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Four Corners 5
Table 1: Btu/lb (13,848)
Table 3: NOx, lb/mmBtu
(1.15)

Ref 4

PERFORMANCE OF A LARGE CELL-BURNER UTILITY BOILER RETROFITTED WITH FOSTER WHEELER LOW-NO_x BURNERS

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ABSTRACT

A comprehensive boiler testing program was performed on Units 4 and 5 of the Four Corners Steam Electric Station to compare the NO_x emissions and thermal performance of a unit retrofitted with low-NO_x burners (Unit 4) with a "sister" unit still equipped with its original turbulent burners (Unit 5). Built in the late 1960s, Units 4 and 5 are 800-MW Babcock & Wilcox supercritical, once-through boilers designed for firing of a western subbituminous coal. In 1989, Unit 4 was retrofitted with low-NO_x circular burners designed by Foster Wheeler Energy Corporation; Unit 5 was left unmodified while awaiting its scheduled retrofit in 1991. Major objectives of the comparative testing program were to establish the NO_x emissions levels and to assess any changes in the performance and operability of Unit 4 due to the installation of low-NO_x burners.

Testing included measurement of NO_x, CO, and SO_2 emissions, unburned carbon, gas temperature leaving the economizer, and heat absorption in various boiler circuits at different levels of unit load and excess air, and with different burner air register adjustments. Test results indicate that the low-NO_x burners reduced NO_x emissions from Unit 4 by 55% compared with the unmodified Unit 5, without any detrimental effect on boiler performance, efficiency, or operability.

This paper should be of interest to any utility evaluating potential NO_x reductions and boiler performance effects that could be anticipated by retrofitting these low-NO_x burners to pulverized-coal-fired utility boilers with "cell" burners or conventional circular turbulent burners.

INTRODUCTION

The Arizona Public Service Company (APS) operates five coal-fired units at the Four Corners Steam Electric Station located near Farmington, New Mexico. The units operate under a state environmental regulation which limits emissions of nitrogen oxide (NO_x) to 0.70 lb/MBtu from coal-fired utility boilers. This regulation was promulgated in 1972, several years after the two units that produce the highest NO_x emissions--Units 4 and 5--went into commercial operation.

Babcock & Wilcox (B&W) boilers manufactured during the late 1960s, like Units 4 and 5, were equipped with closely spaced, two- or three-nozzle "cell" burners specially designed to maximize combustion intensity and produce extremely high heat releases in a compact burner zone. These combustion features result in very high flame temperatures, heavy slagging in the furnace, and NO_x emissions around 1.20 lb/MBtu at full load.

Between 1972 and 1984, APS conducted several testing programs and NO_x control technology studies on Units 4 and 5 in an attempt to achieve compliance with the state regulation. None of these efforts were successful or even promising. In 1985, APS identified the Foster Wheeler Energy Corporation (FWEC) Controlled-Flow/Split-Flame (CF/SF) low-NO_x burner as a promising NO_x control technology for possible application to the Four Corners boilers. Subsequent pilot-scale burner testing programs and design engineering studies supported a retrofit of CF/SF low-NO_x burners on Units 4 and 5.[1] In 1987, the retrofit was approved for major overhauls of Units 4 and 5 scheduled for 1989 and 1991, respectively.

BOILER PLANT DESCRIPTION

Units 4 and 5 are identical B&W opposed-fired, supercritical, once-through, pressurized boilers. Each is capable of a maximum continuous rated output of 5,445,000 lb/h main steam flow at 1000/1000°F. The units fire a western, low-sulfur, high-ash, subbituminous coal with the characteristics shown in Table 1. Units 4 and 5 were originally designed by B&W with nine pulverizers serving 18 three-nozzle cell burners. The closely spaced cell burners illustrated in Figure 1 were arranged in a nonuniform firing pattern in the furnace.

Retrofit of the FWEC CF/SF low-NO_X burners (Figure 2) required major design modifications to the Unit 4 boiler including

- Conversion to eight pulverizers and 48 low-NO_X burners, arranged in four rows of six burners on each firing wall
- New lower furnace waterwall panels designed for a conventional, widened burner spacing
- Replacement of most of the burner piping
- Installation of a new pulverizer/burner control system

These construction modifications were completed during a major two-month overhaul of Unit 4 in the spring of 1989.

TEST PROGRAM DESCRIPTION

Following installation of the low-NO_X burners, APS and the Electric Power Research Institute (EPRI) entered into a cooperative agreement to test and compare the modified boiler's performance and emissions with the performance and emissions of unmodified Unit 5.

Specific objectives of the testing program were

- To assess any changes in Unit 4 boiler performance and operability with the new low-NO_X burners
- To investigate the effects of inner and outer air register positions and burner inner nozzle adjustments on flame shape and stability, NO_X emissions, and boiler absorption rates, particularly in the secondary superheater and pendant reheater sections
- To evaluate the effects of different unit loads and furnace excess oxygen (O_2) levels on NO_X emissions

Tenerx Corporation was hired to collect emissions data on NO_X, excess O_2, carbon monoxide (CO), and sulfur dioxide (SO_2), to measure gas temperatures leaving the economizer, and to collect and analyze coal and ash samples. APS engineers collected all flow, pressure, and temperature data needed to evaluate boiler absorption performance. APS and Tenerx conducted a site inspection of the boilers prior to the testing program to establish acceptable sampling locations and testing procedures. Coal fineness and fuel/air balance testing were performed on the fuel supply systems of both units prior to the main testing program to ensure acceptable boiler test conditions. All permanent plant instrumentation used in the testing was checked for calibration and recalibrated where necessary.

Gaseous emissions and flue gas temperatures were measured in the flue gas ducts between the economizer outlet and the air preheater inlets. Gaseous emissions were collected from an 18-point grid in Unit 4 and an 8-point grid in Unit 5. Gas temperatures were measured from a 27-point thermocouple grid in Unit 4 and a 24-point thermocouple grid in Unit 5. A computer-based data acquisition system was used to collect all thermocouple readings.

TESTING PROCEDURE

The comparative testing program followed the test matrix shown in Table 2 to evaluate the units' emissions and thermal performance over a range of operating conditions. The test plan consisted of a series of 15 parallel tests on Units 4 and 5, along with six tests conducted only on Unit 4. Test variables included unit load, furnace excess O_2 level, burner tip position, and inner/outer air register position. The following tests were conducted:

- Four full-load parallel tests were run on both units at standard burner tip position of +3 inches at low (1.8-2.4%), normal (2.7-2.9%), and high (3.4-3.6%) excess O_2 levels.
- Four full-load, parallel tests were run on both units with burner tip positions moved to zero and -3 inches at low (1.8-2.4%) and high (3.4-3.6%) excess O_2 levels.
- Four full-load tests were run on Unit 4 only while varying inner and outer air register positions. These tests were performed at normal excess O_2 levels (2.7-3.0%). Optimum inner and outer air register positions were identified based on NO_x emission levels. Two additional full-load tests were then run on Unit 4 with both air registers at optimized positions at low (2.0%) and normal (2.7%) excess O_2 levels.

- Four 75% load, parallel tests were run on both units under standard burner operating conditions with all mills in service (AMIS) and with top mill out of service (MOOS) at normal excess O_2 levels (3.2-3.7%); and with AMIS at high excess O_2 levels (4.4-4.5%).
- Three 50% load, parallel tests were run on both units under standard burner operating conditions with two top MOOS at normal excess O_2 levels (4.7-5.0%), and then with two top MOOS O_2 (5.4-5.5%).

Each test lasted about 4-5 hours--1.5 hours of process stabilization, and 3-4 hours of actual testing. Emissions were monitored and recorded as single-point samples and as composite samples. Emissions testing equipment consisted of a chemiluminescent NO_x analyzer, infrared analyzers for CO and CO_2, a zirconia cell analyzer for O_2, and a DuPont SO_2 analyzer.

Two fuel analyses were performed during each test. Coal samples were collected immediately downstream of the coal silos before the coal entered each mill feeder. These samples were riffled together to produce an "average" coal sample, and higher heating value (HHV), proximate, and ultimate analyses were performed. Mineral analyses were also conducted on selected coal samples.

Bottom ash samples were collected once per test from a selected bottom ash hopper. Fly ash samples were collected from two selected baghouse hoppers and one economizer hopper for each unit. Samples were analyzed for mineral constituents, fusion temperature, and carbon carryover (loss on ignition, LOI). Size, quantity, and elemental analyses were performed on selected bottom ash and baghouse fly ash samples.

At the end of Test No. 1 a severe leak in the first point high-pressure feedwater heater of Unit 5 occurred, and the heater had to be valved out of service. Testing revealed that NO_x emissions from Unit 4 were approximately the same with this first point heater in or out of service. Based on this, the Unit 4 first point heater was also valved out of service for the remaining parallel tests to allow a fair performance comparison between Units 4 and 5. During the six tests on only Unit 4, both first point heaters were in service.

EMISSION TEST RESULTS

Because the secondary air supply to the burners out of service on Unit 5 could not be shut off, a staging effect was present that could explain the lower NO_x emissions from Unit 5 under low-load conditions. Figure 3 illustrates NO_x emissions versus stoichiometric air ratio to correct for the staging effect.

The FWEC low-NO_x burners installed on Unit 4 achieved an average 50% reduction in NO_x emissions versus those from the unmodified Unit 5 when operating at full load. Under 75% load and normal (3.4-3.7%) excess O_2 levels, the reduction in NO_x emissions was 47% with AMIS, and 40% with the top MOOS. With the two top MOOS at 50% load conditions, the staging effect on Unit 5 NO_x emission reduction was so obvious that only an average 17% NO_x reduction was observed on Unit 4.

Figure 4 illustrates NO_x emissions versus unit load at various operating excess O_2 levels. A correlation analysis indicated a definite correlation between NO_x emissions and unit load for Unit 5, while the Unit 4 data did not show significant correlation. Reducing unit load can only reduce thermal NO_x, which is a small portion of total NO_x emissions. Because the turbulent burners on Unit 5 were operated at higher peak flame temperatures than the low-NO_x burners on Unit 4, Unit 5 produced more thermal NO_x than Unit 4, and was more sensitive to unit load changes.

Figure 5 indicates that changing the burner tip position had little effect on NO_x emissions. When the burner tip position is adjusted, the primary air velocity is changed because primary airflow is constant. Adjustments are used to optimize the primary air/secondary air ratio to minimize shear-induced turbulence. They may also cause major changes in flame shape. APS had previously identified the optimum burner tip position as +3 inches.

The effects of inner and outer air register position on the performance of the low-NO_x burners in Unit 4 are illustrated in Figure 6. Inner air registers regulate the amount of swirl in the secondary air near the burner tip and control the point of flame ignition. Outer air registers impart initial swirl to the secondary air and control the overall flame shape and size/strength of the internal recirculation zone. Minimum NO_X emissions levels occurred at an inner air register position of 10° open and an outer air register position of 35-40° open. With both inner and outer air registers in their optimum positions, NO_X emission levels were 0.44 lb/MBtu at normal excess O_2 level and 0.42 lb/MBtu at low excess O_2 level.

Figure 7 illustrates the NO_X emissions versus burner zone liberation rate. The effect of staging on Unit 5 NO_X emissions is obvious.

SO_2 flue gas values ranged from 605 to 914 ppm for Unit 4, and 546 ppm to 761 ppm for Unit 5. CO emissions on Unit 5 ranged from 32 to 75 ppm, while Unit 4 CO emissions ranged from 32 to 75 ppm except on one test with low excess O_2, where average CO emissions were 185 ppm.

Analyses of coal and ash samples taken during the testing program revealed the consistency of the coal fired in Units 4 and 5. The coal is fairly reactive, so there was little difference in the unburned carbon levels between Units 4 and 5.

BOILER PERFORMANCE TEST RESULTS

Based on preliminary analyses of boiler performance data, it appears that there was no detrimental effect on boiler performance, efficiency, or operability as a result of the installation of low-NO_X burners on Unit 4. Table 3 presents the results of a typical, full-load, boiler performance test. Further analysis is required to explain the substantial differences between some of the comparative data. APS plans to conduct boiler performance and emissions testing on Unit 5 after the installation of low-NO_X burners. This will provide additional data for a better comparison of the boiler performance before and after the burner retrofit.

Furnace Exit Gas Temperature (FEGT)

The FEGTs at full-load operations calculated using the back-calculation method ranged from 2541 to 2680°F for Unit 4, and 2647 to 2850°F for Unit 5. The difference in FEGT for Unit 4, which ranges from 100 to 209°F lower than Unit 5 FEGT, is due to increased furnace heat absorption as a result of reduced levels of slagging in the furnace. The low-NO_x burners control high-temperature flame regions which promote slagging.

Heat Absorption Rates in Boiler Circuits

Changes in the burner firing arrangement and the retrofit of low-NO_x burners have created a new furnace heat absorption pattern. Figure 8 illustrates a typical comparison of heat absorption rates in the boiler circuits for Units 4 and 5.

Only enthalpies for the boiler circuits are shown in the figure because the water/steam rates for Units 4 and 5 are almost identical. Unit 4 data shows an increase of 31-66% in the upper furnace heat absorption rate compared with Unit 5. This is due to reduced levels of slagging in the furnace. A decrease of 33-43% in the primary superheater heat absorption rate is also indicated in the Unit 4 data. The heat absorption rates for the upper furnace and primary superheater are being investigated further to find out why there are substantial differences between the units. The much higher upper furnace heat absorption rate increases the primary superheater outlet steam temperature such that the superheater spray flow requirement for Unit 4 is increased by 148-180% when compared with Unit 5. Units 4 and 5 data show insignificant changes in the heat absorption rates in other boiler circuits such as the lower furnace, secondary superheater, superheater enclosure, reheater, and economizer

Main Steam and Hot Reheat Temperatures

Data indicate a slight increase in the main steam temperature for Unit 4. Main steam temperatures are in the range of 990-1004°F for Unit 4 versus 983-992°F for Unit 5. However, there is a substantial decrease in the hot reheat temperature for Unit 4. Hot reheat temperatures are in the range of 947-977°F for Unit 4 and 975-1011°F for Unit 5. This is due to the pendant reheater inlet gas temperature for Unit 4, which is 124-177°F lower than the temperature for Unit 5. The effect of lower hot reheat temperature for Unit 4 on turbine cycle efficiency is being investigated.

Boiler Efficiencies

Boiler efficiency increased slightly, in the range of 0.72-1.52%, for Unit 4. This is due to lower air preheater inlet gas temperatures as a result of lower economizer inlet water temperatures. During the only test that Units 4 and 5 had with both first point high-pressure feedwater heaters in service (Test No. 1), the air preheater outlet gas temperatures were almost the same. Therefore, it can be concluded that the boiler thermal efficiencies remained the same after the retrofit.

CONCLUSION

The boiler emissions and thermal performance testing program comparing the performance of Units 4 and 5 at the Four Corners Steam Electric Station revealed that the retrofit of low-NO_x burners to Unit 4 reduced NO_x emissions by about 50% at normal, full-load operating conditions without any detrimental effect on boiler performance, efficiency, or operability.

The average level of NO_x emissions from Unit 4 was 0.53 lb/MBtu, well under the applicable state of New Mexico air-quality standard of 0.70 lb/MBtu.

ACKNOWLEDGMENTS

Special thanks to Four Corners operations, maintenance, and engineering personnel for their assistance in conducting the testing, to Charles Allen for his technical assistance, and to Paul Thompson of Tenerx for conducting the testing.

REFERENCE

1. Vatsky, Joel, and Allen, Charles, "Predicting Boiler and Emissions Performance by Comparative Turbulent/Low-NO_x Burner Testing on a Large Testing Facility." Proc. 1989 Joint Symposium on Stationary Combustion NO_x Control, 2, 23 (1989).

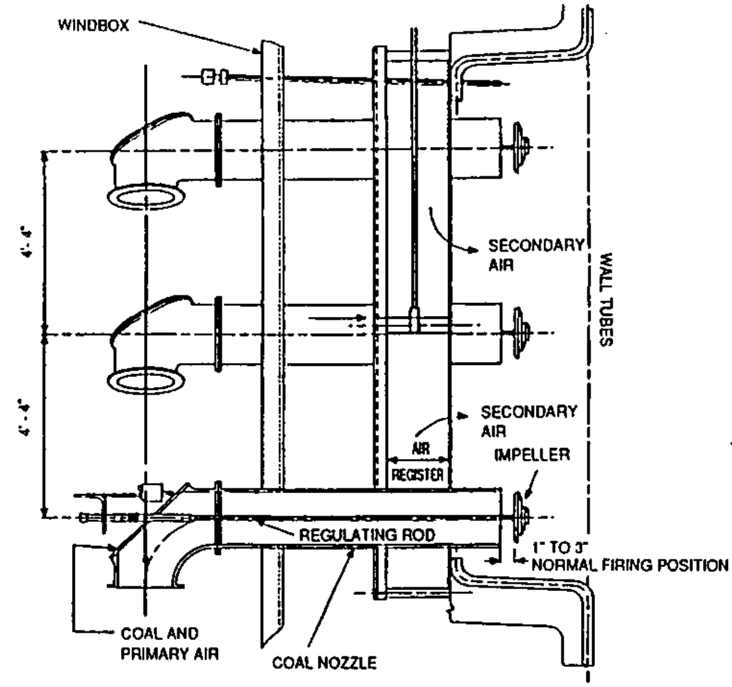

Figure 1 - FWEC Three-Nozzle Cell Burner

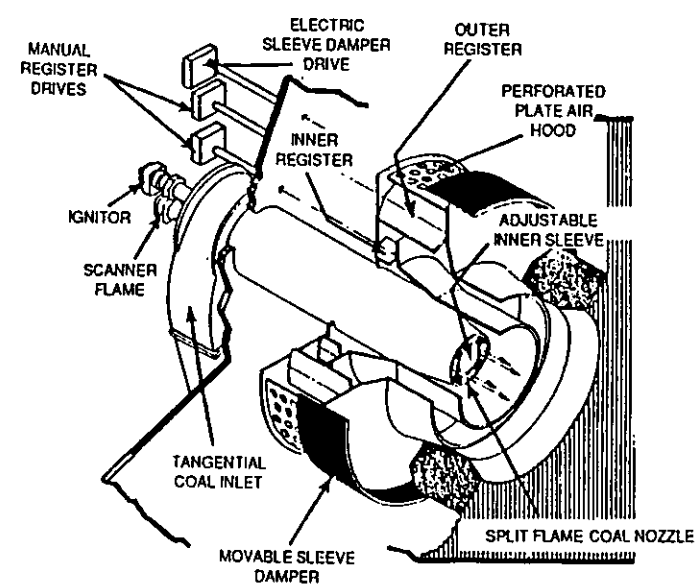

Figure 2 - FWEC Controlled-Flow/Split-Flame Low-NO_X Burner

Figure 3
EFFECT OF STOICHIOMETRY ON NO_X EMISSIONS

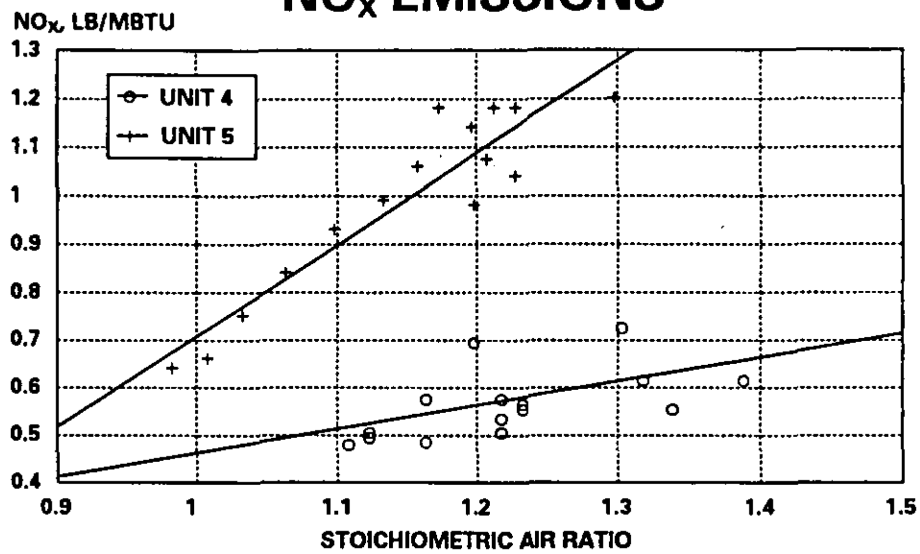

Figure 4
EFFECT OF BOILER LOAD ON NO_X EMISSIONS

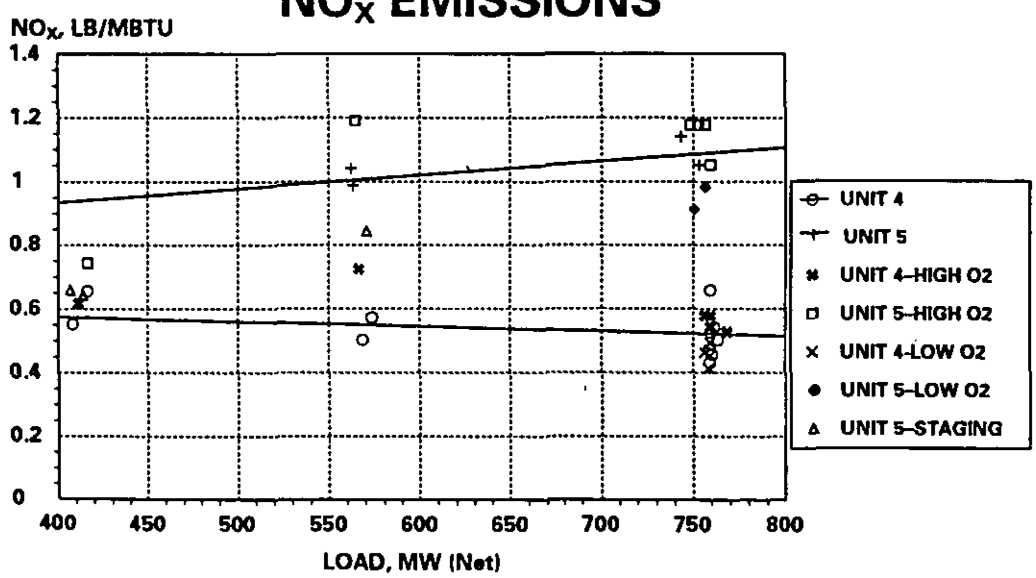

Figure 5
EFFECT OF BURNER NOZZLE POSITION ON NO_X EMISSIONS

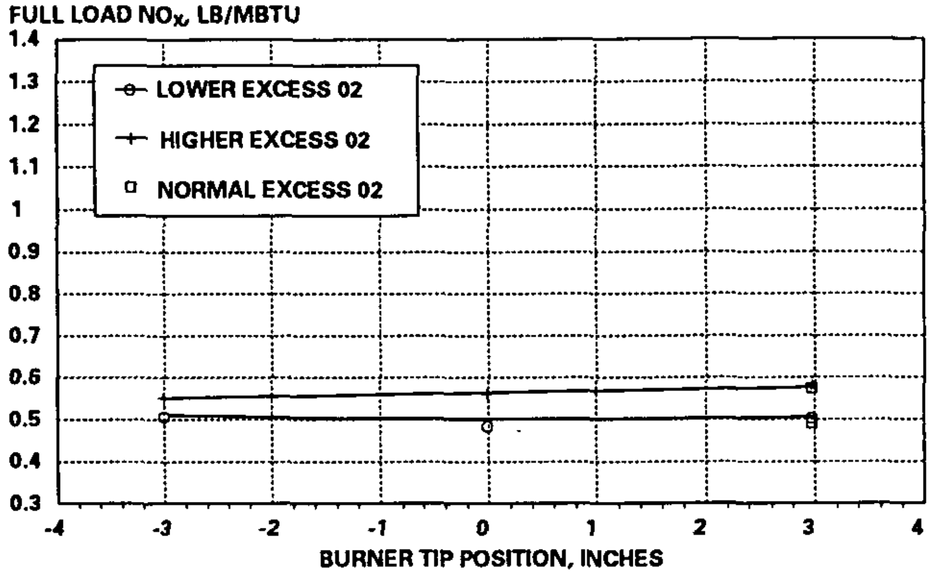

Figure 6
EFFECT OF AIR REGISTER POSITION ON NO_X EMISSIONS

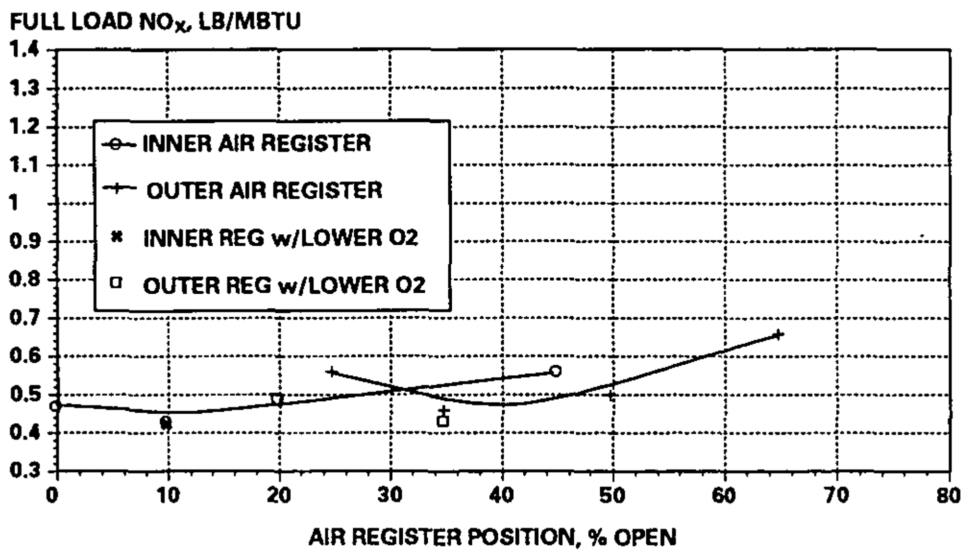

Figure 7
EFFECT OF BURNER ZONE LIBERATION RATE ON NO_X EMISSIONS

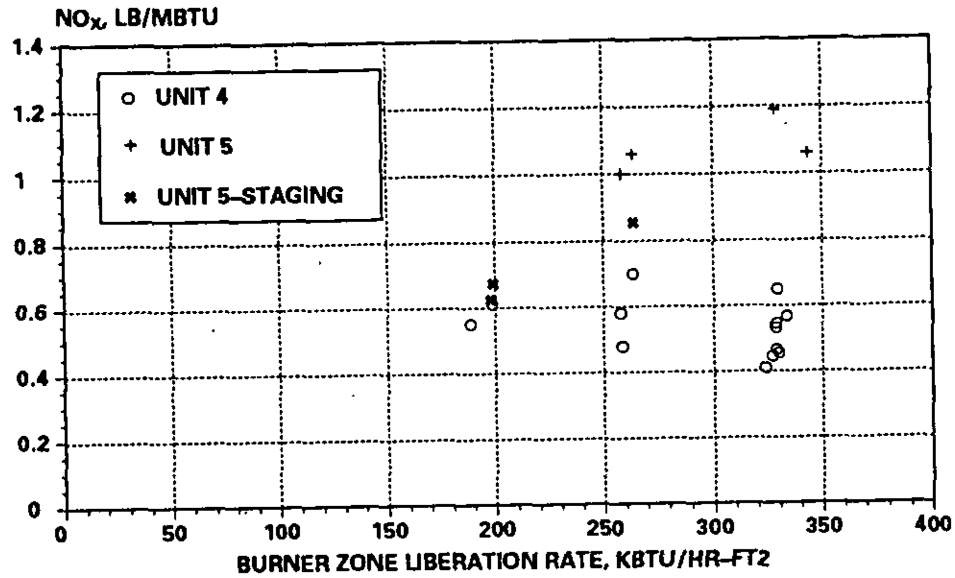

Figure 8
COMPARISON OF SECTIONAL HEAT ABSORPTION

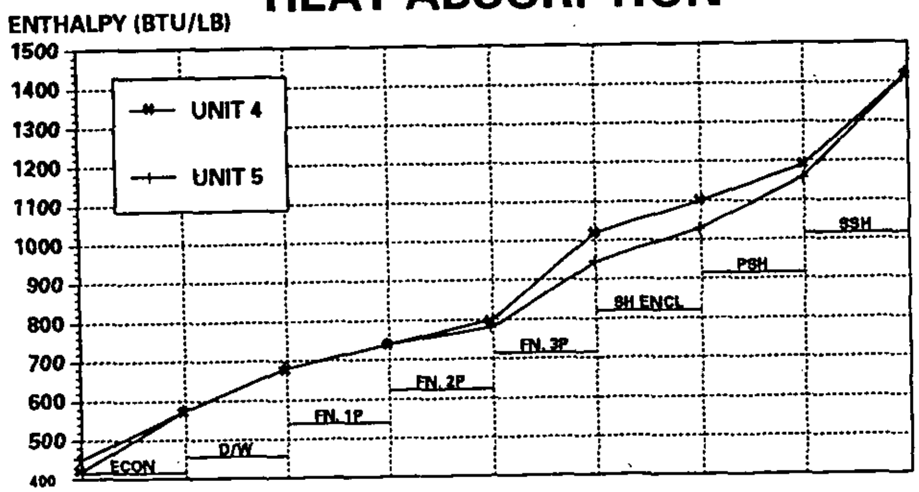

Table 1

COAL ANALYSES SUMMARY

Test	Condition	Unit 4	Unit 5
Proximate Analysis			
% Moisture	--	14.67	14.34
% Ash	As Received	16.33	16.32
	Dry Basis	19.14	19.05
% Volatiles	As Received	26.47	31.32
	Dry Basis	31.02	36.88
% Fixed Carbon	As Received	42.53	37.75
	Dry Basis	49.84	44.07
Energy Content, Btu/lb	As Received	9561	9602
	Dry Basis	11205	11210
% Sulfur	As Received	0.85	0.72
	Dry Basis	1.00	0.84
MAF, Btu/lb	--	13857	13848
% Air Dry Loss	--	9.03	7.57
Ultimate Analysis			
% Moisture	--	14.67	14.34
% Carbon	As Received	53.87	54.55
	Dry Basis	63.13	63.68
% Hydrogen	As Received	3.86	3.96
	Dry Basis	4.52	4.62
% Nitrogen	As Received	1.10	1.15
	Dry Basis	1.29	1.34
% Sulfur	As Received	0.85	0.72
	Dry Basis	1.00	0.84
% Ash	As Received	16.33	16.32
	Dry Basis	19.14	19.05
% Oxygen	As Received	9.32	8.96
	Dry Basis	10.92	10.47

Table 2

TEST MATRIX

Test Number	Load	Units	Excess Air	Test Condition
1	100%	4&5	Normal	Std. Nozzle & Register Positions
2	100%	4&5	Normal	Std. Nozzle & Register Positions
3	100%	4&5	Low	Std. Nozzle & Register Positions
4	100%	4&5	Normal	Repeat Std.
5	100%	4	Normal	Outer Register Open
6	100%	4	Normal	Outer Register Closed
7	100%	4	Normal	Inner Register Open
8	100%	4	Normal	Inner Register Closed
9	100%	4&5	Low	Burner Nozzle In (0)
10	100%	4&5	High	Burner Nozzle In (0)
11	100%	4&5	Low	Burner Nozzle In (-3)
12	100%	4&5	High	Burner Nozzle In (-3)
13	75%	4&5	Normal	Std., All Mills In Service
14	75%	4&5	High	Std., All Mills In Service
15	75%	4&5	Normal	Std., 1 Mill Out of Service
16	75%	4&5	Normal	Std.
17	50%	4&5	Normal	Std., 2 Mills Out of Service
18	50%	4&5	High	Std., 2 Mills Out of Service
19	50%	4&5	Normal	Repeat Std.
20	50%	4&5	Normal	Optimal Nozzle Register Positions
21	50%	4&5	Normal	Optimal Nozzle Register Positions

Table 3

TYPICAL COMPARATIVE BOILER PERFORMANCE DATA, UNIT 5

Parameter	Post-Retrofit	Pre-Retrofit
Load, MW	760	752
Excess O_2, % Wet	2.82	2.74
Feedwater Flow, 1000 lb/h	5478	5493
Superheater Spray Flow, 1000 lb/h	433	286
Main Steam Temp., °F	1004	992
Hot Reheat Temp., °F	965	999
Furnace Exit Gas Temp., °F	2593	2775
NO_x, lb/MBtu	0.49	1.15

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