Technical Paper

Low NO_X Modifications on Front-Fired Pulverized Coal Fuel Burners

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Abstract

Burner optimizations and modifications were performed on Public Service of New Hampshire's Schiller Units 4, 5, and 6. These are Foster-Wheeler 50 MWg pulverized coal and No. 6 fuel oil-fired boilers with six burners each. Burner optimizations consisted of fuel flow, primary air, secondary air testing and balancing. Burner modifications consisted of the addition of circumferentially and radially staged flame stabilizers, circumferentially-staged coal spreaders, and modifications to the existing pulverized coal pipe. NO_X emissions on Unit 6 of .41 lb/mmBtu were achieved at optimized burner settings at full load with all burners in service and without the use of overfire air or bias firing. This represented a 50% NO_X reduction from the average pre-modification baseline NO_X emissions of .81 lb/mmBtu prior to the optimizations and burner modification program. NO_X emissions as low as .38 lb/mmBtu were achieved with the use of overfire air. There was essentially no quantifiable change in LOIs (baseline LOIs averaged 40%). Furnace excess O_2 as low as 1.2% was achieved with CO emissions of less than 200 ppm. Total installed costs including the overfire air system were approximately $7/kW.

Background

Public Service of New Hampshire's Schiller Station is located in the City of Portsmith, New Hampshire on the Piscataqua River separating the States of Maine and New Hampshire. Schiller Station Units 4, 5, and 6 are natural circulation Foster Wheeler Corporation boilers (Figure 1) designed for 425,000 lb/hr of steam at 1,285 psig at 950°F superheat. The boilers were built in the 1950's and designed for firing coal and No. 6 fuel oil. Coal was fired on Unit 4 briefly. In the early 1980's, the units were refurbished to burn 1% sulfur bituminous coal and No. 6 fuel oil. Six Combustion Engineering (CE) RO-type coal and oil burners were installed, arranged in two rows of three burners per row. Two CE pulverizers sized for the capability to operate at approximately 45 MWg were added. In the late 1980's, the burners on all three units were modified in an attempt to reduce LOIs and eliminate windbox fires. The Unit 4 burners were replaced with a design similar to the CE RO burner, however, with a reduced coal pipe length and diameter, reduced burner throat size, and the addition of coal spreaders. The Unit 5 burners were modified to a reduced length and diameter coal pipe and the addition of coal spreaders. The Unit 6 burners were replaced with a design similar to the original CE RO burners, however, with a reduced length and diameter coal pipe, reduced throat diameter, and narrower throat exit angle.

Title I of the 1990 Clean Air Act required that the Schiller Station Units 4, 5, and 6 make a significant reduction in the emission of nitrous oxide (NO_X). Regulations imposed by the State of New Hampshire instituted NO_X limits of .5 lb/mmBtu. Public Service of New Hampshire performed baseline NO_X emission testing on these units and at optimized burner setting, baseline NO_X emissions ranged between .8 and 1.0 lb/mmBtu. Public Service of New Hampshire's assessment of the cost of retrofitting these units with low NO_X burners was prohibitively high. In an attempt to reduce the capital cost requirement of bringing these three units into compliance, Public Service of New Hampshire and RJM Corporation jointly funded a NO_X reduction program to achieve NO_X compliance through burner optimizations and minor burner modifications.

NO_X Reduction Program

The NO_X reduction program stretched over two years for all three units to suit the Schiller Station normal maintenance outage schedule of 24 months for each unit. The initial NO_X reduction program was conducted on Unit 5, including testing with two different design coal spreaders. These results were published in a paper entitled "Modifications of Front Fired Pulverized Coal Burners" [1] given at the May 1994 EPRI NO_X Conference in Scottsdale, Arizona. Unit 5 achieved a 40% NO_X reduction. In order to improve on the NO_X emission results achieved on Unit 5, the flame stabilizer diameter was reduced and an alternate design coal spreader was designed for Unit 4. A 45% NO_X reduction was achieved on Unit 4 from the original baseline NO_X emissions. Further improvements were incorporated into the Unit 6 conversion, including placement of the flame stabilizer at the end of the coal pipe. This resulted in a 50% reduction of NO_X emissions from the original baseline NO_X emissions of .81 lb/mmBtu. The NO_X reduction program on each unit consisted of two phases, an optimization phase and a burner modification phase. There were slight differences in the program for each unit since the burner configurations were different, and an attempt was made on each subsequent unit to improve performance.

The NO_X Optimization phase consisted of testing and balancing the secondary airflow, primary dirty airflow and coal flow. The Burner Modification phase consisted of Computational Fluid Dynamics (CFD) modeling of the baseline and modified burner, modifications to the coal pipe, and the addition of circumferential and radial staged flame stabilizers and circumferentially staged coal spreaders. In the case of Unit 6 the burner throat diameter was enlarged and the exit angle was modified back to the original design.

NO_X Optimization Phase

The objective was to balance secondary airflow, dirty airflow and coal flow within ±5% of the mean. The secondary air was measured utilizing RJM Corporation's proprietary Air Distribution Analysis (ADA) methodology. The ADA has the ability to measure the burner secondary air perimeter loadings while determining the average airflow through the burner. The back plate rings on Unit 5 and shrouds installed on Units 4 and 6 outside the air register vanes were adjusted to achieve a secondary air balance within ±5%. The dirty air and coal flow was measured by a reverse impact pitot tube and rotorprobe. Balancing was achieved by changes to the coal line orifice plates on Units 5 and 6. Adjustable orifice pulverized coal trim dampers were installed in the burner line coal pipes on Unit 4 for balancing. The baseline and final primary airflow, secondary airflow, and coal flow distribution deviations are identified in Table 1.

Table 1

Total % Deviations from the Mean

	Unit 4		Unit 5		Unit 6	
	Baseline	Final	Baseline	Final	Baseline	Final
Primary Dirty Air	7.9	2.1	15.9	6.30	42.2	6.6
Secondary Air	20.17	8.19	11.9	8.50	17.8	8.21
Coal Flow	51.0	10.4	37.9	26.9	--	4.84

Burner Modification Program

RJM Corporation used Fluent CFD and NO_X software on a Sun Sparc 10 computer to model parametric burner changes. The objectives of this portion of the project were to predict the percentage reduction in NO_X with the addition of a flame stabilizer and to determine whether the combustion in the internal recirculation vortex of the burner approximated stoichiometric proportions. The baseline burner geometry (burner as modified in 1990) for Unit 5 is shown in Figure 2. The model predicted NO_X emissions of the baseline burner of .33 lb/mmBtu. The model inputs were altered to reflect the addition of the staged coal flame stabilizer. The model predicted NO_X emissions for the modified burner of .1 lb/mmBtu or a 70% NO_X reduction. Because of the various modeling assumptions involved (coal volatilization and burnout characteristics, coal sizing and distribution, coal composition, turbulence modeling, combustion rate constants, etc.) the absolute levels of NO_X predicted are only approximate. Nevertheless, the computed results are useful in comparing trends and in quantifying the relative effectiveness of the two burner designs. Subsequent to completion of the program, additional CFD modeling determined the assumption for coal distribution exiting the coal pipe was incorrect and had a significant effect on model results.

The radially and circumferentially staged flame stabilizer (patent pending) is a low NO_X enhancement of the patented conventional radially staged flame stabilizer which has already been installed on over 2000 MW of coal-fired utility boilers. The design of the flame stabilizer was established utilizing an axisymmetric three-dimensional model. Figure 3 shows the staged, flame stabilizer design. The design maintains the primary air (15%) to secondary (85%) airflow split, and radially and circumferentially stages the secondary airflow to maximize the cyanide NO_X reduction reaction. The primary air was conveyed in the centrally located coal pipe. The secondary air comprised an outer zone around the flame stabilizer, unstaged and staged zones within the flame stabilizer, and an inner ignition zone. The secondary airflow characteristics were evaluated for design of the flame stabilizer at the flame stabilizer face exit plane diameter.

The flame stabilizer vanes were set to achieve the circumferentially staged zones by varying the vane exit angles and the number of blades in each zone. The staged section had twelve vanes and the unstaged section had four. The more axial flow angle of the unstaged zone and reduced blockage from fewer vanes permitted an increased secondary flow for the unstaged zone. The design ratio of 1.35 was achieved at a five degree flow exit angle difference.

An evaluation was made of the swirl number for the secondary airflow. Swirl number is a measure of the tangential-to-axial momentum of the secondary air exiting the plane of the flame stabilizer. The swirl number determines the size of the internal recirculation zone. For optimum combustion and low NO_X emissions, a swirl number less than 1.0 is desirable when integrated for the flow. Lower swirl numbers (<.5) may cause burner instability and ignition problems. Higher values (>1.5) create overswirl, which results in an oversized recirculation zone creating a hotter, more turbulent flame and the potential of gas recirculation into the register. Table 2 below is a summary of the final aerodynamic analysis results for each unit.

Table 2

Aerodynamic Ananysis
(Per Burner)

	Unit 4	Unit 5	Unit 6
Coal Flow - lb/sec	2.2	2.2	2.2
Primary Airflow - lb/sec	3.9	3.9	3.9
Secondary Airflow - lb/sec	22.4	22.4	22.4
Burner Throat Diameter - Inches	28	28	30
Flame Stabilizer Exit Plane Diameter- Inches	31	40	30
Flame Stabilizer Diameter - Inches	24	27	24
Air Register Vane Setting - % Open	80	80	80
Integrated Swirl Number	.69	.90	.66
Burner Secondary Air Draft Loss - Inches w.c.	5.52	2.88	6.33

The staged flame stabilizer was mounted upstream of the coal pipe discharge except on Unit 6 where it was mounted on the end of the new, extended coal pipe. New coal spreaders were fabricated which provided separation of the individual coal jets to coincide with the staged sections of the flame stabilizer. The coal pipe was extended eleven inches (18 inches on Unit 6) to the beginning of the burner throat. Figures 4, 5, and 6 show the modified burner with the new, staged flame stabilizer and coal spreader for Units 4, 5, and 6, respectively.

Public Service of New Hampshire installed an overfire air system in six (6) existing observation doors one elevation (10 feet) above the upper burner level. Four (4) front-wall ports and two (2) side-wall ports near the rear of the furnace were utilized. On Units 4 and 6 two (2) rear wall ports were utilized instead of the side wall ports. Overfire air was taken from the top of the windbox. Each port was equipped with butterfly dampers.

Test Results

Baseline NO_X emissions were obtained on each unit by Public Service of New Hampshire prior to the NO_X reduction program. This data was taken at optimized settings and included some testing with the boiler observation doors above the burners open.

Final NO_X optimization testing was performed on each unit after the fuel and air were balanced and after the installation of the burner modifications. The baseline and final NO_X versus CO emissions results for each unit at optimized conditions without overfire air is listed in Table 3 below. On Unit 5, 34 MWg was the highest load achievable on coal firing.

Table 3

	Unit 4	Unit 5	Unit 6
Load - MWg	46	34	50
Baseline NO_X Emissions - lb/mmBtu	.99	.84	.81
Baseline CO Emissions - ppm_v	19	11	60
Baseline O_2 - %	4.7	4.9	1.3
Modified NO_X Emissions - lb/mmBtu	.53	.49	.39
Modified CO Emissions - ppm_v	3	20	38
Modified O_2 - %	1.8	1.5	1.5
NO_X Reduction	45%	40%	50%

Test results on Unit 6 with a smaller diameter, staged flame stabilizer located at the end of the coal pipe yielded significantly improved results over Units 4 and 5. Boiler operational adjustments for each unit provided similar results. With the reduced NO_X emission values on

Unit 6, adjustments such as excess oxygen and overfire air had less of an impact than on Units 4 and 5. The following summarizes operational test results on Unit 6.

Boiler Load

Testing was conducted at the 2 mill maximum load of 50 MWg, and the 2 mill minimum load of 37 MWg. This was both with and without overfire air. At 50 MWg, average NO_X emissions were .41 lb/mmBtu reducing to .36 lb/mmBtu at 37 MWg. Opening the overfire air dampers reduced average NO_X at the full load condition to .40 lb/mmBtu and .33 lb/mmBtu at the 37 MWg condition. At the 1 mill minimum load of 21 MWg with the upper burners firing coal and the center lower burner on oil, NO_X emissions were .37 lb/mmBtu. This was without overfire air. Figure 7 is a plot of NO_X emissions versus boiler load at 37 MWg and 50 MWg at optimized burner settings.

Furnace Excess O_2

Throughout the boiler and burner optimization testing, data was taken at various excess furnace O_2 levels both with and without overfire air. Figure 8 is a plot of NO_X emissions versus furnace excess O_2 for the optimized burner settings. This is plotted at 50 MWg and 37 MWg with and without overfire air. At 50 MWg furnace excess O_2 ranged between 1.2% and 2.8% O_2 without overfire air. NO_X emissions at 1.5% O_2 were .39 lb/mmBtu. With the overfire air ports open at 50 MWg, furnace excess O_2 ranged between 2.3% and 2.8% O_2. Reducing excess O_2 from 2.8% to 1.2% resulted in a 21% NO_X reduction.

Figure 9 is a plot of furnace excess O_2 versus CO emissions for the optimized data at both 50 MWg and 37 MWg with and without overfire air. CO emissions at 50 MWg ranged between 0 ppm and 250 ppm at O_2 levels of 2.75% and 1.2%, respectively, without overfire air. At 60 ppm of CO emissions, furnace excess O_2 without overfire air would have been 1.5% versus 2.6% with the overfire air ports open, or a 1.1% O_2 reduction.

Overfire Air

Various combinations of overfire air ports and percent openings were tested to determine the effect of the overfire air system. The amount of overfire air was calculated from the decrease in the windbox-to-furnace differential pressure. Opening the four front ports to 50% open yielded approximately 4% overfire airflow, resulting in a negligible NO_X reduction. Opening the four front ports to 100% open yielded 8.2% overfire airflow, with a 4.7% reduction of NO_X emission. Closing the four front ports and opening the two rear ports to 100% yielded approximately 4% overfire airflow, however, a 3.7% NO_X reduction was realized. Opening the six overfire air ports to 100% resulted in 9.7% overfire air yielding an 8.1% reduction of NO_X emissions. The rear ports, although only adding 1.5% additional overfire airflow, resulted in an additional 3.4% of NO_X reduction. Figure 10 is a plot of NO_X reduction versus the amount of overfire air. This data is with the six dampers 100% open.

Loss on Ignition

Loss on Ignition (LOI) averaged approximately 40% on the units prior to the NO_X reduction program. Contributing to the cause of the high LOIs were the high moisture content of the coal (12%), operating the pulverizers above their maximum rating, and insufficient grinding of the coal due to high pulverizer amps with less than 70% passing through 50 Mesh. Post NO_X reduction program LOIs were essentially unchanged averaging within ±5% of the pre-modification average.

Summary

NO_X reductions on Unit 6 of 50% were achieved from the pre-NO_X reduction program optimized baseline conditions. This resulted in NO_X emission levels of .41 lb/mmBtu without overfire air. Figure 11 is a plot of NO_X versus CO emissions at 50 MWg for both the baseline and modified burner. NO_X reductions of 54% were achieved with the use of overfire air ducted into existing observation doors. Furnace excess oxygen levels of 1.5% were achieved without overfire air with CO emissions of 60 ppm_v. LOIs averaged approximately 40% with the modified burners. This was within ±5% of the premodified burner average LOIs.

Installed Costs

The complete installed costs for each unit are identified below. The costs include direct and indirect expenses, exempt and non-exempt labor, materials, and outside purchases. The total cost includes the burner optimizations and modifications, secondary air shrouds, removing windbox partition plates, air register repairs, refractory throat repairs or in the case of Unit 5 and 6 replacement of the burner throats, the overfire air system, and testing.

- Unit 4 $6.81/kW
- Unit 5 $6.25/kW
- Unit 6 $7.62/kW

References

1. Owens, B., Hitchko, M., and Broderick, R. G., "Modifications on Front-Fired Pulverized Coal Fuel Burners", presented at the Members Only EPRI NO_X Conference, Scottsdale, AZ (May 1994).