_X emissions and flame characteristics of the TSV Burner. The results of these tests were compared to results of combustion tests on Riley Stoker's CCV Burner (high swirl) and Directional Flame Burner (axial flow). Both of these burners are commercially available low-NO_X burners.

EXPERIMENTAL SET UP

The combustion tests were all performed in Riley Stoker's CBTF at 100 million Btu/hr. The CBTF, shown in Figure 1, is a horizontally-fired tunnel. The inside surface of the test furnace is partially covered with insulating refractory to simulate radiant flame temperatures experienced in operating furnaces. The furnace is equipped with outboard tertiary air ports on the burner front, and downstream staging ports along the side wall to simulate overfire air. There are sufficient access points along the furnace side walls for wide angle viewing, videorecording, temperature probing, gas sampling, and other data collection.

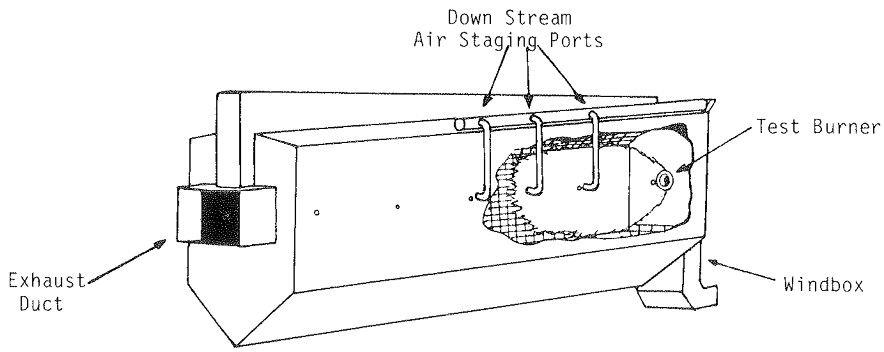

Figure 1 The Coal Burner Test Facility (CBTF)

The fuel for all three burner tests was a West Virginia Lower Kittanning coal from Ashland Coal's Hobet #7 mine. This is a low sulfur, high volatile bituminous coal. A typical analysis for the test coal is shown in Table 1.

	AS RECEIVED	DRY
MOISTURE	8.2	—
VOLATILE	31.7	34.5
ASH	8.6	9.4
FIXED CARBON	51.6	56.1
N	1.2	1.3
S	0.6	0.7
BTU/LB	12,402	13,503

Table 1 Test Coal Analysis

CCV BURNER

The Riley high swirl stabilized CCV Burner is shown in Figure 2. The CCV Burner is an internally staged low-NO_X burner. Secondary air enters an annulus through a set of register vanes used to control swirl. Pulverized coal and transport air are introduced through a nozzle at the center of the burner. The coal nozzle is Riley Stoker's venturi nozzle with a low swirl coal spreader. The burner is equipped with outboard tertiary air ports similar to the EPA Distributed Mixing Burner.

The CCV Burner was the first burner tested in the CBTF. This allowed the performance of the CBTF to be gauged against previous data. Full load NO_X emissions for an unstaged CCV Burner firing at 100 million Btu/hr were expected to average 400 ppm normalized to 3% O_2 (*3*). This proved to be true: NO_X emissions at a burner zone stoichiometry (SR_B) of 1.2 and at 100 million Btu/hr in the CBTF were 410 ppm at 3% O_2.

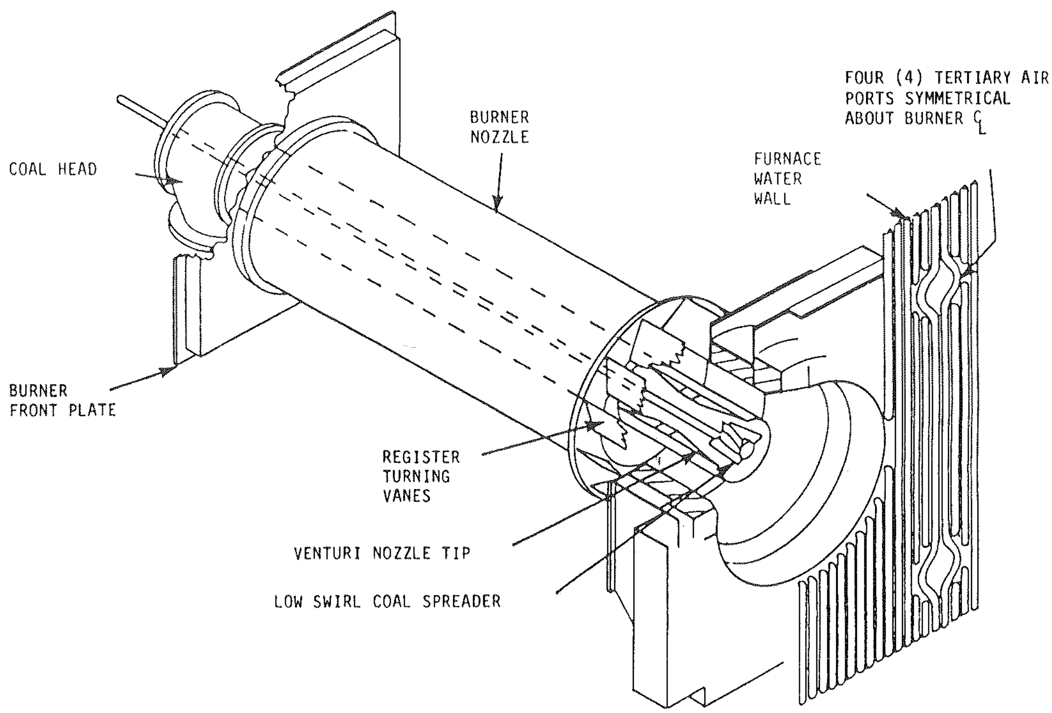

Figure 2 The Controlled Combustion Venturi CCV Burner

The burner setting which had the greatest effect on NO_X emissions was register vane position. Flame shape classification Types I and II were developed by the International Flame Research Foundation to describe flames with general aerodynamic, chemical, and thermal characteristics (*4*). A Type II flame is short and intense with a large central recirculation zone. A Type I flame occurs when the primary jet penetrates the central recirulation zone producing a longer, less intense flame. As secondary swirl increased, the CCV flame shape changed from a Type II flame to a Type I flame. When the flame changed from Type II to Type I, NO_X dropped by 17%.

The effect of total excess air on the CCV Burner was examined at two loads (Figure 3). The two curves are virtually parallel. NO_X emissions from the CCV Burner were sensitive to changes in total excess air under these test conditions. This may be caused by changes in burner aerodynamics caused by changes in secondary air velocity.

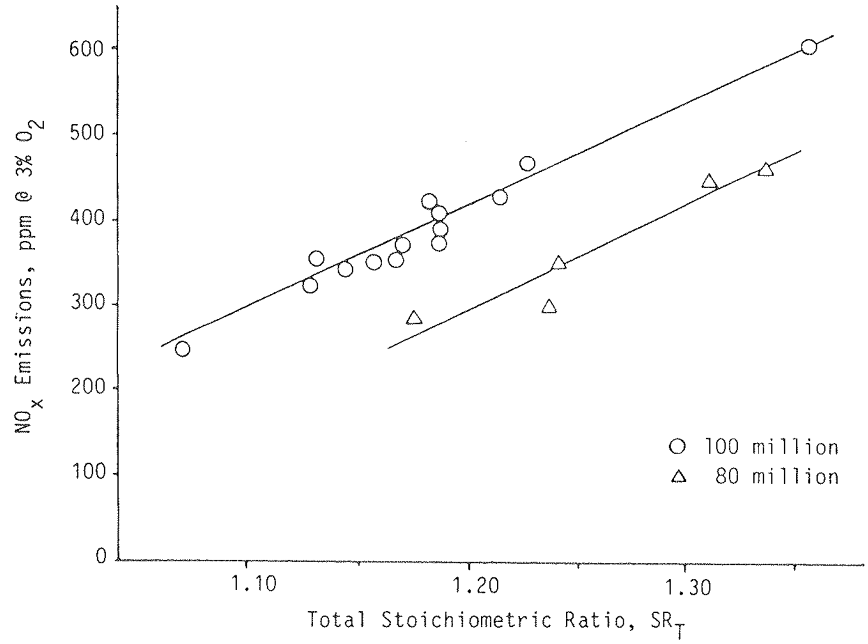

Figure 3 The Effect of Total Stoichiometry on NO_X Emissions from an Unstaged CCV Burner

The burner was also tested using tertiary air ports staged down to a burner stoichiometry (SR_B) of 0.7 while the total stoichiometry was maintained at 1.2. The change in NO_X with burner zone stoichiometry is shown in Figure 4. The curve for changes of NO_X with SR_B for unstaged combustion is much steeper than the curve for staged combustion. The drop in NO_X with minimal staging is large. Looking at how the staged combustion curve intersects the unstaged curve, it may be that staging to $SR_B = 1.10$ is the same as running with an excess air of 10%. When the burner was staged down to $SR_B = 0.68$, NO_X emissions were 147 ppm at 3% O_2.

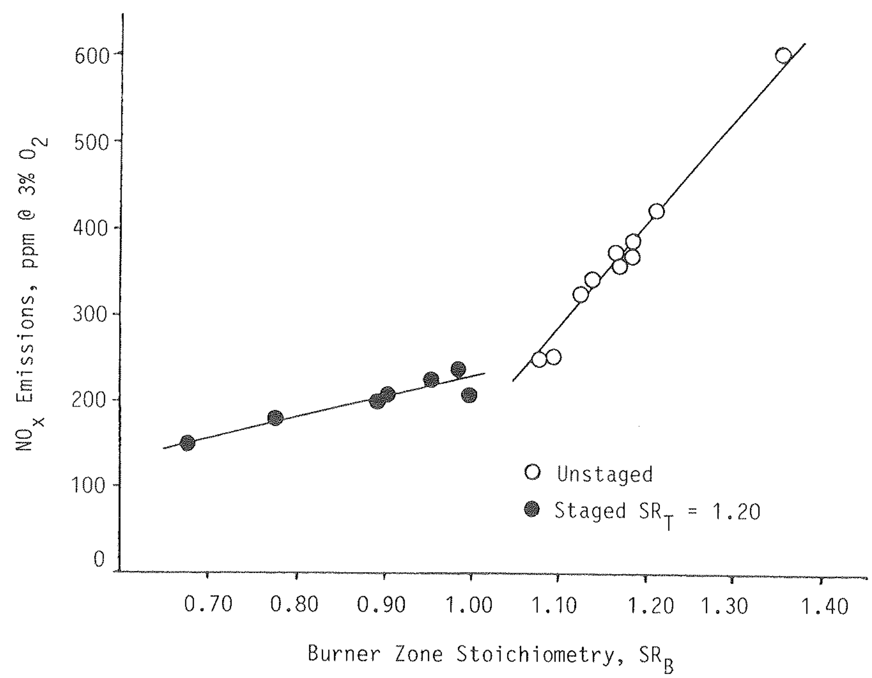

Figure 4 The Effect of Air Staging with Tertiary Ports on NO_X Emissions from a CCV Burner

In general, the CCV Burner tests in Riley's CBTF were comparable to previous experience. The characteristic flame shape of the CCV Burner was achieved along with the expected NO_X emissions (*1*). The unstaged flame length of 20 feet was comparable to the flame length experienced during previous 50 million Btu/hr tests, when changes in burner size were taken into account.

The flame was well rooted in the burner quarl under all conditions. No standoff or flame instability was observed when the burner was staged to $SR_B = 0.7$. For constant stoichiometry, changes in burner settings reduced NO_X by 20%. Staged combustion with tertiary air ports reduced NO_X by as much as 60%. CO emissions for the CCV Burner were very low, averaging about 20 ppm for unstaged conditions. When burner stoichiometry was dropped below 0.95, CO emissions ranged from 30 to 50 ppm corrected to 3% O_2.

To compare NO_X emissions at various unit sizes, Riley Stoker's Basket Area Heat Release (BAHR) parameter was used. This compares the total heat release rate to effective cooling surface in the unstaged flame zone (*5*). The data for nominal conditions (20% excess air and no air staging) is compared to data for comparable conditions in Energy and Environmental Research's Medium Tunnel (MT) furnace and in two utility units in Figure 5 (*1*). This illustrates how well the data from the CBTF agrees with data from other systems fired by the CCV Burner.

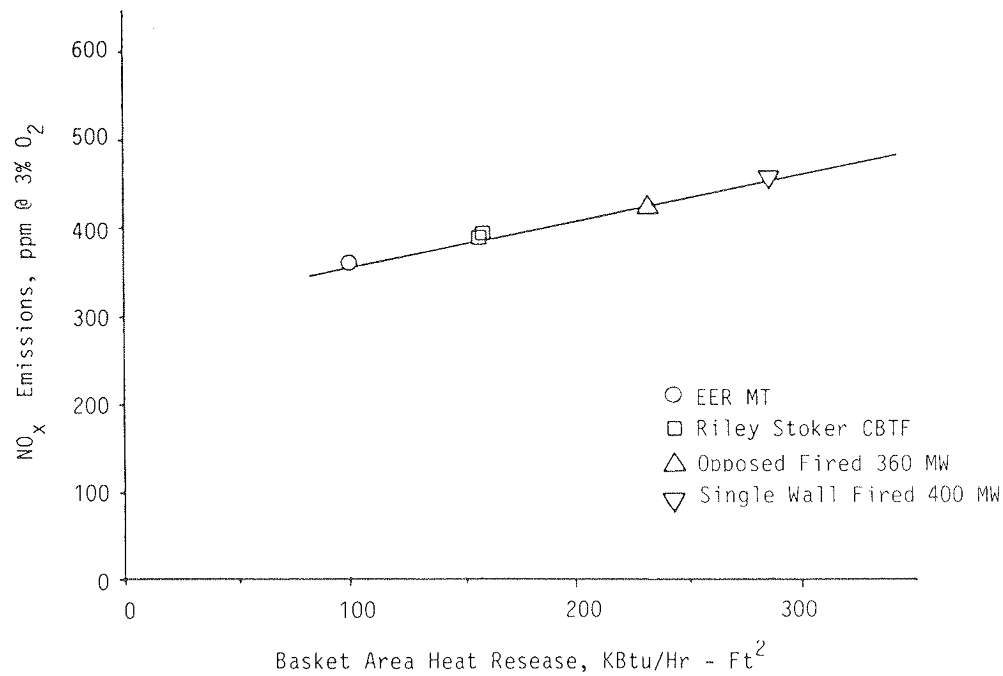

Figure 5 Unstaged NO_X Emission Scaling Criteria for CCV Burners in Wall-fired Boilers

DIRECTIONAL FLAME BURNER

Riley Stoker's Directional Flame Burner, shown in Figure 6, is an axial flow burner normally used in the TURBO Furnace. In the TURBO Furnace the burners are mounted in an opposed downward tilt configuration. The Directional Flame Burner consists of two rectangular coal nozzles with secondary air above and below the nozzles. This burner is equipped with converging coal spreaders which direct the coal toward the burner centerline. Mixing of the secondary and primary streams is controlled by directional vanes in the secondary air throat (3,6).

In our single burner test configuration, staged combustion was achieved by introducing the staged air through ports downstream of the burner on the side walls of the test furnace. These ports were designed to simulate the use of overfire air in a field installation. The downstream air ports were arranged as opposing jets at 17, 23, and 30 feet downstream of the burner wall.

The secondary air vanes were used to direct air into or away from the primary coal jets. Changing the directional vane position from directing the air away from the coal (position 2) to directing air paralled to the coal (position 10) increased NO_X emissions from 200 ppm to 350 ppm at 3% O_2. Two things occur during this change. There is less internal staging of the burner, increasing the overall rate of mixing. The air velocity around the coal jet increases, pushing the flame front further from the burner, allowing more premixing before ignition.

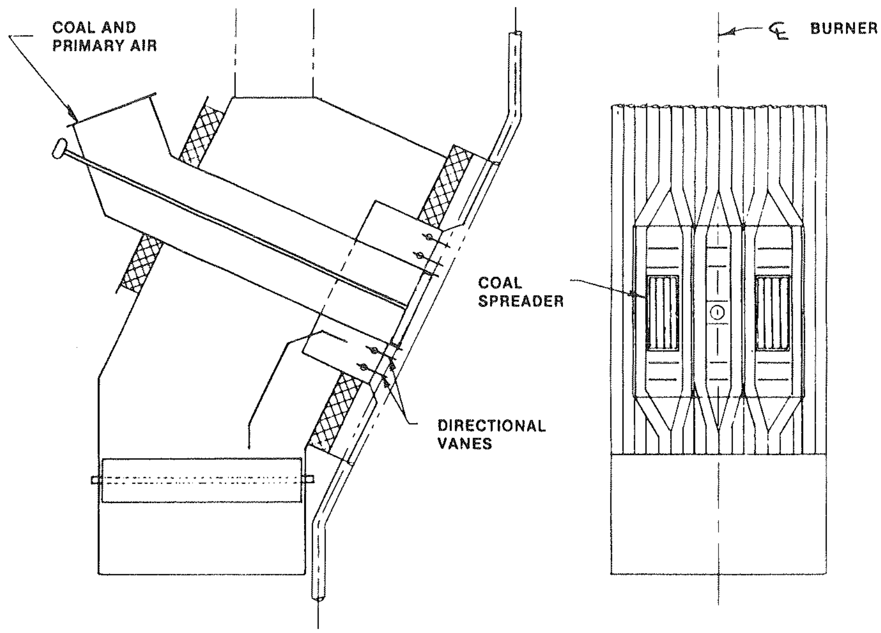

Figure 6 Riley Stoker Directional Flame Burner

The effects of total stoichiometry were investigated at various secondary air vane positions. The results for two of these conditions are shown in Figure 7. As stated above, position 2 corresponds to the air vanes directed away from the coal nozzle while in position 10 the vanes are parallel to the coal nozzle. NO_X emissions for vane position 10 were consistently about 150 ppm greater than for positon 2. The effect of total stoichiometry on NO_X emissions is greater for vane position 10.

The effect of lowering burner zone stoichiometry (Figure 8) was also investigated at directional vane positions 2 and 10. Burner zone stoichiometry also had a greater effect at vane position 10 than position 2. The lowest NO_X achieved were 156 ppm at 3% O_2 at $SR_B = 0.76$, vane position 2.

The effect of downstream staging air location is shown in Figure 9. As the air was moved further downstream, NO_X emissions were reduced. When air was injected at 23 feet, NO_X emissions were the same as the unstaged burner.

Under all conditions, the flame was 15 to 25 feet long and stand-off ranged from 6 inches to 5 feet. With the Directional Flame Burner, burner settings affected NO_X emissions by 40%. Lowering SR_B with the Directional Flame Burner from 0.15 to 0.85 gave NO_X reductions of 20%. CO emissions at vane position 2 were higher than for any other setting, ranging from 90 to 290 ppm. CO emissions for all the other settings ranged from 40 to 130 ppm. The highest CO emissions were experienced under staged combustion.

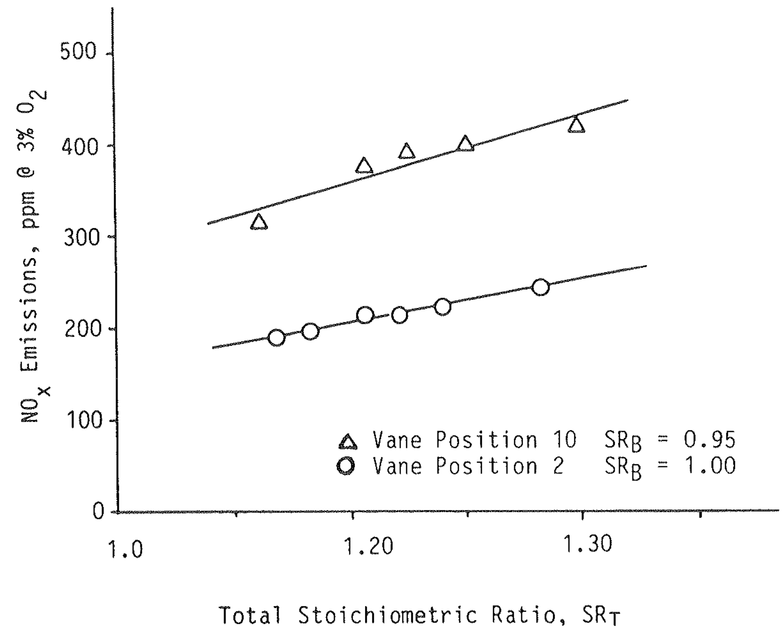

Figure 7 Directional Flame Burner NO_x Emissions as a Function of Total Stoichiometry at Two Directional Vane Positions

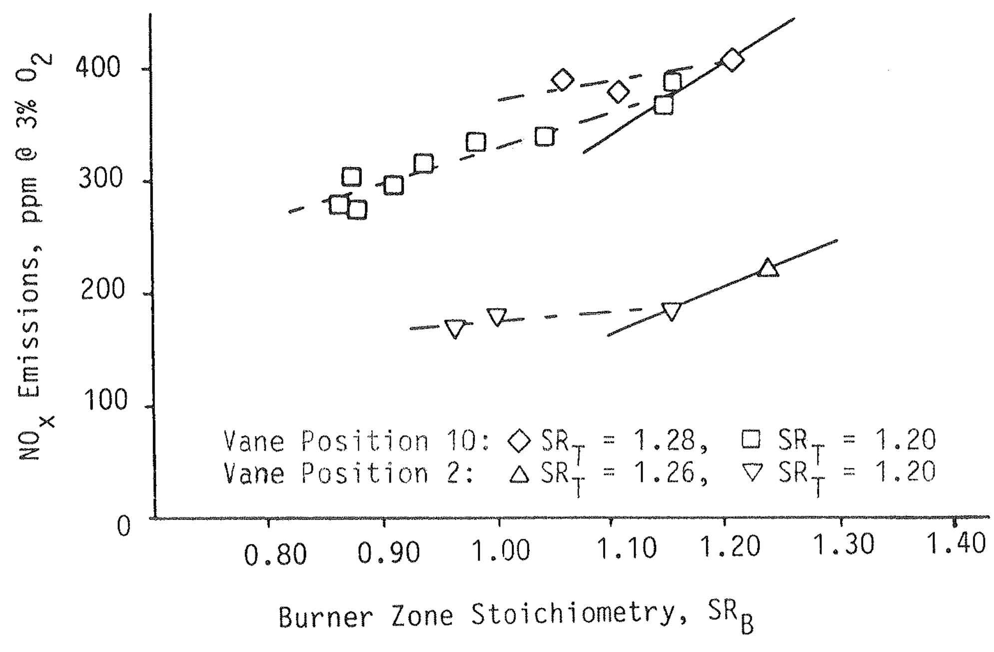

Figure 8 Effects of Air Staging at 30 Feet on NO_x for the Directional Flame Burner

Riley Stoker has conducted NO_X emission testing on 26 utility and industrial TURBO Furnaces (*3,5,6*). These tests have shown that changes in secondary air vane position can affect NO_X by 15%. Similarly staged combustion reduces NO_X by about 15% (*3,5,6*). In light of this data, changing burner settings appears to have a greater effect in the single burner facility than in the opposed fired downward tilt TURBO Furnace. This indicates that furnace mixing in the TURBO Furnace may have a large effect on NO_X emissions.

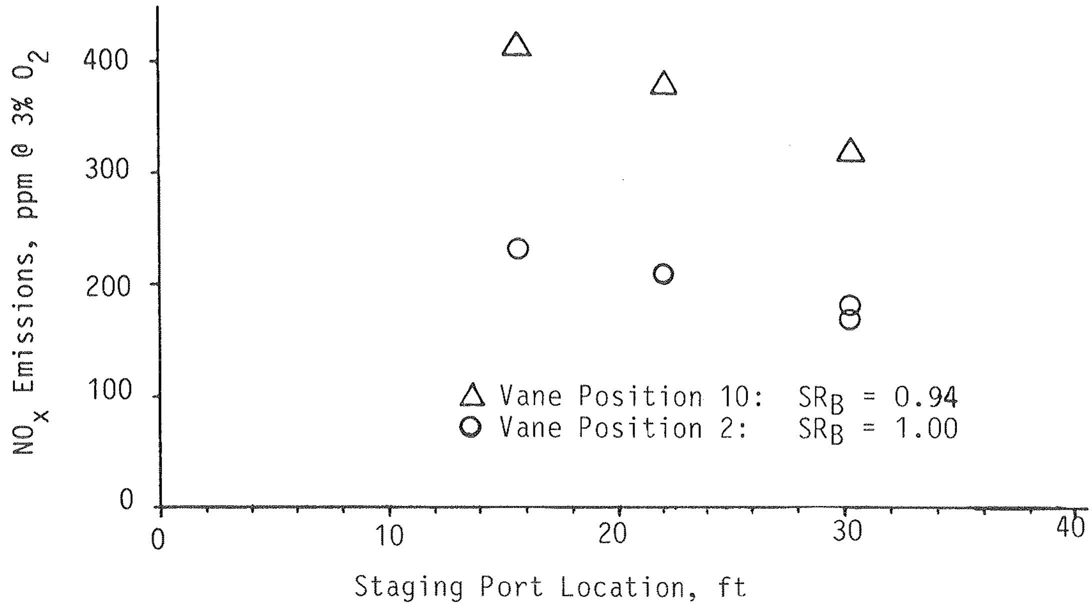

Figure 9 Changes in Directional Flame Burner Emissions with Staging Port Location

TSV BURNER

The TSV Burner, shown in Figure 10, is stabilized by recirculation achieved at a medium swirl number. This burner was designed so that the stoichiometric ratio of the secondary air in the burner throat (SR_B) could be reduced to 0.4. The secondary air is admitted into a narrow annulus through register vanes which swirl the air. This burner does not have an expanding quarl, so that the burner throat is flush with the burner front. The TSV Burner incorporates the CCV Burner coal nozzle design. Tertiary air ports equipped with directional turning vanes are positioned near the burner throat. These tertiary air ports are used to bring the total burner front stoichiometry (SR_{BF}) up to 0.7-1.0. The remainder of the air was added through the downstream air staging ports.

The burner adjustments used on the TSV Burner were register vane position, axial coal spreader position, and the angle of the tertiary air turning vanes. Coal spreader design was also optimized during the TSV Burner testing.

With the final spreader design the flame was very well rooted at the coal nozzle for register vane positions less than 25°. NO_x emissions were lowest at a register vane position of 25°. The swirl number measured during the aerodynamic model testing at this setting was 0.6. As the register vanes were opened, swirl decreased, the flame front became detached from the burner nozzles, and NO_x emissions increased from 300 ppm to 500 ppm. The position of the final coal spreader also had an effect on NO_x. NO_x emissions dropped by 275 ppm when the spreader was flush with the tip of the coal nozzle. The drop in NO_x was accompanied by elimination of flame stand-off. NO_x emissions were highest with the tertiary air vanes set so that the tertiary flow was injected tangent to the swirling flame. With the tertiary air directed radially into the flame, NO_x was slightly lower. NO_x dropped by 25% when the tertiary air was directed away from the flame.

NO_x emissions were very sensitive to SR_{BF} as shown in Figure 11. The lowest NO_x emissions achieved were 156 ppm at SR_{BF} = 0.71. CO emissions for the burner were low, 15-20 ppm with no apparent dependency on NO_x emissions.

Burner settings had a large effect on NO_x emissions. Changing the spreader design had an effect on the flame shape and NO_x. With the final spreader design there was no stand-off with a swirl number greater than 0.6. Both register and spreader adjustments could reduce NO_x by 40%. However, reducing the burner front stoichiometry also had an effect. Reducing SR_{BF} from 0.9 to 0.7 reduced NO_x by 50%.

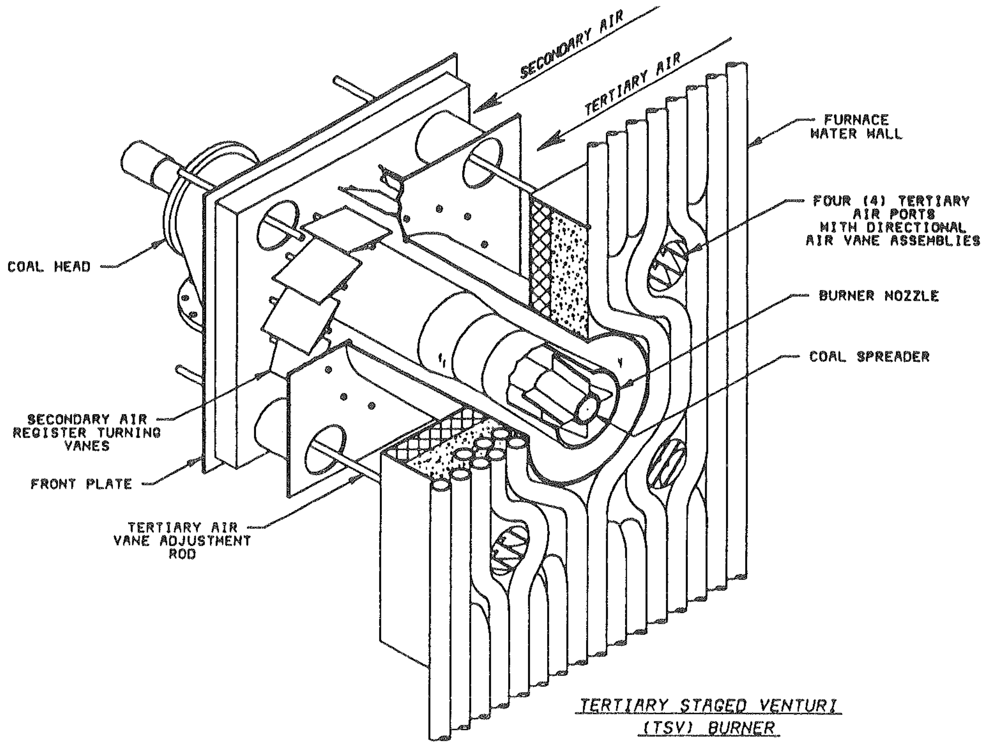

Figure 10 The Tertiary Staged Venturi (TSV) Burner

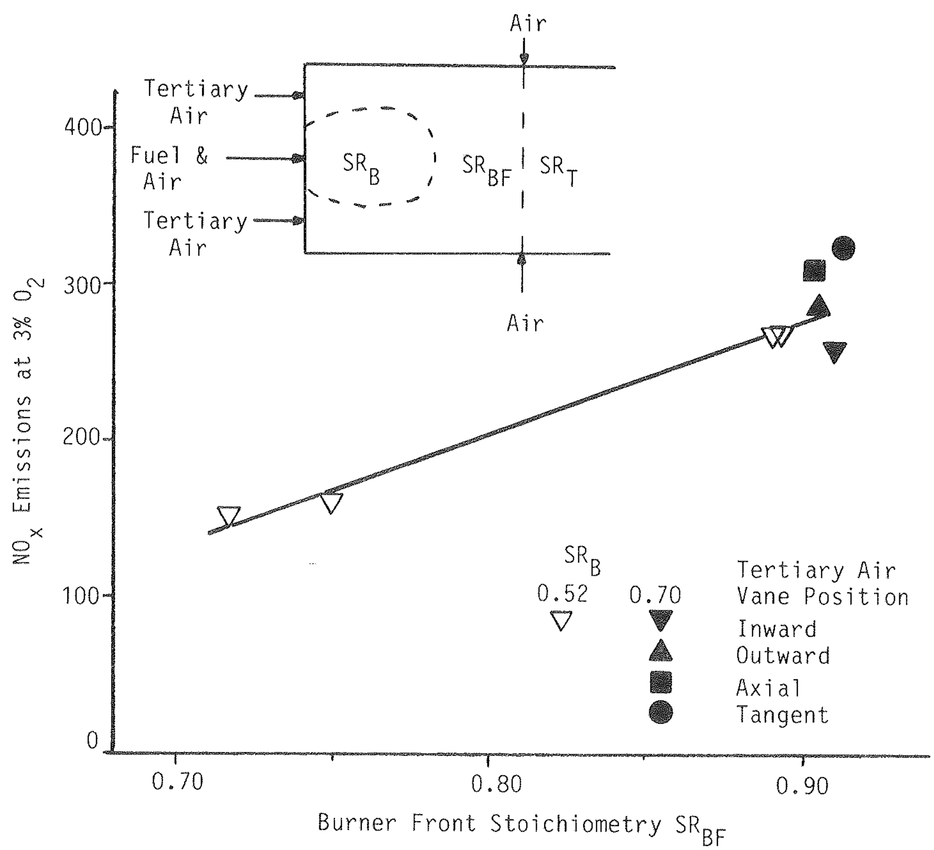

Figure 11 The Effect of Burner Front Stoichiometry and Tertiary Air Vane Position on TSV Burner NO_x Emissions

CONCLUSIONS

All three test burners were capable of achieving low-NO_X emissions levels given the proper burner settings. To achieve NO_X emissions in the vicinity of 150 ppm corrected to 3% O_2, all three burners had to be staged down to a burner zone or burner front stoichiometry of 0.7. At this condition the CCV and TSV Burner flames were well rooted at the coal nozzle. Flame stand-off with the Directional Flame Burner was 1-2 feet under all conditions, staged and unstaged.

BURNER	BURNER ZONE STOICHIOMETRY	BURNER SETTINGS
CCV	HIGH	MEDIUM
DIRECTIONAL FLAME	MEDIUM	HIGH
TSV	HIGH	HIGH

Table 2 Sensitivity of NO_X Emissions to Burner Operating Conditions

The sensitivity of NO_X emissions to burner settings and stoichiometry is summarized in Table 2. The CCV Burner is designed for wall firing. The TSV and Directional Flame Burners are both designed for the TURBO furnace, providing a direct comparison. Under low-NO_X conditions, the TSV Burner had lower CO emissions and better flame stability at low burner zone stoichiometries than the Directional Flame Burner.

The TSV Burner is being installed in an industrial TURBO furnace. Demonstration tests of the TSV Burner in the TURBO furnace will be conducted in January 1984. The CCV Burner with tertiary air is being installed in an industrial wall-fired furnace, also scheduled for start-up in 1984.

REFERENCES

1. Penterson, C.A., "Development of an Economical Low-NO_X Firing System for Coal-fired Steam Generators," 1982 Joint Power Conference.
2. Claypole, T.C., Syred, N., "The Effect of Swirl Burner Aerodynamics on NO_X Formation," Eighteenth Symposium on Combustion, The Combustion Institute, 1981.
3. Lisauskas, R.A., Rawdon, A.H., "Status of NO_X Control for Riley Stoker Wall-fired and TURBO Furnaces," EPA-EPRI Joint Symposium on Stationary Combustion NO_X Control, 1982.
4. Roberts, P.A., "Near Field Aerodynamics Research Program," International Flame Research Foundation, 1983.
5. Rawdon, A.H., Johnson, S.A., "Application of NO_X Control Technology to Power Boilers," 1973 American Power Conference.
6. Lisauskas, R.A., Marshall, J.J., "An Evaluation of NO_X Emissions from Coal-fired Steam Generators," 1980 EPA/EPRI Joint Symposium on Stationary Combustion NO_X Control.