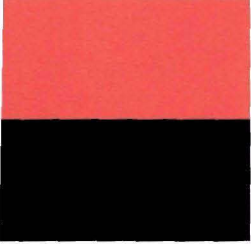


May 1995



EPRI/EPA 1995 Joint Symposium on Stationary Combustion NO_x Control

**Book 3: Thursday, May 18, 1995
Sessions 6A, 6B, 7A, 7B**

Sponsored by
Electric Power Research Institute
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U.S. Environmental Protection Agency
Air and Energy Engineering Research Laboratory
Combustion Research Branch

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Prepared by
ELECTRIC POWER RESEARCH INSTITUTE

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IN-FURNACE, RETROFIT ULTRA-LOW NO_x CONTROL TECHNOLOGY FOR TANGENTIAL, COAL-FIRED BOILERS: THE ABB C-E SERVICES TFS 2000™R SYSTEM

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Abstract

United Illuminating and ABB C-E Services, Inc. report the first commercial retrofit installation and performance results from a TFS2000™R firing system. Pre-retrofit and post-retrofit field trials were conducted to evaluate the impact of the retrofit design on the boiler emissions and thermal performance. During testing, the retrofitted 390-MW_e utility boiler demonstrated NO_x emissions on the order of 0.25 lb/10⁶ Btu, while firing Eastern bituminous coal over the entire load range, without increase in unburned carbon (UBC). A potential minimum NO_x emission level of 0.16 lb/10⁶ Btu was achieved in parametric testing. The effects of the retrofit on boiler emissions, thermal performance and operating experience are reported.

Introduction

United Illuminating (UI) provides electricity to south-central Connecticut. In 1984, the electricity produced in the UI system came from an energy mix that was 94% fuel oil and 6% nuclear. To diversify its fuel base, in that year UI reconverted the Bridgeport Harbor Station Unit 3 (Figure 1) for coal firing. By 1985, the contribution of oil to UI's energy mix was reduced to 53%; nuclear was 9%, and coal had provided 37%. Continuing with its strategy of utilizing diverse fuels, UI shifted its energy mix to 1% natural gas, 5% hydro, 8% trash-to-energy, 17% oil, 35 % nuclear, and 34% coal by 1992.¹

The city of Bridgeport is located in a "Severe" ozone nonattainment area under the 1990 Clean Air Act Amendments (CAAA) Title I. Bridgeport Harbor Station Unit 3 (BHS Unit 3) is a Phase II unit under CAAA Title IV. The State of Connecticut's Reasonably Achievable Control Technology (RACT) NO_x limitation is 0.38 lb/10⁶ Btu for tangential coal-fired boilers. With UI's fuel strategy in place, the utility decided to retrofit BHS Unit 3, its only coal-burning unit, with an aggressive low NO_x firing system.

ABB C-E Services invited UI to participate in a research and development project in which BHS Unit 3 would serve as the first commercial field demonstration of TFS

2000™R technology. Similar technology had previously demonstrated ultra-low NOx emissions at the laboratory scale.²

Unit Description

BHS Unit 3 is a Combustion Engineering, Inc., Controlled Circulation® steam generator with radiant reheat cycle and a pressurized furnace (Figure 2). It was designed in 1965 and commissioned in 1968. The steam generator is rated at 2,700,000 lb/hr primary steam flow at maximum continuous rating (MCR), with a corresponding reheat flow of 2,387,000 lb/hr. The MCR design superheat and reheat outlet steam temperatures are 1005 F. Operating pressure at the superheater outlet is 2629 psig.

Nominally rated at 390 MWe, the unit was equipped with a Tilting Tangential Firing System for firing pulverized coal from five elevations and oil from four elevations. During the reconversion to coal firing in 1984, close-coupled overfire air was added. BHS Unit 3 operates with Eastern U.S. bituminous coals from sources in Kentucky. The coal composition is relatively uniform, with a low sulfur content and low slagging/fouling potential. Table 1 shows a typical coal analysis for BHS Unit 3.

BHS Unit 3 is typically operated on automatic load dispatch, generating steam at MCR on weekdays and at control load or lower on nights and weekends. Pre-retrofit NOx emissions under normal operating conditions were in the range of 0.55-0.60 lb NOx/10⁶ Btu. The unit had no history of significant slagging or fouling, and no history of pressure part failures related to the coal properties.

TFS 2000™R SYSTEM DESIGN

The TFS 2000™R System at BHS Unit 3 is an integrated retrofit design based on the successful laboratory development of Combustion Engineering, Inc.'s (ABB C-E) TFS

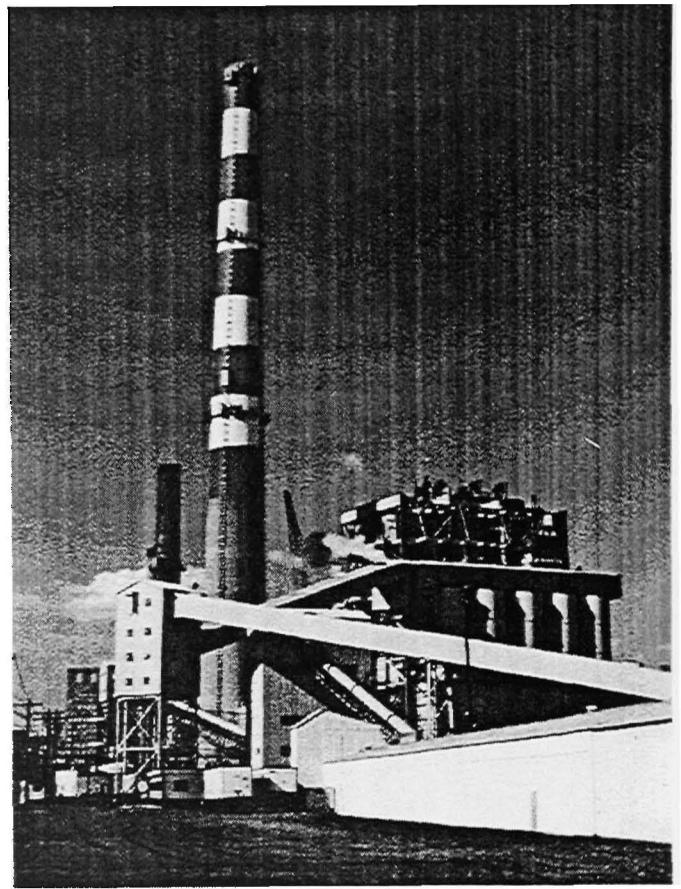


Figure 1: United Illuminating's Bridgeport Harbor Station

Moisture	5.4%
Volatile Matter	30.1%
Fixed Carbon	57.7%
Ash	6.8%
Nitrogen	1.4%
Sulfur	0.7%
FC/VM	1.92
HHV (Btu/lb)	13,400
Hardgrove Index	45

Table 1: Typical Coal Analysis

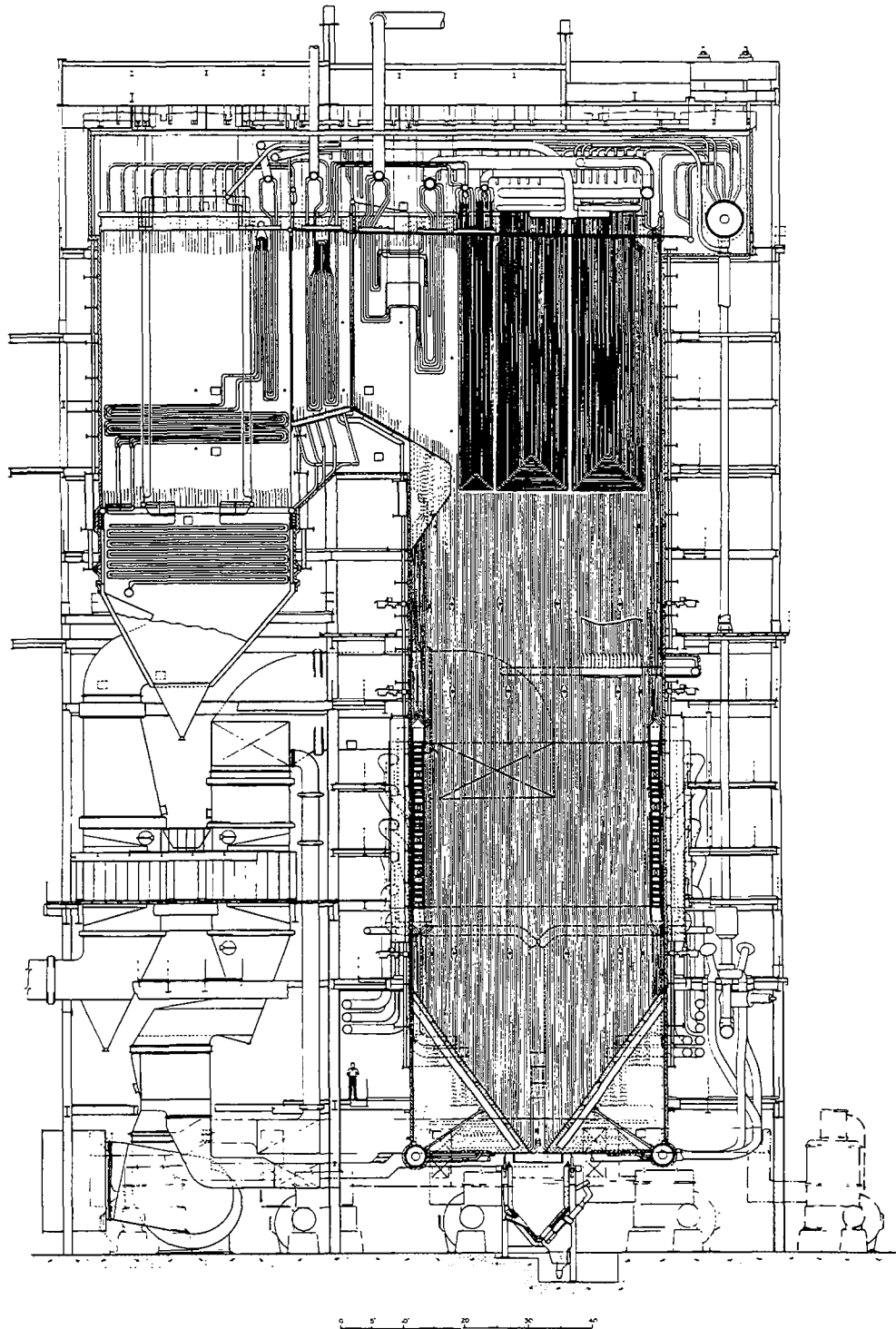


Figure 2: Bridgeport Harbor Station Unit 3, Pre-Retrofit Side Elevation

2000™ system for new boilers.² The challenge is to provide the most aggressive control of NO_x emissions possible within the constraints of a fixed furnace geometry, without introducing any radical or negative departures from either design or operating

practices. Previous research and development efforts suggested that the laboratory results for absolute NO_x emissions, and trends for carbon monoxide and unburned carbon, were consistent with a utility boiler.³ Therefore, the next step in the commercialization of the TFS 2000™R technology was a field demonstration on a large utility boiler.

The basic design philosophy of the TFS 2000™R firing system is based on the integration of four major principles:

1. Firing zone stoichiometry control
2. Pulverized coal fineness control
3. Initial combustion process control
4. Concentric firing

Laboratory testing has indicated that there is an optimum main firing zone stoichiometry for minimizing NO_x emissions.² However, achieving this level of stoichiometry can result in high levels of CO and UBC. The TFS 2000™R system (Figure 3) controls the process of NO_x formation and destruction in distinct regions of the furnace by “staging” the introduction of air through flame attachment coal nozzle tips and multiple levels of separated overfire air (SOFA) and close-coupled overfire air (CCOFA). The TFS 2000™R system thereby optimizes the entire stoichiometry history of the coal particles, to minimize NO_x emissions.

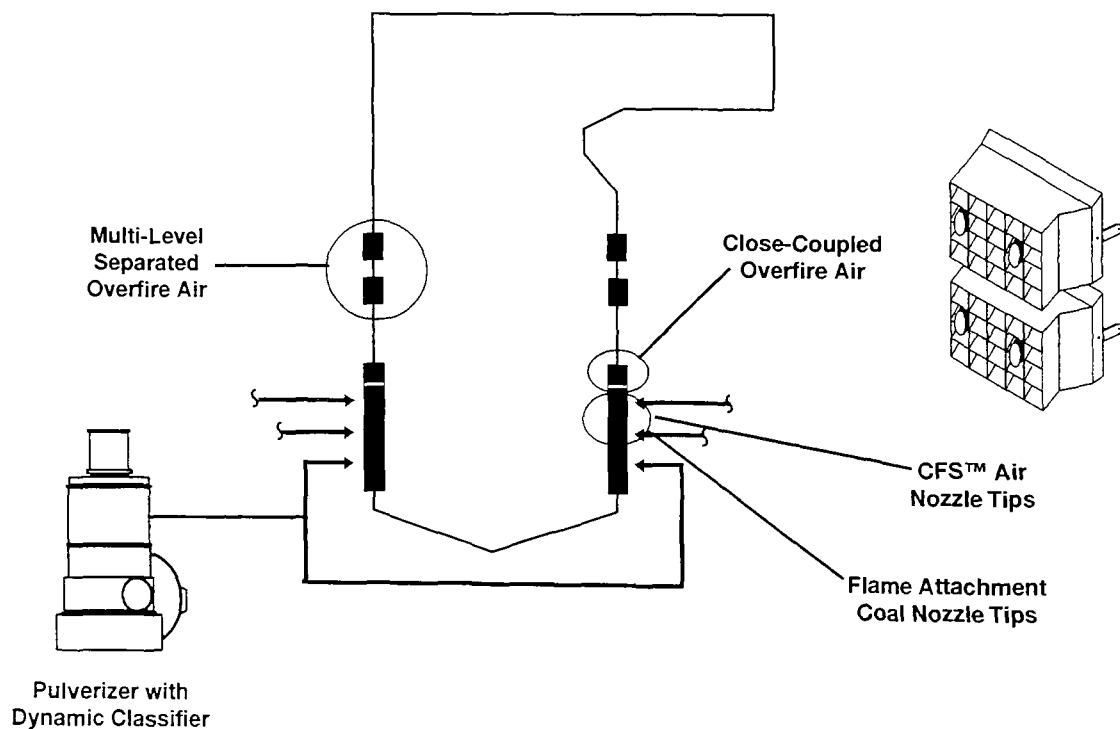


Figure 3: Schematic Diagram of a TFS 2000R Firing System

Pulverized coal fineness is controlled by use of a Dynamic™ classifier. The rotating classifier vanes more effectively prevent larger coal particles from exiting the pulverizer, and this helps decrease the UBC levels in the flyash. Finer coal particles can also enhance fuel-bound nitrogen conversion and its subsequent reduction to molecular nitrogen under staged firing conditions by allowing rapid ignition near the coal nozzle tip.

Flame attachment coal nozzle tips are incorporated in the TFS 2000™R system design to provide early fuel devolatilization within an oxygen-deficient zone. With conventional firing systems, coal is devolatilized in an oxygen-rich environment, and the fuel nitrogen released can readily react with the available oxygen to form nitrogen oxide compounds. With the flame attachment coal nozzle tip, rapid coal devolatilization is accomplished by establishing a flame front near the exit of the tip. The coal nozzle tip design is based on existing flame characteristics, coal constituents, and fuel line transport conditions. Besides the NO_x emissions control benefits, establishing coal ignition early in the combustion process improves flame stability and minimizes increases in unburned coal levels.

ABB's patented CFS™ concentric firing system air nozzle tips direct some of the secondary air in the main firing zone away from the fuel streams. Offsetting the air decreases the local firing zone stoichiometry during the initial combustion stages.

Concentric firing also creates an oxidizing environment near the furnace waterwalls in and above the main firing zone. This reduces ash deposition quantity and tenacity. Increased oxygen levels along the waterwalls also decreases the potential for corrosion, especially with coals having high concentrations of sulfur, iron, or alkali metals.

The specific equipment components selected to achieve these elements of combustion will vary for different retrofit installations, depending on the design and maintenance condition of the installed equipment, and on the constructability constraints at the site.

TFS 2000™R System Implementation

The retrofit equipment described below for the field demonstration of TFS 2000™R technology at BHS Unit 3 was installed in the Fall of 1993. The installation coincided with a scheduled maintenance outage for the turbine-generator. The outage duration was 8.5 weeks.

Windboxes

Because the existing main windboxes at BHS Unit 3 were in a deteriorated condition and the planned outage duration was short, the main windboxes were completely replaced with new, pre-assembled units. Each new main windbox (Figure 4) contains one bottom air compartment, four elevations of air/oil compartments with CFS™ air nozzle tips above and below the oil gun tips, two elevations of CCOFA compartments, and five elevations of coal compartments with flame attachment coal nozzle tips. New

tilt mechanisms were provided at the compartments, re-using existing tilt drives. Secondary air flow to the windbox air registers is controlled by means of louver dampers equipped with self-lubricating damper bearing assemblies.

With ABB's flame attachment coal nozzle tips, the ignition point of the coal occurs closer to the nozzle tip than it does for conventional coal nozzle tips. The rapid fuel ignition produces a stable volatile matter flame and minimizes NOx production in the fuel-rich stream.

The CFS™ air nozzle tips supplied at BHS Unit 3 are equipped with manually-adjustable horizontal yaw mechanisms. The yaw adjustment is set so that a portion of the secondary air is directed away from the fuel streams toward an imaginary circle that is concentric with the main firing circle. The yaw angle is set during commissioning and is not changed during normal operation of the boiler.

The CCOFA elevation air registers direct a portion of the secondary air into the furnace at the top of the main windboxes. Each CCOFA compartment is equipped with ABB's patented horizontal yaw adjustment mechanism. The manual yaw adjustment enables each CCOFA air jet to be independently directed for effective mixing.

Two new SOFA registers were added above each of the new main windboxes. Each SOFA register contains three air compartments with adjustable horizontal yaw and vertical tilt mechanisms (Figure 5). During commissioning, the yaw angle is set to minimize carbon monoxide and UBC emissions. This is a manual adjustment that is not intended to be varied during operation.

To measure the SOFA air flow, an annular venturi (Figure 6) was installed in each SOFA air supply duct. ABB's patented annular venturi design requires only about two-thirds the length of a standard venturi and measures air flow with an accuracy of ± 5 percent. It has a signal-to-noise ratio of approximately 10. Annular venturi are not required components for a TFS 2000™R system retrofit.

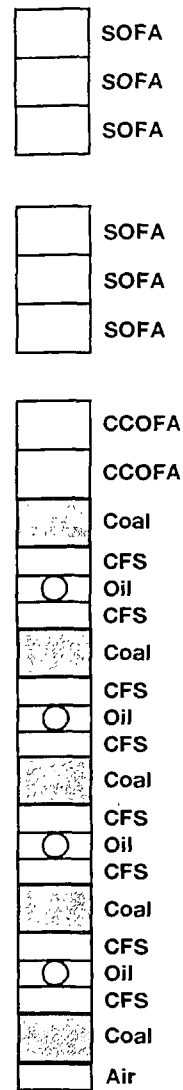


Figure 4: Schematic Diagram of TFS 2000R Windboxes at BHS Unit 3

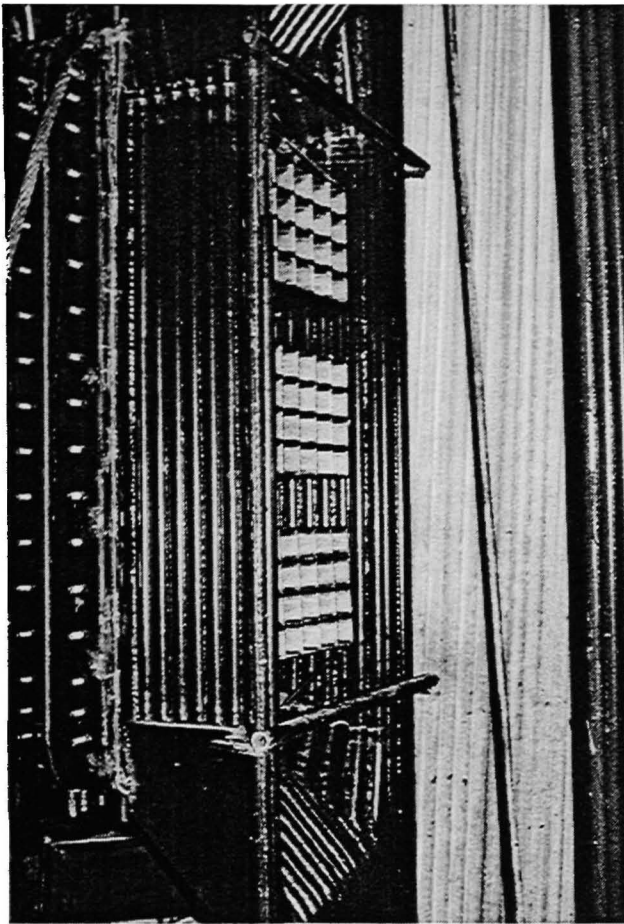


Figure 5: New SOFA Register During Installation

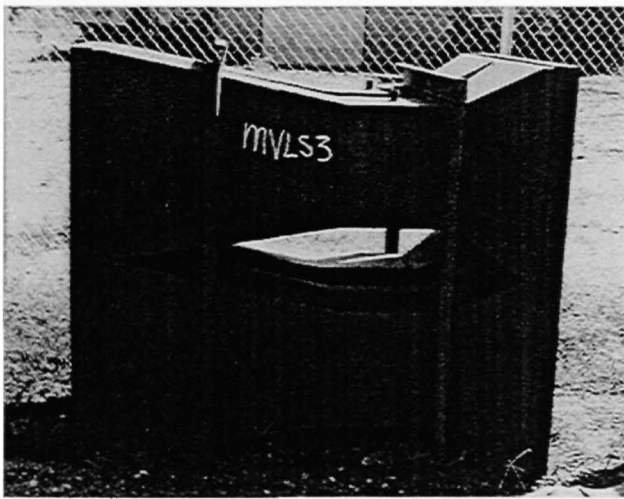


Figure 6: Annular Venturi for SOFA Ductwork in Laydown Area

Pulverizer Modifications

Pulverizer modifications to implement TFS 2000™R technology are also site-specific, and depend greatly on the condition of the existing pulverizers, as well as the coal to be fired after the retrofit. BHS Unit 3's five pulverizers were well-maintained and in good operating condition prior to the retrofit. The pulverizers were upgraded to permit operation at higher fineness levels without coal flow de-rating. The existing "spider" fan wheels were replaced by new high efficiency fans (HEF) utilizing the existing exhauster casings. In addition, the existing 600-Hp pulverizer motors were replaced with new 700-Hp motors. Figure 7 shows one of the new HEF wheels.

In each pulverizer, a new Dynamic™ classifier replaced the existing static classifier. The Dynamic™ classifier has a vaned rotor that is supported by two bearings. It is driven by a 40-Hp motor, and the speed of rotation is controlled through an ac variable-speed controller. Figure 8 is a photograph of one of the pulverizers during the installation of the Dynamic™ classifier. The Dynamic™ classifier effectively eliminates large coal particles (+50-mesh or +70-mesh) and minimizes the fraction of +100-mesh coal particles. It allows extensive operational flexibility, and can be used to compensate for the effects of pulverizer wear, load changes, and changes in coal type or grindability.

Additional Work

Pressure part replacements requiring four main windbox tube panels and four SOFA tube panels accompanied the new windboxes and SOFA registers. Additional pressure part modifications were made at BHS Unit 3 to eliminate interferences with the SOFA register installation.

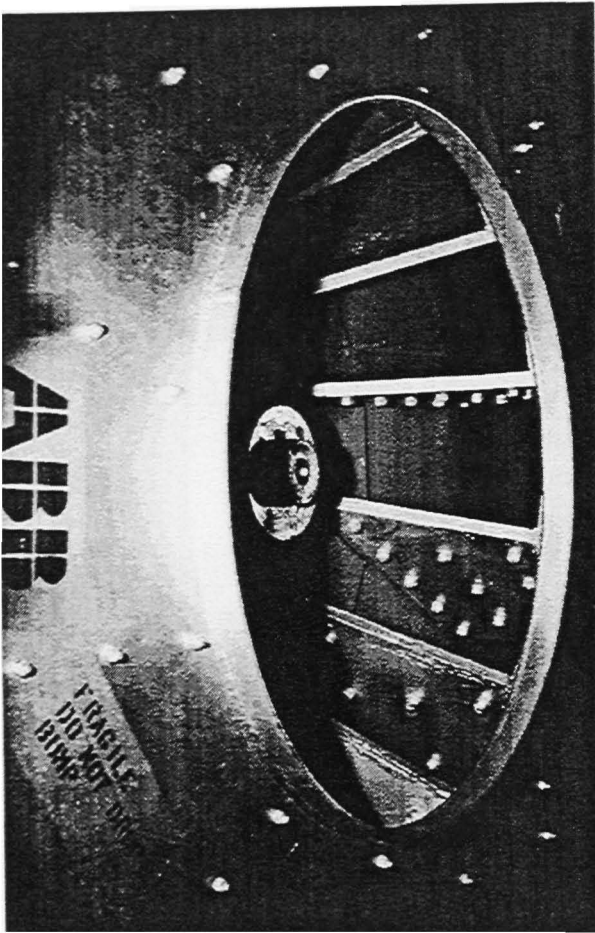


Figure 7: New HEF Wheel in the Existing Exhauster Casing

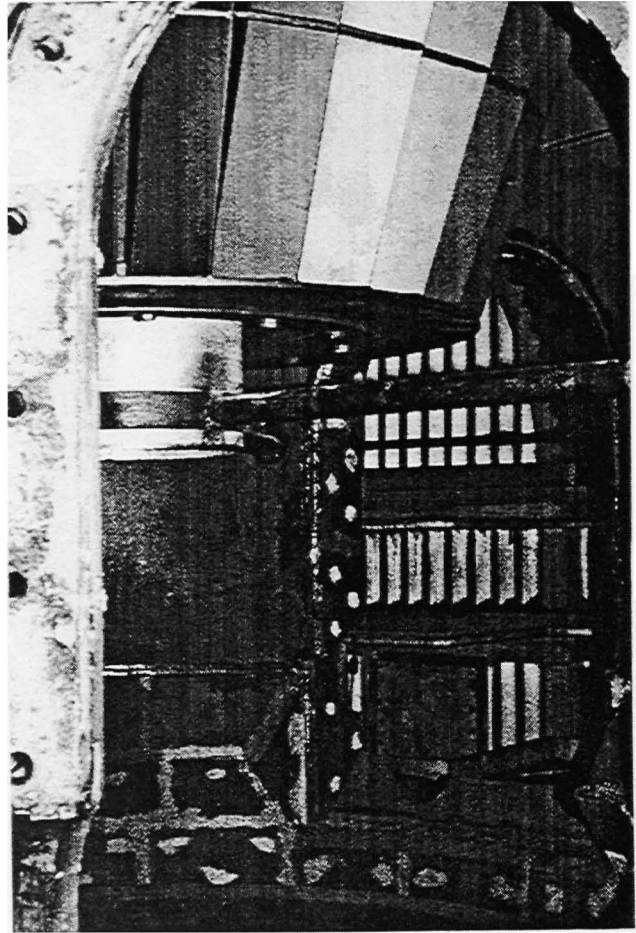


Figure 8: New Dynamic™ Classifier During Installation

As part of the research and development project, 39 waterwall chordal thermocouples and 135 convective section thermocouples were installed to provide accurate and convenient measurements of the boiler's thermal performance under load. In addition, six waterwall test panels were installed to investigate industry concerns regarding long-term waterwall tube wastage under substoichiometric firing conditions. These panels were fabricated of new waterwall tubing and were subjected to ultrasonic thickness measurement prior to installation. Tubing thickness will be regularly monitored during future maintenance outages. Figure 9 shows the approximate locations of this test equipment.

Control system inputs/outputs and logic were added for operation of SOFA dampers and Dynamic™ classifiers, and to expand the operational flexibility of all windbox dampers. In addition, UI elected to perform additional back pass modifications, to upgrade the DCS control system and to add continuous stack emissions monitors and stack elevator during the outage. These modifications were not required for the new firing system.

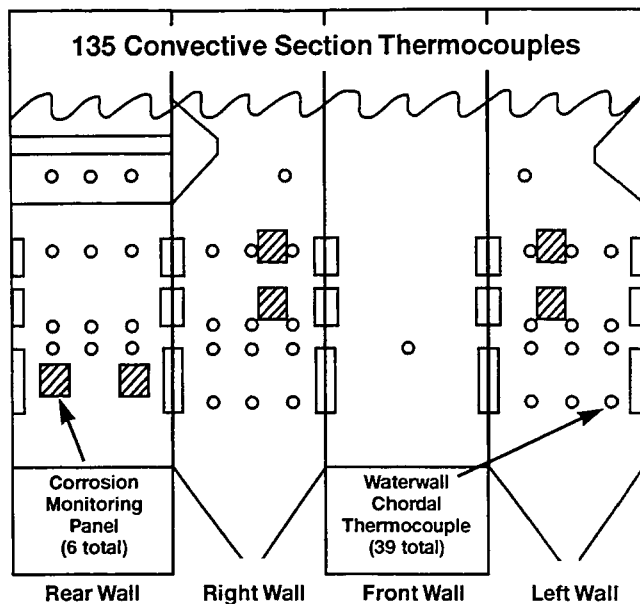


Figure 9: Locations of Test Thermocouples and Test Panels

TFS 2000™R System Performance Evaluation

Pre-retrofit and post-retrofit field trials were conducted to evaluate the impact of the new design on the boiler emissions and thermal performance. The focus of the field trials was to quantify the impact of the new firing system over the full operating range of the boiler.

Boiler Emissions Performance

The boiler emissions performance was characterized through a series of parametric tests during which certain operational parameters were varied in a systematic fashion for several scenarios of boiler load, staged firing, and secondary air biasing.

NO_x Emissions

Except where noted, all NO_x measurements in this paper were determined via EPA Method 7E, using a chemiluminescent NO_x analyzer, and are reported in units of lb NO_x/10⁶ Btu. Figure 10 shows the relationship of the measured NO_x emissions from BHS Unit 3 to the calculated stoichiometry at the top coal elevation for both the pre-retrofit and post-retrofit configurations of the boiler. All measurements were taken at MCR. The characteristic decrease in NO_x emissions with decreasing stoichiometry is evident. Pre-retrofit NO_x testing with the use of CCOFA showed NO_x levels in the range of 0.46 - 0.58 lb NO_x/10⁶ Btu.

Sixty-six post-retrofit tests were conducted while varying the coal fineness and the degree of staging and mixing, along with a number of operating variables such as excess air. Post-retrofit NO_x emissions as low as 0.20 lb NO_x/10⁶ Btu were achieved with no increase in the UBC in the flyash.

The two data points labeled "Potential Minimum NO_x" (0.18 and 0.16 lb NO_x/10⁶ Btu) represent short-term (approximately 3 hours) test results. These results were achieved with carbon monoxide emissions less than 200 ppm and only a two-percentage point increase in UBC emissions over the pre-retrofit level. *It is significant that the potential minimum NO_x results were achieved at a higher stoichiometry than many of the higher post-retrofit testing results, demonstrating that stoichiometry is not the only variable affecting NO_x emissions.*

The post-retrofit test NO_x emissions as a function of boiler load are shown in Figure 11. The secondary air dampers and tilts were controlled to operate the boiler with NO_x

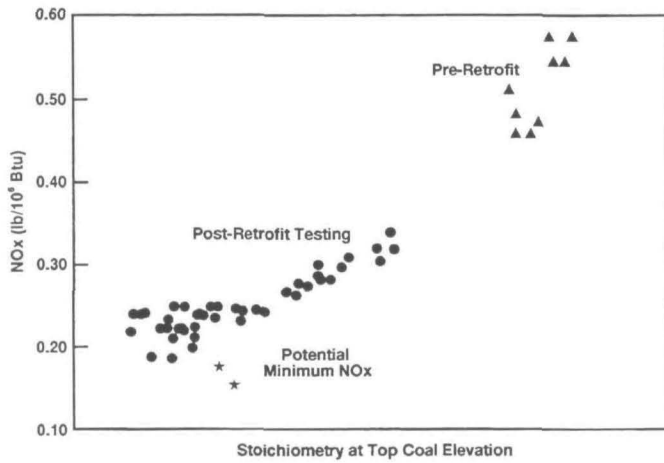


Figure 10: NOx Emissions vs. Stoichiometry at MCR

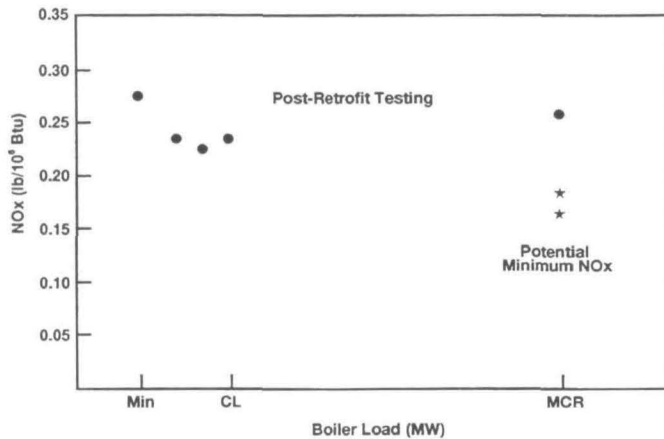


Figure 11: NOx Emissions vs. Boiler Load

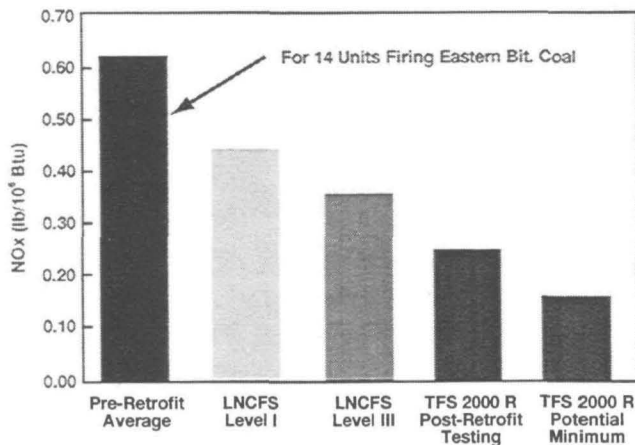


Figure 12: Comparison of ABB Retrofit Results for NOx Emissions

emissions on the order of 0.25 lb NOx/10⁶ Btu from MCR through control load (CL), to minimum load, with no increase in UBC in the flyash. Although it is typically expected that NOx levels will increase dramatically at low boiler loads because of the required increase in excess air, at BHS Unit 3, the post-retrofit NOx emission at minimum load can be controlled to less than 0.30 lb/10⁶ Btu.

Figure 12 compares the BHS Unit 3 post-retrofit testing for NOx emissions to other low NOx retrofit results for similar coals in tangentially-fired boilers. The pre-retrofit average NOx emissions of 0.62 lb/10⁶ Btu for 14 other units firing Eastern bituminous coals is shown in the first (left) bar. ABB C-E Services' LNCFS™ firing systems were applied in these units.⁴ As shown in Figure 12, LNCFS™ system field results reached a lower limit for NOx emissions at an average of 0.36 lb/10⁶ Btu. The BHS Unit 3 field demonstration test results for NOx emissions are significantly lower.

Limited testing was performed to evaluate firing system performance using No. 6 fuel oil, currently used as an emergency backup fuel to coal at BHS Unit 3. These brief tests, under non-optimized conditions, indicated that NOx levels on the order of 0.12 lb/10⁶ Btu to 0.15 lb/10⁶ Btu can be obtained from control load through 365 MW, with opacity in the range of 2-7 percent.

Carbon Monoxide Emissions

All carbon monoxide (CO) measurements reported in this paper are given in units of parts per million

(ppm) of gas and are corrected to 3% oxygen in the flue gas. The test protocols used are in accordance with EPA Method 10. Pre-retrofit CO emissions were less than 50 ppm. During the post-retrofit testing the SOFA yaw angles were varied to demonstrate the variation of CO emissions with NO_x. During the tests documented in Figure 10, at full load, CO levels of 44 ppm were obtained at NO_x emissions of 0.34 lb/10⁶ Btu; CO emissions of 22 ppm occurred with NO_x emissions of 0.24 lb/10⁶ Btu; and CO emissions of 178 ppm were found with NO_x emissions of 0.16 lb/10⁶ Btu.

Opacity

Opacity measurements were taken with the plant instrumentation. At BHS Unit 3, the regulated opacity limit is 20%. The pre-retrofit opacity averaged less than 10%. During the post-retrofit testing, the opacity remained less than 10% for most tests, and below the regulated limit under all test conditions. Isokinetic sampling of the flue gas entering the unit's electrostatic precipitator (ESP) confirmed that there was no significant change in the flyash (dust) loading entering the ESP. No significant change in the mass ratio of flyash-to-bottom ash was observed.

ESP collection efficiency prior to TFS 2000™ retrofit was 99.3 percent. During the outage for the TFS 2000™ retrofit, routine maintenance was performed on the ESP. Measured post-retrofit ESP efficiency is on the order of 99.2-99.5 percent.

Boiler Operational Performance

During post-retrofit testing on the BHS Unit 3 boiler, multiple aspects of boiler operation were investigated to ensure that there were no adverse impacts on boiler operation related to the changes in the firing system.

Ash and Slag Deposition Patterns

A long-term change in the ash and slag deposition during operation was noted. Post-retrofit ash deposition has increased in the superheater sections closest to the furnace outlet, the superheater division panels and superheater platen assemblies (Figure 2). These ash deposits are friable and easily removed. No other significant changes in ash accumulation have been observed in the convective sections of the boiler. Slagging has decreased on about one-third of the furnace wall, in the areas near the CFS™ air elevations. Although the ash and slag deposition patterns have changed, they are controllable with the existing sootblowers and wall blowers on the boiler.

The boiler had no history of waterwall corrosion before the retrofit. After approximately 14 months of post-retrofit operation, no evidence of accelerated waterwall wastage has been observed.

Coal Fineness

Calibration runs for the Dynamic™ classifier with the "B" pulverizer established the relationships among coal feed rate, fineness, and classifier rotation speed. Generally, a

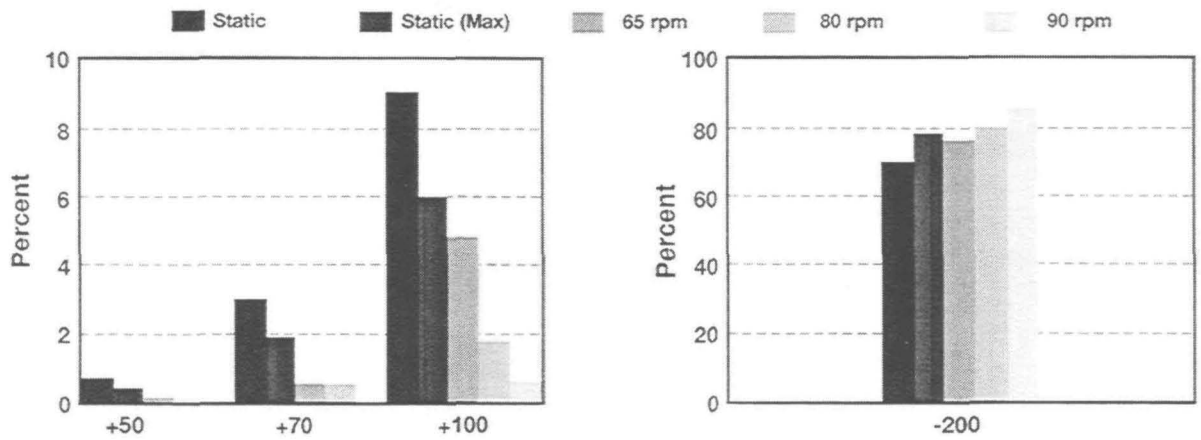


Figure 13: Comparison of Static and Dynamic Classifier Fineness Results

higher classifier rpm produces greater fineness, and rpm can be decreased as coal feed rates are decreased. At all coal feed rates, the coal fineness achievable with the Dynamic™ classifier is finer than with the static classifier, particularly in terms of decreasing or eliminating the largest +50 and +70-mesh particles. Coal particles in these size ranges have significant impact on UBC. Figure 13 compares the performance of the static classifier and the Dynamic™ classifier at BHS Unit 3 with five pulverizers, each in service at 55,000 lb coal/h.

Pulverizer performance has met expectations, with the exception of a “rumble” condition that occurred during testing at high classifier rotation speeds. High fineness “rumble” can occur with either dynamic or static classifiers on a high-fineness setting. High fineness “rumble” is an instability, leading to vibrations, that is caused by an increase in recirculation of fine particles. At BHS Unit 3, the Dynamic™ classifier rotational speed is currently limited to avoid high fineness “rumble”. A study is in progress at the ABB Power Plant Laboratories Pulverizer Development Facility in Windsor, Conn., to develop a methodology for predicting/preventing the onset of high fineness “rumble”.⁵

Furnace Oxygen Imbalance

The oxygen concentration in the flue gas was measured at the economizer outlet in accordance with EPA Method 3A. Post-retrofit left/right oxygen imbalance is less than or equal to the pre-retrofit performance.

Boiler Thermal Performance

Boiler Efficiency

The installation of the TFS 2000™R firing system did not affect the boiler thermal efficiency (ASME Performance Test Code 4.1). Pre-retrofit and post-retrofit boiler

efficiencies were calculated at MCR and at control load, and the efficiency remained at 91.4 - 91.7 percent, regardless of the NO_x emissions level.

Steam Temperature/Flow Control

All post-retrofit operation of the boiler confirms that the superheater and reheater design outlet steam temperatures can be maintained at loads from MCR through control load. In addition, the superheater and reheater design pressures and mass flow rates are maintained at all loads from MCR through control load.

Steam temperature control is accomplished through the use of the adjustable tilts and the interstage desuperheaters. The windbox tilts continue to operate within their normal range.

At both the maximum and potential minimum NO_x emissions levels, the post-retrofit reheater desuperheater spray water flows were about the same as the pre-retrofit levels. Thus, the implementation of TFS 2000TMR technology does not adversely impact the unit's heat rate.

Element Steam Temperature Imbalance

Eight pre-retrofit tests and two post-retrofit tests were analyzed. Two of the pre-retrofit tests were for normal operation, three were for operation with the top secondary air dampers closed, and three were for operation with three tilt positions. One post-retrofit test was conducted with maximum SOFA and acceptable boiler operation, and the other was at the minimum NO_x emission. The (low temperature) superheater rear pendant outlet steam temperatures, (high temperature) superheater finishing pendant outlet temperatures, and the high temperature reheater outlet temperatures were measured and analyzed. As compared to the initial operation of the unit, firing oil, in 1968, there was no significant difference in the element steam temperature profiles caused by the TFS 2000TMR system.

Maximum Local Heat Absorption Rates

The peak waterwall heat absorption rates calculated from readings with the chordal thermocouples installed in the furnace walls were well below the design values and confirm that the post-retrofit departure from nucleate boiling (DNB) margin for the boiler remains within ABB C-E design standards.

Vertical Heat Absorption Profile

The vertical heat absorption profile, as measured through the chordal waterwall thermocouples is similar under all post-retrofit operating conditions. There is a slight shift in the furnace vertical heat absorption profile towards the upper furnace under potential minimum NO_x conditions. This shift did not adversely affect boiler waterwall circulation.

UBC as a Function of NOx Emissions

Significant increases in UBC levels in the flyash have been documented for boilers retrofitted with earlier low NOx firing systems.⁴ Pre-retrofit UBC levels at BHS Unit 3 were in the range of 5.8 - 8.0 percent carbon. For a tangentially-fired boiler with an Eastern bituminous coal, this range is about average.

Except where noted, the flyash samples for both the pre-retrofit and post-retrofit UBC results were obtained in accordance with EPA Method 17. Carbon content was determined directly, not by loss of ignition (LOI).

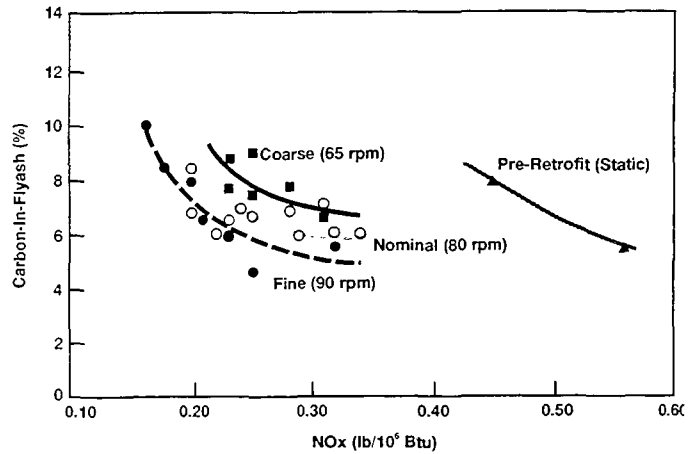


Figure 14: UBC in Flyash vs. NOx Emissions at MCR

UBC levels for post-retrofit operation at BHS Unit 3 with three different fineness levels are given in Figure 14.

For this comparison, boiler load was held constant at MCR. The trend of increasing UBC with decreasing NOx emissions is evident for the three post-retrofit data sets. The trends also illustrate that UBC control is dependent upon the particle size of the coal. NOx emissions as low as $0.20 \text{ lb}/10^6 \text{ Btu}$ were obtained with no increase above pre-retrofit levels of UBC in the flyash.

Commercial Operating Experience

The unit has been operating commercially, post-retrofit, firing coal for over 14 months. The unit operates under load dispatch at MCR on weekdays from about 8:00 am to 11:00 pm. At night and on weekends, the unit load is decreased to as low as 140 MW. Operators report no significant operational problems, and no indication of accelerated waterwall wastage or corrosion has been observed.

Daily Average Value for Megawatts, NOx, and UBC

Figure 15 is a plot of the megawatt load and NOx emissions during the period from January 3, 1995 to February 27, 1995. The values given for NOx emissions in $\text{lb}/10^6 \text{ Btu}$ are as measured on the Continuous Emissions Monitor (CEM) at the stack. The CEM is RATA certified. NOx emissions during this period of normal operation averaged $0.23 \text{ lb}/10^6 \text{ Btu}$.

During the pre-retrofit period from January 2, 1993 to September 25, 1993, a survey of weekly ash truck samples (combining flyash and bottom ash) showed an average of 7.6 percent carbon in the ash. For the post-retrofit period from January 2, 1994 to February

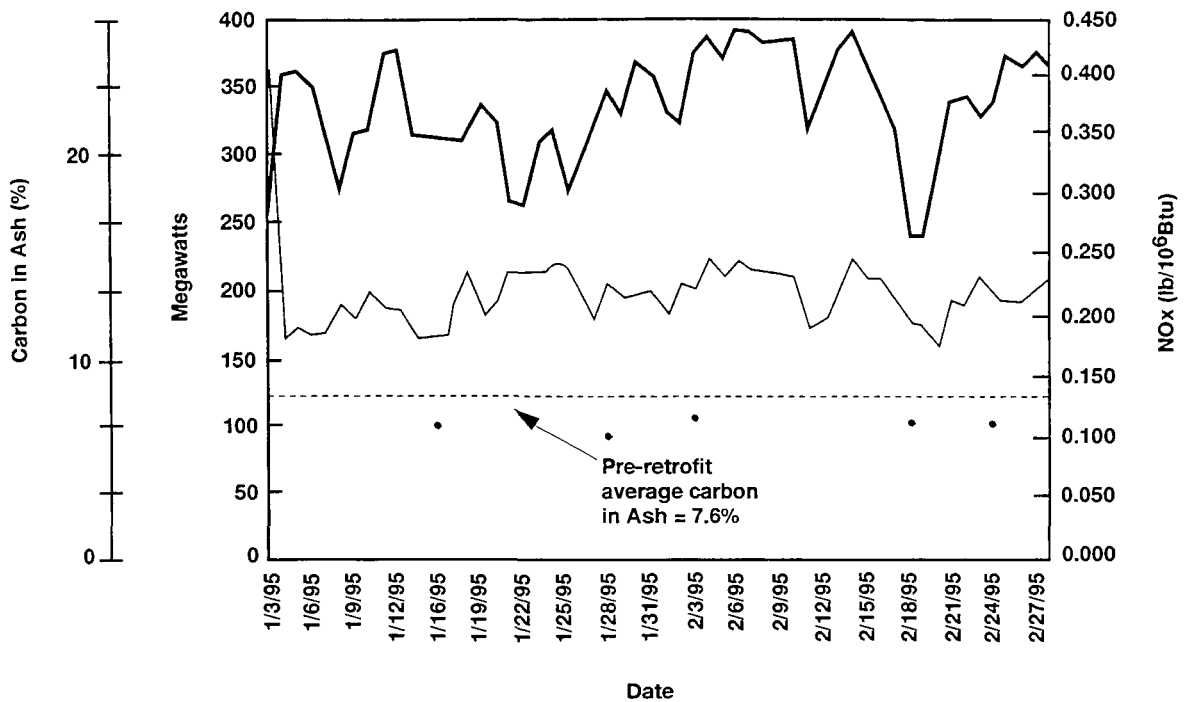


Figure 15: BHS Unit 3 NOx Emissions vs Megawatt Load and Unburned Carbon

25, 1995, the weekly survey of the ash truck samples averaged 5.8 percent. Figure 15 also shows the weekly ash truck sample carbon content.

Unit Availability and Heat Rate

Table 2 shows the five leading causes per year for lost generation at BHS Unit 3 from 1990 through 1994. Comparisons of the equivalent forced outage rates, which take into account any capacity reduction as well as shutdown, show that the unit's overall post-retrofit availability is consistent with its historical performance. Post-retrofit availability losses caused by economizer leaks and coal pulverizers are higher than the historical levels. The economizer leaks were definitely not related to the TFS 2000™R installation, and problems have been corrected. The increased availability loss caused by the coal pulverizers is attributable to problems with the initial design of the seals for the Dynamic™ classifiers, which have since been corrected. No ongoing loss of availability attributable to the Dynamic™ classifiers is expected.

Figure 16 shows the year-to-date effective availability factor (EAF), calculated both including overhauls and excluding overhauls, for the years 1990 through 1994, and for January through February of 1995. For 1993, the year-to-date figure is taken from the pre-retrofit period of January through September. For 1994, the year-to-date figure is entirely post-retrofit experience. The data in Figure 16 confirm that the post-retrofit availability is consistent with the pre-retrofit experience.

	1994	1993	1992	1991	1990
Annual Overhaul	4.4	16.5	4.4	6.2	4.8
Superheater Leak					1.4
Reheater Tube Leak	1.9			1.8	1.2
Economizer Tube Leak	2.6				
Precipitator Repair					1.2
Waterwall Leak	1.5	3.8	5.5	1.6	0.7
Coal Mill	1.5				
Main Boiler Feed Pump (MBFP)			1.5		
Casing Leak				1.5	
Condenser Cleaning		0.9			
Boiler Circulating Pumps				1.5	
Lube Oil System			1.9		
Boiler Circ. PP			1.0		
Boiler Water Chemistry		1.6			
Turbine Vibration		1.6			
Total of 5 Causes	11.9%	24.4%	14.3%	12.6%	9.3%
Total Lost for Year	17.8%	27.8%	17.9%	15.6%	11.4%
Equivalent Forced Outage Rate (EFOR)	13.4%	11.3%	13.5%	9.4%	6.8%

Table 2: BHS Unit 3 – Five Leading Causes Per Year of Lost Generation (Retrofit Work Done October – November, 1993)

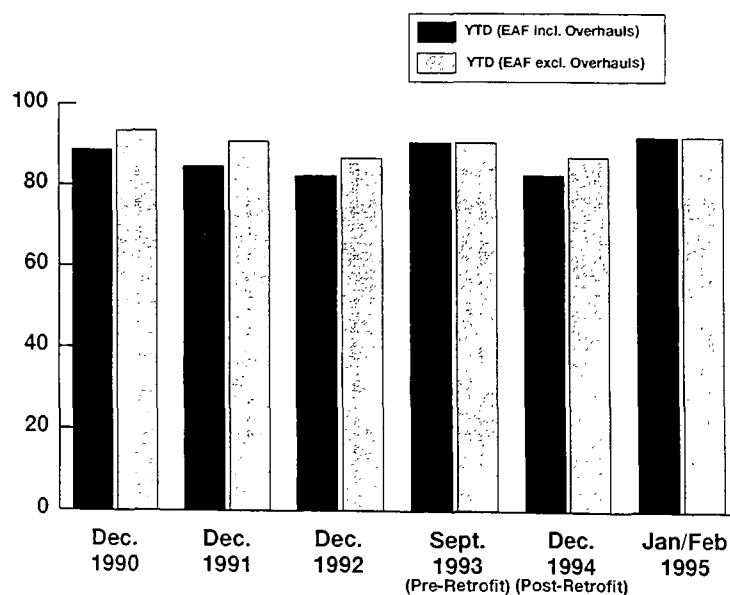


Figure 16: BHS Unit 3 Equivalent Availability Factor Including and Excluding Overhauls (Post-retrofit start-up was December, 1993)

It is also apparent that the heat rate for BHS Unit 3 has not deteriorated as a result of the TFS 2000™R retrofit. Figure 17 is a graph of the year-to-date heat rate in Btu/kW-h for the unit from December of 1987 through December of 1994. The heat rate post-retrofit (1994) is well within the historical trend of heat rate for the unit.

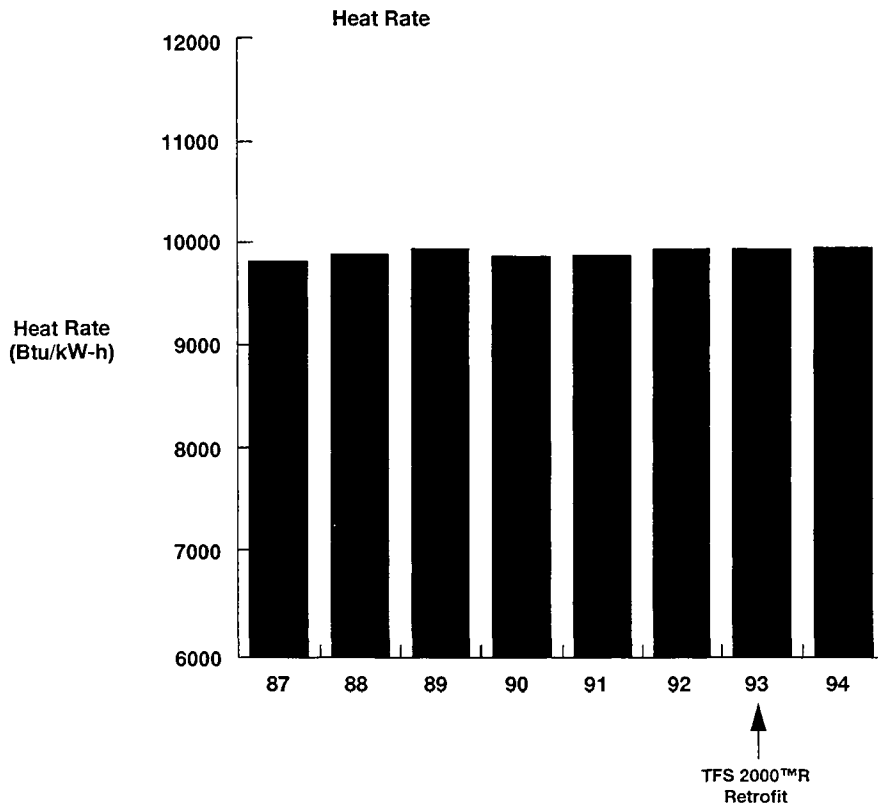


Figure 17: BHS Unit 3 Heat Rate Performance History

Equipment Operational Experience and Inspection

During a scheduled maintenance outage inspection conducted in the fall of 1994, the new firing system condition was assessed as excellent. Tilts were stroked with no evidence of binding or erratic operation. Eight of twenty coal nozzle tips had slight warpage in splitter plates that was not affecting performance, and repair was not required. One oil nozzle tip bluff body diffuser was slightly cracked, and repair was not required. SOFA-related components were in "as new" condition. The ignitor system was also in "as new" condition.

Detailed visual inspections were made of the economizer, steam drum, lower waterwall drums, waterwalls, bottom ash hopper, superheater steam cooled roof and wall headers, backpass steam cooled outlet headers, low temperature superheater, superheater division wall panels and pendant platen assemblies, and reheater

assemblies, and all were found to be in a condition typical of pre-retrofit experience. Service recommendations in the outage report were consistent with pre-retrofit experience on this unit.

A visual inspection of the Dynamic™ classifier during the 1994 fall outage showed no visible wear on the rotor assembly. An exhauster inspection indicated no required maintenance after nine months (approximately 8500 hours) of service.

Conclusions

United Illuminating and ABB C-E Services consider the retrofit of Bridgeport Harbor Station's Unit 3 to be a commercially and technically successful full-scale demonstration of TFS 2000™R technology. The boiler thermal performance and efficiency are unchanged from the pre-retrofit conditions. Although the slagging/fouling patterns have changed slightly from pre-retrofit, the existing sootblowers and wall blowers are capable of controlling them.

During testing, the boiler consistently demonstrated NOx emissions on the order of 0.25 lb/10⁶ Btu over the entire load range, with no increase in unburned carbon in the flyash. The lowest NOx emissions measured for this boiler during post-retrofit parametric testing is 0.16 lb/10⁶ Btu. The potential for long-term operation of the boiler at this level has not been thoroughly investigated. In over 14 months of commercial operation, operation of the boiler with the TFS 2000™R technology has caused no significant adverse impact on boiler operation or availability.

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