Technical Paper

Low NO_X Burner Modifications to Front-fired Pulverized Coal Boilers

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Abstract

Madison Gas & Electric's Blount Street Station Units 8 and 9 are Babcock & Wilcox pulverized coal fired and natural gas fired boilers. These boilers were built in the late 1950's and early 1960's with each boiler rated at 425,000 lb/hr of steam producing 50 MW of electricity. The boilers are rated at 950°F at 1350 psig. Each unit is equipped with one Ljungström air heater and two B&W EL pulverizers. These units burn a low sulfur bituminous coal with a higher heating value of 10,950 Btu/lb on an as-received basis. The nitrogen content is approximately 1.23% with 15% moisture. Baseline NO_X emissions on these units range between .68 - .83 lb/mmBtu after optimizations. LOIs averaged approximately 8%. In order to comply with the early election provision of Title IV of the 1990 Clean Air Act Amendment, Madison Gas & Electric needed to reduce NO_X on these units to less than .5 lb/mmBtu. Madison Gas & Electric contracted with RJM Corporation to modify the existing burners to achieve this objective. These modifications consisted of adding patented circumferentially and radially staged flame stabilizers, modifying the coal pipe, and replacing the coal impeller with a circumferentially staged coal spreader. RJM Corporation utilized computational fluid dynamics modeling in order to design the equipment to modify these burners. The equipment was installed in March 1997 and start-up and optimization were conducted in April 1997. NO_X emission reductions of over 50% were achieved down to .40 lb/mmBtu. LOI increased to 15-20%. Modifications are planned to the coal spreaders to reduce LOIs.

Background

Madison Gas & Electric's Blount Generating Station is located in Madison, Wisconsin, approximately six blocks from the State Capital. Boilers 8 and 9 are Babcock and Wilcox (B&W) front fired, radiant, pulverized coal units installed in 1957 and 1961, respectively. The units' design capability is 400,000 pounds of steam per hour (with a maximum continuous rating of 425,000 lb/hr for four hours) at a temperature (design) of 950°F at the superheater outlet. Each boiler is equipped with two B&W EL-64 pulverizers, each of which feeds three burners in an "L" configuration. Figure 1 is a cross section of the Unit 8 boiler. Figure 1A shows the arrangement of the burners in the windbox.

The design coal for the units was a high sulfur eastern coal. To comply with Wisconsin's Acid Rain Law, the units were switched to a lower sulfur Illinois basin coal in the early 1990s. The units can also achieve full load on natural gas and were retrofitted to co-fire other fluffed solid feedstocks in 1979. Presently this feedstock is a high Btu, non-recyclable, pre-consumer plastic which is co-fired at 10-20% of total heat input. A representative coal analysis is shown in Table 1.

Table 1

Proximate Analysis	A/R	Dry	Ultimate Analysis	A/R	Dry
% Moisture	15.00		Moisture	15.00	
% Ash	9.50	11.18	Carbon	61.12	71.90
% Volume	34.10	40.12	Hydrogen	4.21	4.95
% Fixed Carbon	41.40	48.70	Nitrogen	1.23	1.45
HHV- Btu/lb	10950	12882	Chlorine	0.02	0.02
% Sulfur	1.55	1.82	Sulfur	1.55	1.82
MAF HHV-Btu/lb	14503		Ash	9.50	11.18
			Oxygen (Diff.)	7.38	8.68

In 1996 MGE initiated its NO_X reduction program. Initial work focused on available operational changes. Coal mill operation, coal fineness, and fuel distribution to the burners were examined. It was determined that the mills were in good condition and that fineness was sufficient — over 70% through 200 mesh screen. However, on Unit 8, the primary airflow to the burners for a given mill differed by more than the 5% recommended by B&W. Coal pipe restrictors were recommended by B&W and were installed in one of the three pipes for each mill on Unit 8 only.

Successive parametric testing — examining various register, excess air, and mill loading settings — demonstrated that some NO_X reductions were achievable without retrofits. By reducing excess oxygen to approximately 2% at full load and determining an optimum configuration for the secondary air dampers, a NO_X emission reduction of 20% was obtained. However, the resultant emission rate of approximately 0.68 lb/mmBtu was not sufficient to meet the 0.50 lb/mmBtu heat input provision of the Early Election option under Title IV of the Clean Air Act Amendments (CAA) of 1990. Thus MGE began to evaluate options for physical alteration of the boilers to achieve emission reductions of NO_X. Retrofit options and costs for the units were evaluated. Based on cost, expected NO_X reductions, relative ease of installation, and lead times, it was decided to pursue the flame stabilizer and modified coal spreader option with RJM Corporation in December 1996.

NO_X Reduction Program

Secondary airflow testing on Unit 8 was conducted by RJM Corporation utilizing its Air Distribution Analysis (ADA) technology. The testing was conducted with the unit off line at maximum fan loading and all secondary air registers full open. The test results indicated the unit was close to being within the acceptable tolerance of ±5% and ±10% on average velocity and perimeter loading distributions, respectively. Therefore, no further balancing of secondary air was recommended. The actual results are shown in Table 2 below:

Table 2

Burner #	% Deviation from Mean	% Perimeter Loading Distribution
A1	-1.55	+2 / -2
A2	-6.59	+5 / -8
A3	+2.21	+4 / -6
B1	-0.47	+3 / -3
B2	+6.11	+4 / -11
B3	+0.28	+5 / -9

Computer Modeling

RJM Corporation used Fluent Computational Fluid Dynamics (CFD) and NO_X software to model parametric burner changes. The objective of this portion of the project was to predict the percentage reduction in NO_X with the addition of a flame stabilizer and segmented coal spreader. The model predicted NO_X emissions of the unaltered baseline burner of 1.0 lb/mmBtu. Model inputs were then altered to reflect the addition of the staged coal flame stabilizer and segmented coal spreader. The model predicted NO_X emissions for the modified burner of .45 lb/mmBtu. 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 were only approximate. Nevertheless, the computed results continue useful in comparing trends and in quantifying the relative effectiveness of the baseline and modified burner designs.

The original burner design had a gas ring in the windbox located at the furnace wall. The gas ring was equipped with 15 gas spuds pointing radially in toward the centerline of the burner. The gas spuds protruded approximately 2″ from the inside diameter of the burner throat and 4.5″ behind the beginning of the diverging section of the burner throat.

Since the modified burner design included extending the coal pipe 6.5″ with a flame stabilizer mounted on the end of the coal pipe, there was concern about overheating of the flame stabilizer when the unit was operated on gas fuel. Additional modeling was performed simulating gas fuel operation. Modeling determined that modifications to the gas spuds would be required to ensure flame stabilizer life.

Burner Modifications

The patented, radially and circumferentially staged flame stabilizer is a low NO_X enhancement of the patented conventional radially staged flame stabilizer which RJM Corporation has already installed on over 2000 MW of coal-fired utility boilers. The design of the flame stabilizer was established utilizing an axisymmetric two-dimensional model. Figure 2 shows the staged, flame stabilizer design. The design maintains the primary air (20%) to secondary (80%) airflow split, and radially and circumferentially stages the secondary airflow to maximize the cyanide NO_X reduction reaction. The primary air is conveyed in the centrally located coal pipe. The secondary air comprises 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 at the diverging section of the burner throat for the design of the flame stabilizer. This was the planned location of the flame stabilizer.

The flame stabilizer vanes were located to achieve circumferentially staged zones. This was achieved 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.

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 on this unit, a swirl number of 0.55 was desirable when integrated for the flow. This was achieved with a 28″ outside diameter flame stabilizer with the secondary air register vanes set at 30% open from the full closed position. Table 3 below is a summary of the final aerodynamic analysis results for Unit 8 and 9.

Table 3

Aerodynamic Analysis
(Per Burner)

Coal Flow - lb/sec	2.20
Primary Airflow - lb/sec	4.16
Secondary Airflow - lb/sec	16.85
Burner Throat Diameter - Inches	34
Flame Stabilizer Exit Plane Diameter- Inches	34
Flame Stabilizer Diameter - Inches	28
Air Register Vane Setting - % Open	30
Integrated Swirl Number	.55
Burner Secondary Air Draft Loss - Inches w.c.	2.17

Based upon the model results six circumferentially and radially staged flame stabilizers and six circumferentially staged coal spreaders were designed and fabricated. The coal pipe was extended 7.5″ to the beginning of the diverging section of the burner throat. The staged flame stabilizer was mounted on the end of the new, extended coal pipe. New coal spreaders were fabricated to provide separation of the individual coal jets to coincide with the staged sections of the flame stabilizer.

Seven of the existing fifteen gas spuds on each burner were cut off and capped. The remaining eight were cut off and new axial flow gas spuds were welded over the old gas spud nipples. The gas spud orientation was set for maximum stability since the NO_X emissions limit on gas fuel is .50 lb/mmBtu.

The existing UV and IR scanner sight tube angles were modified to allow the scanners to view between the flame stabilizer outside diameter and the inside diameter of the burner throat.

Figure 3 shows the modified burner with the new, staged flame stabilizer and coal spreader. All the equipment was installed by MGE maintenance personnel during a March 1997 outage.

Test Results

Baseline NO_X emissions were obtained on the unit by MGE prior to the NO_X reduction program. This data was taken at various settings. Final NO_X optimization testing was performed on Unit 8 after the installation of the burner modifications. The baseline and modified burner NO_X

results for Unit 8 at optimized conditions are listed in Table 4 below.

Table 4

	Unit 8
Load - MWg	50
Baseline NO_X Emissions - lb/mmBtu	.81
Baseline CO Emissions - ppm_v	4
Baseline O_2 - %	2.6
Modified NO_X Emissions - lb/mmBtu	.39
Modified CO Emissions - ppm_v	60
Modified O_2 - %	2.5
NO_X Reduction - %	52

The following describes the modified burner performance as a function of various boiler operational parameters:

Boiler Load

Testing was conducted on the modified burners at the maximum load of 50 MWg and an intermediate load of 30 MWg. NO_X emissions were less than .40 lb/mmBtu at 50 MWg reducing to less than .35 lb/mmBtu at 30 MWg. Figure 4 is a plot of NO_X emissions versus boiler load at 35 MWg and 30 MWg at optimized burner settings for both the baseline and modified burner conditions, respectively, up to 50 MWg.

Furnace Excess O_2

Throughout the boiler and burner optimization testing, data was taken at various excess furnace O_2 levels. Figure 5 is a plot of NO_X emissions versus furnace excess O_2 for the optimized burner settings for the baseline and modified burner conditions at 50 MWg. The furnace excess O_2 during testing ranged between 2.0% and 3.5% O_2. NO_X emissions at 2.0% O_2 were .39 lb/mmBtu. The plot shows there was a 50% NO_X reduction with the modified burner across the operating excess O_2 range. CO emissions were measured at the economizer outlet during various test conditions. CO measurements never exceeded 100 ppm under any condition tested.

Flame Monitoring

Prior to the modifications the unit experienced numerous pulverizer trips due to loss of flame scanner signals. Secondary air adjustments had to be made to try to perserve flame scanner signal strengths.

The pulverizer trips due to loss of coal (IR) flame signals have been reduced through various adjustments since the burner modifications. The secondary air vane adjustments no longer impact flame stability and flame scanner signals since the majority of the swirl control is now a function of the design of the flame stabilizer.

The sensitivity of the UV ignitor and main gas flame scanners was adjusted to discriminate individual burner flames. Both ignitor and main gas flame scanner signals are steady and reliable. However, UV radiation from the burner coal flames is occasionally detected by the UV scanners affecting the operators ability to start a gas ignitor on a coal burner already in service.

Gas Firing

The unit cycles off line at night or weekends when power demand is low. The unit is started with gas ignitors igniting the main gas burners. A minimal amount of testing was conducted on the unit in a gas only mode of operation.

Test results indicated that boiler load can be sustained on gas only fuel with the modified burners. No changes were required to the boiler gas controls as this gas orifice area was unchanged from the baseline burner configuration. NO_X emissions on gas fuel at 44 MWg were .29 lb/mmBtu at 1.6 O_2.

Since the NO_X limit on gas fuel was .5 lb/mmBtu no special gas spud orientation was utilized. If, in the future, regulations require NO_X emission reductions on gas fuel, simple modifications to the gas spuds can be implemented.

Co-Firing Coal and Gas

The unit has the capability of co-firing coal and natural gas in the same burner at ratios from 33% to 100% of gas input and 50% to 100% on coal input. Co-firing is used to supplement capacity in the event of wet coal or a pulverizer out of service. The modified burners have demonstrated the ability to successfully co-fire across these ranges.

Loss on Ignition

Loss on Ignition (LOI) ranged between 6-8% on the unit prior to the NO_X reduction program. Post NO_X reduction program LOIs increased to 20% and furnace excess oxygen increased to 3.0%. Lowering the primary air to coal flow ratio decreased the LOIs to between 14-16%. Coal spreader modifications are planned to further reduce LOI levels.

Installed Costs

The complete installed costs for Unit 8 were approximately $3.30/kW. The costs include direct and indirect expenses, exempt and non-exempt labor, materials, and outside purchases. The total cost includes the burner modifications, air register repairs, refractory throat repairs and modifications to the gas spuds. This cost does not include efficiency losses due to fan changes, or LOI.

Summary

NO_X reductions on Unit 8 of greater than 50% were achieved from the pre-NO_X reduction program optimized baseline conditions. This resulted in NO_X emission levels of less than .4 lb/mmBtu. Furnace excess oxygen levels of 2.0% were achieved during testing with CO emissions of 60 ppmv. LOIs ranged between 14-16% with the modified burners. Redesign and installation of new staged coal spreaders are planned to reduce LOIs and improve flame detection.