Demonstration of Coal Reburning for Cyclone Boiler NO_x Control

APPENDIX Book 1

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APPENDIX NO. 1

Small Boiler Simulator Description

Appendix A

SMALL BOILER SIMULATOR (SBS)

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Based on the industry need for a pilot-scale cyclone boiler simulator, Babcock & Wilcox (B&W) designed, fabricated, and installed such a facility at its Alliance Research Center (ARC) in 1985. The project involved conversion of an existing pulverized coal-fired facility to be cyclone-firing capable. Additionally, convective section tube banks were installed in the upper furnace in order to simulate a typical boiler convection pass. The small boiler simulator (SBS) is designed to simulate most fireside aspects of full-size utility boilers such as combustion and flue gas emissions characteristics, fireside deposition, etc.

Simulation Criteria

Prior to the design of the pilot-scale cyclone boiler simulator, the various cyclone boiler types were reviewed in order to identify the inherent cyclone boiler design characteristics which are applicable to the majority of these boilers. The cyclone boiler characteristics that were reviewed include NO_x emissions, furnace exit gas temperature (FEGT), carbon loss, and total furnace residence time. Previous pilot-scale cyclone-fired furnace experience identified the following concerns:

- Operability of a small cyclone furnace (e.g., continuous slag tapping capability).
- The optimum cyclone(s) configuration for the pilot-scale unit was debated. Commercial cyclone boiler systems can include front-wall fired, opposed-wall fired, and single or multiple cyclone elevations. In addition, there are different cyclone burner and cyclone furnace designs presently in operation.
- Compatibility of NO_x levels, carbon burnout, cyclone ash carryover to the convection pass, cyclone temperature, furnace residence time, and FEGT. Due to the various sizes/types/fuels burned, commercial cyclone units operate within a large range of combustion and pollutant conditions.

Originally, an opposed-wall fired, cyclone design was proposed, based on the large number of cyclone utility boilers falling into this design category. Using this as the design basis for the pilot-scale unit would involve having two 3-million Btu/hr cyclones. A review of past experience revealed that the smallest cyclone ever designed/operated was 10-million Btu/hr. Based on this and coupled with concerns about fabrication and slag tap operation (due to size), it was decided to proceed with designing a single 6-million Btu/hr cyclone to accommodate the SBS facility.

Pilot-Scale Furnace Design Criteria

The design of the pilot-scale cyclone-fired furnace offers many challenges to the designer. A design criteria is required in order to obtain experimental results that can be directly scaled-up to commercial cyclone boilers. Pertinent parameters were identified and incorporated in the pilot furnace design. These parameters are as follows:

- Cyclone exit conditions: coal burn-out, gaseous species concentrations, and flue gas temperatures.

- Flue gas time/temperature history within the furnace/convective surface regions.

Cyclone Exit Conditions. One concern of designing a 6-million Btu/hr size cyclone is that a high amount of combustion heat is transferred through the cyclone barrel water-cooled walls. Thus, the cyclone exit temperature and slag tapping capability of the cyclone could be affected. To ensure slag tapping capabilities, one approach is to overheat the combustion air to compensate for the extra heat loss. In addition, coal particle size can be reduced from the typical utility cyclone size coal (crushed) in order to intensify the combustion process. An additional concern is to simulate the cyclone collection efficiency, or percent of the fuel burned in the molten slag layer versus in-suspension. This is a function of cyclone design parameters such as cyclone barrel diameter, air velocities, and coal particle size. Therefore, the following design parameters had to be considered simultaneously to satisfy the above-stated potential operational problems:

- Cyclone design parameters

  - Combustion air velocities
  - Surface-to-volume ratio

- Average cyclone gas residence time

- Available cyclone heat per unit cooling area

- Combustion air temperature

- Coal particle size

The cyclone furnace was then designed by geometrically scaling down a single-wall-fired utility cyclone unit to 6-million Btu/hr. Air velocities to the cyclone were considered the major parameter and, thus, they were scaled one-to-one with the commercial cyclone unit. Average coal particle size was reduced to approximately duplicate the commercial unit's centrifugal force and, consequently, the cyclone collection efficiencies. The reduced particle size also increased the combustion intensity. Finally, to simulate the available heat per unit surface area, the design temperature of the combustion air for the 6-million Btu/hr cyclone was higher than for normal utility cyclone operation.

Flue Gas Time/Temperature History. The various cyclone boiler design types were reviewed in order to predict furnace gas residence times. Based upon this review, a range of residence times was generated in order to bracket the general cyclone boiler population. Generally, the study showed that single-wall-fired cyclone units contain furnace residence times on the lower side of the general population range. Although this is true, the majority of single-wall fired units do have sufficient residence time available for the reburning technology. Thus, the SBS cyclone design criteria was to simulate the geometry of B&W's commercially operated, single-wall-fired cyclone boiler type. In addition, the SBS furnace was insulated in order to achieve a comparable flue gas time/temperature relationship to actual field operating experience.

Pilot-Scale Furnace Facility Description

B&W's 6-million Btu/hr small boiler simulator (Figure 1) was utilized to perform the pilot-scale cyclone reburning tests. The SBS is fired by a single, scaled-down version of B&W's cyclone furnace. Coarse pulverized coal (44% through 200 mesh), carried by primary air, enters tangentially into the burner. (Pulverized coal had to be utilized in the SBS instead of crushed coal in order to obtain complete combustion in this small cyclone.) Preheated combustion air at 700°F enters tangentially into the cyclone furnace. The larger coal particles are captured and burn in the molten slag layer formed within the cyclone furnace, while the finer particles burn in suspension. The mineral matter melts, exits the cyclone furnace from the tap at the cyclone throat, and is dropped into a water-filled slag tank. Only 15 - 20% of the ash leaves the cyclone with the flue gases and enters the main furnace.

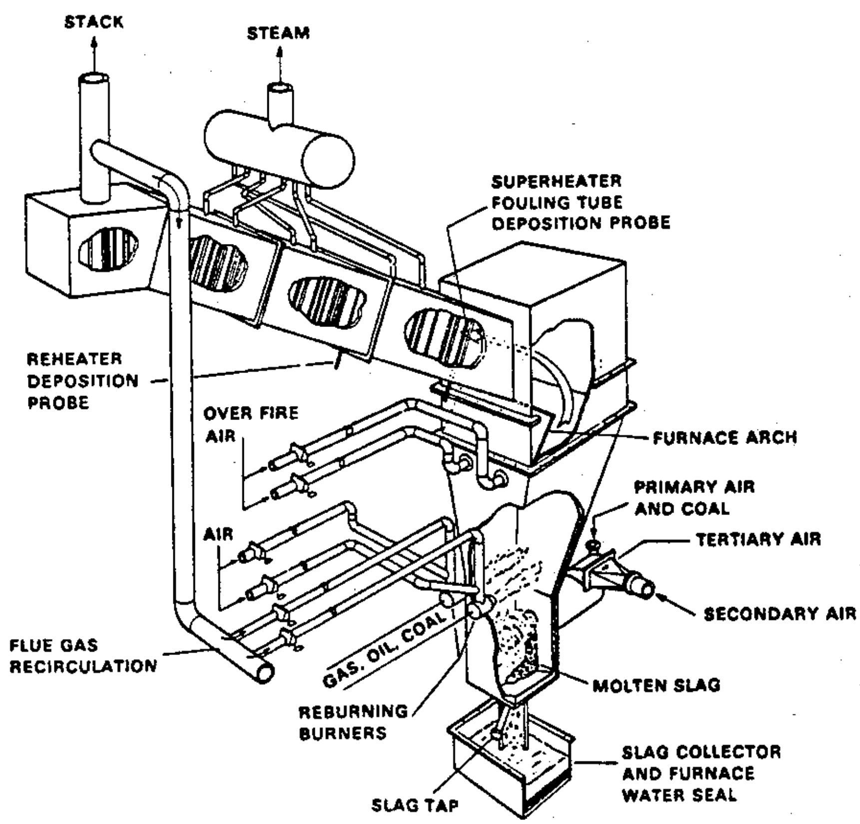

Figure 1 Small Boiler Simulator (SBS) Facility

The furnace is water-cooled and simulates the geometry of B&W's single-cyclone, front-wall fired cyclone boilers. It consists of four separate water-cooled sections. The SBS facility has been operating for a total of 8 years, with the last 6 years being operated in the cyclone configuration. This cyclone facility has been proven to simulate typical full-scale cyclone units via furnace/convective pass gas temperature profiles and residence times, NO_x levels, cyclone slagging potential, ash retention within the resulting slag, unburned carbon, and fly ash particle size. A summary of these comparisons is shown in Table 1.

Table 1

COMPARISON OF BASELINE CONDITIONS FOR SBS FACILITY AND COMMERCIAL UNITS

	SBS	Typical Cyclone-Fired Boilers
Cyclone Temperature	>3000°F	>3000°F
Residence Time	1.4 sec at full load	0.7 - 2 sec
Furnace Exit Gas Temperature	2265°F	2200° - 2350°F
NO_x Level	900 - 1200 ppm	600 - 1400 ppm
Ash Retention	80 - 85%	60 - 90%
Unburned Carbon	<1% in ash	1 - 20%
Ash Particle Size (MMD; Bahco)	6 - 8 microns	6 - 11 microns

The inside surface of the furnace is insulated to yield an FEGT of 2265°F at the design heat input rate of 6-million Btu/hr. A water-cooled tube bank simulates the flue gas time/temperature history inherent in full-scale cyclone convective passes. The tube bank consists of four separate sections for simulating a secondary superheater, reheater, primary superheater, and economizer. Each section consists of a water-cooled jacket and tubes to quench the flue gases. All four sections are connected to a common atmospheric drum. This use of convective tubes to cool the gas, in conjunction with the cyclone furnace, makes this a unique facility among pilot-scale combustors.

Two reburning burners were installed on the SBS furnace rear wall, above the cyclone burner/barrel. The facility is capable of firing natural gas, oil, or coal at the reburning burner region. The multi-fuel reburning burners were designed to accommodate the required velocities for furnace penetration and also to allow for enough flexibility for varying mixing characteristics. Each burner consists of essentially two zones: an outer zone housing a set of spin vanes and an inner zone contains the reburn fuel injector. Air and flue gas recirculation (FGR) flow can be introduced through the outer zone. Figure 2 is a photograph of the actual reburn burners location and associated air/gas recirculation/fuel piping.

OFA ports are available on both the front and rear walls of the SBS at three elevations, with each elevation containing two ports. Locating the OFA ports at different elevations assists in assessing the effects of residence time on fuel burnout and NO_x reduction. Rear OFA ports were used in this project to simulate a reburning system.

The SBS furnace and convective pass sections are equipped with numerous observation ports at different elevations to allow for complete evaluation of the process under investigation. Utilizing the viewports for in-furnace probing assists in determining temperatures and gas/solids composition.

Two air-cooled ash deposition probes are available in the convective section (simulating secondary superheater and reheater tubes) in order to allow for fouling (deposition) studies to be performed. These probes are equipped with thermocouples for measuring metal wall and inlet/outlet air temperatures. The probe metal temperature is maintained at a typical boiler tube temperature in order to assure meaningful ash deposition results. The effect of ash deposition on heat transfer is determined by energy balance calculations for each probe. In addition, a simulated commercial sootblower is available to determine the required sootblower pressure necessary to remove the deposits and restore maximum heat flux potential. In this project, only the superheater probe was used.

APPENDIX NO. 2

Statement of Work by Task and Subtask

1.0 Phase I: Design and Permitting

All activities which were part of design of the reburn system were included in Phase I. Research and development activities as well as engineering design were performed in Phase I.

1.1 Task 1 Project Management and Reporting

This task provided for overall project coordination, leadership, guidance, reporting, and supervision for Phase I of the Coal Reburning project. Additionally, this task included a single point contact within B&W for DOE on the Coal Reburning project for reporting and resolution of technical and cost issues. While B&W, EPRI, Wisconsin Power & Light, DOE, and the State of Illinois were all participating on the project, the responsibilities for the above issues rested with the B&W Project Manager. B&W was responsible for the overall management of the project and for coordination of the activities throughout all tasks with all project participants.

1.2 Task 2 Review of Reburning Technology and Pilot-Scale Cyclone Boiler

For the reburning technology, B&W reviewed recently available information in order to further evaluate the major process variables and their potential side effects. An evaluation of this data along with data from the pilot-scale tests further defined the feasibility of the application of reburning to cyclone boilers.

Pilot-scale tests were performed using B&W's six million Btu/hr capacity, cyclone-equipped Small Boiler Simulator. The objective of this subtask was to examine and predict the effectiveness of reburning for NO_x reduction and to assess the associated side effects (fireside corrosion, ash deposition on superheater tube bank, impact on ESP performance, FEGT, and unburned combustibles) while simulating WP&L's Nelson Dewey Unit No. 2 typical operating conditions. The results from these tests were compared with previous pilot-scale cyclone study results.

Pilot-scale baseline testing followed by reburning testing with selected coals was performed in the SBS. The specific objectives were as follows:

- Evaluate process performance with Lamar coal (demonstration host site coal) and a high sulfur Illinois coal
- Obtain data on NO_x reduction potential and predict process performance at full scale
- Study the effect of flue gas recirculation (FGR) added at the reburn burners on reburning technology

- Identify changes in unburned combustibles and particulate loading at the stack

- Assess the impact of the reburning technology on electrostatic precipitator (ESP) performance

- Evaluate the effect of the reburn technology on furnace exit gas temperature (FEGT)

- Identify changes in superheater tube bank heat flux

- Determine the effect of high sulfur/medium sulfur coal on fireside corrosion

The evaluation of this test work was primarily based on the comparison of this study with the previous cyclone reburning study (EPRI/GRI Pilot-Scale Testing Project described under previous work).

As part of the pilot study, the mathematical model for predicting flow and mixing for the SBS equipped with reburn was validated by comparing its results with actual test data. The model was then available for application to the full scale demonstration design.

1.3 Task 3 Physical Numerical Flow Modeling

Using information derived from Pilot Scale testing, B&W developed the preliminary design of a reburning system for the host site boiler at WP&L's Nelson Dewey Station. This design included equipment locations, fuel/air flow rates, and operating stoichiometries, and was used as initial configurations for the physical flow and numerical flow models.

Physical Flow Modeling

Physical flow model studies were performed at the Alliance Research Center (ARC) to characterize the expected mixing between the combustion gas and the injected reburn fuel/OFA for the retrofit of Nelson Dewey No. 2 with reburning burners and dual-air zone OFA ports. The objectives of this subtask were to:

- Evaluate the mixing between combustion flue gas and the injected reburn fuel and air and, also, the mixing of the reburn zone gases with the overfire air

- Determine the best locations and spin directions for the reburning burners and overfire air ports

This work was carried out in a 1/12 scale, three-dimensional model of the WP&L Nelson Dewey Station Unit No. 2 furnace. The model was constructed of transparent plexiglass and was designed and fabricated to allow for flexible variation in reburning burners and overfire air port arrangements.

Baseline flow tests were made to determine the existing flow patterns in the furnace and to establish a basis for reburning burner and OFA port placement. Baseline furnace gas velocity measurements were taken at Nelson Dewey Unit No. 2 for comparison. After verifying that the model and field results agreed, model tests were made to separately characterize and optimize the mixing of the reburning burner gases and overfire air with the furnace combustion gases.

Reburn testing began with an initial arrangement of the reburning burners and continued by varying the arrangement as determined necessary to achieve adequate mixing. Results included furnace flow patterns and temperature profiles. Temperature measurement traverses were performed at the 681 ft. elevation in the model furnace to determine degree of mixing of the combustion gases with air/coal from the reburning burners. Wool tuft probes were also used to evaluate jet penetration and mixing. The following variables were investigated: burner spin direction, spin angle, number of burners, and burner-to-burner spacing. The OFA ports were subsequently installed and mixing with the reburn zone flow was investigated. Temperature measurements were made at the 700 ft. elevation to investigate degree of mixing by determining homogeneity of gas temperature as was done for burners alone. The test results were then examined to determine the final reburning burner and overfire air port arrangements for use at WP&L, Unit 2.

Numerical Flow Modeling

The objective of this work was to benchmark three-dimensional FORCE™ cyclone furnace predictions for the full-scale unit by comparing them to data obtained from the hot and cold velocity traversing at Nelson Dewey Unit No. 2 and also the physical flow model tests described above.

Qualitative agreement between numerical predictions and cold flow modeling predictions was obtained. It was this model which served as the main tool in analyzing/optimizing numerous reburning system arrangements quickly and cost effectively. Simulation of different reburn arrangements was carried out using the mathematical model in the analysis to determine the required number of burners and OFA ports, as well as location. The result was a recommendation to use four reburn burners and four OFA ports in the reburn system for Nelson Dewey.

1.4 Task 4 Baseline Characterization Tests

Data required to characterize the boiler's pre-retrofit operating conditions were obtained through a series of baseline tests. The objective of these tests was to characterize the boiler operating parameters, efficiency, and emissions characteristics under a variety of load and power demand conditions.

Baseline testing was conducted from the last week of April through the first week of June 1990, prior to installation of the reburning system. These tests provided the benchmark data to which the subsequent reburning results could be compared. The host utility coal at that time, which was a bituminous, medium sulfur coal from Lamar, Indiana, was used for the majority of the baseline tests. The tests while firing the Lamar coal were performed at three load conditions, 100, 75 and 50%, and at different excess air/flue gas recirculation levels. The objectives of baseline characterization testing were to identify normal or typical conditions for boiler operations, emissions characteristics, ESP performance, and changes in these parameters when excess air and flue gas recirculation rates were varied.

Data on boiler operating conditions and emissions as a function of boiler load and excess air levels were regularly collected by the data acquisition system. This information included:

- Superheater steam temperature and pressure
- Steam drum temperature and pressure
- Feedwater temperature and pressure
- Recirculation or tempering gas flow (if any)
- Gas and air temperatures entering and leaving the air heater
- Economizer outlet gas temperatures
- Gas and air differential pressure across the airheater
- Feedwater flow
- Steam flow
- Secondary air temperature
- Generator output
- FD fan amperage and voltage
- Operating conditions and continuous gas samples for O_2, CO_2, CO, NO_x, and Opacity were taken for all tests

Also, physical measurement of the FEGT at each of the various test conditions was conducted, as well as in-furnace probing for O_2, CO, NO_x, H_2S, and temperatures at optimum conditions. Sample extraction from the furnace was performed using High Velocity Thermocouple (HVT) probes. Gaseous emission data (NO_x, O_2, CO, CO_2, SO_2) were collected by the Acurex test crew at the precipitator outlet using the EPA certified continuous Emissions Monitoring System. B&W's economizer gas outlet grid was also available to cross check Acurex's gaseous emissions data (NO_x, O_2, CO, CO_2).

The in-furnace probing was performed at four different furnace elevations: 1) cyclone exit, 2) reburn burner elevation, 3) reburn zone area, and 4) furnace exit. During cold flow conditions (FD fans only), an anemometer grid system was used to measure velocity profiles. During hot conditions (coal/oil firing), water-cooled probes were used to measure temperatures, gaseous species, or gas velocity profiles.

Acurex was responsible for collecting additional data via EPA methods at the precipitator inlet and outlet which allowed precipitator performance analysis to be carried out. These data characterized particulate loading, particulate sizing, trace metal concentrations, volatile/non-volatile organics, unburned carbon and electrical resistivity of the ash at the precipitator inlet and outlet.

Qualitative agreement between the numerical modeling predictions of furnace flow patterns and full-scale measured velocity distribution was obtained, further validating the modeling tools.

1.5 Task 5 Design of Reburning System and Development of Test Plan

The mixing characteristics and residence time data obtained from the physical flow model tests and the mathematical model activity provided information input to the system design. Using this information, B&W with the help of Sargent & Lundy for balance of plant requirements, performed a detailed engineering design for the reburning system retrofit that met all required design and construction codes. This included:

(1) Engineering calculations for the final determination of the proper size, capacity, performance requirements, and mounting location of all items of equipment; the dimensions and configuration of all building enclosures, foundations, structural work, piping, ductwork, insulation, and electrical work; and the requirements for instrumentation and controls.

(2) Preparation of detailed drawings showing dimensions and configuration and noting all special construction features of mechanical equipment.

(3) Specifications covering all materials and equipment to be used and all construction work to be performed

in providing the completed plant. These included building enclosures, foundations, steelwork, ductwork, piping, electrical work, and instrumentation.

(4) Preparation of description outlining procedure(s) required to operate the plant to meet the performance requirements of the process design.

Burner/Overfire Air (OFA) Port Design

B&W "S-Type" burner and dual air zone OFA port designs were used in the reburning system. Once the number of burners/OFA ports required was determined, detailing of the actual components was carried out. This included burner/OFA port throat sizes, coal nozzle size, coal impeller/swirler design, secondary air inlet design, burner supports, burner lighter, burner/lighter flame safety system considerations, and seal air requirements.

Pulverizer System Design

A B&W MPS 67 pulverizer was required to provide pulverized coal to the reburning burners. The pulverizer design/operation allows sufficient flexibility to accommodate variation of the resulting coal fineness. This parameter was considered to be critical during optimization of the coal reburn system with respect to NO_x versus unburned carbon.

Based upon the reburn burner requirements, the pulverizer size and operating characteristics were determined in order to accommodate coal/primary air flow rates, flexible coal fineness capability and turn down requirements.

The technical documentation and specifications for the pulverizer auxiliary equipment and the coal handling/storage requirements were developed. Auxiliary equipment included such items as the pyrite removal system, pulverizer tire maintenance/replacement system, seal air and lubricating systems, inerting system, primary air fan, gearbox, motors, etc. Coal handling/storage requirements included designing a system to modify the existing coal conveyor to accommodate feeding coal to a new coal silo and to install a 150 ton coal silo, piping/low coal alarm system between the silo and feeder, and a new gravimetric feeder.

Flue/Duct/Coal Piping Design

General arrangement drawings identifying the layout of the cyclone coal reburning system at Nelson Dewey No. 2 were prepared. The drawings showed the overall reburn system from the new coal handling system to the new boiler penetrations for the burners/OFA ports. This included flue/duct/coal piping locations.

These systems were sized to accommodate the worst case anticipated flow rates in each of the gas recirculation/air/fuel streams. Once these drawings were complete, system pressures were calculated along with identification of the number and location of dampers/monitoring equipment needed to control and measure flows. The flue system included transporting FGR from the existing FGR fan to the reburning burners secondary air zone. The duct work included the reburning burners secondary air system, OFA port system, primary/tempering air for the pulverizer system and miscellaneous seal air systems. The coal piping involved the piping from the pulverizer to each of the reburn burners.

Controls/Electrical Design

Because the reburning technology is dependent upon accurately controlling the air/fuel ratio at various boiler elevations, one of the major design subtasks was the design of the control system. The state-of-the-art Bailey Network 90® Microprocessor System was proposed to control the reburn system. In addition, because the reburn system included various new equipment (e.g. pulverizer, primary air fan, seal air blower, damper drives) which required power, the electrical system at Nelson Dewey needed to be upgraded with the engineering help of Sargent & Lundy.

Finalized control/electrical packages allowing engineering design for all the equipment and subsystems were developed. The packages included the following:

(a) Final B&W/Sargent & Lundy/Bailey Control drawings of the control/electrical system upgrades
(b) Materials/equipment specifications
(c) Control operating philosophy manuals

Pulverizer Enclosure/Structural Steel

The objective of this activity was to prepare the drawings/specifications required for the new pulverizer system enclosure and any structural steel modifications. Sargent & Lundy designed the enclosure structural steel and conveyor system modifications for inclusion in a general mechanical/structural bid specification.

Test Plan Development

B&W prepared a detailed test plan structured to enable demonstration of the operating capabilities of a retrofitted reburning system at normal boiler operating conditions. Based on results from pilot scale tests and numerical modeling, the test plan encompassed the parameters required to demonstrate the effect of reburning with the minimum impact on boiler operations. The test plan provided for parametric tests to define the optimum reburning parameters for the specific applications and for long-term performance tests needed to demonstrate the reliability of the reburning system.

A quality assurance/quality control (QA/QC) plan was also developed to accompany the test plan. Acurex, using its in-house QA/QC personnel, prepared a plan for the emissions portion of field testing.

1.6 Task 6 Environmental Assessment and Permitting

The work to be performed under this task was related to permitting activities, the majority of which entailed environmental considerations.

An environmental monitoring plan was developed to describe B&W's monitoring tasks and the rationale for the scope of any type of monitoring proposed. It defined the scope of monitoring to be performed during each phase of the project, as appropriate, including a list of substances to be monitored, the general locations where measurements and monitoring would take place, and the general types of sampling techniques, including frequency and duration, of such sampling.

Permits

Permits and operating licenses as required were obtained by the host site utility, Wisconsin Power & Light, to facilitate installation of the cyclone coal reburning technology and to conduct the NO_x control testing.

While no special permits were identified as being necessary for this project, the objective of this subtask involved the preparation and development of information to support applications and procedures for securing all National, State, and Local environmental permits and licenses required for construction and operation of the reburning demonstration. These procedures included meetings with the permitting agencies.

2.0 Phase II - Procurement, Fabrication, Installation and Start-Up

In an effort to prevent schedule delays due to long-lead-time item procurement, Phase II was divided into Phase IIA and IIB. Phase IIA allowed such items to be ordered under budget period 1 to avoid construction delays.

2.1 Phase IIA - Long Lead-Time Item Procurement

2.1.1 Task 1 Management & Reporting

The management activities including resolution of technical and cost issues, reporting and coordination of activities in Phase IIA were performed under this task.

2.1.2 Task 2 Procurement of Long-Lead-Time Items

The objective of this task was to initialize procurement activities for equipment requiring an extraordinary lead time, relative to the construction schedule. This was carried out to assure equipment deliveries within the schedule requirements of construction.

Long-lead-time items included:

(1) OFA port boiler tube panels for modification of the furnace walls during installation activities

(2) Modified reburn burner boiler tube panel revisions

(3) MPS-67 pulverizer fabrication as well as purchase of:

- Primary air fan
- Drive motor
- Gear drive

(4) Network 90® control system upgrade components and associated equipment

(5) Foundation construction

Foundation construction is dependent on ground conditions. The project schedule originally called for foundation construction in March 1991. However, WP&L advised that ground conditions at the plant are unsuitable at that time for excavation and subsequent concrete work due to ground water levels during the spring thaw. Pushing the foundation work to later in the year jeopardized the schedule for heavy construction because of concrete curing requirements. Therefore, the decision was made to complete the bulk of the concrete work in November/December 1990 when ground conditions were more suitable, as part of long- lead-time procurement activities.

Substructure installation entailed pulverizer and enclosure foundation installation. A large mass of concrete is required by the pulverizer to dampen vibration.

2.2 Phase IIB - Procurement, Construction, and Start-Up

This phase entailed the remaining procurement activities as well as installation and start-up.

2.2.1 Task 1 Project Management and Reporting

All management and reporting activities as well as cost monitoring that apply to all tasks collectively in Phase IIB were performed under this task.

2.2.2 Task 2 Procurement and Fabrication of the Reburning System

A number of long-lead-time items already were ordered as a result of Phase IIA Long-Lead-Time Item Procurement Activities. The items are:

1. MPS Pulverizer gear drive
2. MPS Pulverizer drive motor
3. MPS-67 Pulverizer
4. MPS inching drive
5. Primary air fan
6. Primary air fan motor
7. Gravimetric feeder and associated components
8. 480 volt motor control center
9. 4160/480 volt step down transformer
10. Data acquisition system
11. Bailey Network 90® control system upgrade
12. Substructure installation

Remaining items for procurement and fabrication to be carried out in Phase IIB were:

1. Coal reburning burners
2. OFA ports and NO_x registers
3. Coal piping and valving
4. Ductwork and piping
5. Air flow monitors
6. Dampers and damper drives
7. Pulverizer and primary air fan seal air system
8. Pulverizer lube oil system
9. Pulverizer rotating classifier hydraulic drive and hydraulic tire pressure loading system
10. Burner lighter control system
11. Various instrumentation requirements (thermocouples, etc.)
12. Asbestos removal

These items as well as miscellaneous small items were procured and fabricated as needed to maintain overall project schedule.

2.2.3 Task 3 Installation and Start-up

Installation was categorized into a total of three separate construction activities beyond Phase IIA substructure work. These were for:

(1) Asbestos removal - Nelson Dewey Unit No. 2 is insulated extensively with asbestos. Consequently, any retrofit activity entails removal of asbestos prior to mechanical work performance. A separate contractor was chosen to perform this work prior to arrival of a general contractor on site. Scope of asbestos removal covered most of the rear wall of the boiler and areas where penetrations into existing ductwork and the air heater were to be made.

(2) General mechanical/structural work - This work included mechanical installation of the reburn system. The scope for the general contractor was installation of the following major items:

   (a) Coal handling modifications and coal silo for the reburn system
   (b) An MPS-67 Pulverizer with auxiliary equipment
   (c) Primary, secondary and OFA as well as gas recirculation ductwork
   (d) Four reburn burners and a lighter control package
   (e) Four dual air zone OFA ports
   (f) Four 12 inch coal pipes with shut off valves
   (g) Tube wall panels for the reburn burners and OFA port penetrations into the boiler
   (h) Pulverizer enclosure building

(3) Electrical specification - This work consisted of installation of electrical wiring and connecting instrumentation and control systems within the reburn system and between the reburn system and the existing plant. Connection of the Network 90® Control System upgrade occurred as part of this activity.

General mechanical installation was carried out in two phases: 1) Spring outage work, taking advantage of an early boiler outage and 2) actual reburn installation.

Spring Outage Work

Spring outage activities took place over a two week scheduled outage for normal boiler maintenance in March 1991. This outage was offered to the project as additional time to do preliminary construction work, freeing up time in the fall outage for reburn system installation. These activities included the following, all of which could not be performed while the boiler was in operation:

1. High pressure service water tie-in
2. Station air tie-in
3. Instrument air tie-in
4. Slag tank penetration for the pyrite sluicing system
5. Relocation of piping and valves in the path of the reburn ductwork
6. Existing ductwork modifications for reburn system requirements
7. 4160 volt breaker installation
8. Panel board modifications for reburn instrument installation
9. Asbestos insulation removal

The major item in this list was asbestos removal. By carrying out removal in March 1991 and temporarily replacing the insulation with fiberglass block (without final mastic application), a major bottleneck in the fall outage was eliminated.

Reburn Installation

The bulk of the reburn system installation occurred in June through October 1991. Construction work from June through mid-September consisted of the following activities:

1. Mobilization and set up on the site
2. Erection of structural steel for the pulverizer enclosure
3. Fabrication of the coal silo
4. Removal of existing building siding where applicable/installation of new building siding
5. Erection of the primary air fan
6. Erection of the pulverizer and accessories
7. Installation of the coal piping and hangers up to the burner area
8. Installation of the coal silo
9. Installation of the gravimetric feeder
10. Installation of primary, secondary and OFA ducts to a point up-steam of where burners and OFA ports would be installed
11. Installation of miscellaneous piping
12. Installation of stairs, platforms and doorways
13. Installation of miscellaneous equipment electrical wire pull and terminations
14. Installation of building lighting
15. Installation of air monitors, dampers and damper drives
16. Insulation of ductwork and piping

These activities could be carried out with the boiler in operation. The boiler was scheduled to shut down on September 16, 1991. The remaining work requiring a boiler outage was performed from that date through the end of October 1991, in a six week outage. This work consisted of:

1. Relocate the tripper conveyor head pulley and install belt extension via vulcanized joints
2. Cut and remove existing boiler tubes at burner and OFA port locations (eight total locations)
3. Install new boiler tubes at burner and OFA port locations (eight locations)
4. Install four burners with associated lighters and piping
5. Install four NO_x ports
6. Install boiler casing and refractory
7. Tie-in air and flue gas recirculation ductwork to burners
8. Tie-in coal piping to burners
9. Tie-in OFA ductwork to OFA ports
10. Complete insulation work
11. Complete electrical installation
12. Demobilize

Ultrasonic test (UT) data were collected during the outage to establish a UT baseline. Tube thicknesses were measured throughout selected locations within the furnace envelope to provide baseline information for assessing potential corrosion effects of reburning.

Equipment Start-Up/Shakedown

This task consisted primarily of inspection and general checkout of all equipment installed as part of the cyclone coal reburning system.

Prior to start-up and after installation of the cyclone coal reburning system equipment, a detailed inspection was conducted to ascertain that all equipment was installed per the design specifications, that all field tolerances were adhered to, that no interferences exist, and that all moving parts operate properly. Adjustable S-type burner, OFA port and pulverizer components were set at predetermined positions in preparation for start-up. Electrical components installed as part of the retrofit were checked at this time to insure operability. B&W field service personnel conducted the inspection of all equipment installed as part of the overall cyclone coal reburning system.

3.0 Phase III - Operation and Disposition

3.1 Task 1 Project Management and Reporting

All management and reporting activities and cost monitoring that apply to all tasks collectively in Phase III were carried out under this task.

3.2 Task 2 Parametric Optimization Tests of Reburn System

Coal reburning tests were performed to evaluate the effect of the key parameters on the NO_x reduction and potential side effects. The major parameters investigated were:

- Mixing optimization was explored by changing the dispersion/penetration of the reburning fuel via burner hardware adjustments and flue gas recirculation. The OFA ports were adjusted to optimize penetration and side-to-side mixing. The reburning burner hardware was first optimized followed by OFA adjustment under optimum burner conditions.

- Stoichiometry in the reburning zone was varied while maintaining cyclone furnace stoichiometry above 10% excess air to minimize potential cyclone corrosion problems.

- Performance testing at three loads under optimum operating conditions was carried out once these conditions were determined via parametric optimization testing.

The effects of reburning on particle mass loading and flyash particle size (entering and exiting the ESP), carbon utilization, *insitu* resistivity and H_2O were evaluated during testing in addition to continuous monitoring of outlet gases.

Initial parametric optimization testing was performed by B&W alone to determine range of operating parameters for the system. This sequence consisted of approximately 50 tests and was termed the "T" series. This series is discussed under Section 7.0, Coal Reburning Technical Impacts.

Once the system range of operation was determined, Acurex was brought on site to verify gaseous emission data. Specific parametric optimization tests were rerun with Acurex continuous emissions monitoring (CEM) capability engaged to verify results. Tests on particulate loading at the precipitator inlet and outlet were also preformed by Acurex. This group of optimization tests are termed the "A" series as discussed in Section 7.0.

Prior to long-term testing initiation, a series of performance tests at three loads and optimum conditions was carried out. These are termed the "P" series and are discussed in Section 7.0.

3.3 Task 3 Long-Term Performance Test

During the long-term performance tests, the boiler was operated under the authority of Wisconsin Power & Light dispatch control. Optimum reburning conditions determined during the parametric tests were programmed into the control system over the load range to reproduce desired conditions during long-term operation.

The duration of the long-term test was four months. This period of time, coupled with five months of parametric tests, provides a total test duration of nine months.

At the end of long-term performance operation another series of performance tests ("F" series) were carried out with both B&W and Acurex on site. This occurred at the end of September 1992. These test results, when compared with performance tests taken at the end of parametric optimization would provide an indication of long-term effects of reburn operating, if any exist. This information is also discussed in Section 7.0.

Hazardous Air Pollutant Testing (HAP)

As an addition to the scope of the project and in support of DOE's efforts to develop and promote commercialization of Clean Coal technologies, Hazardous Air Pollutant (HAP) testing was undertaken at the reburn demonstration site in early November 1992. Trace elements, acid gases and organic substances were tested in the coal feed, slag, ESP inlet, ESP outlet, and ESP bottom ash streams both with and without reburn in operation. Results of this testing are discussed in Section 7.3.3 HAP Testing Results.

Western Fuel Testing

Driven by SO_2 emission reduction requirements in Wisconsin, WP&L was required as of January 1, 1993 to comply with an SO_2 emission limit of 1.2 $lb/10^6$ Btu. Compliance philosophy was to fuel switch to Western coal. Interest in system performance on this second coal resulted in an addition to the scope of the original demonstration. Accordingly, parametric optimization testing as well as performance testing, a condensed version of the T, P, and F series tests, were undertaken from November 16 through December 11, 1992. The results are discussed in Section 7.0 Coal Reburning Technical Impacts.

3.4 Task 4 Performance, Economic and Application Studies

The results of the Small Boiler Simulator (Phase I) pilot-plant tests and field tests were analyzed. The NO_x emissions from the baseline condition were analyzed for the effects of: boiler load' overall excess air; chemical characteristics of fuel such as volatile matter, sulfur, and fuel nitrogen content; boiler/cyclone geometries (heat release per unit of surface area/volume of the furnace); and combustion air temperature.

The reburning system parameters such as FGR, reburning burner load, reburning zone stoichiometry/residence time/temperature, and boiler geometry were analyzed to develop trends of NO_x emissions and reburning zone conditions.

The long-term performance data was evaluated to determine the effect of reburning on overall boiler performance, and continuous gaseous emissions were characterized.

Based on the results of the general application information developed throughout the program, B&W developed base case preliminary designs of reburning systems applied to a generic boiler design typified by the host site boiler used in this program. These cases were for a 110 MW and 605 MW_e unit. Capital and operating costs associated with each case study were developed and the EPRI *TAG*™ Technical Assessment Guide analysis was performed for each case.

The cost estimates were compared to determine the relative cost effectiveness of coal reburning application as a function of unit size. For each case study, a sensitivity analyses was performed to determine the relative impact of various performance, design, operating and economic variables on the costs of NO_x control.

3.5 Task 5 Final Report

The project final report was prepared under this task.

3.6 Task 6 Disposition

With the completion of testing at the Nelson Dewey plant, the reburning burners, pulverizer and associated equipment remain in place for commercial operation. Title to the material supplied and installed during the cyclone boiler coal reburning retrofit was transferred to Wisconsin Power & Light. Further operation and maintenance of the reburning burners will be the responsibility of the host site utility operating company.

APPENDIX NO. 3

Evaluation of Reburning for NO_x Control

from Lignite-Fired Cyclone Boilers

EVALUATION OF REBURNING FOR NO_x CONTROL FROM LIGNITE-FIRED CYCLONE BOILERS

Final Report — August 1992 through April 1993

Babcock & Wilcox Report RDD:93:47313-005-001:01

May 1993

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EXECUTIVE SUMMARY

INTRODUCTION

Standard low-NO_x combustion modification technologies are not applicable for cyclone-equipped boilers operation. The emerging reburning technology offers cyclone boiler owners a promising alternative to expensive flue gas cleanup techniques for NO_x emission reduction. Reburning involves the injection of a supplemental fuel (natural gas, oil, or coal) into the main furnace in order to produce locally reducing conditions which convert NO_x produced in the main combustion zone to molecular nitrogen, thereby reducing overall NO_x emissions.

After obtaining encouraging results from engineering feasibility and pilot-scale proof-of-concept (POC) studies[1][2], Babcock & Wilcox (B&W) is presently completing a U.S. Department of Energy (DOE) Clean Coal II project to demonstrate the cyclone coal reburning technology on a commercial utility boiler. The host site for the demonstration is the Wisconsin Power & Light's (WP&L's) 110-MW_e Nelson Dewey Station Unit No. 2.

There are presently over 100 operating, cyclone-equipped utility boilers representing approximately 14% of pre-New Source Performance Standards (NSPS) coal-fired generating capacity (over 26,000 MW_e). However, these units contribute approximately 21% of the NO_x emitted since their inherently turbulent, high-temperature combustion process is conducive to NO_x formation. Although the majority of cyclone units are 20 - 30 years of age, utilities plan to operate many of these units for at least an additional 10 - 20 years. These units (located primarily in the Midwest) have been targeted for the second phase of the federal acid rain legislation scheduled to go into effect in 1995. In some instances, Title I —Ozone Non-Attainment will accelerate the timetable for compliance. The cyclone boilers that use lignite located in the Dakotas represent 2000 MW_e generating capacity.

Despite many years of B&W research on coal reburning, no pilot- or full-scale lignite-fired reburning evaluation had been undertaken prior to this project. The main characteristics of North Dakota lignite — high moisture content, low Btu, and low fixed carbon/volatile matter (FC/VM) ratios — are unique and required pilot-scale evaluation prior to full-scale cyclone reburning application. Therefore, this pilot-scale testing was performed to evaluate the applicability of reburning technology to reduce NO_x emissions from cyclone-equipped utility boilers which use North Dakota lignite as a primary fuel. The performance goals for the lignite reburning program were:

- Greater than 50% reduction in NO_x, as referenced to the uncontrolled (baseline) conditions at full-load
- No significant impact on cyclone furnace operation, boiler efficiency, fireside corrosion, and deposition

Fly ash was isokinetically sampled from the stack of the SBS during baseline and reburning conditions and analyzed for unburned combustibles. Unburned carbon (UBC) of the fly ash was always below 1%. Also, CO emissions remained low (less than 40 ppm) throughout the various test conditions. Thus, based upon this data, no UBC or CO emission problems are anticipated during full-scale reburning application.

Furnace exit gas temperature (FEGT) was measured (nine points at three elevations) with a high-velocity thermocouple (HVT) water-cooled probe. FEGT was approximately 1800 - 1850F for the full-load baseline condition. With reburning in service, FEGT changed by less than ±50F during the pilot-scale North Dakota lignite tests. When FGR was added into the reburn burners, FEGT decreased from baseline by less than 50F. Since lignite-fired cyclone boilers are using gas tempering to quench the FEGT, the effect of reburning on FEGT should not adversely impact boiler performance.

Fireside deposition was studied during two 32-hour baseline and reburning tests using a superheater deposition probe. Each test contained four sootblowing cycles. Baseline fly ash concentrations at the stack showed that approximately 50% of the coal ash was leaving the boiler and this level did not change with reburning. Presumably, better cyclone slagging characteristics during reburning operation was the reason that no increase in fly ash levels were observed. The superheater probe deposit thickness was also similar in both tests. Heat flux dropped from approximately 14,500 to 10,000 Btu/hr/ft^2 during an approximate 8-hour period for both baseline and reburning conditions. The maximum heat flux was recoverable with soot blowing operation. In order to regain the maximum heat flux for either the baseline or reburning cases, the same sootblowing pressure was required. This was supported by the chemical analysis of the deposits on the superheater probe which were similar between baseline and reburning tests.

The in-furnace probing data with the North Dakota lignite show that only up to 160 ppm H_2S concentration was observed in the reburn zone and thus the majority of the sulfur component remained as SO_2. In addition, most of the higher H_2S levels were observed at the middle of the boiler and lower H_2S levels near the walls. If these results can be duplicated at the full-scale, increased fireside corrosion should not be a consequence of the reburning technology.

COMMERCIALIZATION AND ECONOMICS

A separate economic evaluation was not performed in this report. But due to the importance of economics, a summary of the DOE Clean Coal II Cyclone Reburning Project Economics is presented here. The reburning technology is considered to be commercially available through Babcock & Wilcox. B&W is presently completing a successful 110-MW_e demonstration at WP&L's Nelson Dewey Unit No. 2. Although it is desirable to perform larger demonstrations (e.g., 600 MW_e) prior to commercialization, B&W is confident that similar NO_x emission reductions can be achieved in larger boilers. The evaluation of potential side-effects of the technology are yet to be determined in larger boilers.

Table 1 shows the costs of the reburning technology for two boiler generating capacities. The costs presented in this table are site-specific and each reburning application will require a final review.

Currently, the Dakotas have approximately 2000 MW_e of cyclone boilers in operation using lignite. The majority of these units are not using any NO_x control technology because they are exempt from NO_x regulation until 1995. In 1995, these units may be forced to choose a NO_x control technology to comply with federal legislation (Phase II CAA). Since cyclones cannot use standard low-NO_x burner technology,

- The cyclone furnace must operate under an oxidizing environment to minimize possible corrosion in the cyclone.

- Mixing between reburn fuel/air and cyclone gases is a key factor on the performance of the reburn system. Mixing performance of the SBS and Nelson Dewey Unit No. 2 should be considered as a minimum criteria in design of full-scale retrofits.

- Utilize the SBS stoichiometries and average residence times in the design of the full-scale retrofit as a starting point. Physical and/or numerical modeling is recommended to assess/improve the mixing performance if required.

REFERENCES

1. G. J. Maringo, et al., "Feasibility of Reburning for Cyclone Boiler NO_x Control," 1987 EPA/EPRI Joint Symposium on Stationary Combustion NO_x Control, New Orleans, Louisiana, March 23-27, 1987.

2. H. Farzan, et al., "Pilot Evaluation of Reburning for Cyclone Boiler NO_x Control," in the Proceedings of EPRI/EPA Joint Symposium on Stationary NO_x Control," San Francisco, California, March 6-9, 1989.

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Section 1

INTRODUCTION

There are presently 105 operating, cyclone-equipped utility boilers representing approximately 14% of pre-New Source Performance Standards (NSPS) coal-fired generating capacity (over 26,000 MW_e). However, these units contribute approximately 21% of the NO_x emitted, since their inherently turbulent, high-temperature combustion process is conducive to NO_x formation. Although the majority of cyclone units are 20 - 30 years of age, utilities plan to operate many of these units for at least an additional 10 - 20 years. Although cyclone boilers are exempt from Phase I NO_x emission control requirement under Title IV of the federal Clean Air Act Amendment (CAAA) of 1990, future federal and state regulations could target these boilers for NO_x emission control.

Cyclone-equipped boilers have a unique configuration which prevents application of standard low-NO_x burner technology; that is, the combustion occurs within a water-cooled horizontal cylinder attached to the outside of the furnace. Furthermore, other conventional NO_x reduction techniques, such as two-stage combustion, cannot be applied to the full extent due to associated cyclone operational concerns (cyclone corrosion and slagging). The use of selected catalytic reduction or selected non-catalytic reduction (SCR/SNCR) technologies offers promise of controlling NO_x from these units, but at high capital and/or operating costs. Reburning is, therefore, a promising alternative NO_x reduction approach for cyclone-equipped units at more reasonable capital and operating costs.

Reburning technology involves injection of a second fuel into the main furnace (above the cyclone region) to produce a secondary combustion zone where a reducing atmosphere exists. These local chemical reducing conditions convert NO_x to molecular nitrogen, thus destroying a portion of the NO_x produced in the primary cyclone combustion zone. Since reburning can be applied to the cyclone while it is operating under normal oxidizing conditions, this technology merits development for ultimate commercialization.

Babcock and Wilcox (B&W) has been evaluating the reburning technology for NO_x control from cyclone boilers[1,2,3]. Prior to this pilot-scale study, the entire data base consisted of medium- and high-sulfur eastern bituminous coals in a pilot-scale cyclone. In addition, the U.S. Department of Energy (DOE) under its Clean Coal II solicitation is currently sponsoring B&W to perform a 100-MW_e demonstration of coal reburning using a medium-sulfur bituminous coal and a low-sulfur subbituminous western coal. The characteristics of North Dakota lignite — high moisture content, low Btu, and low fixed carbon/volatile matter (FC/VM) ratios — are unique and required pilot-scale evaluation prior to full-scale reburning retrofit to cyclone boilers.

OBJECTIVES

The purpose of this pilot-scale study was to evaluate cyclone reburning technology using lignite and to from a tap at the cyclone throat, and is dropped into a water-filled slag tank. The flue gases and remaining ash leave the cyclone and enter the main furnace. No commercially-demonstrated combustion modifications have significantly reduced NO_x emissions without adversely effecting cyclone operation. Past tests with combustion air staging achieved 15 - 30% reductions. Cyclone tube corrosion concerns due to the resulting reducing conditions were not fully addressed because of the short duration of these tests. Further investigation of staging for cyclone NO_x control was halted due to utility corrosion concern. Additionally, since no mandatory federal/state NO_x emission regulation was enforced, no alternative technologies were pursued.

The recent emergence of the reburning technology offers a promising alternative to conventional combustion controls and SCR systems. The reburning process employs multiple combustion zones in the furnace, as shown in Figure 1-2. The main combustion zone is operated at a reduced stoichiometry and has the majority of the fuel input (70 - 85% heat input). The majority of investigations on natural gas-/oil-/coal-fired units have shown that the main combustion zone of the furnace should be operated at a stoichiometry of less than 1.0. This operating criterion is impractical for cyclone units due to the potential for highly corrosive conditions, since most cyclones burn high-sulfur, high-iron content bituminous coals. To avoid this situation and its potentially catastrophic consequences, the cyclone main combustion zone was determined to be operated at a stoichiometry of no less than 1.1 (2% excess O_2 at the stack).

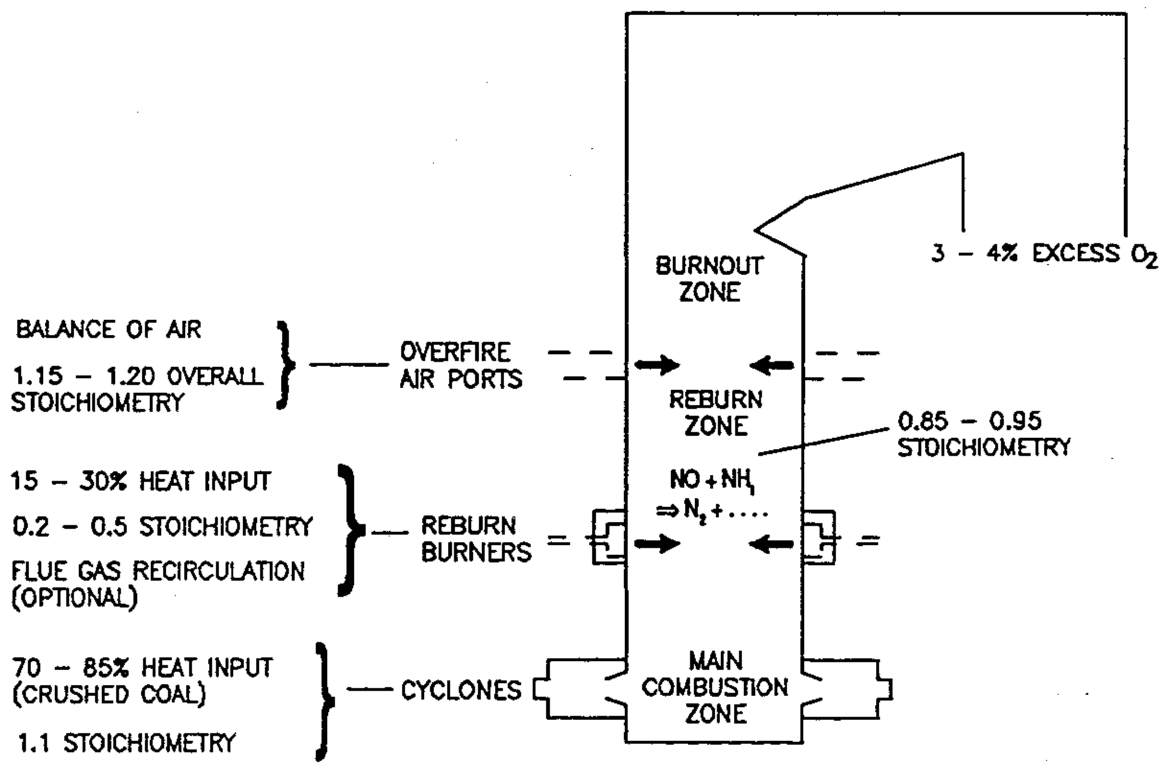


Figure 1-2 Reburning technology

Section 2

EXPERIMENTAL FACILITY

SMALL BOILER SIMULATOR (SBS)

Babcock & Wilcox's 6-million Btu/hr small boiler simulator (SBS) was utilized to perform the pilot-scale study (Figure 2-1). This facility is described in detail in Appendix A. A short description of the facility pertinent to this project is presented here.

The SBS is fired by a single, scaled-down version of B&W's cyclone furnace. Coarse pulverized coal (44% through 200 mesh), carried by primary air, enters tangentially into the burner. Pulverized coal has to be utilized in the SBS instead of crushed coal to obtain complete combustion in this small cyclone. Preheated combustion air at 600 to 800F enters tangentially into the cyclone furnace.

The water-cooled furnace simulates the geometry of B&W's single-cyclone, front-wall fired cyclone boilers. The inside surface of the furnace is insulated to yield a furnace exit gas temperature (FEGT) of 2250F at the design heat input rate of 6-million Btu/hr. This facility simulates furnace/convective pass gas temperature profiles and residence times, NO_x levels, cyclone slagging potential, ash retention within the resulting slag, unburned carbon, and fly ash particle size of typical full-scale cyclone units. A comparison of baseline conditions of these units with the full-scale cyclone boilers is shown in Table 2-1.

Two reburn burners were installed on the SBS furnace rear wall above the cyclone furnace. Each burner consists of two zones with the outer zone housing a set of spin vanes while the inner zone contains the reburn fuel injector. Air and flue gas recirculation (FGR) can be introduced through the outer zone. Overfire air (OFA) ports are located on both the front and rear walls of the SBS at three elevations with each elevation containing two ports.

Table 2-1

COMPARISON OF BASELINE CONDITIONS FOR THE SBS FACILITY AND COMMERCIAL UNITS

	SBS	Typical Cyclone-Boilers
Cyclone Temperature	>3000F	3000F
Residence Time	1.4 seconds at full load	0.7 - 2 seconds
Furnace Exit Gas Temperature	2265F	2200 - 2350F
NO_x Level	900 - 1200 ppm	600 - 1400 ppm
Ash Retention	60 - 80%	60 - 80%
Unburned Carbon	<1% in ash	1 - 20%
Ash Particle Size (MMD; Bahco)	6 - 8 microns	6 - 11 microns

Fuel Analysis

Two coals were tested. They were Decker — a western subbituminous coal that is being fired at the Nelson Dewey Station — and a representative lignite from North Dakota. The same coals were ground (Appendix C shows the size distributions) and utilized as the reburn fuels during the coal reburning tests.

The Decker coal proximate and ultimate analyses are shown in Table 2-2. The coal ash analysis is shown in Table 2-3. Decker coal is high in moisture and low on fixed carbon/volatile matter (FC/VM) ratio (1.13) which is typical of western coals. Fuel nitrogen and sulfur content are very low. But fly ash content of 3.6% is not typical of coals fired in cyclone boilers.

North Dakota lignite analyses are shown in Tables 2-4 through 2-7. As received analysis shows 36% moisture, 6% ash, and 7159 Btu/hr which is a little higher Btu than typical North Dakota lignite but very close. To ensure that lignite properties remain constant during the tests, Btu, ash, and moisture content were checked periodically. Heating value dropped from 12,411 to 12,203 Btu/lb on a dry ash-free basis. We concluded that during the entire tests, the lignite's heating value did not change significantly (refer to Table 2-8).

Table 2-2
DECKER COAL PROXIMATE AND ULTIMATE ANALYSES

Basis	As Rec'd	Dry
Proximate Analysis, %		
Moisture	24.7	---
Volatile Matter	33.66	44.71
Fixed Carbon	37.99	50.47
Ash	3.63	4.82
Gross Heating Value		
Btu per lb	9384	12466
Btu per lb (M&A Free)	---	13097
Ultimate Analysis, %		
Moisture	24.72	---
Carbon	54.60	72.53
Hydrogen	3.82	5.08
Nitrogen	0.71	0.94
Sulfur	0.24	0.32
Chlorine	<0.02	<0.02
Ash	3.63	4.82
Oxygen (Difference)	12.28	16.31
Total	100.00	100.00

Table 2-5

NORTH DAKOTA LIGNITE FLY ASH ANALYSIS

Ash Analysis (I.C.P.)*, %

Silicon as SiO_2	10.77
Aluminum as Al_2O_3	8.05
Iron as Fe_2O_3	13.26
Titanium as TiO_2	0.24
Calcium as CaO	22.47
Magnesium as MgO	6.51
Sodium as Na_2O**	6.20
Potassium as K_2O**	0.47
Sulfur as SO_3	32.02
Phosphorus as P_2O_5	1.53

* The results of I.C.P. analysis are reported by the Research Center as the oxides. This does not necessarily mean that the elements occur as such in the sample.

** By Flame Photometer

Table 2-6

NORTH DAKOTA LIGNITE ASH FUSION TEMPERATURES

Atmosphere	Red.	Oxid.
A (I.D.)	2320F	2360F
B (S.T., Sp)	2400F	2400F
C (S.T., HSp)	2405F	2410F
D (F.T., 1/16")	2410F	2750F
E (F.T., Flat)	2410F	*

* Laboratory furnace maximum temperature is 2750F.

Table 2-7

NORTH DAKOTA LIGNITE HARDGROVE GRINDABILITY INDEX (HGI)

At 35.96% moisture (as received)	56
At 22.30% moisture	44
At 12.64% moisture	48
At 5.34% moisture (air dried)	46

INSTRUMENTATION

Gas Analyzers

The gas analysis system uses on-line analyzers to continuously monitor and record stack concentrations of O_2, SO_2, NO_x, CO, and CO_2 (see Table 2-9 and Figure 2-2).

In this program, the analyzers were calibrated daily (before and after the tests) with standard gases. The calibrated gases were injected at two locations: 1) at the stack into the gas sampling line, and 2) at the inlet of the gas analyzers. First, the analyzer was calibrated with the calibration gases introduced into the analyzer inlet. To ensure that there is no interference with the NO_x/SO_2 reading, the calibration gases were introduced at the stack. When the gas analyzer readings were compared to the known concentration of the calibration gases, they showed less than 2% deviation. The flue gas cleanup system utilizes a water trap system to dehumidify the flue gases. A Perma-Pure dryer is used for additional dehumidifying before the gases enter the analyzers.

Suction Pyrometer

Gas temperature measurements were obtained with a single-shield suction pyrometer. In the uninsulated convection pass, the temperature measurements could be in error by as much as 80F (at 2200F) due to radiation heat loss to the cold walls. The measured gas temperatures in the insulated furnace are fairly accurate and were not corrected for the radiation loss (since it is small).

H_2S Measurements

In-furnace sulfur species (H_2S and SO_2) sampling were performed by a water-cooled probe, SO_2 analyzer, and drager tubes. A water-cooled probe was utilized to cool the flue gas, but not below 300F to avoid condensation of water vapor. The gas temperature was adjusted by inlet water temperature as well as flow rate. H_2S drager tubes were used to measure the H_2S concentration. These drager tubes are hydrogen sulfide #29801 and #67-19001 (purchased from Safety First Supply Co., Pittsburgh, Pennsylvania). The detection ranges are 1 to 200 ppm and 5 to 600 ppm. The drager tubes were randomly calibrated against H_2S standard calibration gas. A minimum of one tube from each package was calibrated and good agreement (within ±5%) was observed. Duplicate measurements were performed in the majority of the tests to ensure the reliability of the data. In addition, SO_2 concentrations were measured (with an on-line analyzer) to ensure that the H_2S measurements were reasonably accurate. An accuracy of ±10% was achieved with this technique and is acceptable for corrosion rate calculations.

Section 3

RESULTS

INTRODUCTION

Prior to this investigation, the reburning technology has never been applied to cyclone-equipped boilers using lignite as the cyclone and reburn fuel. Our technical approach for evaluation of lignite was to utilize B&W's 6-million Btu/hr small boiler simulator (SBS) to fully characterize lignite as the cyclone and reburn fuel. Two coals were used: Decker — a western subbituminous coal that is fired at the Nelson Dewey Station — and a representative lignite from North Dakota. The experimental results of lignite reburning in the SBS were evaluated against other coals fired in both the SBS and full-scale boilers.

Baseline conditions simulated conditions similar to the full-scale lignite-fired boilers. Baseline tests (no reburning) were performed as a point of reference. All other reburning results compared to the baseline test results. The major parameters affecting NO_x emissions were investigated. For example, fuel split between cyclone and reburn burners were varied. In some test conditions, flue gas recirculation (FGR) was introduced into the reburn burners to enhance the mixing between reburn fuel and flue gases from the cyclone.

Potential side-effects of the technology were also studied. Unburned combustibles and dust loading samplings were performed at the stack to assess the potential of higher combustible losses under reburning conditions. Furnace exit gas temperature (FEGT) was measured in order to evaluate the potential variation in FEGT. Since the reburn zone is operated under reducing conditions, potential for corrosion in this zone was studied. By operating the cyclone under normal oxidizing conditions, the majority of the sulfur will be oxidized to SO_2. Some H_2S could be formed inside of the reburn zone. High levels of H_2S near the tubes can be conducive to corrosion. In-furnace H_2S measurements within the reburn zone were performed to assess potential for fireside corrosion. The simulated superheater ash deposition was studied for potential higher ash concentrations and/or fly ash compositions in the flue gas.

WESTERN SUBBITUMINOUS COAL EVALUATION

NO_x Emission Levels

Baseline NO_x emission levels adjusted to 3% O_2 ranged from 736 to 829 ppm while varying the stack O_2 from 2.2 to 4.1%, respectively, at 5-million Btu/hr. Since 3% stack O_2 is typical of Nelson Dewey Station operation, all subsequent reburning conditions are shown while maintaining an overall stack O_2 of 3%. Thus, the referenced baseline NO_x level when operating at 3% O_2 is 769 ppm. Reducing the SBS load to 3.7-million Btu/hr reduced the NO_x level to 717 ppm. This was the minimum load of the SBS as judged from the cyclone slag tapping and darkness. Figures 3-1 and 3-2 show these results of the NO_x emissions versus stack O_2 concentrations and SBS load, respectively.

Incorporating the coal reburning system at the SBS revealed NO_x reductions on the order of 48 to 68% from the baseline depending on reburn zone stoichiometry (0.93 to 0.85). Maintaining the cyclone furnace stoichiometry at 1.1 throughout the test sequence is critical due to the potential corrosion/operating concerns (slag tapping) of commercial cyclones. Thus, while maintaining cyclone stoichiometry of 1.1, the reburn zone stoichiometry is varied by increasing the amount of the heat input diverted to the reburn burners (while also maintaining a constant reburn burner stoichiometry). To obtain these NO_x reductions, the corresponding cyclone/reburn burner coal splits are approximately 79/21 (0.95 stoichiometry) and 65/35 (0.85 stoichiometry). At a reburn zone stoichiometry of 0.9 (29% reburn fuel which is typical in the Nelson Dewey Station operation), NO_x emissions of 340 ppm were measured which corresponds to 55.8% NO_x reduction from the baseline conditions. There is a data point at 0.95 stoichiometry which corresponds to 30% NO_x reduction, but the NO_x level was much above the least-square fit and was considered scatter in data and not the general trend. Figure 3-3 shows the NO_x levels versus reburn zone stoichiometry. Figure 3-4 shows that reburning NO_x levels increased from 270 to 429 ppm when the SBS load increased from 4 to 5.8-million Btu/hr and at the reburn zone stoichiometry of 0.9.

All of the aforementioned data correspond to 0% flue gas recirculation (FGR) in the reburn burners. Adding FGR to the reburn burners increases the mass flow through the burner and thus results in higher burner velocities. When approximately 5 and 9% FGR was added to the reburn burners (at 5-million Btu/hr and reburn zone stoichiometry of 0.9), NO_x levels of 278 and 260 ppm were achieved, respectively.

Furnace Exit Gas Temperature (FEGT)

Furnace exit gas temperature (FEGT) did not change significantly between baseline and reburning operation. Baseline FEGT at 5-million Btu/hr and 3% stack O_2 was 2003F. Incorporating reburning revealed minimum FEGT effects within a range of ±50F for the majority of test conditions. FEGT increased to 2132F (approximately 130F increase) at the reburn zone stoichiometry of 0.85. This corresponds to a 34.8% heat input to the reburn burners. FEGT decreased to 1934F when approximately 5% FGR was introduced into the reburn burners. Although changes in FEGT are low for most of the tests (with exception of high reburn fuel heat input), convection pass metal temperatures should be monitored in future full-scale retrofits to assure that no problems are encountered.

Combustion Efficiency

The unburned combustibles in the SBS were all very low during baseline and reburn conditions. Unburned combustibles in the fly ash were below 1% (refer to Appendix D) and did not increase with the reburning operation. These results were obtained with a fine grind reburn fuel (84% through 200 mesh; refer to Appendix C). This grind size is similar to the nominal coal reburn size (90% through 200 mesh) that is used at Nelson Dewey. The total ash input to stack increased, as expected, from approximately 20% for the baseline to 30% at reburning conditions. Although unburned carbon content of the fly ash did not change, the total ash loading at the stack increased. This would predict an increase in full-scale operation.

NORTH DAKOTA LIGNITE EVALUATION

Reburn burner flame with North Dakota lignite was stable and attached to the burner during all reburning test conditions. A commercial infrared (IR) flicker-type flame scanner detected the reburn burner flame firing North Dakota lignite. The flame detector worked satisfactorily with 29% reburn fuel and was insensitive to the background radiation.

NO_x Emission Levels

Baseline NO_x emission levels adjusted to 3% O_2 ranged from 602 to 707 ppm while varying the stack O_2 from 3.3 to 5.2%, respectively, at 5-million Btu/hr. In these tests, nominally 3.5% of the total fuel input and 15% of total air were introduced to the main furnace to simulate the lignite-fired coal dryer system. Therefore, the cyclone furnace was running between 1 to 3% excess oxygen. Since 4% stack O_2 is average of lignite-fired cyclone boilers, the referenced baseline NO_x level when operating at 4% O_2 is 690 ppm (corrected to 3% O_2).

All subsequent reburning tests were performed while maintaining an overall stack O_2 of 3%. Incorporating the coal reburning system at the SBS revealed NO_x reductions on the order of 45 to 58% from baseline depending on reburn zone stoichiometry (0.95 to 0.86). Maintaining the cyclone furnace stoichiometry at 1.1 throughout the test sequence is critical due to the potential corrosion/operating concerns (slag tapping) of the cyclone furnace. Thus, while maintaining cyclone furnace stoichiometry of 1.1, the reburn zone stoichiometry is varied by increasing the amount of the heat input diverted to the reburn burners (while also maintaining a constant reburn burner stoichiometry). To obtain these NO_x reductions, the corresponding cyclone/reburn burner coal splits are approximately 78.1/21.9 (0.95 stoichiometry) and 66.6/33.4 (0.86 stoichiometry). At a reburn zone stoichiometry of 0.9 (28% reburn fuel), NO_x emissions of 335 ppm were measured which corresponds to 51.4% NO_x reduction from the baseline conditions. Figure 3-5 shows the NO_x levels versus reburn zone stoichiometry. All of the aforementioned data correspond to 0% flue gas recirculation (FGR) in the reburn burners. Adding FGR to the reburn burners increases the mass flow through the burner and thus results in higher burner velocities. Figure 3-6 shows that when approximately 10% FGR was added to the reburn burners, NO_x levels of 202 and 279 ppm were achieved depending on reburn zone stoichiometry (0.85 and 0.93, respectively). The corresponding NO_x reduction is 70.7 to 59.6%. The effect of FGR on NO_x has been observed in the SBS with various coals. However, the NO_x levels from the Nelson Dewey Station tests did not vary with FGR. This effect must be substantiated on full-scale lignite-fired boilers.

Figure 3-7 shows that reburning NO_x levels decreased slightly from 323 to 303 ppm when SBS load decreased from 5.7 to 3-million Btu/hr and at the reburn zone stoichiometry of 0.91. Baseline NO_x levels decreased substantially. NO_x levels dropped from 754 to 471 ppm when SBS load decreased from 5.7 to 3.6-million Btu/hr. This indicates that although the NO_x reduction at the SBS full-load conditions was 57%, the reduction at a lower load (3.5-million Btu/hr) was only 35% (see Figure 3-8). This lower NO_x reduction at the lower load could be due to lower cyclone temperature at the SBS with the lignite. Higher NO_x reductions can be obtained by using FGR and/or more reburn fuel. However, if the lower NO_x reduction is duplicated at the commercial units at lower loads, the NO_x levels are still very low.

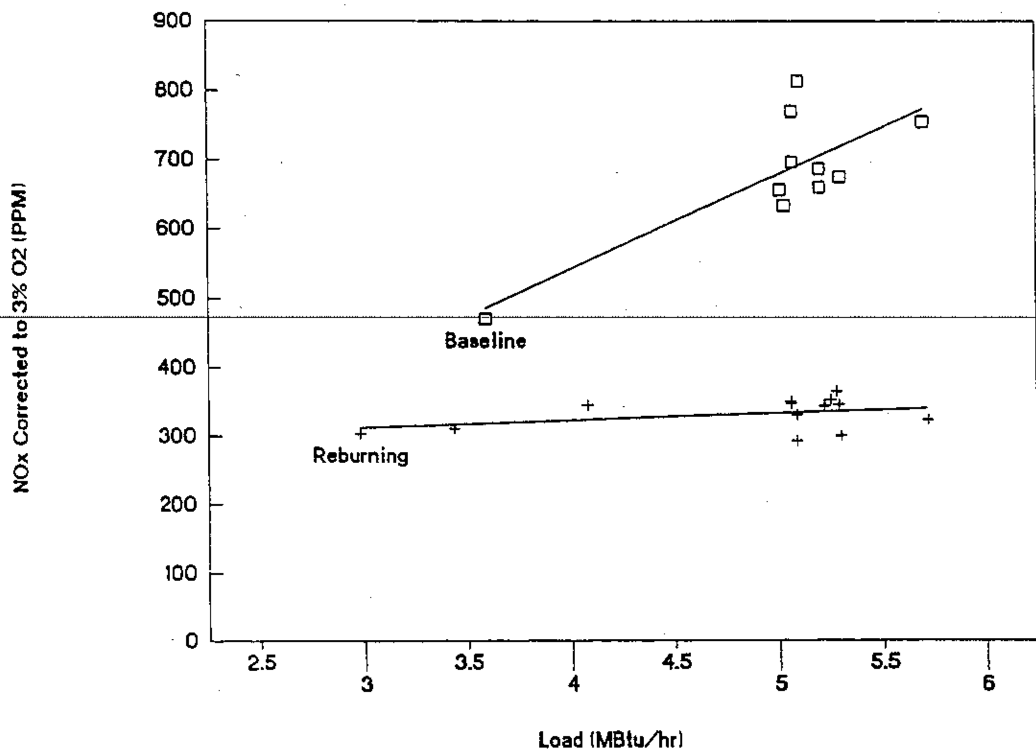


Figure 3-7 SBS NO_x levels with North Dakota lignite at different loads

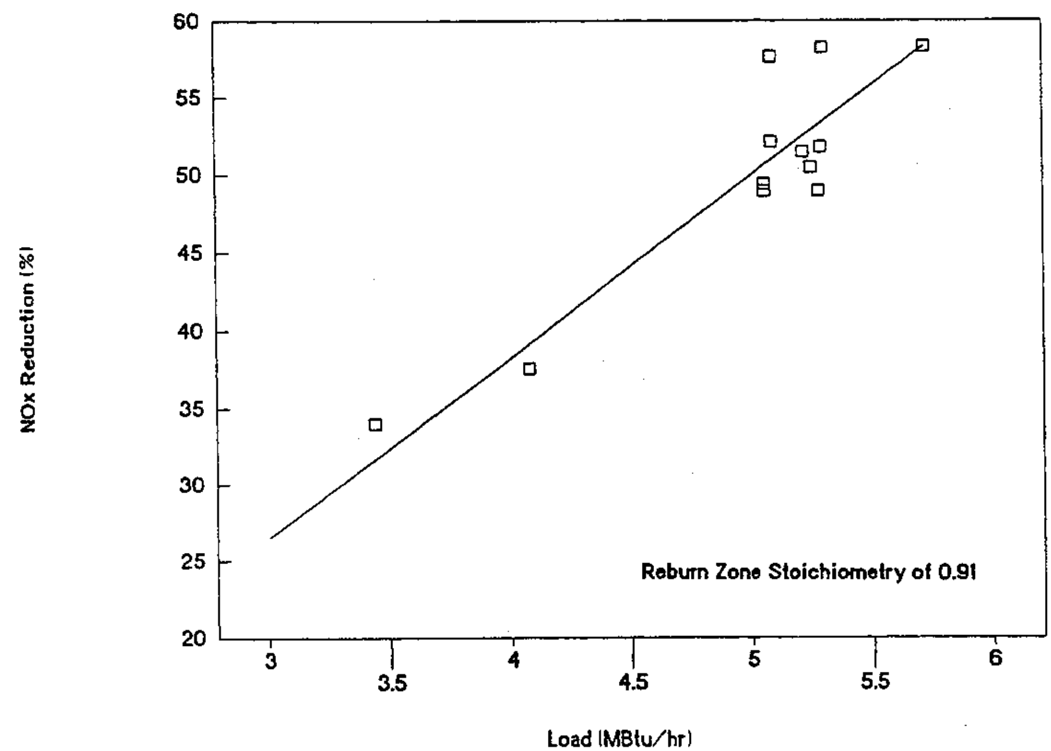


Figure 3-8 SBS NO_x reduction with North Dakota lignite at different loads

High concentrations of H_2S can be conducive to increased rates of corrosion. Flue gas chemistry analyses were obtained throught the SBS baseline and reburning tests with Decker coal and North Dakota lignite to help quantify this potential concern. The main objective was to evaluate the formation of H_2S within the reburn zone. The Decker coal data were taken in order to evaluate the potential for tube corrosion in the Nelson Dewey Station Unit No. 2.

Table 3-1 shows the H_2S levels during firing of the Decker coal and the North Dakota lignite tested under baseline and reburning conditions. In the baseline conditions, 0 ppm H_2S was found with both the Decker coal and North Dakota lignite. The reburning system produced up to 13 ppm with the Decker coal. SO_2 measurements in the reburn zone also showed that most of the sulfur was SO_2 and not other corrosive species (e.g., H_2S, COS, etc.). The North Dakota lignite produced higher H_2S levels — up to 160 ppm. H_2S concentrations were low near the rear (reburn burner) wall indicating that good reburn burner flame penetration exists in the SBS. Also, in most cases, H_2S levels were low near the side walls with the exception of one point. SO_2 concentrations within the reburn zone was much higher (about one order of magnitude) than H_2S levels indicating that only small amount of sulfur was converted to H_2S. If the design of the future reburning retrofits produces H_2S within the reburn zone inside the boiler and low H_2S levels near walls (like Nelson Dewey Station where up to 15 ppm were detected near rear wall with a medium-sulfur eastern bituminous coal) then the corrosion potential should not be a concern. In-furnace H_2S, SO_2, and other gaseous species are shown in Appendix E.

Table 3-1
H_2S CONCENTRATIONS IN REBURN ZONE

	Baseline	*Reburning*
Decker coal (0.32% sulfur, dry)	0 ppm	0-13 ppm
North Dakota lignite (1.61% sulfur, dry)	0 ppm	0-160 ppm

Fireside Ash Deposition

Convective surface ash deposition is a potential concern during operation of a reburning system. Since reburning involves delaying the combustion process, slightly lower/higher FEGTs could result and thus change the boiler deposition characteristics during lignite reburning. Also, lignite reburning may present deposition concerns due to the potential added dust loading to the convection pass which results during this mode of reburning operation. Not only could the increased mass loading magnify an ash build-up problem, but a change in particle size distribution and increases in average gas velocity through the convection surface could promote deposition and erosion. Two 32-hour convective surface deposition tests were performed during baseline and lignite reburning conditions to investigate simulated superheater surface deposition, heat flux variations, and sootblower cycle frequency and jet energy requirements.

Furnace waterwall deposition is also a potential area which needs to be addressed. Unfortunately, no provisions to investigate this parameter at the pilot-scale were included in this test project. Since the SBS furnace walls are refractory-board covered to maintain proper gas temperature at this scale, full-scale utility conditions are not simulated such that general deposition observations in this region would not be directly applicable. However, no change in SBS furnace deposition was observed between the baseline and reburning conditions.

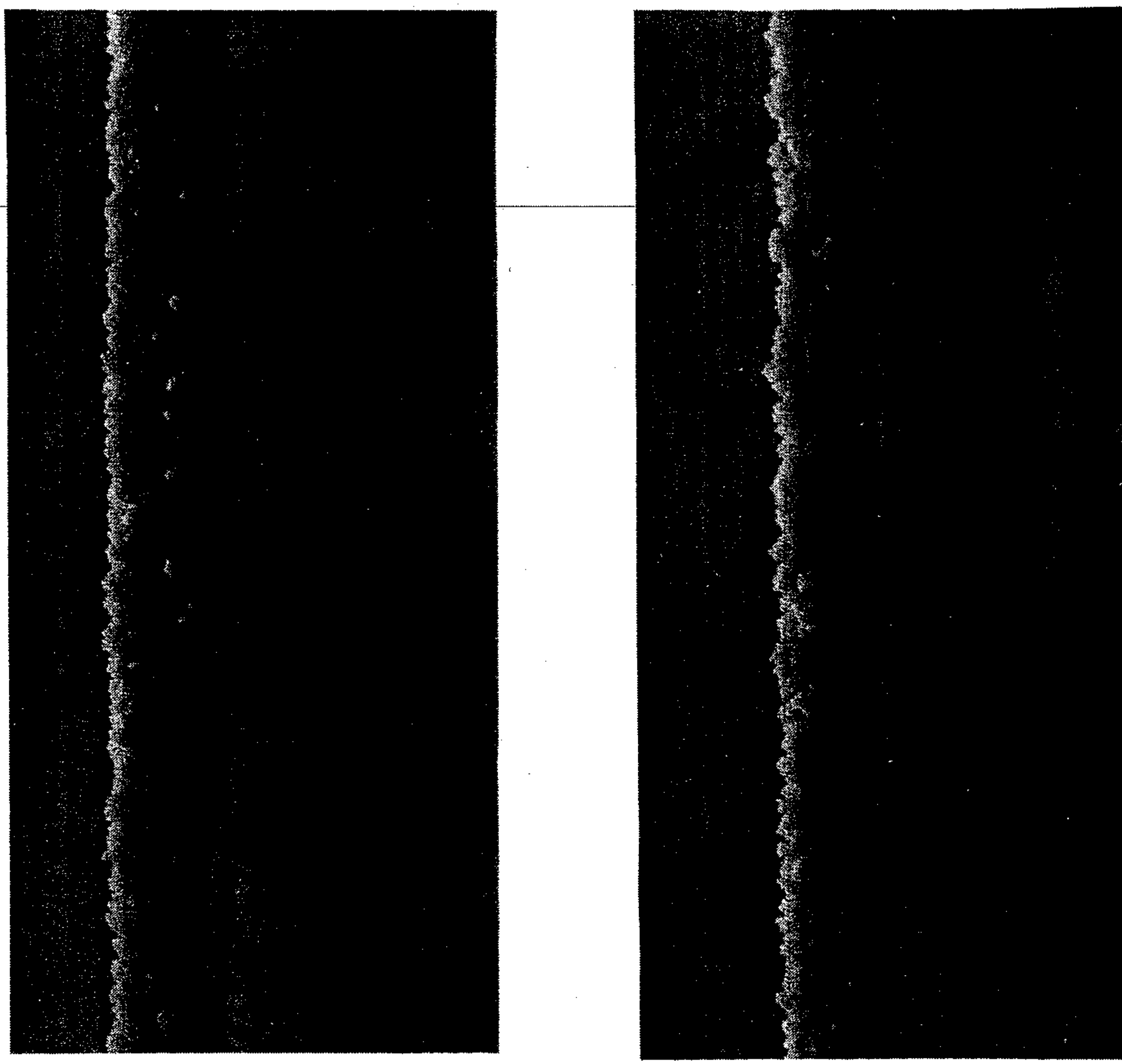
deposits during baseline and deposition tests were critical data for lignite reburning and were not affected by tube material. In addition, heat recovery could be somewhat different but still the data can be used for relative comparison of baseline and reburning tests.

Heat Flux. Two 32-hour, 5-million Btu/hr baseline and lignite reburning tests were performed with the North Dakota lignite to evaluate the heat flux variations versus time and sootblower pressure. Figures 3-9 and 3-10 illustrate the simulated superheater probe heat flux data during the 32-hour baseline and coal reburning tests, respectively. The clean superheater probe initial heat flux was approximately 14,500 Btu/hr-ft^2.

Prior SBS deposition investigations revealed that sootblower pressure requirements ranged from 30 to 100 psi. Utilizing this pressure range corresponds to PIPs of 9 to 20 inches Hg, which is well within the capabilities of commercial (approximately 60 inches Hg) sootblowing systems.

During the baseline tests, four sootblowing cycles were performed. The results show that the heat flux degradation leveled out to about 75% of the initial clean probe values in about a 7- to 8-hour time span. Utilizing sootblower pressure of 90 psi provided the necessary jet energy to restore initial clean heat flux levels. Thus, 90 psi was utilized throughout the sootblowing cycles. The lignite reburning deposition test sequence involved another four sootblowing cycles of approximately 8 hours in duration. The data reveal that the heat flux decreased and leveled out to approximately 70% of the initial clean probe values at approximately the 8-hour time span. The data indicate that slightly more sootblowing may be required in a commercial application but sootblower pressure will not be affected. This was confirmed by analyzing superheater probe deposits. Figure 3-11 shows the deposition probe prior and after sootblowing during baseline and reburning tests.

Chemical Analysis of Superheater Probe Deposit. Chemical analysis of the fly ash, coal ash, and superheater probe deposits for the baseline and lignite reburning are shown in Tables 3-2 and 3-3 , respectively. As expected, the data show that concentrations of sodium and potassium are higher in the probe deposits than in lignite ash. However, concentrations of sodium and potassium in the superheater probe deposits are very similar for the baseline and the reburning conditions of lignite firing in the SBS. Previous work with two eastern bituminous coals showed that superheater probe deposit under reburning conditions contains less sodium and potassium than the baseline conditions. Typical cyclone-equipped boiler superheater deposits contain more sodium and potassium than pulverized coal (PC) boilers since these compounds evaporate in the cyclone barrel and then condense out on the superheater tube surface. Also, fly ash concentrations in the boiler convective bank are lower in cyclone boilers than in PC boilers due to cyclone slagging capability. With the eastern bituminous coals under reburning conditions, sodium and potassium concentrations of the superheater probe were less than the baseline conditions. Those data suggest that the ash from the PC reburn burner did not evaporate as much as ash from the cyclone. With lignite, approximately 50% of the ash was entrained as fly ash during the baseline tests. The fly ash concentrations were similar for both baseline and reburning conditions presumably due to better cyclone slagging at the reburning conditions (refer to the previous discussion on combustible losses in this section). These recent data with lignite suggest that since the cyclone furnace is cooler with lignite firing than with eastern bituminous coals, sodium and potassium were evaporated similarly in the cyclone and the reburn burner. The chemical analysis of the deposits and required sootblowing pressure to recover the heat flux indicates that the fouling potential on the superheater tubes should not be adversely affected with lignite reburning.



BASELINE TESTS REBURNING TESTS

Figure 3-11 Center of the superheater deposition probe during the baseline and reburning tests

Comparison of the Results from the SBS and Nelson Dewey Station

The SBS data show the potential of reburning technology for NO_x reduction from cyclone boilers that utilize North Dakota lignite. In order to assess the potential of the technology at full-scale, the data from SBS are compared to the SBS data from other coals and the 110-MW_e data from the Nelson Dewey Station utilizing an eastern bituminous coal and Decker coal. It is important to mention that a major difference between SBS and full-scale boilers is the number of cyclones — the SBS is fired by a single cyclone versus full-scale boilers firing multiple cyclones. As a result, with the turndown on load, the SBS fuel input is reduced to the single cyclone but in a full-scale boiler, cyclone(s) can be taken out of service. NO_x emissions and other boiler characteristics could be substantially different at lower loads. Therefore, it is reasonable to compare the results of the full-load conditions for the SBS and Nelson Dewey Station.

Figure 3-12 shows the SBS NO_x levels with an eastern bituminous coal (Lamar), a western subbituminous coal (Decker), and the North Dakota lignite. At the baseline conditions, Lamar produced the highest NO_x emissions and North Dakota lignite the lowest (940, 769 and 690 ppm for Lamar, Decker, and North Dakota lignite, respectively). Incorporating the reburning system produced NO_x reductions of 44 to 62% for Lamar, 48 to 68% for Decker, and 45 to 58% for lignite. The difference in NO_x emission levels can be partially explained by the flame temperature, coal volatile matter, and nitrogen contents. Lamar is a high-volatile-matter coal with a fixed carbon/volatile matter (FC/VM) ratio of 1.15 and a fuel nitrogen content of 1.57 on a dry-ash-free (DAF) basis. Decker has a FC/VM ratio of 1.13 and a much lower fuel nitrogen content of 0.99 on a DAF basis. The North Dakota lignite has a FC/VM of 0.92 and nitrogen content of 1.12 on a DAF basis. Generally, fuels with low FC/VM and high nitrogen content

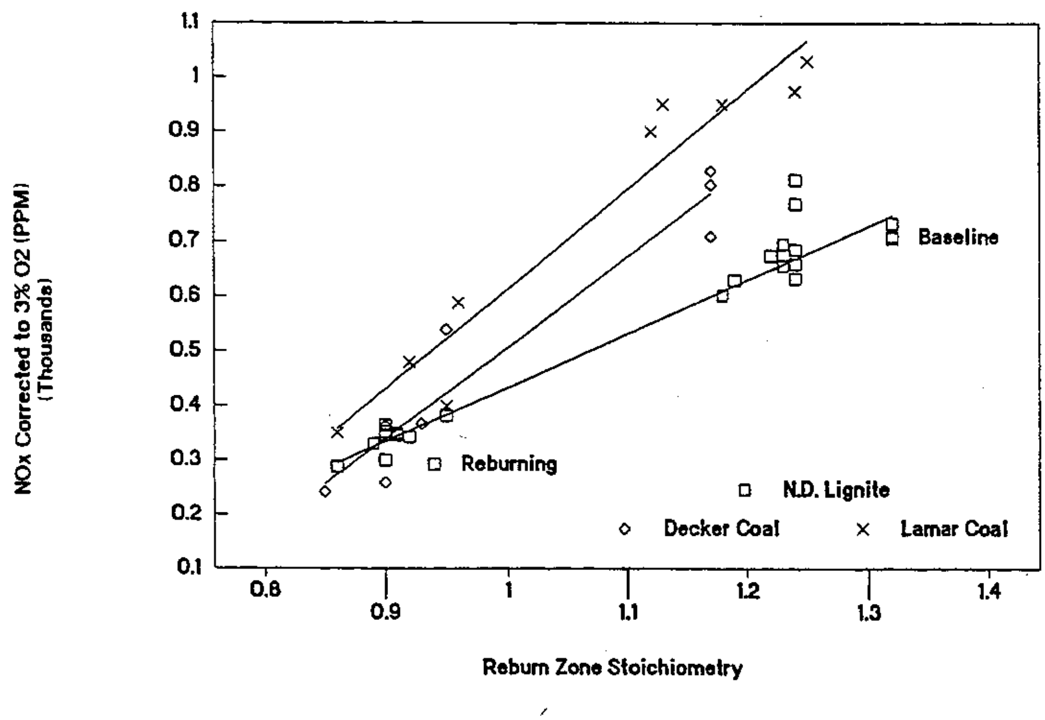


Figure 3-12 SBS NO_x levels with North Dakota lignite, western subbituminous coal, and eastern bituminous coal

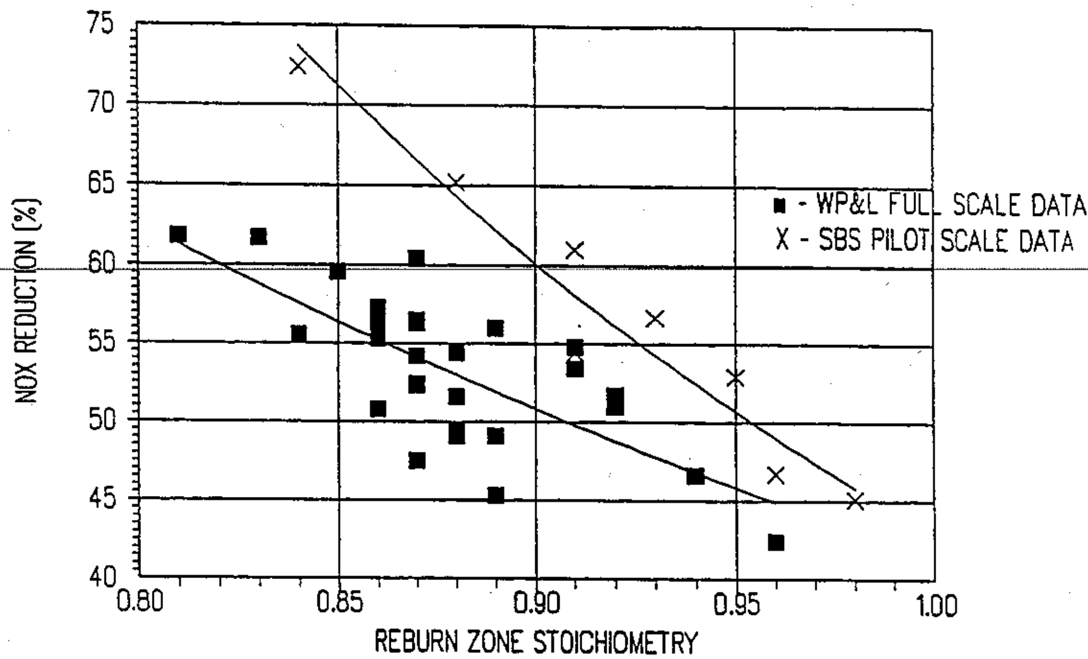


Figure 3-13 Comparison of the SBS and Nelson Dewey NO_x levels with the eastern bituminous coal

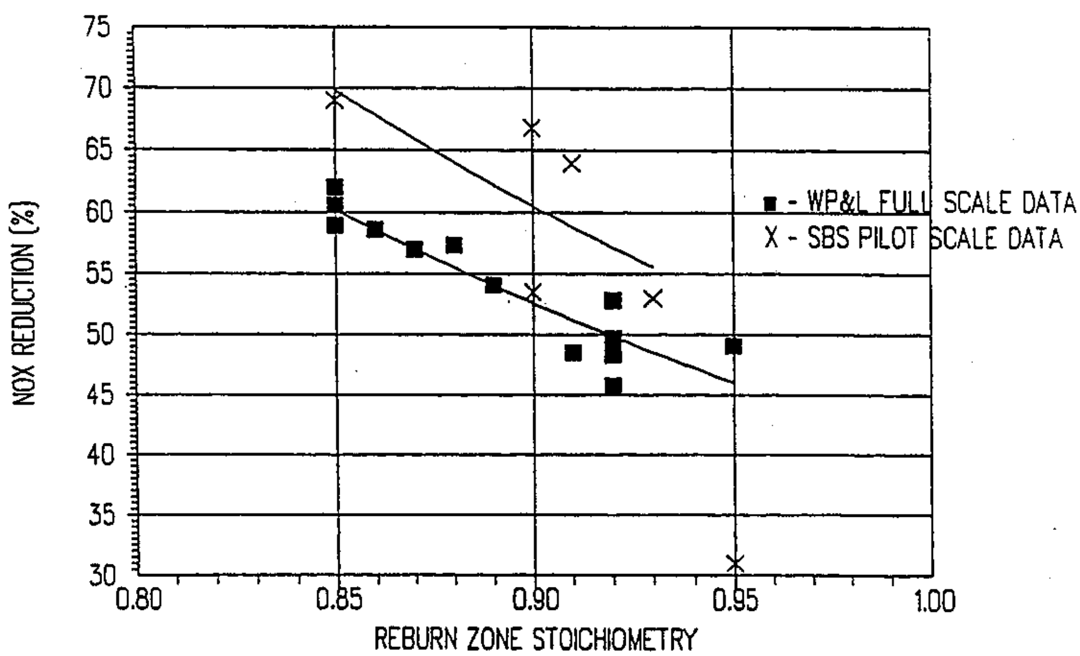


Figure 3-14 Comparison of the SBS and Nelson Dewey NO_x levels with the western subbituminous coal

Section 4

CONCLUSIONS

Based on the Babcock & Wilcox small boiler simulator (SBS) pilot-scale results and comparison of data with the full-scale Wisconsin Power & Light's Nelson Dewey Station Unit No. 2, the following conclusions can be derived:

- Reburning is a technically feasible NO_x reduction technology for cyclone boilers firing lignite.

- A 45 - 58% overall NO_x reduction was achievable in pilot-scale testing using North Dakota lignite. This overall NO_x reduction is attributed to two different mechanisms:
  - NO_x reduction in the reducing environment of the reburn zone via the reburning process
  - NO_x reduction via reduced heat input at the cyclone

- Flue gas recirculation (FGR) to the reburn burners improved the NO_x reduction capabilities at the SBS facility. The overall NO_x reduction with 10% FGR was 59.6 - 70.7% while firing the North Dakota lignite. The effect of FGR on NO_x levels has been observed in the SBS with various coals. The Nelson Dewey Station results did not show a significant effect of FGR on the NO_x levels. The effect of FGR on the NO_x levels is not clear and requires full-scale evaluation on lignite-fired cyclone boilers.

- The lower reburn zone stoichiometry provided the overall best NO_x reduction.

- SBS NO_x reduction levels were approximately 8% greater than those observed during the Nelson Dewey Station test project. The higher NO_x reduction in the SBS is attributed to better mixing between the reburn fuel and boiler gases and also possibly due to the higher baseline NO_x levels. However, SBS baseline NO_x levels during lignite firing were substantially lower than that observed while firing bituminous coal (690 ppm versus 950 ppm). Therefore, similar NO_x reduction is expected in full-scale lignite-fired cyclone boilers and the SBS if the mixing characteristics of the SBS can be duplicated.

- Combustible losses were not affected by the reburning process while firing North Dakota lignite at full-load conditions in the SBS. Unburned carbon (UBC) content of the fly ash was always below 1%.

- CO emission levels were low (less than 40 ppm) throughout the various conditions and thus should not be a problem when using the reburning process.

Section 5

RECOMMENDATIONS

- For retrofit applications, site-specific engineering and economic evaluations, will be required in order to determine the reburning technology potential.

- Improved combustion controls, including air and fuel input to cyclones, reburn burners, and overfire air (OFA) ports, are essential to the successful application of the reburning technology.

- Cyclone must operate under an oxidizing environment to minimize possible corrosion in the cyclone.

- Mixing between reburn fuel/air and cyclone gases is a key factor on the performance of the reburning system. Mixing performance of the SBS and Nelson Dewey Unit No. 2 should be considered as a minimum criteria in design of full-scale retrofits

- Utilize the SBS stoichiometries and average residence times in the design of the full-scale retrofit as a starting point. Physical and/or numerical modeling is recommended to assess/improve the mixing performance if required.

Section 6

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Appendix A

SMALL BOILER SIMULATOR (SBS)

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Based on the industry need for a pilot-scale cyclone boiler simulator, Babcock & Wilcox (B&W) designed, fabricated, and installed such a facility at its Alliance Research Center (ARC) in 1985. The project involved conversion of an existing pulverized coal-fired facility to be cyclone-firing capable. Additionally, convective section tube banks were installed in the upper furnace in order to simulate a typical boiler convection pass. The small boiler simulator (SBS) is designed to simulate most fireside aspects of full-size utility boilers such as combustion and flue gas emissions characteristics, fireside deposition, etc.

Simulation Criteria

Prior to the design of the pilot-scale cyclone boiler simulator, the various cyclone boiler types were reviewed in order to identify the inherent cyclone boiler design characteristics which are applicable to the majority of these boilers. The cyclone boiler characteristics that were reviewed include NO_x emissions, furnace exit gas temperature (FEGT), carbon loss, and total furnace residence time. Previous pilot-scale cyclone-fired furnace experience identified the following concerns:

- Operability of a small cyclone furnace (e.g., continuous slag tapping capability).

- The optimum cyclone(s) configuration for the pilot-scale unit was debated. Commercial cyclone boiler systems can include front-wall fired, opposed-wall fired, and single or multiple cyclone elevations. In addition, there are different cyclone burner and cyclone furnace designs presently in operation.

- Compatibility of NO_x levels, carbon burnout, cyclone ash carryover to the convection pass, cyclone temperature, furnace residence time, and FEGT. Due to the various sizes/types/fuels burned, commercial cyclone units operate within a large range of combustion and pollutant conditions.

Originally, an opposed-wall fired, cyclone design was proposed, based on the large number of cyclone utility boilers falling into this design category. Using this as the design basis for the pilot-scale unit would involve having two 3-million Btu/hr cyclones. A review of past experience revealed that the smallest cyclone ever designed/operated was 10-million Btu/hr. Based on this and coupled with concerns about fabrication and slag tap operation (due to size), it was decided to proceed with designing a single 6-million Btu/hr cyclone to accommodate the SBS facility.

this review, a range of residence times was generated in order to bracket the general cyclone boiler population. Generally, the study showed that single-wall-fired cyclone units contain furnace residence times on the lower side of the general population range. Although this is true, the majority of single-wall fired units do have sufficient residence time available for the reburning technology. Thus, the SBS cyclone design criteria was to simulate the geometry of B&W's commercially operated, single-wall-fired cyclone boiler type. In addition, the SBS furnace was insulated in order to achieve a comparable flue gas time/temperature relationship to actual field operating experience.

Pilot-Scale Furnace Facility Description

B&W's 6-million Btu/hr small boiler simulator (Figure 1) was utilized to perform the pilot-scale cyclone reburning tests. The SBS is fired by a single, scaled-down version of B&W's cyclone furnace. Coarse pulverized coal (44% through 200 mesh), carried by primary air, enters tangentially into the burner. (Pulverized coal had to be utilized in the SBS instead of crushed coal in order to obtain complete combustion in this small cyclone.) Preheated combustion air at 700°F enters tangentially into the cyclone furnace. The larger coal particles are captured and burn in the molten slag layer formed within the cyclone furnace, while the finer particles burn in suspension. The mineral matter melts, exits the cyclone furnace from the tap at the cyclone throat, and is dropped into a water-filled slag tank. Only 15 - 20% of the ash leaves the cyclone with the flue gases and enters the main furnace.

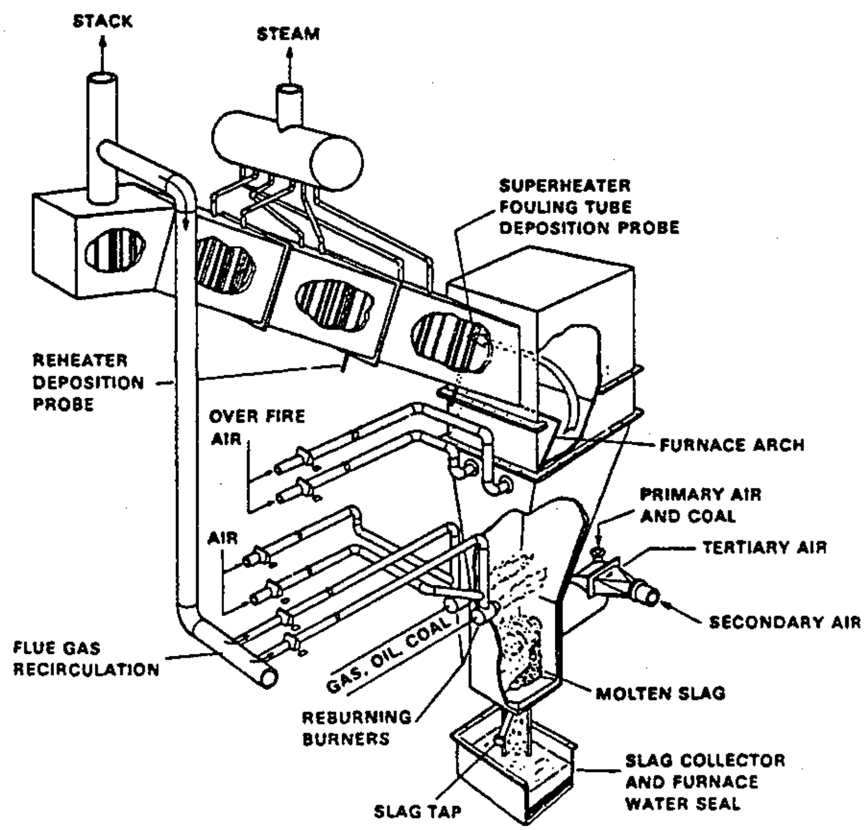


Figure 1 Small Boiler Simulator (SBS) Facility

Figure 2 SBS Reburning Burners and Associated Piping Location

Appendix B

LIGNITE-FIRED CYCLONE BOILER OPERATIONAL CONDITIONS

	MR Young U2 Data	Coyote Data	LOS Data	Test Parameters
Cyclone Coal Rlow Rate (Lift Line)	95–96%	96.5%	98%	96.5%
Cyclone Coal Feed Particle Size Distribution	12%–200 Mesh	N/A	16%–200 Mesh	14%–200 Mesh
Primary Air Flow Rate	10–12%	15%	11–15%	13%
Secondary Air Flow Rate	70–75%	75%	65–75%	70%
Secondary Air Temperature	720–750 Deg. F	720 Deg. F	650–750 Deg. F	720 Deg. F
Tertiary Air Flow Rate	0.5–1%	5%	1–2%	2%
Cyclone Excess Oxygen	2% O2	N/A	2–3% O2	2% O2
Vent Line Coal Flow Rate	4–5%	3.5%	2%	3.5%
Vent Line Coal Moisture Content	6–7%	16.5%	20–23%	15%
Vent Line Coal/Air Temperature	140 Deg. F	140 Deg. F	120 Deg. F	140 Deg F.
Vent Line Static Pressure	2–4"H2O	1" H2O	–1" to +3" H2O	1.5" H2O
Vent Line Coal Fineness	95%–325 Mesh	98%–200 Mesh	86%–200 Mesh	95%–200 Mesh
Vent Line Air Flow Rate	12–14 %	15%	15–19%	15%
Fuel Conditioner Discharge Line	N/A	N/A	N/A	N/A
Static Pressure & Temperature	270–300 Deg. F	140 Deg. F	120 Deg. F	140 Deg. F
Gas Temperaing/Recirculation Flow Rate	33–40%	1.4 MLB/HR All Loads GT/GR – 50/50 varies w/ FEGT & MS Temp	1.3 MLB/HR–Full Load 600 KLB/HR–Half Load	1.4 MLB/HR–Full Load 600 KLB/HR–Half Load
Temperature vs Load	670–700 Deg. F	650 Deg. F @ 400 550 Deg. F @ 280	580 Deg. F–Full Load 440 Deg. F–Half Load	650 Deg. F–Full Load 550 Deg. F–Half Load
Furnace Exit Gas Temperature (FEGT)	1780–1850 Deg. F	1850 Deg. F @400	1750–1850 Deg. F	1850 Deg. F
Furnace Pressure at the Vent Line Elevation vs Load	0"+–0.2" H2O	–0.5" H2O	0" to –0.5" H2O	0" H2O
Economizer Outlet Oxygen (%) vs Load	3.8–4.0 %	3.2% @ 400 4.5% @ 280	4%–FULL LOAD 6%–Half Load	3.8%–Full Load 5%–Half Load
Air Heater Outlet (Air) Pressure vs Load	42–44" H20	46" H2O	40–42" H2O	44" H2O
Air Heater Outlet (Air) Temperature vs Load	720–750 Deg.	725 Deg. F	650 Deg. F–Full Load 550 Deg. F–Half Load	700 Deg. F–Full Load 550 Deg. F–Half Load
Unburned Combustibles/NOx/CO Data vs Load	0.6–2% LOI	1.5% LOI	2% LOI	1.5% LOI
Secondary Superheater/Reheater Attemperator	0–Clean	250 KLB/HR–SSH	10 KLB/HR–SSH	10 KLB/HR–SSH
Spray Flow Rates vs Load (Dirty vs Clean)	0–Dirty	0 KLB/HR–RSH	5 KLB/HR–RSH	5 KLB/HR–RSH
Fly Ash/Slag Split	45% Fly Ash 55% Bot. Ash	50% Fly Ash 50% Bot. Ash	40% Fly Ash 60% Bot. Ash	45% Fly Ash 55% Bot. Ash

Appendix C

PARTICLE SIZE DISTRIBUTION OF DECKER COAL AND NORTH DAKOTA LIGNITE

C-21128, PULVERIZED COAL
FROM BELT, 2/2/93 @
0500 HRS.

MICRONS	% LESS	DIFF
4800.00		
3394.11		
2400.00	100.00	.65
1697.06	99.35	.49
1200.00	98.86	1.76
848.53	97.10	1.31
600.00	95.79	3.87
424.26	91.92	2.74
300.00	89.18	4.41
212.13	84.77	5.99
150.00	78.78	9.69
106.07	69.09	13.13
75.00	55.96	11.64
53.03	44.32	10.84
37.50	33.49	8.90
26.52	24.59	6.34
18.75	18.25	4.94
13.26	13.31	5.38
9.38	7.93	2.91
6.63	5.02	1.44
4.69	3.58	1.37
3.31	2.20	.88
2.34	1.32	.45
1.66	.87	.37
1.17	.50	.28
.83	.22	.16
.59	.06	.06
.41	.00	.00
.29		
.21		
.15		

CS(CAL SURF AREA)= .27 M**2/CM**3
MMD(D43)=142.57 MICRONS
SMD(D32)= 22.51 MICRONS

C-21087, PULVERIZED COAL,
12/8/92 @ 1645 HRS., DECKER
COAL SUB-BITUMINOUS-WESTERN,
BELT OF WEIGH FEEDER(POST CAL)

MICRONS	% LESS	DIFF
4800.00		
3394.11		
2400.00		
1697.06		
1200.00	100.00	.17
848.53	99.83	.13
600.00	99.70	.23
424.26	99.47	.17
300.00	99.30	.30
212.13	99.00	.70
150.00	98.30	3.21
106.07	95.09	10.90
75.00	84.18	17.92
53.03	66.26	17.72
37.50	48.54	13.14
26.52	35.40	12.17
18.75	23.23	7.40
13.26	15.83	5.36
9.38	10.47	4.77
6.63	5.70	2.74
4.69	2.96	1.50
3.31	1.45	.74
2.34	.72	.30
1.66	.41	.24
1.17	.18	.14
.83	.04	.04
.59	.00	.00
.41		
.29		
.21		
.15		

CS(CAL SURF AREA)= .30 M**2/CM**3
MMD(D43)= 49.38 MICRONS
SMD(D32)= 20.26 MICRONS

C-21118, BASIN ELECTRIC/
ARC SBS PILOT, AS FIRED
LIGNITE, 1/11/93 @ 1500 HRS.,
BASELINE TEST

MICRONS	% LESS	DIFF
4800.00		
3394.11		
2400.00	100.00	.01
1697.06	99.99	.00
1200.00	99.99	.22
848.53	99.77	.17
600.00	99.60	1.00
424.26	98.60	.70
300.00	97.90	9.67
212.13	88.23	12.39
150.00	75.83	12.29
106.07	63.55	17.42
75.00	46.13	10.46
53.03	35.67	9.39
37.50	26.29	7.55
26.52	18.74	3.00
18.75	15.74	6.77
13.26	8.97	1.55
9.38	7.42	1.94
6.63	5.48	3.07
4.69	2.41	1.10
3.31	1.31	.58
2.34	.73	.30
1.66	.43	.22
1.17	.22	.15
.83	.07	.06
.59	.01	.01
.41	.00	.00
.29		
.21		
.15		

CS(CAL SURF AREA)= .21 M**2/CM**3
MMD(D43)=105.73 MICRONS
SMD(D32)= 28.45 MICRONS

Appendix D

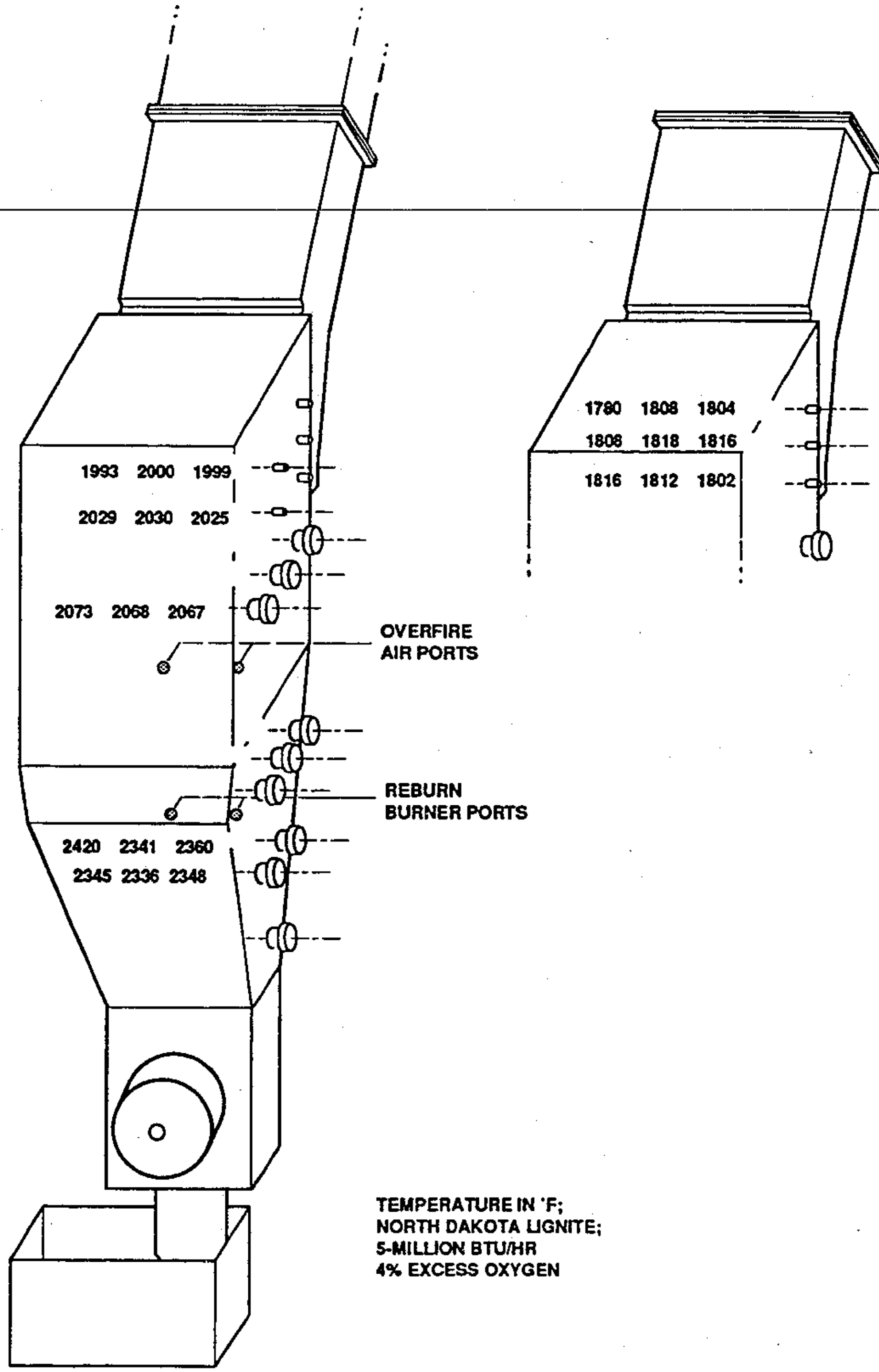
PARAMETRIC LIGNITE REBURNING EVALUATION RESULTS

Parametric Lignite Reburning Evaluation Results

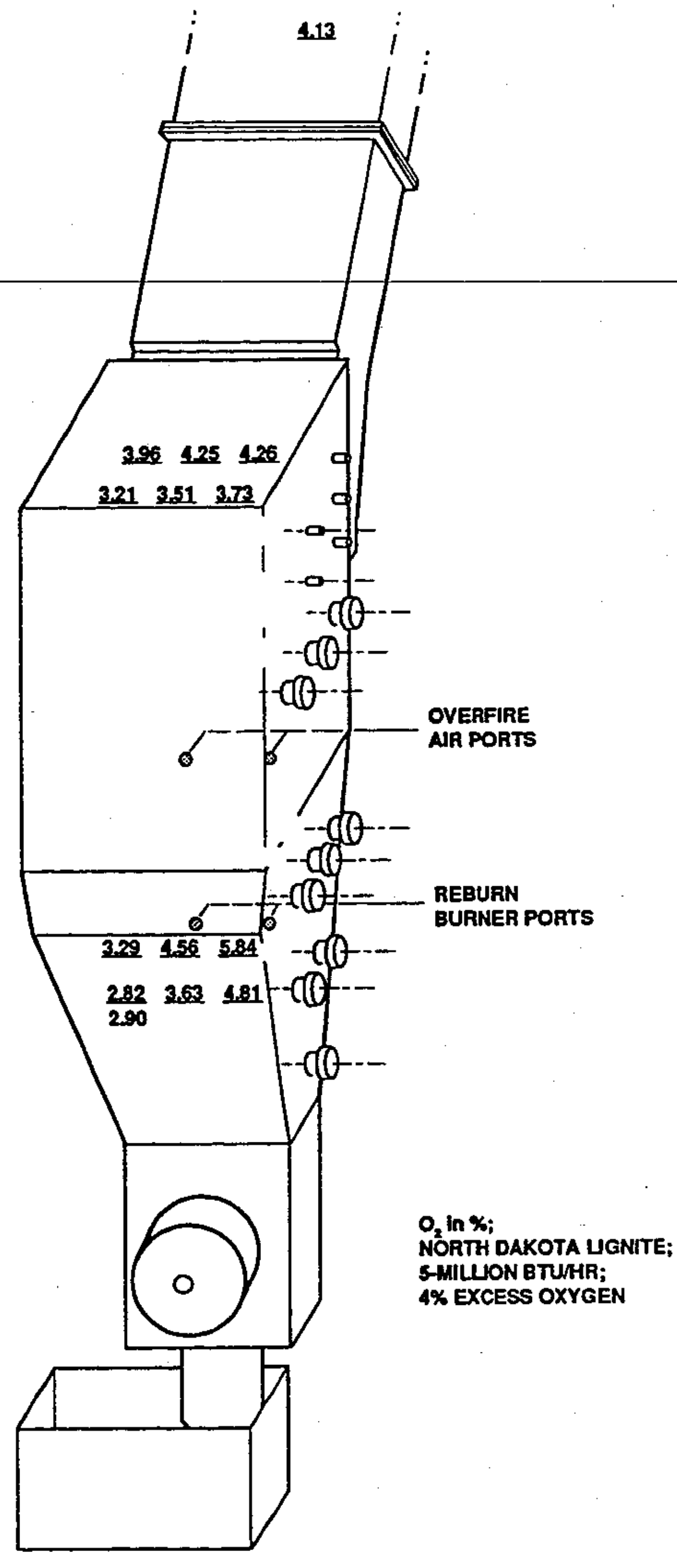
Test No.	Coal	Load	O2	NOx	NOx @ 3%	CO	C	SO2	CO2	SA Temp	Stoichiometries Cyclone	Reb. burner	Reb. Zone	Reb. Fuel	FGR	FEGT
		MBtu/hr	%	PPM	O2 PPM	PPM	%	PPM	%	F				% of Total	%	F
WB52	Deckor	5.02	2.8	610	602	34		269	16.27	678	1.15	N/A	1.15	0	0	
WB53	Deckor	5.00	3.3	699	710	14	0.98	238	15.69	645	1.17	N/A	1.17	0	0	2003
WB52R	Deckor	4.85	2.2	767	736	24		295	16.57		1.11	N/A	1.11	0	0	
WB54R	Deckor	5.03	4.2	740	791	20		246	14.84		1.25	N/A	1.25	0	0	
WB53RR	Deckor	5.00	3.2	797	804	27		215	15.96	672	1.17	N/A	1.17	0	0	
WB53RRR	Deckor	4.89	3.1	825	828	26		174	15.74	705	1.17	N/A	1.17	0	0	
WB54	Deckor	4.99	4.1	778	829	27	1.5	275	14.9	660	1.25	N/A	1.25	0	0	
WB43	Deckor	4.04	3.0	717	717	22		205	15.92	663	1.16	N/A	1.16	0	0	
WB33	Deckor	3.72	3.0	717	718	20	0.77	174	15.69	700	1.16	N/A	1.16	0	0	
WRB4sr1	Deckor	4.1	3.5	263	270	23	0.26	196	15.67	684	1.06	0.43	0.86	26.36	0	1927
WRB5sr3	Deckor	5.1	2.9	244	242	26	0.37	196	16.38	686	1.1	0.37	0.85	34.8	0	2132
WRB5sr1	Deckor	5.0	3.0	259	259	27	0.36	173	16.16	680	1.11	0.38	0.9	29.06	0	
WRB5sr1R	Deckor	5.1	3.1	362	363	25		213	16.05	663	1.1	0.4	0.9	26.33	0	2061
WRBer1rr	Deckor	5.0	3.2	362	367	29		188	15.96	679	1.15	0.39	0.93	29	0	1986
WRB5sr2	Deckor	5.2	2.9	542	539	25	0.21	186	16.08	700	1.08	0.44	0.95	21.45	0	2039
WRB6sr1	Deckor	5.8	3.8	410	429	30	0.26	157	15.07	665	1.14	0.44	0.93	29.77	0	2125
WRBFGR1	Deckor	4.9	3.1	276	279	27	0.24	169	16.09	698	1.12	0.42	0.91	29.16	5.05	1934
WRBFGR2	Deckor	4.9	2.9	260	259	37					1.12	0.41	0.91	29.23	9.34	
LB44	Lignite	3.6	4.4	435	471	29	0.42	1134	14.97	649	1.06	N/A	1.26	3.39		
LB55	Lignite	4.97	5.2	621	707	37	0.43	1269	14.07	656	1.16	N/A	1.32	3.56		1675
LB53	Lignite	5.0	3.3	591	602	36	0.3	1244	15.57	672	1.06	N/A	1.18	3.58		1924
LB54R	Lignite	5.03	4.1	594	633	38		1415	14.98	676	1.1	N/A	1.24	3.48		1976
LB54RR	Lignite	5.1	4.1	721	769	29		1540	15.28	674	1.12	N/A	1.24	3.52		1807
LB54	Lignite	5.1	4.2	760	813	24	0.23	1517	15.07	698	1.09	N/A	1.24	3.18		
LB54R4	Lignite	5.2	4.0	670	709	27					1.11	N/A	1.32	3.45		
LB54R3	Lignite	5.2	4.0	693	734	36					1.1	N/A	1.32	3.45		
BD11501	Lignite	5.2	4.1	619	659	23	0.2	1100	15.76	679	1.1	N/A	1.24	3.48		1657
BD11402	Lignite	5.3	3.6	645	675	33	0.22	1241	15.64	682	1.06	N/A	1.22	3.36		1609
BD11401	Lignite	5.01	4.3	609	656	36		1385	14.98	686	1.12	N/A	1.23	3.56		1790
BD11404	Lignite	5.2	4.1	643	686	27		1050	15.45	679	1.11	N/A	1.24	3.42		1652
BD11502	Lignite	5.1	3.9	660	696	24		1026	15.11	690	1.1	N/A	1.23	3.51		1679
BD11403	Lignite	5.23	3.45	614	630	28		1089	15.72	673	1.06	N/A	1.19	3.41		
LB64	Lignite	5.7	4.1	707	754	27		1394	15.11	656	1.13	N/A	1.25	3.84		
LRB5SR1	Lignite	5.09	2.98	331	331	29	0.23	1138	15.96	683	1.08	0.43	0.89	26.65	0	1609
LRB5SR1R	Lignite	5.06	3.21	343	347	37				684	1.08	0.45	0.9	26.01	0	
LRB5SR1FGF	Lignite	5.1	3.13	289	291	33	0.2	1029	15.86	670	1.08	0.44	0.9	27.8	10.51	1768
LRB5SR2	Lignite	5.14	2.88	290	288	29	0.26	1002	16.41	668	1.07	0.45	0.86	33.41	0	1828
LRB5SR2FGF	Lignite	5.41	2.9	234	233	45	0.42	1032	16.21	676	1.08	0.44	0.87	32.03	9.34	1801
LRB5SR2NAF	Lignite	5.45	2.7	205	202	54		1002	16.31		1.08	0.34	0.85	31.61	9.68	
LRB5SR3FGF	Lignite	5.07	3.0	279	279	33	0.7	927	16.11	665	1.09	0.39	0.93	22.36	9.86	1777
LRB5SR3	Lignite	5.17	3.1	360	362	22		1002	16.23	674	1.09	0.45	0.95	21.94		1625
LRB6SR1	Lignite	5.72	2.91	325	323	30		1022	16.02	664	1.09	0.44	0.91	27.73		1907
LRB6SR1GT	Lignite	5.7	3.17	348	348	26		927	16.02		1.1	0.43	0.91	27.53	20.6	1763
LRB3.5SR1	Lignite	3.44	6.4	252	311	23		561	13.02	738	1.11	0.47	0.93	28.99	0	
LRB3SR1	Lignite	2.98	7.52	227	303	18		580	11.65	731	1.12	0.49	0.93	30.65	0	
LRB4SR1	Lignite	4.08	3.95	327	345	170				733	1.08	0.46	0.92	27.47	0	
LRB501	Lignite	5.28	2.81	369	365	31		926	16.71	672	1.06	0.42	0.9	27.06	0	1820
LRB502	Lignite	5.3	2.89	302	300	85		1168	16.54	696	1.07	0.43	0.9	26.97	0	1804
LRB502A	Lignite	5.06	3.16	347	350	40		1223	16.24	661	1.11	0.42	0.91	26.21	0	
LRB503	Lignite	5.29	3.36	339	346	36		1251	16.04	674	1.09	0.43	0.91	27	0	1692
LRB503A	Lignite	5.22	3.18	340	343	30		1139	16.19	665	1.1	0.43	0.92	27.38	0	
LRB504	Lignite	5.09	3.45	285	292	24		1176	15.78	696	1.14	0.41	0.94	26.06	0	1909
LRB504B	Lignite	5.25	2.82	356	352	75		1006	15.85	690	1.06	0.42	0.9	27.19	0	

Appendix E

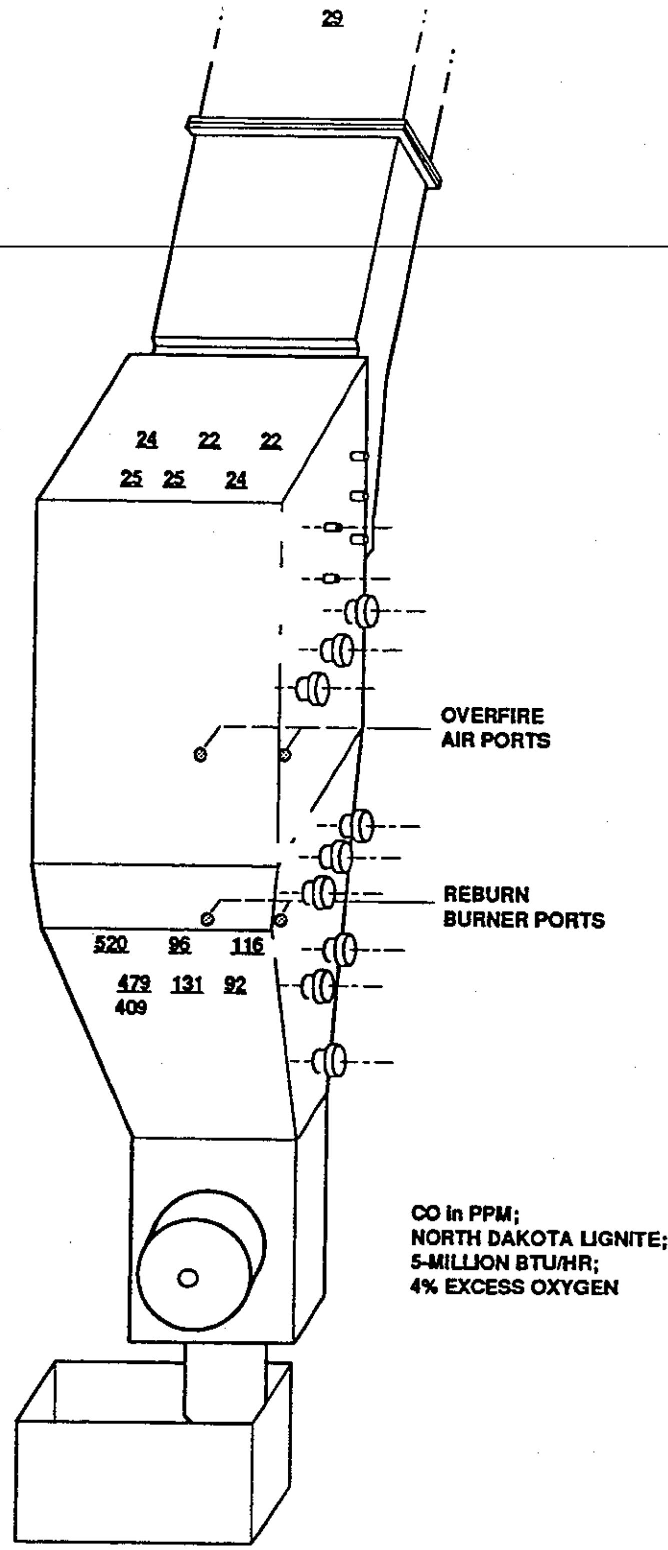
IN-FURNACE PROBING DATA



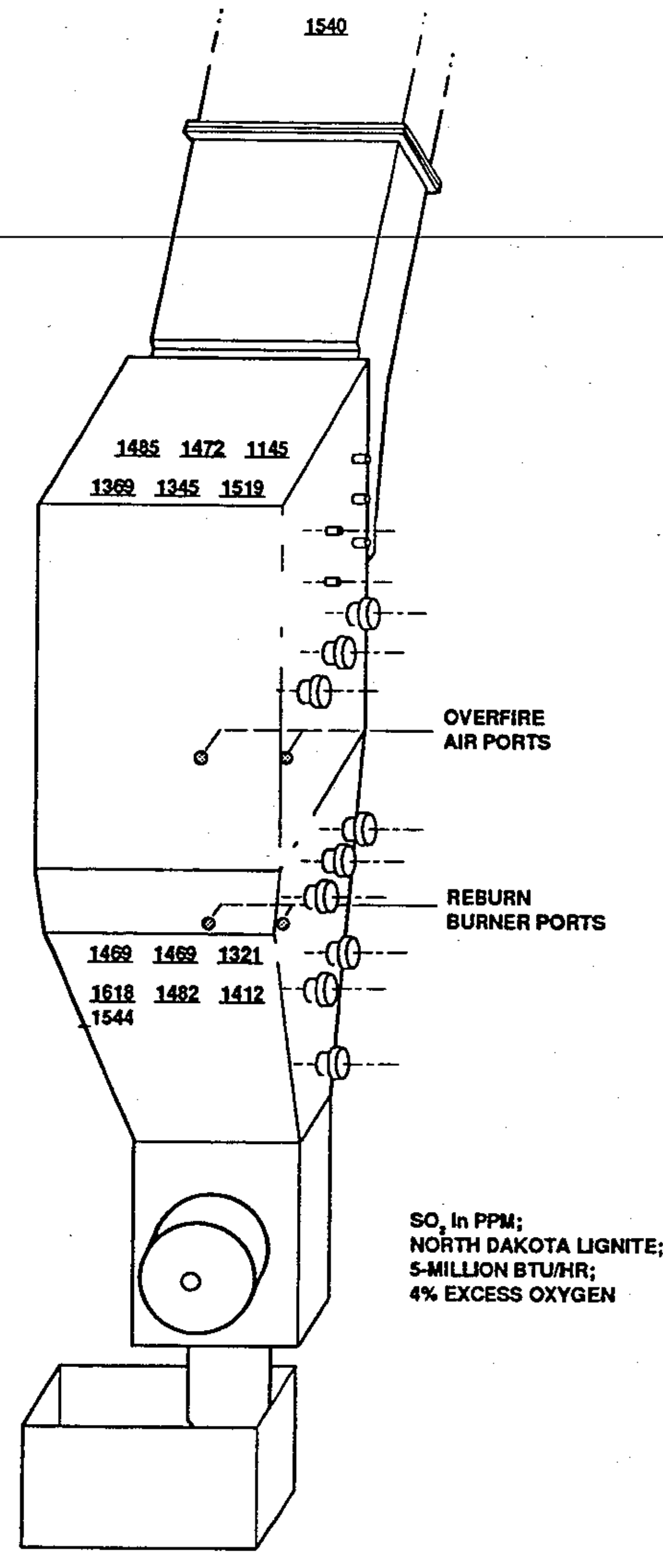
IN-FURNACE TEMPERATURE LEVELS – BASELINE CONDITIONS



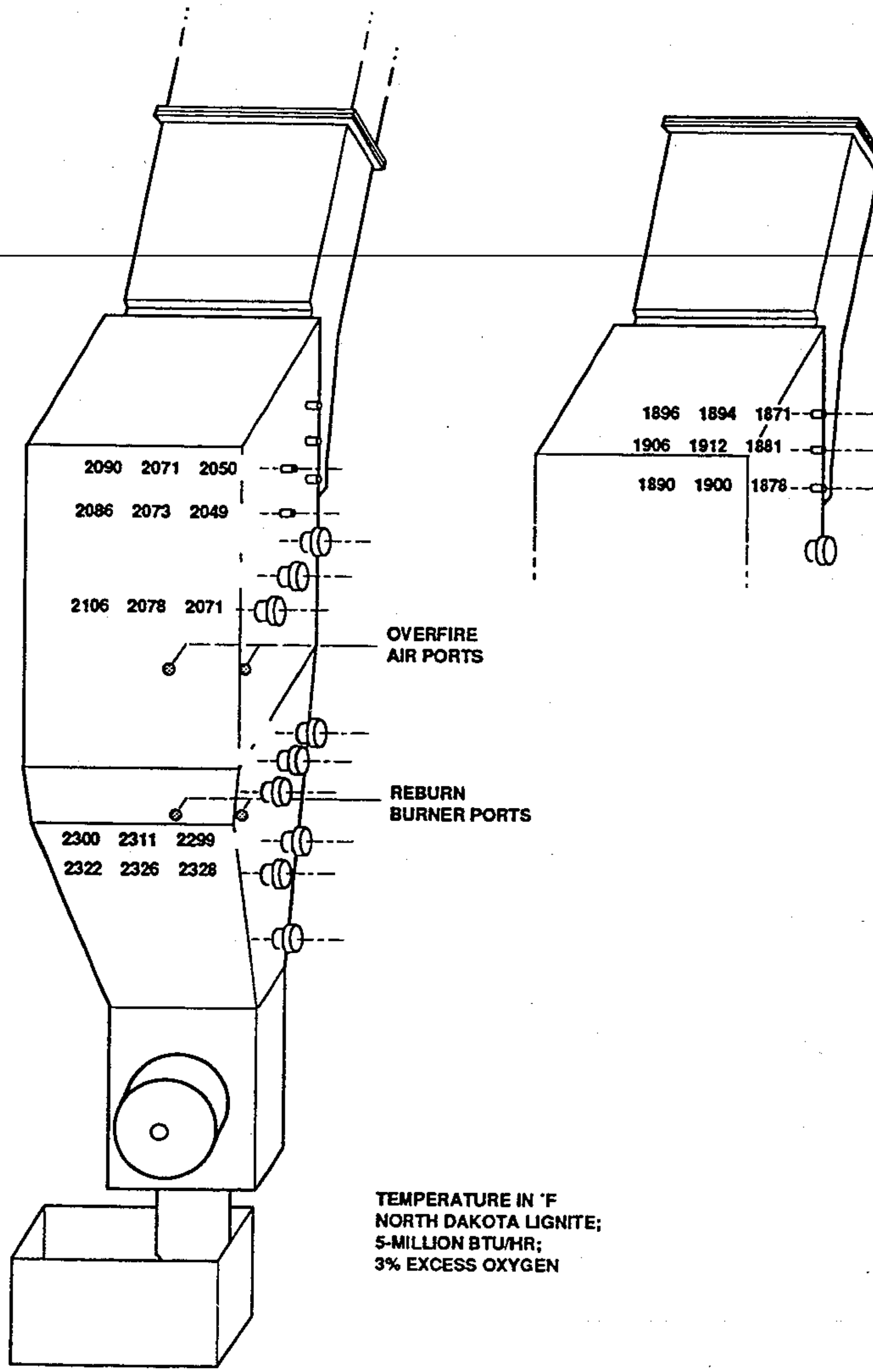
IN-FURNACE O_2 LEVELS – BASELINE CONDITIONS



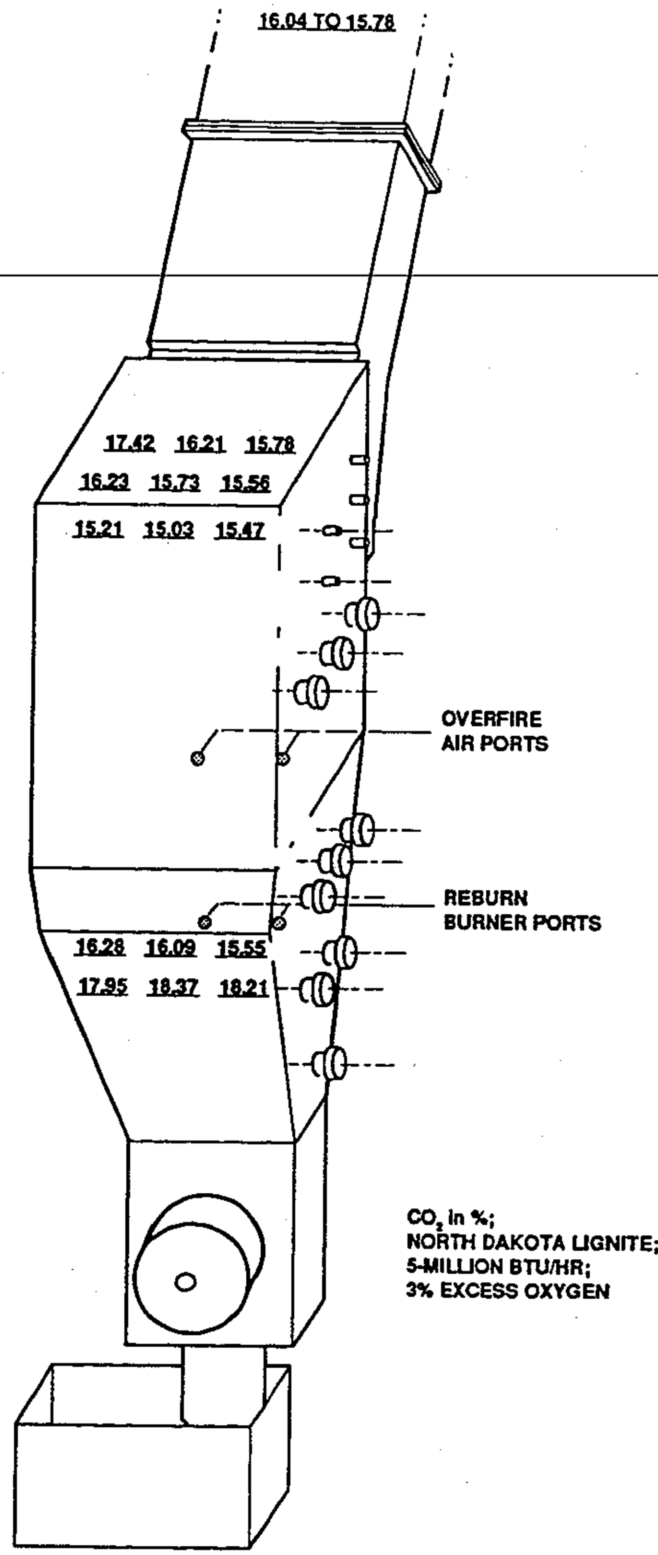
IN-FURNACE CO LEVELS – BASELINE CONDITIONS



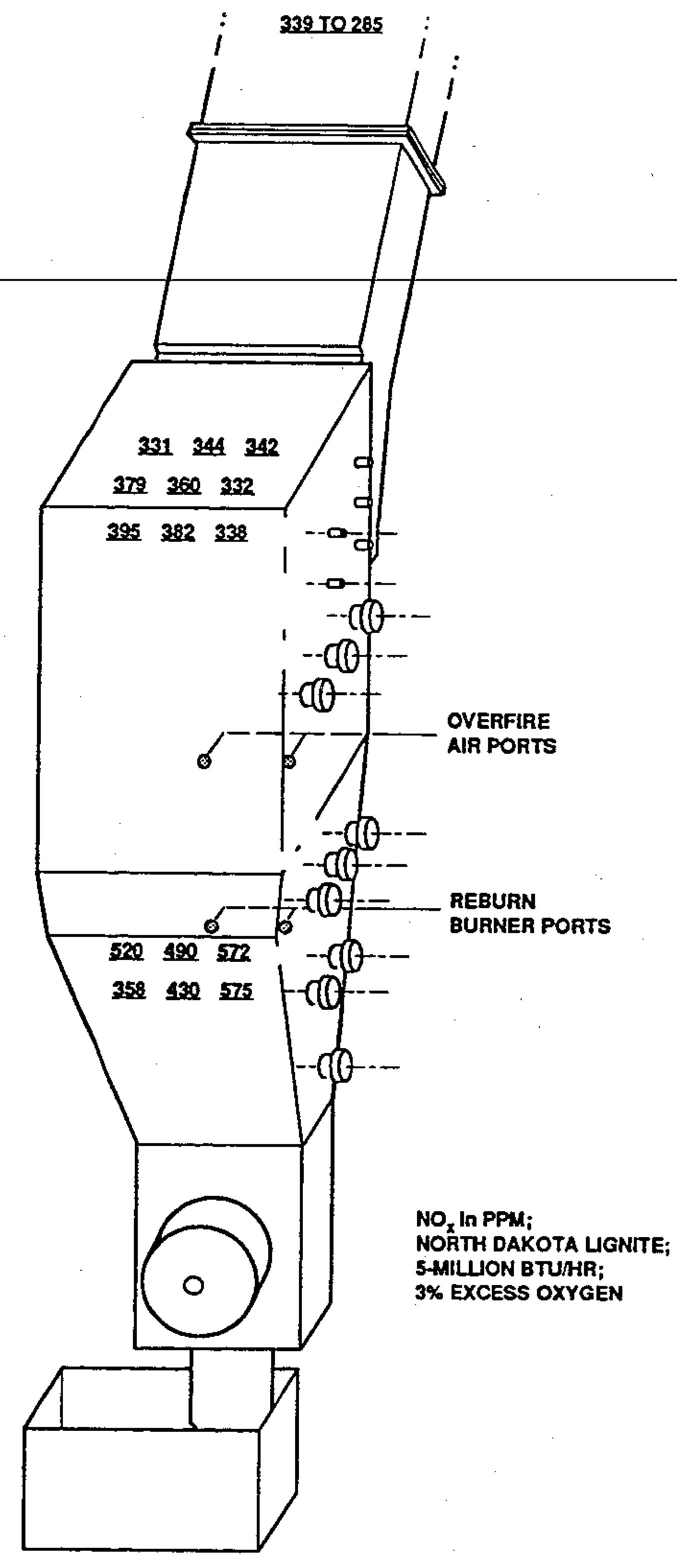
IN-FURNACE SO_2 LEVELS – BASELINE CONDITIONS



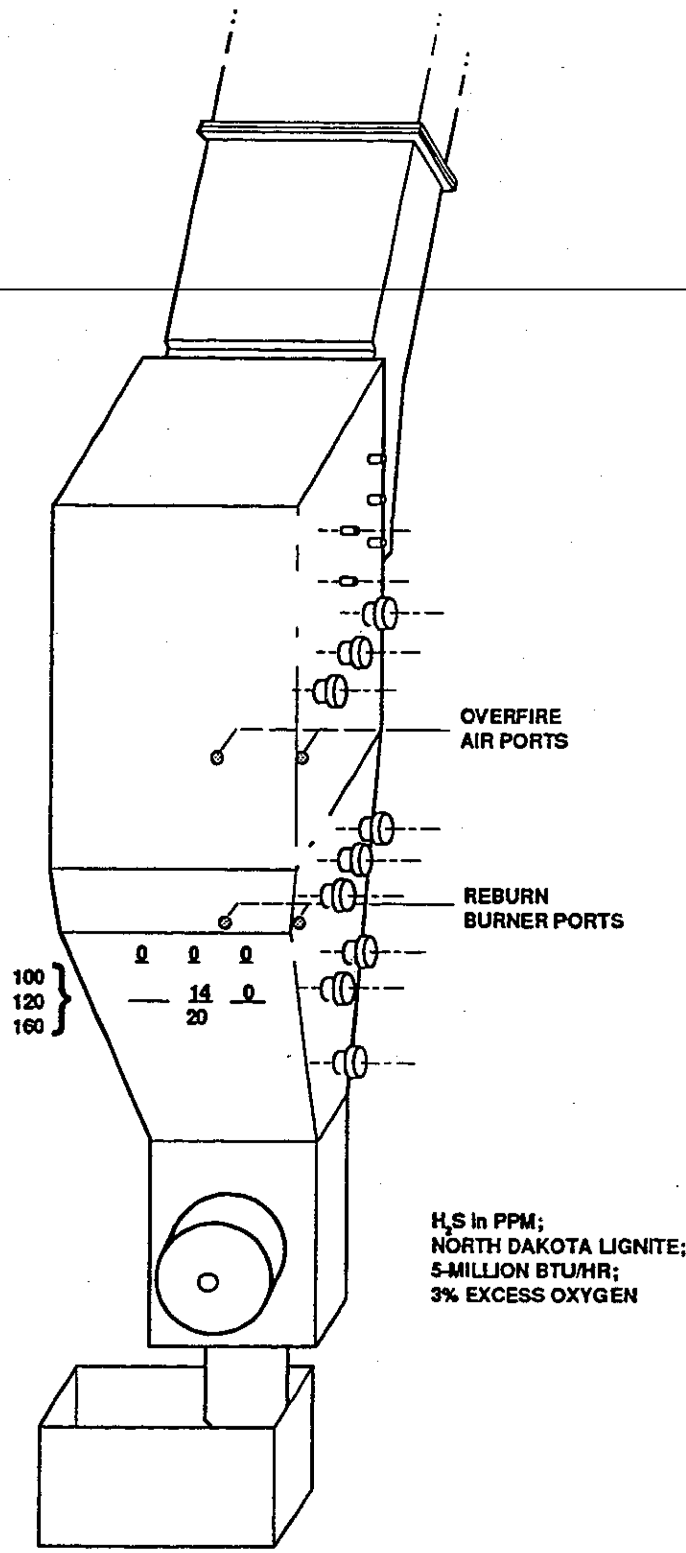
IN-FURNACE TEMPERATURE LEVELS – REBURNING CONDITIONS



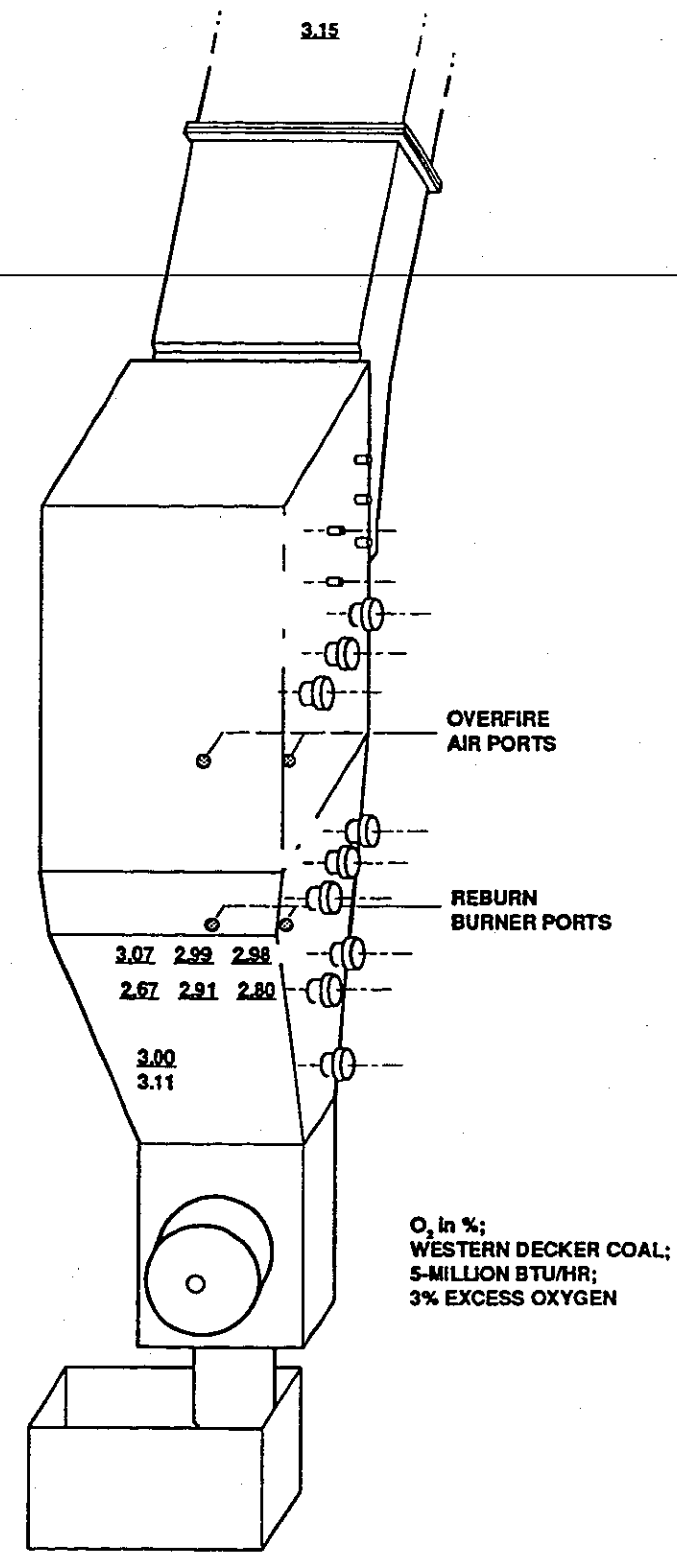
IN-FURNACE CO_2 LEVELS – REBURNING CONDITIONS



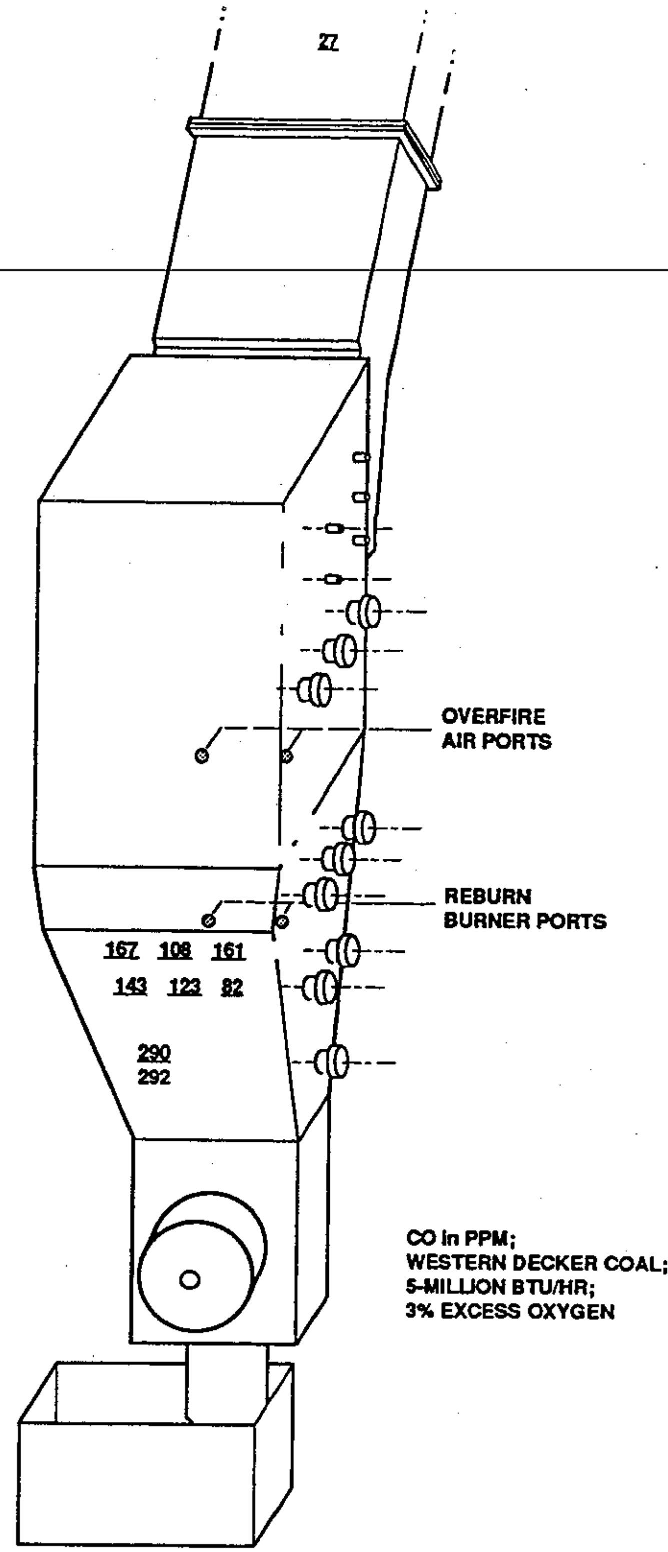
IN-FURNACE NO_x LEVELS – REBURNING CONDITIONS



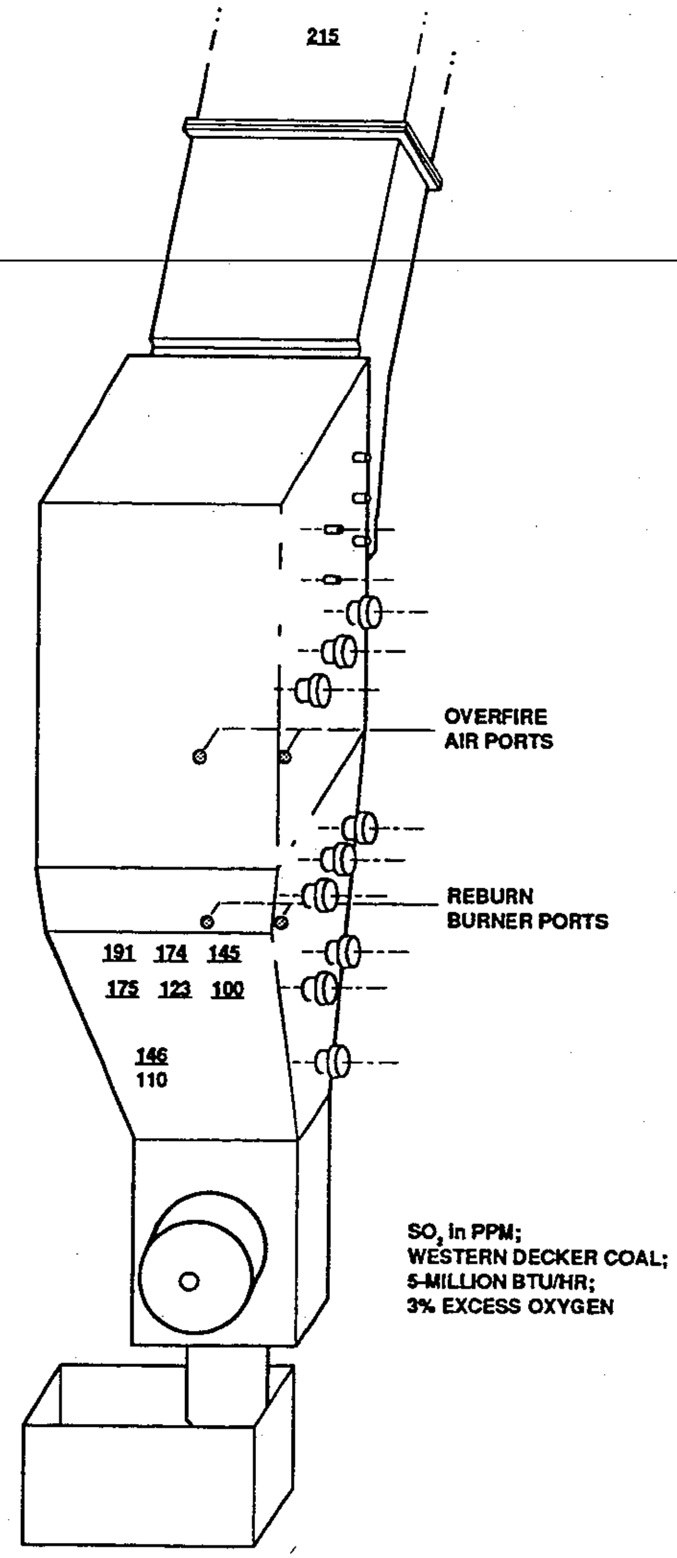
IN-FURNACE H_2S LEVELS – REBURNING CONDITIONS



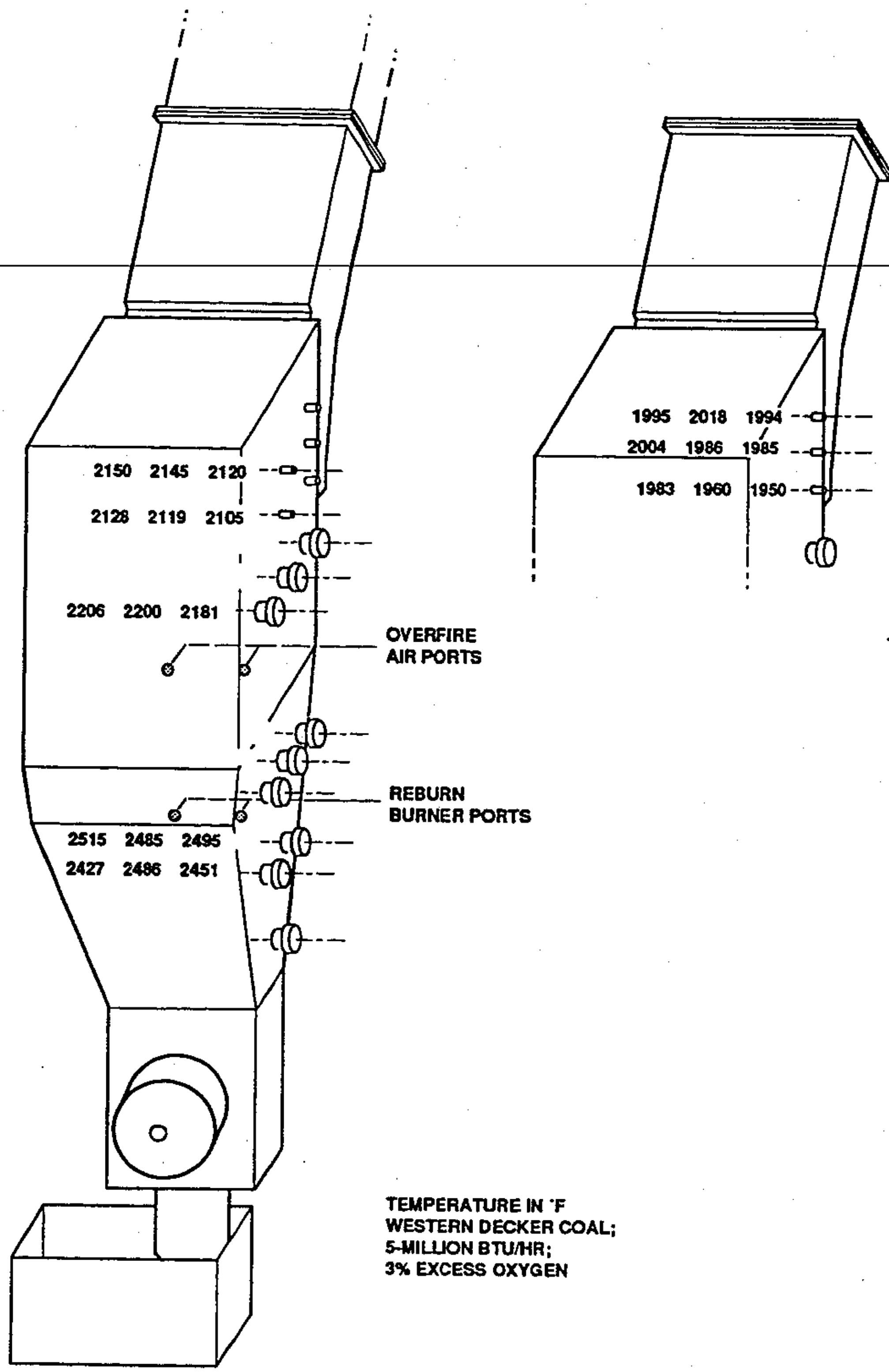
IN-FURNACE O_2 LEVELS – BASELINE CONDITIONS



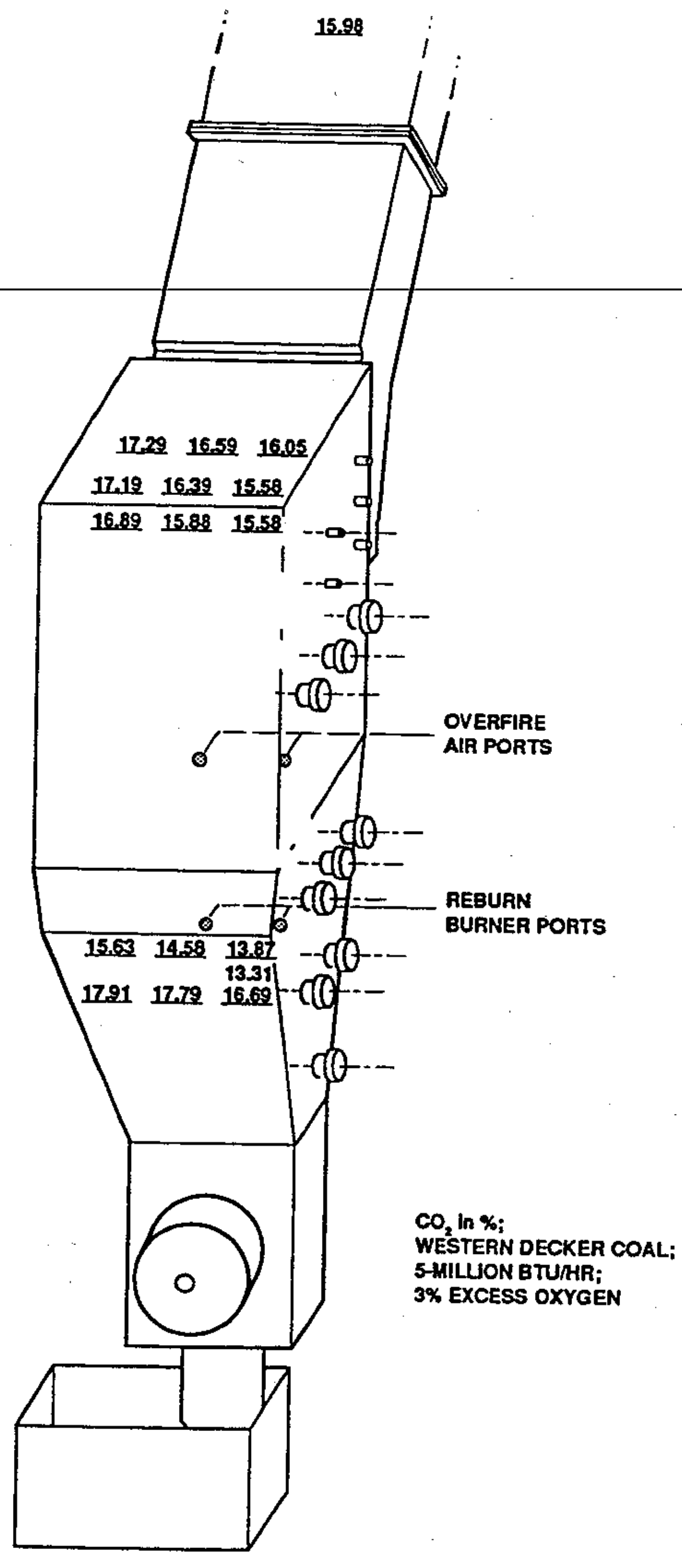
IN-FURNACE CO LEVELS – BASELINE CONDITIONS



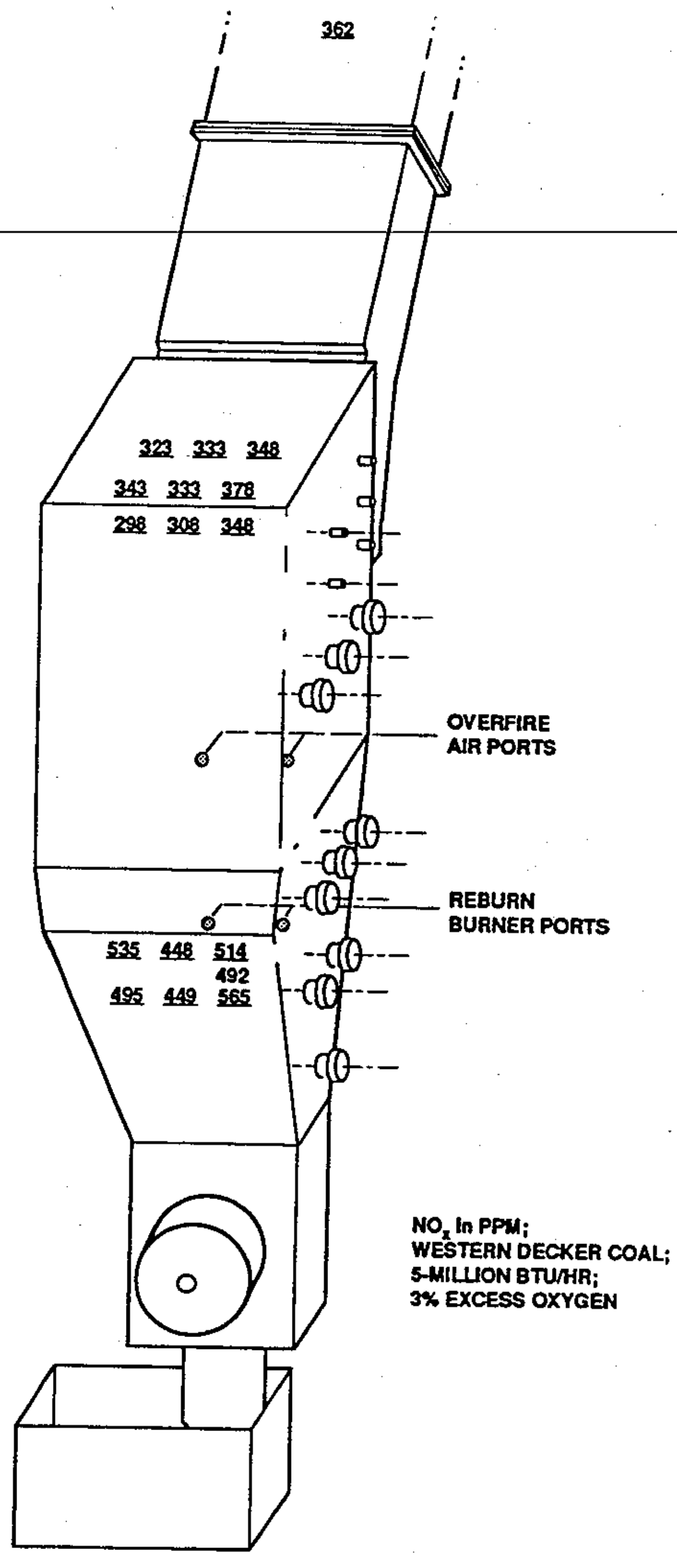
IN-FURNACE SO_2 LEVELS – BASELINE CONDITIONS



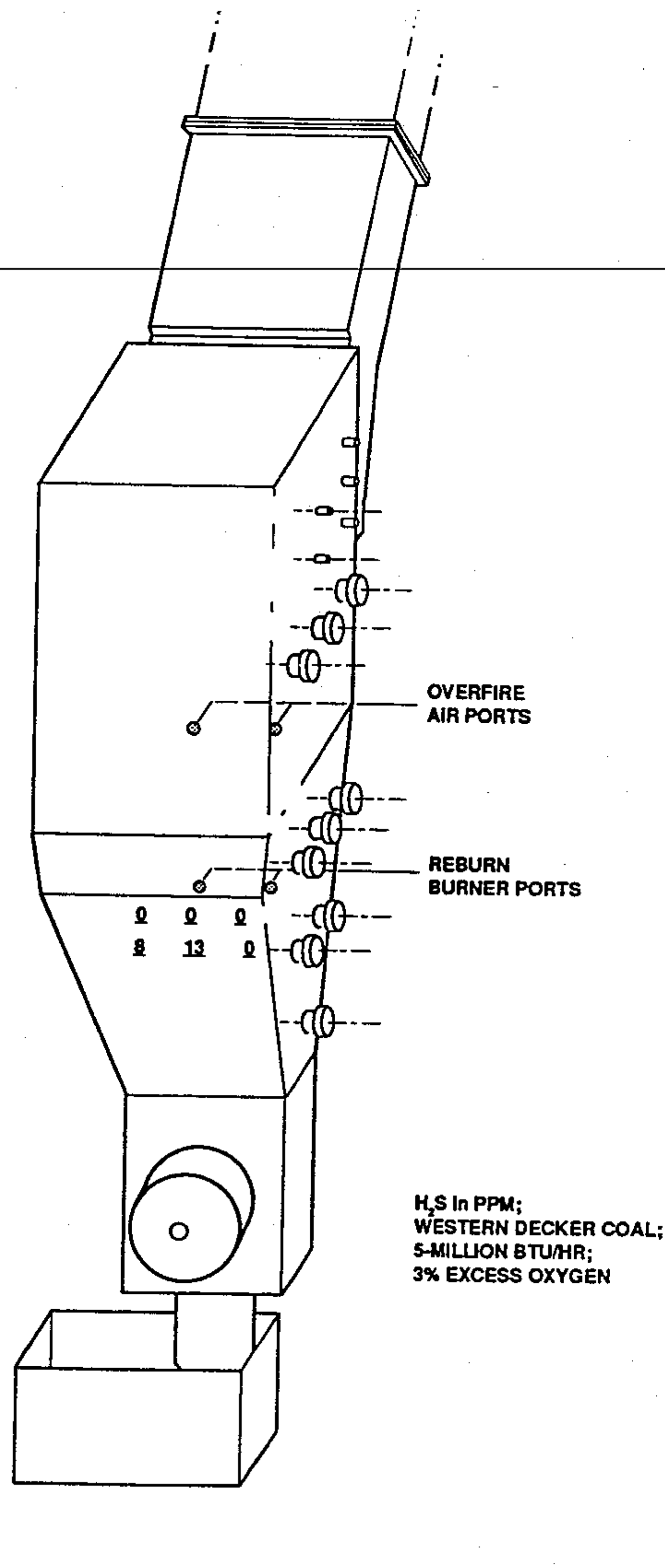
IN-FURNACE TEMPERATURE LEVELS – REBURNING CONDITIONS



IN-FURNACE CO_2 LEVELS – REBURNING CONDITIONS



IN-FURNACE NO_x LEVELS – REBURNING CONDITIONS



IN-FURNACE H_2S LEVELS – REBURNING CONDITIONS

APPENDIX NO. 4

Nelson Dewey In-Furnace Gas Species and Temperature Measurements

- Baseline/Reburning In-Furnace Probing Data at 110 MW
- Baseline/Reburning In-Furnace Probing Data at 82 MW

BASELINE/REBURNING IN-FURNACE MEASUREMENTS AT 110 MW

Wisconsin Power & Light
Nelson Dewey Station Cyclone Reburn
In-furnace Probing Elevation 700

Test ID: 2B
Condition: Post-retrofit baseline
110 MW

Temperatures F

Rearwall

AVG: 2246

2297	2285	2263	2277	2258	2223	2097	2071	2294	2318	2323

LHSW **RHSW**

AVG: 2269

	2266	2276	2327	2313	2279	2298	2249	2225	2239	2222

Averaged Economizer Outlet Data

O_2	3.5
CO @3% O_2	70
NO_x @3% O_2	603

Frontwall

Test ID: 20T
Condition: Reburning - 110 MW
GR fan on/GR to BNR
optimized secondary air

Temperatures F

Rearwall

AVG: 2087

1973	2054	2037	2013	2010	2032	2088	2110	2124	2161	2241

LHSW **RHSW**

AVG: 2190

1989	2125	2174	2197	2234	2237	2206	2246	2244	2230	2203

Averaged Economizer Outlet Data

O_2	3
CO @3% O_2	77
NO_x @3% O_2	270

Frontwall

Test ID: Similar to 8P
Condition: Reburning - 110 MW
GR fan on/GR to BNRS
optimized secondary air

Temperatures F

Rearwall

AVG: 2203

1957	2098	2125	2132	2153	2227	2282	2315	2333	2412	

LHSW **RHSW**

AVG: 2217

2078	2108	2162	2215	2266	2266	2253	2258	2279	2284	

Averaged Economizer Outlet Data

O_2	2.84
CO @3% O_2	81
NO_x @3% O_2	272

Frontwall

Wisconsin Power & Light
Nelson Dewey Station Cyclone Reburn
In-furnace Probing Elevation 700

Test ID: 2B
Condition: Baseline - 110 MW

O_2%

Rearwall

AVG: 2.5

1.5	1.6	2.6	3.0	3.5	3.8	2.1	2.1	2.2	2.5	2.1

LHSW **RHSW**

AVG: 3.7

	3.7	3.7	3.9	3.8	3.8	3.6	3.8	3.7	3.6	3.8

Averaged Economizer Outlet Data

O_2	3.5
CO @3% O_2	70
NO_x @3% O_2	603

Frontwall

Test ID: 20T
Condition: Reburning - 110 MW
GR fan on/GR to BNR
optimized secondary air

O_2%

Rearwall

AVG: 5.1

	3.3	3.1	4.3	5.6	6.3	6.2	5.8	5.5	5.2	5.4

LHSW **RHSW**

AVG: 2.8

2.8	2.8	3.2	2.7	2.7	2.5	2.8	3.0	2.9	2.9	2.8

Averaged Economizer Outlet Data

O_2	3
CO @3% O_2	77
NO_x @3% O_2	270

Frontwall

Test ID: Similar to 8P
Condition: Reburning -110 MW
GR fan on/GR to BNRS
optimized secondary air

O_2%

Rearwall

AVG: 2.7

1.8	1.9	1.6	3	3.2	3.3	3.6	3.2	2.3	3.1	

LHSW **RHSW**

AVG: 4

4.8	4.1	3.9	3.8	3.6	3.8	3.9	4.1	4.1	4.3	

Averaged Economizer Outlet Data

O_2	2.84
CO @3% O_2	81
NO_x @3% O_2	272

Frontwall

Wisconsin Power & Light
Nelson Dewey Station Cyclone Reburn
In-furnace Probing Elevation 700

Test ID: 2B
Condition: Baseline - 110 MW

CO ppm

Rearwall

AVG: 174

180	185	165	180	170	180	175	175	175	170	160

LHSW **RHSW**

AVG: 213

220	215	225	205	210	200	210	200	205	215	250

Averaged Economizer Outlet Data

O_2	3.5
CO @3% O_2	70
NO_x @3% O_2	603

Frontwall

Test ID: 20T
Condition: Reburning - 110 MW
GR fan on/GR to BNR
optimized secondary air

CO ppm

Rearwall

AVG: 653

	2350	2110	1175	90	40	110	170	220	70	200

LHSW **RHSW**

AVG: 1481

1080	700	1220	1920	1520	2050	2070	*****	1640	1390	1210

Averaged Economizer Outlet Data

O_2	3
CO @3% O_2	77
NO_x @3% O_2	270

Frontwall

Test ID: Similar to 8P
Condition: Reburning - 110 MW
GR fan on/GR to BNRS
optimized

CO ppm

Rearwall

AVG: 1320

3500	2750	3000	1000	367	312	275	200	1200	600	

LHSW **RHSW**

AVG: 246

170	175	170	200	275	670	400	160	115	130	

Averaged Economizer Outlet Data

O_2	2.84
CO @3% O_2	81
NO_x @3% O_2	272

Frontwall

Wisconsin Power & Light
Nelson Dewey Station Cyclone Reburn
In-furnace Probing Elevation 676

Test ID: 2B
Condition: Baseline - 110 MW

Temperatures F

Rearwall

2354	2462
2570	2602
2580	2572

LHSW **RHSW**

AVG: 2260

2181	2188	2183	2211	2243	2260	2281	2334	2383

Averaged Economizer Outlet Data

O_2	3.5
CO @3% O_2	70
NO_x @3% O_2	603

Frontwall

Test ID: 20T
Condition: Reburning - 110 MW
GR fan on/GR to BNR
optimized secondary air

Temperatures F

Rearwall

LHSW **RHSW**

AVG: 2658

2555	2626	2702	2699	2671	2639	2674	2696	2659

Averaged Economizer Outlet Data

O_2	3
CO @3% O_2	77
NO_x @3% O_2	270

Frontwall

Wisconsin Power & Light
Nelson Dewey Station Cyclone Reburn
In-furnace Probing Elevation 676

Test ID: 2B
Condition: Baseline - 110 MW

O_2%

Rearwall

3.5	3.2
3.2	3.0

LHSW **RHSW**

AVG: 3.7

	4.0	4.1	3.6	3.8	3.6	3.5	3.7	3.5

Averaged Economizer Outlet Data

O_2	3.5
CO @3% O_2	70
NO_x @3% O_2	603

Frontwall

Test ID: 20T
Condition: Reburning - 110 MW
GR fan on/GR to BNR
optimized secondary air

O_2%

Rearwall

LHSW **RHSW**

AVG: 0.5

0.2	0.1	0.4	0.2	0.1	0.1	0.5	1.5	1.6

Averaged Economizer Outlet Data

O_2	3
CO @3% O_2	77
NO_x @3% O_2	270

Frontwall

Wisconsin Power & Light
Nelson Dewey Station Cyclone Reburn
In-furnace Probing Elevation 676

Test ID: 2B
Condition: Baseline - 110 MW

CO ppm

Rearwall

330	160
190	170

LHSW **RHSW**

AVG: 239

	230	230	255	250	280	260	210	200

Averaged Economizer Outlet Data

O_2	3.5
CO @3% O_2	70
NO_x @3% O_2	603

Frontwall

Test ID: 20T
Condition: Reburning - 110 MW
GR fan on/GR to BNR
optimized secondary air

CO ppm

Rearwall

LHSW **RHSW**

AVG: 6639

6650	7200	6400	6400	7200	7200	6900	5900	5900

Averaged Economizer Outlet Data

O_2	3
CO @3% O_2	77
NO_x @3% O_2	270

Frontwall

Wisconsin Power & Light
Nelson Dewey Station Cyclone Reburn
In-furnace Probing Elevation 676

Test ID: 2B
Condition: Baseline - 110 MW

NO_x ppm

Rearwall

495	525
390	390

LHSW **RHSW**

AVG: 490

	585	377	350	390	600	615	600	401

Averaged Economizer Outlet Data

O_2	3.5
CO @3% O_2	70
NO_x @3% O_2	603

Frontwall

Test ID: 20T
Condition: Reburning - 110 MW
GR fan on/GR to BNR
optimized secondary air

NO_x ppm

Rearwall

LHSW **RHSW**

AVG: 443

340	460	440	480	460	390	440	500	480

Averaged Economizer Outlet Data

O_2	3
CO @3% O_2	77
NO_x @3% O_2	270

Frontwall

Wisconsin Power & Light
Nelson Dewey Station Cyclone Reburn
In-furnace Probing Elevation 666

Test ID: 20T
Condition: Reburning - 110 MW
GR fan on/GR to BNR
optimized secondary air

O_2%

Rearwall

AVG: 1.96

LHSW **RHSW**

	2.3	1.9	2.0	1.3	1.8	2.0	2.4

Averaged Economizer Outlet Data

O_2	3
CO @3% O_2	77
NO_x @3% O_2	270

Frontwall

Test ID: 20T
Condition: Reburning - 110 MW
GR fan on/GR to BNR
optimized secondary air

CO ppm

Rearwall

AVG: 364

LHSW **RHSW**

	195	260	460.0	850	390	195.0	200

Averaged Economizer Outlet Data

O_2	3
CO @3% O_2	77
NO_x @3% O_2	270

Frontwall

BASELINE/REBURNING IN-FURNACE MEASUREMENTS AT 82 MW

Wisconsin Power & Light
Nelson Dewey Station Cyclone Reburn
In-furnace Probing Elevation 700

Test ID: 4B
Condition: Baseline - 82 MW

Temperatures F

Rearwall

AVG: 2119

2130	2136	2097	2136	2121	2109	2090	2094		2135	2143

LHSW **RHSW**

AVG: 2089

	2030	2122	2122	2101	2087	2077	2063	2069	2110	2110

Averaged Economizer Outlet Data

O_2	3.65
CO @3% O_2	94
NO_x @3% O_2	237

Frontwall

Test ID: 47T
Condition: Reburning - 82 MW
GR fan on/GR to BNR
optimized condition

Temperatures F

Rearwall

AVG: 1989

1792	1929	1957	1970	2008	2027	2030	2017	1989	1975	1990

LHSW **RHSW**

AVG: 2120

1962	2056	2069	2095	2102	2103	2125	2160	2166	2184	2142

Averaged Economizer Outlet Data

O_2	2.83
CO @3% O_2	121
NO_x @3% O_2	237

Frontwall

Wisconsin Power & Light
Nelson Dewey Station Cyclone Reburn
In-furnace Probing Elevation 700

Test ID: 4B
Condition: Baseline - 82 MW

O_2%

Rearwall

AVG: 3.5

3.4	3.2	3.5	3.4	3.5	3.8	3.7	3.7	3.8	3.1	3.1

LHSW **RHSW**

AVG: 3.0

	3.9	3.0	2.9	2.8	3.0	3.1	2.9	2.9	2.9	3.0

Averaged Economizer Outlet Data

O_2	3.65
CO @3% O_2	94
NO_x @3% O_2	237

Frontwall

Test ID: 47T
Condition: Reburning - 82 MW
GR fan on/GR to BNR
optimized condition

O_2%

Rearwall

AVG: 6.2

6.2	5.9	5.7	6.2	5.8	5.7	6.2	6.6	6.9	7

LHSW **RHSW**

AVG: 3.2

4.2	4.6	4.4	4.2	3.7	3.8	2.4	2	2	0.5

Averaged Economizer Outlet Data

O_2	2.83
CO @3% O_2	121
NO_x @3% O_2	237

Frontwall

Wisconsin Power & Light
Nelson Dewey Station Cyclone Reburn
In-furnace Probing Elevation 700

Test ID: 4B
Condition: Baseline - 82 MW

CO ppm

Rearwall

AVG: 42

80	70	60	50	50	50	50	50	5	0	0

LHSW — RHSW

AVG: 3

	50	70	40	40	40	80		0	0	0

Frontwall

Averaged Economizer Outlet Data

O_2	3.65
CO @3% O_2	94
NO_x @3% O_2	237

Test ID: 47T
Condition: Reburning - 82 MW
GR fan on/GR to BNR
optimized condition

CO ppm

Rearwall

AVG: 96

	70	35	35	30	190	170	200	100	60	70

LHSW — RHSW

AVG: 2175

	800	1575	650	400	900	1600	2000	3250	4525	6050

Frontwall

Averaged Economizer Outlet Data

O_2	2.83
CO @3% O_2	121
NO_x @3% O_2	237

Wisconsin Power & Light
Nelson Dewey Station Cyclone Reburn
In-furnace Probing Elevation 676

Test ID: 4B
Condition: Baseline - 82 MW

Temperatures F

Rearwall

2358	2358
2381	2381

LHSW **RHSW**

AVG: 1952

1873	1926	1966	1943	1982	1945	1942	2040

Averaged Economizer Outlet Data

O_2	3.65
CO @3% O_2	94
NO_x @3% O_2	237

Frontwall

Test ID: 47T
Condition: Reburning - 82 MW
GR fan on/GR to BNR
optimized condition

Temperatures F

Rearwall

LHSW **RHSW**

AVG: 2489

2470	2535	2566	2474	2483	2434	2461	2499	2457

Averaged Economizer Outlet Data

O_2	2.83
CO @3% O_2	121
NO_x @3% O_2	237

Frontwall

Wisconsin Power & Light
Nelson Dewey Station Cyclone Reburn
In-furnace Probing Elevation 676

Test ID: 4B
Condition: Baseline - 82 MW

O_2%

Rearwall

3.4	3.3
2.8	3.2

LHSW **RHSW**

AVG: 3.4

4.9	3.3	3.2	3.1	3	3.1	3.3	3.2

Averaged Economizer Outlet Data

O_2	3.65
CO @3% O_2	94
NO_x @3% O_2	237

Frontwall

Test ID: 47T
Condition: Reburning - 82 MW
GR fan on/GR to BNR
optimized condition

O_2%

Rearwall

LHSW **RHSW**

AVG: 0.4

0.8	0.7	0.4	0.1	0	0.1	0.1	0.6

Averaged Economizer Outlet Data

O_2	2.83
CO @3% O_2	121
NO_x @3% O_2	237

Frontwall

Wisconsin Power & Light
Nelson Dewey Station Cyclone Reburn
In-furnace Probing Elevation 676

CO ppm

Test ID: 4B
Condition: Baseline - 82 MW

Rearwall

60	100
0	80

LHSW **RHSW**

AVG: 48

60	45	45	40	45	50	53	47

Averaged Economizer Outlet Data

O_2	3.65
CO @3% O_2	94
NO_x @3% O_2	237

Frontwall

Test ID: 47T
Condition: Reburning - 82 MW
GR fan on/GR to BNR
optimized condition

CO ppm

Rearwall

LHSW **RHSW**

AVG: 6156

5900	5300	6100	6250	6850	6350	6200	6300

Averaged Economizer Outlet Data

O_2	2.83
CO @3% O_2	121
NO_x @3% O_2	237

Frontwall

Wisconsin Power & Light
Nelson Dewey Station Cyclone Reburn
In-furnace Probing Elevation 676

Test ID: 4B
Condition: Baseline - 82 MW

NO_x ppm

Rearwall

495	525
480	465

LHSW **RHSW**

AVG: 480

420	420	435	480	510	525	540	510

Averaged Economizer Outlet Data

O_2	3.65
CO @3% O_2	94
NO_x @3% O_2	237

Frontwall

Test ID: 47T
Condition: Reburning - 82 MW
GR fan on/GR to BNR
optimized condition

NO_x ppm

Rearwall

LHSW **RHSW**

AVG: 358

425	450	390	280	210	330	380	400

Averaged Economizer Outlet Data

O_2	2.83
CO @3% O_2	121
NO_x @3% O_2	237

Frontwall

APPENDIX NO. 5

Balance of Plant Details

1.0 Pulverizer & Feeder Enclosure

An enclosure was built to house the coal reburn fuel preparation equipment and its auxiliaries. The new structure is attached to, and integrated with the existing Unit #2 boiler house.

1.1 Foundation

A new foundation was installed for the pulverizer/feeder enclosure. Design of the foundation indicated a need for 81 pilings to be driven, reinforced with steel bar internally and filled with concrete. These reinforcing bars are tied into the foundation concrete reinforcing bars. Once this was complete and the reinforcing steel was placed into position for the main slab, the bulk of the concrete was poured. The main slab is 5-1/2 feet deep, about 60 feet long and 30 feet wide. All anchor bolts for major equipment and structural steel were set prior to pouring the concrete.

1.2 Structure

The coal reburn enclosure consists of insulated metal siding, a metal sided roof, and is approximately 61 feet long by 28 feet wide and has an overall approximate height of 71 feet. The enclosure, which is directly attached to the east side of the existing Unit #2 boiler house, consists of two (2) main floors; the pulverizer floor and the feeder floor.

The facility includes the following items:

- Insulated rolling steel door
- Floor drainage system
- Gutters and downspouts
- Heating and ventilation system
- Lighting
- Public address system
- Fire protection system
- Access platforms and stairways
- Direct access to the existing boiler house

1.3 Steam Heating & Pulverizer Inerting System

Steam is supplied for both building heat and the pulverizer inerting process. The steam source is from the plant's existing heating steam piping. Steam is available from both Unit #1 and Unit #2 heating systems.

1.4 Fire Protection System

Four (4) fire hose stations are located throughout the new reburn facility. Water for the new fire protection system is sourced from the plant's existing service water system.

1.5 Conveyor Extension Enclosure

A newly built enclosure accommodates the extension of the existing tripper conveyor equipment. The new enclosure is attached to the main boiler house directly above the reburn coal silo and pulverizer enclosure. The conveyor extension is now an integral part of the existing conveyor system. A new coal chute directs the coal from the feeder extension enclosure at elevation 738′ - 0" to the top of the new coal silo at elevation 718′ - 0".

The new enclosure consists of insulated aluminum siding and roof. The structure, attached to the East side of the existing boiler house, extends out approximately 12′. The structure is approximately 16′ wide with a nominal height of 12′.

The new enclosure houses the following equipment:

- Relocated conveyor head pulley & drive
- Relocated dust collection pick-up duct
- Relocated belt cleaner
- Miscellaneous related hardware

2.0 Auxiliaries

2.1 Service Water

Service water is required for the pulverizer inerting and clearing process, pyrites removal system, providing the cooling medium for the pulverizer lube oil set, PA fan bearings, and the pulverizer hydraulic loading system. A 4" pipe connection ties into the existing 12" High Head Service Water line, located in the main boiler house, to satisfy the service water requirements.

2.2 Instrument Air

Instrument air is required to operate the various components involved in the coal reburn process. The existing plant instrument air system is capable of meeting the total needs for the newly installed equipment.

2.3 Service Air

Service air requirements will be met with the existing plant station air system. The majority of plant station air will be used for the atomizing air requirements at the reburn burner front.

2.4 Seal Air

Two (2) separate seal air systems were installed to meet the needs of various equipment. One system, a skid mounted package, provides the seal air for the pulverizer, gravimetric feeder, hot primary air fan, and the rotating classifier gearbox. The newly installed seal air blower and motor are capable of supplying approximately 3100 scfm at 79" w.c. boost. The blower/motor skid is mounted on the feeder floor.

The reburn burner flame scanners require seal (cooling) air to provide adequate protection for the flame scanner hardware during conditions when overheat damage can occur. The primary source of cooling air is the forced draft fan discharge duct.

In order to provide adequate cooling when the primary system fails or becomes inoperable (FD fans/boiler trips), a skid mounted blower will provide back-up protection. The single blower system was installed and tied into the primary scanner cooling air system.

3.0 Miscellaneous Mechanical Modifications

3.1 Observation & Test Ports

Observation test ports were installed in the furnace walls to provide access for test equipment and for monitoring furnace conditions. This was done in April, 1990, prior to baseline testing.

3.2 Furnace Wall Throat Openings

Two (2) bi-metallic (carbon steel with a stainless cladding) furnace wall throat openings were installed to monitor the affects of the inherent reducing atmosphere of the reburn process at the reburn burner throat region on two of the four burners. The other two burner throat regions were made up of standard carbon steel tubes. Impact of the reducing atmosphere on two materials are thus studied.

3.3 Furnace Wall Corrosion Test Tubes

An additional corrosion evaluation to determine if corrosion is more of a problem at higher metal temperature was done via thicker-walled tubes installed at three (3) selected furnace regions. The thicker walled tubes artificially elevate tube OD metal temperatures. The location of these new thicker tubes was between the reburn burners (EL. 664′- 6") and the overfire air ports (EL. 681′- 2"). Three (3) sets of straight tubes were installed on the left-hand sidewall, right-hand sidewall, and rear wall locations. Each set of tubes consists of one tube made of standard (thicker) material, and the other of bi-metallic (thicker) material.

3.4 Metal Temperatures/Attemperators/Thermocouples

Due to the nature of reburn operation, cyclone firing with simultaneous combustion of pulverized fuel at a higher elevation within the furnace, higher furnace exit gas temperatures can be expected. Consequently, higher component metal temperatures are likely. Operating the unit at 110% of it′s maximum continuous rating also contributes to higher furnace exit gas temperatures than used for the original design.

With the expectation of higher metal temperatures, many boiler operational scenarios were evaluated, and worst case conditions were studied. Five (5) potential components were identified which exhibit the possibility of exceeding allowable metal temperature. These were:

1. Rear Vertical PSH Outlet Leg
2. Top Horizontal PSH Outlet Leg
3. PSH Outlet Piping Bend
4. SSH Intermediate Header
5. RH Intermediate Header

Prior to the baseline testing of Unit #2 at WP&L's Nelson Dewey Station, thermocouples were installed on the secondary superheater and reheater intermediate header outlet legs. Ten thermocouples were installed per header. During construction, eleven (11) additional thermocouples were installed on the primary superheater outlet legs and header wall. The primary superheater is expected to exhibit the greatest potential for exceeding the maximum allowable stresses due to increased metal temperatures. Additionally, two thermocouples were installed on the reheater intermediate header end caps. The end caps are theoretically the limiting factor for maximum allowable temperature of the header.

In recognizing the potential for higher metal temperatures, B&W installed an ample number of thermocouples to confidently monitor the major components within the unit when the reburn system is in service. In addition, temperature alarms were set for the various components.

4.0 Control System Modifications

An upgrade of the plant's Bailey Net 90 System was installed to control the reburn system and to interface with the existing controls for Nelson Dewey Unit No. 2. Control functions impacted by the reburn system are described below:

4.1 Cyclones

Cyclone operation is governed by the existing Net 90 system which interfaces with the reburn Net 90 control system. With the reburn burners in service, the cyclones contribute approximately 70-75% of the total required fuel (BTU) input to the boiler. Total fuel flow to the cyclones is based on the summation of the individual cyclone feeder mass flows. The fuel (BTU) demand for each cyclone establishes the stoichiometric combustion requirements for the cyclones. This stoichiometry is then adjusted to the desired value (1.1 expected) with the reburn burners in service. Measured O_2 correction or trim apply to the cyclone firing parameters when the reburn burners are out-of-service only.

4.2 Fuel Preparation Equipment & Reburn Burners

Fuel input to the coal reburn system, during "normal" boiler firing conditions, ranges between 25-30% of the total heat (fuel) required to maintain a specific boiler load. The existing Net 90 control system, at an estimated minimum boiler fuel loading of approximately 30-35% boiler MCR, "releases" the reburn system for operation.

The energy flow demand to the reburn burners is established as a function of the total boiler energy release demand from the Boiler Master, or the actual cyclone energy release rate. The reburn burner firing rate is not used to automatically make up cyclone fuel flow which has been lost or cross limited. The Reburn Master serves as the "Pulverizer" Master due to the single pulverizer system. The Reburn/Cyclone Ratio Controller allows the control room operator to make minor (small) adjustments to the reburn firing rate in direct proportion to the cyclone firing rate.

Feeder Speed

The coal feeder delivers coal to the pulverizer on a weight flow basis, but the pulverizer firing rate demand is on an energy flow basis. This energy (BTU) flow demand is converted to a weight flow demand using the actual fuel heating value before it is utilized by the feeder. The feeder demand is sent directly to Stock's gravimetric feeder control package (local panel), which converts the demand into a coal flow rate (feeder speed), via a closed loop system. The feeder demand has a cross limiting function to prevent coal flow from exceeding the limits of the reburn system.

Primary Air (PA) Fan

Primary air serves to transport the pulverized coal from the pulverizer to the reburn burners, and its flow requirements are based solely on the fuel flow demand to the feeder. The difference between the primary air flow demand and the measured primary air flow entering the pulverizer windbox, is used to control the primary air fan variable speed drive. The primary air flow is temperature compensated, and in order to maintain required burner line velocities, a minimum limit on primary air flow is provided.

Reburn Air Flow

Total reburn air flow consists of the summation of the primary air flow, secondary air flow, and gas recirculation flow to the reburn burners. Both the secondary air and gas recirculation flow are controlled by individual dampers with integrated electric drives. In-line flow monitors, situated downstream of the control dampers, measure the respective flows.

The total reburn air flow demand developed from the pulverizer demand is on a stoichiometric basis (0% excess air). Controls allow for adjustment of the stoichiometric demand to the desired fuel/air ratio at the burners. The operators also have the means to adjust the ratio between the secondary air and gas recirculation flow.

Burner Gas Recirculation Flow

The burner gas recirculation flow demand is established as a function of the reburn flow demand. This allows adjustment of the mass flow to the burners to achieve the desired penetration into the furnace while maintaining the desired stoichiometric conditions. The operator can use a secondary air/gas recirculation ratio controller, but the controller has a limited adjustment range.

Pulverizer Outlet Temperature

In addition to using primary air for transporting the pulverized coal to the burners, the hot primary air is also used to partially dry the coal in the pulverizing process. The primary air system is comprised of separate hot air and tempering (cold) air ducts, where the junction point is located upstream of the primary air fan.

Each hot air and tempering air duct is equipped with a single control damper for regulation of their respective flows. A single element control using the pulverizer outlet temperature modulates the dampers to maintain the pulverizer outlet temperature at its set point. The hot air and tempering air dampers are positioned inversely, and at no time during normal operation does the control system allow for both dampers to be closed at the same time.

Burner Management Coordination

The burner management system coordinates the actions of the pulverizer/reburn system with the overall unit controls, during start-up and shutdown of the pulverizer/reburn system. For example, the operator has the means to start-up or shut down the reburn system in a controlled manner, prior to or after full automatic operation of the boiler.

4.3 Overfire Air Ports

The overfire air (OFA) ports provide the remainder of the required secondary air flow, based on the total boiler air flow demand. The secondary air flow to the OFA ports is regulated by a butterfly damper located downstream of the air heater air recirculation duct.

The total boiler air flow is established as a function of the total boiler energy release demand. Flow through the OFA ports is regulated to provide any additional air flow needed to make up the difference between the total boiler air flow demand and the summation of the measured individual cyclone air flows, and the pulverizer group flows. The pulverizer group flows include the measured primary air flow, secondary air flow, and gas recirculation flow.

When the reburn burners are in service, the existing O_2 trim control station will adjust the OFA port air flow rate to meet the total air flow requirement based on the O_2 set point. Measured O_2 trim may be used with the OFA control where the O_2 set point also serves as the excess air set point for the total boiler air flow demand.

5.0 Electrical

5.1 Main Switchgear

A new 4160 Volt switchgear circuit breaker was added to the plant's existing 4160 Volt switchgear to service the coal reburn motor control center (MCC). The electrical contractor made all the necessary high voltage bus and grounding connections to existing switchgear.

5.2 Coal Reburn Transformer

A "step-down" transformer was required to lower the voltage to accommodate the 480 Volt Coal Reburn MCC. Accordingly, a 1500 kVA transformer was installed to decrease the voltage to the required 480/277 volts.

5.3 480V Coal Reburn MCC

To meet the requirements of the coal reburn system equipment, a newly installed motor control cabinet was provided. The coal reburn MCC provides power distribution to small and medium sized motors, heaters, and lighting. The MCC also provides 120-Vac distribution to the coal reburn equipment. The motor control center consists of the following twenty-five (25) compartments connected directly to the 2000 Amp bus:

- Incoming Feed
- Lighting Transformer
- Gravimetric Feeder Motor
- Primary Air Fan Shut-off Damper
- Rotating Classifier/Hydraulic Loader
- Welding Receptacles 2-1 & 2-2
- Pulverizer Lube Oil Set
- Coal Feeder Discharge Valve
- Pulverizer/Feeder Seal Air Fan
- Coal Reburn Roof Vent Fan 2B
- Roll Wheel Pump
- Coal Reburn Building Motor Operated Door
- Coal Reburn Roof Vent Fan 2A
- Primary Air Fan VFDS
- Diverter Gate Motor Operator
- Silo Fill Chute Heating Panel
- 120/240V Distribution Panel
- Damper Drive Distribution Panel
- 4 Spares

5.4 Damper Drive Distribution Panel

A distribution panel, powered by the 480V Coal Reburn MCC, is available to power the individual coal reburn process damper control drives. These drives include the following:

- Burner Secondary Air Damper Control Drive
- Burner Gas Recirculation Damper Control Drive
- Hot Air Damper Control Drive

- Secondary Air/Gas Recirc. Damper Control Drive
- Overfire Air Damper Control Drive

5.5 120/240V Distribution Panel

Power from the 120/240V distribution panel is supplied from the 480V Coal Reburn MCC. The voltage is reduced to the necessary 120/240V via a transformer located within the 480V Coal Reburn MCC cabinet. The following equipment is tied into the 120/240V distribution panel, all with 20 Amp breakers.

- Steam Unit Heater Fans
- Coal Reburn Roof Vent Fan 2C
- Coal Reburn Roof Vent Fan 2D
- Silo Level Detector
- Junction Box RB03
- Pulverizer Motor Space Heater
- Secoal III Monitor Cabinets
- Stock Feeder Cabinets
- 24 Spares

5.6 Variable Frequency Drive

An Allen-Bradley variable frequency drive is used for controlling the speed of the primary air fan. The VFDS is installed adjacent to the 480V Coal Reburn MCC.

5.7 Lighting

All of the lighting was furnished and installed to conform to the specifications set forth in Sargent & Lundy Specification W-2595, "Electrical Installation Work."

5.8 Bailey NET-90 Cabinets

Three (3) Bailey Net-90 cabinets were furnished for the coal reburn project. The cabinets were installed in the control room near the existing Net-90 cabinets.

5.9 Control Room Panel Board

Panel board modifications were required to meet the needs of the newly installed reburn equipment. The modifications basically consisted of control switches and lights, manual/auto control stations for the reburn process, annunciators, and ammeters.

6.0 Start-Up Review

Once the construction work was completed, start-up activities were formally initiated by B&W on October 29, 1991. The start-up activities included operator training, cold and hot air flow calibrations of all the air/gas recirculation duct/flue systems, and then actual reburn equipment operation. Based upon the reburn system start-up unknowns, it was decided to initiate reburn operation at 90 MW. This would provide adequate boiler capability for any temperature/pressure excursions that might occur with the units control system. Each of these activities will now be discussed.

6.1 Operator Training

A series of five training sessions were provided by B&W and WP&L for the Nelson Dewey plant operators prior to initiation of reburn system operation. The five sessions were:

1) General overview

This session provided an overview of the reburn system including background and emphasizing reburn combustion equipment (burners, flame scanners, ignitors, etc.).

2) Pulverizer Training

This session consisted of classroom instruction emphasizing MPS pulverizer operation and safety. The pulverizer hydraulic and lubrication systems were also reviewed.

3) Inerting and Clearing Procedure

This session consisted of hands-on operation of the pulverizer inerting and clearing system as well as the pyrite removal system.

4) Reburn Auxiliary Equipment

Topics for this hands-on session were the seal air system, the rotating classifier lube set, hydraulic loading system and the primary air fan variable frequency drive operation.

5) Controls and Interlocks

Reburn equipment start and stop sequences were reviewed and training was provided at the main control board to explain interlocks and alarm indications.

6.2 Boiler Start-up

Prior to actual boiler start-up, cold air flow calibrations were performed on each of the new reburn systems flow paths in order to ensure accurate air monitor indications. The actual measured values were compared to the air monitor indications. The following ducts were tested at various flow rates/damper positions: overfire air (OFA), gas recirculation to the burners, secondary air, and the primary air. Based upon initial indications, leakage rates for the control dampers appeared to exceed specification and the damper vendor was notified and attempts were made to reduce the flows to meet the specifications. Subsequent to these tests, the boiler start-up was initiated.

With the boiler in operation and firing a blend of bituminous and sub-bituminous coals, cooling air flow rates for the reburn burners and overfire air (OFA) ports were optimized to maintain acceptable metal temperatures. The air control damper's limit switches were set to stop the dampers from closing beyond the minimum position for adequate flow. In addition, the boiler controls were modified to accommodate the extra air flow required for cooling the reburn system components.

Operating the boiler under no reburn conditions, hot air flow calibrations of the same instruments previously tested on cold air flow were carried out. Inconsistencies between the measured flow rates and the air monitor indications were identified for a few of the systems and investigations commenced to identify the problems. Other activities carried out to ready the reburn system for operation included check out of the reburn burner oil lighters and flame scanners. These systems were successfully started-up and debugged as oil and air pressures were optimized to minimize lighter heat input while maintaining successful scanner operation. This was done to reduce impacts on boiler operation during reburning start-up/shut-down sequences. Also, as part of burner and lighter system start-up, verification of all the control interlocks was completed to assure safe operation.