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ENGINEERING DEVELOPMENT OF ADVANCED
COAL-FIRED LOW-EMISSION BOILER SYSTEMS

QUARTERLY TECHNICAL PROGRESS REPORT

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Quarterly Report
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I. Project Management

Technical papers entitled "10 MW_e Prototype Testing of LIDS™ as Part of the Babcock & Wilcox Low Emission Boiler System," and "B&W's Advanced Coal-Fired Low Emission Boiler System: Preparation for and Preliminary Results of Subsystem Testing" were presented at the 21st International Technical Conference on Coal Utilization & Fuel Systems. The conference was held in Clearwater, Florida, March 18-21, 1996. In addition, abstracts entitled, "The Worldwide Applicability of B&W's Advanced Coal-Fired Low-Emission Boiler System," and "A Low-NO_x Burner Prototype Developed for B&W's Advanced Coal-Fired Low-Emission Boiler System," were submitted for inclusion in the 13th Annual International Pittsburgh Coal Conference and the 1996 AFRC Fall International Symposium being held September 30 - October 2, 1996 in Baltimore, Maryland respectively.

Several delinquent reports were completed and released to DoE and a meeting was held with subsystem leaders to discuss the effect of extending the program through March 1997. A new schedule and budget were developed to reflect this change.

II. NO_x Subsystem

The goal of the NO_x Subsystem is to achieve continuous operation of the Low-Emissions Boiler System (LEBS) at NO_x emissions at or below 0.20 lb/MBtu through combustion techniques only, with a further target of 0.1 lb NO_x/MBtu using supplementary advanced flue gas cleanup technologies if necessary. These goals place practical constraints that must be considered on the NO_x Subsystem design. Not only must the boiler be designed to achieve time-temperature mixing histories that minimize NO_x, but it must also be designed to operate that way throughout its working lifetime. Therefore, NO_x minimization strategies must be integrated into the control systems for every boiler component from the pulverizers to the stack. Furthermore, these goals must be met without increases in carbon loss and CO emissions from the levels achieved with current low-NO_x combustion systems. Therefore, the NO_x Subsystem requires not only sound mechanical designs of burners, furnace surface, and staging air/fuel injectors, but also sensors and software to allow control of their operation. Through engineering analysis, experimental testing, and numerical modeling in Phase II, an advanced low-NO_x control system is being developed. The progress of these activities is presented in this report.

II.1 Summary of Activities

The NO_x Subsystem Testing originally scheduled for January/February 1996 was postponed until May 1996 due to insufficient funding from DOE as a result of government budgetary problems, and due to an extension of the program currently using the test facility.

Installation of the overfire air ports was completed this quarter. Shakedown of the system will occur in late fall 1996. Fabrication of various burner hardware pieces continued in preparation of the next test series. A test matrix was developed and distributed.

Combustion modeling of the DRB-4Z™ burner continued at the subsystem scale. This modeling is providing preliminary evaluation of potential hardware configurations and burner performance prior to

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the planned NO_x Subsystem testing in the CEDF.

A meeting was held with Stamet Inc. to discuss their solids transfer and metering system for possible use with the Subsystem/POC test facilities. This feed system allows for more even flow of material (in the NO_x subsystem case, pulverized coal), no bridging problems, and little or no maintenance. Stamet Inc. has suggested the possibility of B&W trying the system on the CEDF during the burner test series scheduled for Summer 1996. The NO_x subsystem is working with Stamet Inc., to look into this possibility.

II.2 Key Accomplishments

II.2.1 Subsystem Test Unit

B&W's 100 MBtu/hr Clean Environment Development Facility (CEDF) was used as the Combustion 2000 burner development Subsystem Test Facility. The advantage of using the CEDF for Subsystem scale testing is in the ability to test a near-full size burner in an environment which closely simulates a utility boiler. During the first test series, the only modification necessary on the CEDF was a modification to the burner throat to accommodate the advanced low-NO_x burner.

Data analysis continued this quarter from the first burner test series in the CEDF. The plots being made help to show how the burner prefers to operate and where the optimum conditions are found. Minor hardware changes and various mixing devices were tested during this initial round of Subsystem Testing. Operating conditions, including load and excess air, were varied for each hardware configuration and data was collected in terms of operating conditions, stack gaseous emissions, and fly ash samples.

Baseline testing was performed in the CEDF utilizing the DRB-XCL[®] low-NO_x burner firing the LEBS Illinois #6 design coal. This information was used as a comparison for the advanced low-NO_x burner to current state-of-the-art commercial low-NO_x burner technology.

Two coals were fired during the burner testing, the Illinois #6 design coal, and a Mahoning 7A coal. The Mahoning coal had been used for part of the characterization testing of the CEDF. The DRB-4Z[™] burner was utilized during the Combustion 2000 SO_x Subsystem Testing, firing an Ohio blend coal. This blend of Ohio coals was also used during a previous test in the CEDF with the DRB-XCL[®] burner. Limited data was acquired while firing the Ohio blend (no parametric data), however, this information is being provided for an overall comparison.

Figures II-1 through II-3 show a comparison of the DRB-4Z[™] burner to the DRB-XCL[®]. While firing the project's design coal, an Illinois #6, NO_x emissions were reduced in comparison to the 100 MBtu/hr DRB-XCL[®] by 15-20% with virtually no difference in LOI or CO emission. A 50% reduction in NO_x emissions was seen with the DRB-4Z[™] while firing the Mahoning 7A coal, however, the LOI and CO emissions increased for the one burner configuration tested. The limited information collected while firing the Ohio Horizon coal shows again about a 50-60% reduction in NO_x emissions, however, the average CO emissions are comparable. LOI data was not collected while firing the Ohio Horizon coal. Further development of the DRB-4Z[™] is continuing in preparation for the second test series planned in the Spring 1996.

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Figure II-1 Comparison of NO_x Emission to Burner Configuration

Figure II-2 Comparison of CO Emissions to Burner Configuration

Figure II-3 Comparison of LOI to Burner Configuration

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Similar to the process used for the pilot-scale component design, numerical combustion modeling is being used to evaluate potential burner modifications and hardware configurations prior to testing. This allows subsystem scale tests to focus on burner variations with desired characteristics and high probability of success.

Combustion cases completed for the DRB-XCL[®] burner and the initial DRB-4Z[™] configuration were compared with measured furnace exit data and observed flame characteristics from the initial round of Subsystem Testing to baseline the models prior to parametric runs. A series of combustion models have been completed for the DRB-4Z[™] to evaluate the distributed introduction of secondary combustion air into the flame and key hardware components planned for the May Subsystem Testing campaign. Two near-flame predictions resulting from variations in the distribution of secondary air are shown in Figure II-4. The lower flame exhibits a detached flame, with poor combustion performance, while the upper predictions shows a stable, attached flame with improved unburned carbon and CO levels.

III. SO₂/Particulate/Air Toxics/Solid By-Product Subsystem

The scope of the SO₂ subsystem comprises the control of SO₂, particulate matter, hazardous air pollutants (commonly called "air toxics"), and solid byproducts from the B&W LEBS plant. The specific minimum performance requirements for the SO₂ subsystem are:

- SO_x -- Less than 0.20 lb (SO₂ equivalent)/MBtu for coals with sulfur levels of 3 lb of sulfur per MBtu and no more than 0.067 times the sulfur content (lb/MBtu) for coals with less than 3 lb of sulfur per MBtu.
- Particulate -- Less than 0.015 lb particulate/MBtu
- Potential to comply with possible emissions control regulations for targeted air toxics.
- Produce environmentally benign solid byproduct.
- Integrate with other plant subsystems to yield optimal overall performance and cost.

In addition, the following performance targets have been established:

- SO_x -- Less than 0.10 lb (SO₂ equivalent)/MBtu for coals with sulfur levels of 3 lb of sulfur per MBtu and no more than 0.0333 times the sulfur content (lb/MBtu) for coals with less than 3 lb of sulfur per MBtu.
- Particulate -- Less than 0.01 lb particulate/MBtu (B&W plans to achieve 0.005 lb/MBtu)

On the basis of the results compiled during the concept selection process completed in Phase I, the Limestone Injection Dry Scrubbing (LIDS) process was selected for further development and evaluation in B&W's LEBS project. The LIDS process is a cost-effective integration of three commercially proven flue gas cleanup technologies: furnace limestone injection, dry scrubbing, and pulse-jet fabric filtration. Through engineering analysis, experimental testing, and numerical modeling, a LIDS process is being developed that is capable of ultra-high SO₂ removal and superior particulate control while addressing the potential issues of air toxic emissions and solid byproduct utilization. The progress of the LIDS activities follows.

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Figure II-4 Comparison of Attached and Detached Near-flame Predictions

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III.1 Summary of Activities

A technical paper entitled "*10 MW_e Prototype Testing of LIDS™ as Part of the Babcock & Wilcox Low Emission Boiler System*," was written and presented at the 21st International Technical Conference on Coal Utilization & Fuel Systems. The conference was held in Clearwater, Florida, March 18-21, 1996. (Task 1)

The solid by-product cognizance effort continued. B&W is aggressively pursuing ways to reduce or utilize the solid waste produced by its various clean coal and FGD processes through a variety of in-house and externally-funded development programs. The effort will continue throughout the project. (Task 7.1)

The air toxics cognizance effort continued. B&W is conducting a wide variety of air toxics-related research projects, and is closely following the regulatory process. The effort will continue throughout the project. (Task 7.1)

Final results of the LIDS Process Definition test series (5 MBtu/hr in the SBS) performed in January, 1995, were compiled to become part of the Phase II final report. This effort is covered under the key accomplishment section. (Task 7.2)

Evaluation of the information gathered during the first CEDF LIDS (100 MBtu/hr) test series continued. Preparations for the next round of CEDF LIDS testing were started. The testing is currently scheduled to occur in June 1996. (Task 11.2 and 11.3)

III.2 Key Accomplishments

III.2.1 LIDS Process Definition Final Test Results Completed (Task 7.2)

The LIDS Process Definition test series was completed in *January 1995*, therefore, the details of the testing effort are covered in a previous quarterly report. This quarterly report contains an area that was not covered in any previous documentation.

In Phase II of the LEBS project, the main goal of the LIDS Process Definition test series was to achieve the LEBS SO₂ emissions goal of 0.10 lb SO₂/MBtu while addressing base LIDS system limitations that had been identified in Phase I. Areas considered to address the basic LIDS limitations and to optimize the process included alternate system configurations (unit operations) and/or additives. Early in the test series an alternate system was identified and will be referred to as Enhanced LIDS (E-LIDS) in the future. The details of the enhancement are currently proprietary and will be covered at a later date.

Testing was conducted in the Small Boiler Simulator (SBS)/LIDS facility at 5 MBtu/hr. Several LIDS and E-LIDS process conditions were tested to optimize the LIDS process. Test phases included E-LIDS and LIDS with coarse limestone injection, E-LIDS with coarse limestone and chloride addition, E-LIDS with fine limestone and chloride bleed-down, and E-LIDS & LIDS with fine limestone without chlorides.

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The LEBS SO₂ emissions goal of 0.10 lbs SO₂/MBtu (98% SO₂ removal) was achieved during the Phase II Process Definition Test Series. The goal was met using the E-LIDS process with fine limestone injection. Figure III-1 shows the SO₂ removal achieved at the outlet of each E-LIDS unit operation. The potential limitations inherent to the basic LIDS system identified during the Phase I LIDS feasibility demonstration were addressed with the E-LIDS system.

The E-LIDS process was shown to improve SO₂ removal efficiency and calcium utilization in comparison to the base LIDS process. Figures III-2, III-3 and III-4 show LIDS versus E-LIDS comparisons. Figures 2 and 3 show dry scrubber and baghouse SO₂ removal for the fine and coarse limestone, respectively. Figure 4 shows a total SO₂ removal comparison. Significant SO₂ removal improvements were accomplished with the E-LIDS process.

Figure III-1 Phase II E-LIDS SO₂ Removal

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Figure III-2 E-LIDS versus LIDS - Dry Scrubber and Baghouse SO₂ Removal Performance with FINE LIMESTONE

Figure III-3 E-LIDS versus LIDS - Dry Scrubber and Baghouse SO₂ Removal Performance with COARSE LIMESTONE

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Figure III-4 E-LIDS versus LIDS - Total System SO₂ Removal

IV. Boiler Subsystem

At the heart of the LEBS is the boiler. Within this advanced B&W boiler, all of the low emission technologies are integrated. To achieve the net plant efficiency minimum requirement of 38% and the target of 42% at generating cost no greater than a conventional PC plant, the boiler must be designed not only to achieve the proper conditions for low NO_x combustion with air staging and accommodate the in-furnace injection of the limestone for the E-LIDSTM process, but it must also efficiently capture the heat to produce high temperature steam at well above critical pressure. The steam conditions selected for the boiler in the Commercial Generating Unit Design are 4500 psi, 1100°F/1100°F/1100°F.

Since the steam-side pressure and main and reheat steam temperatures are higher than conventional cycles and operation of low NO_x burners creates sub-stoichiometric conditions in portions the furnace, additional challenges are presented. Higher alloy materials must be used in the outlet portions of the superheater and reheater banks to obtain acceptable surface metal temperatures. In addition, materials must be selected that will resist corrosion since the surface of these outlet tubes will operate at temperatures which will allow the coal ash to remain molten on their surfaces. Consideration must also be given to furnace wall corrosion in the combustion zone. Thus, boiler design work has been identified to address the integration of the NO_x and SO₂ subsystems while applying B&W's advanced supercritical boiler technology. Work addressing furnace corrosion based on gas-side sampling during burner testing is reported separately under the NO_x subsystem.

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IV.1 Summary of Activities

Computer models from Phase 1 were retrieved and run in preparation for the arrival of preliminary turbine heat balances from Raytheon.

Some rough calculations were done on the amount of sorbent penetration into the furnace with the current injection points. This was done because of concerns of the sorbent stratifying in the gas stream and not being able to mix with the entire gas stream once it enters the convection pass.

Since the power output from the steam turbine is more dependent on temperature than pressure, an investigation was made to determine the effect of going to higher temperatures and lower pressures on the steam cycle. The thought was if we could use thinner wall tubes with higher steam temperatures and maintain the same outer tube temperature we could improve the cycle efficiency. Comparison calculations were made on design pressures of 4700 psig and 3400 psig.

IV.2 Key Accomplishments

IV.2.1 Sorbent Injection into the Boiler

Calculations verified that the current location of the sorbent injection points would cause the sorbent to stratify in the gas stream between the convection pass side walls and the superheater sections. Once the sorbent is trapped in this area it is believed there is little chance of the sorbent mixing into the center of the boiler. This stratification would cause a low percentage of calcination plus high temperature unbalances across the width of the unit. A more innovative method of sorbent injection or a change in location of the injection points needs to be found.

IV.2.2 Evaluation of Benefits of Reducing Steam Cycle Pressure to Increase Steam Temperature

The calculations for higher steam temperatures and lower design pressure were done in an attempt to improve steam cycle efficiency. The thought was that thinner tube walls would have less of a temperature differential across the wall and thus a higher steam temperature could be achieved with the same outer tube metal temperature. A representative superheater tube from Phase 1 was selected for comparison. The tube was SA-213TP304H with an outer diameter of 1.75 inches. At 4700 psig, a steam temperature of 1049 F and a minimum wall of 0.352 inches, the outer metal temperature was 1116 F. Holding this same outer metal temperature with 3400 psig design pressure, the minimum wall thickness decreased to 0.280 inches but the steam temperature only increased to 1052 F. This steam temperature increase was not enough to be significant so no further work was performed with this investigation.

IV.2.3 Enhancement of Corrosion Work

DOE has provided positive feedback on our proposal to change to the RD&T Plan to more extensively address furnace wall corrosion due to the low stoichiometries associated with staged combustion. Approval to proceed is expected shortly. Preparations were also made to remove the test section from Dayton Power & Light's Stuart station for metallurgical evaluation. The panel is expected to be removed in early April and shipped to the Alliance Research Center.

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V. Balance of Plant Subsystem

In order to develop an overall plant design and to evaluate plant efficiency and cost, B&W subcontracted with Raytheon Engineers and Constructors of Denver, Colorado. Together a Phase I concept was developed that achieved the initial LEBS goal of 38% net plant efficiency. That design resulted in identification of a number of potential improvements to the turbine cycle and auxiliary equipment needed to meet the Phase II goal of 42% net plant efficiency. Although several concepts have been identified, the DoE budget delays have postponed work on the balance-of-plant systems until early spring 1996.

V.1 Summary of Activities

A meeting was held in February in Denver with Raytheon Engineers to determine the work scope split between B&W and Raytheon. During the meeting it was decided to change to a 400 MWe Commercial Generating Unit plant size. In response, RE&C provided a detailed statement of work and cost proposal. B&W reviewed and approved their proposal and forwarded it to DOE for review and approval.

V.2 Key Accomplishments

V.2.1 Subcontracting

The scope and split were agreed on and Raytheon was requested to issue a proposal for their work scope. The proposal was received and is now awaiting DOE approval.

Raytheon also submitted a work schedule for B&W approval. With some minor changes the schedule was agreed upon. Since the turbine heat balance is needed for boiler and balance of plant design, a release for work on a preliminary heat balance was given. The preliminary heat balance is expected in mid May.

VI. Controls & Sensors Subsystem

in order to maintain low stack emissions and optimum boiler performance throughout the operating range and lifetime of the LEBS, a state-of-the-art integrated control system must be developed. This control system must include new sensors as well as old sensors used in new ways. It must make sense out of the data provided while initiating or directing the operator to take appropriate action. The control system that will help assure that the LEBS will meet its stack emission, efficiency, availability, and cost of electricity goals.

The overall philosophy of the LEBS control system is to use conventional, state-of-the-art solutions to satisfy new control requirements. Existing sensors, hardware, and software are specified whenever possible and new measurements or advanced equipment are recommended for development only where necessary to assure the success of the project. The progress of the Controls & Sensors Subsystem is as follows.

VI.1 Summary of Activities

A planning meeting was held with the Controls & Sensors team to address the extension the program through March 1997 with a revised schedule and budget being prepared.

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Technical paper entitled "Advanced Sensors and Control Requirements for Multi-Burner Pulverized Coal-Fired Boilers" providing an overview of the LEBS program Controls & Sensors activities was accepted and submitted for presentation at ISA Cleveland Symposium in June 1996.

Preparations were initiated for simultaneous high speed data collection on the CEDF from acoustic emission sensors, the Endress + Hauser microwave meter and the Kurz insertion mass flow sensor being evaluated for coal flow measurement as well as the burner pressure, optical, and acoustic data being used for the chaos analysis. The burner tests on which the data will be collected appear to be slipping from April to early May.

Preliminary discussions were held with several additional vendors on their possible participation in the program including on-line particle measuring sensor (Insitex) and POC facility coal feeders (Stamet).

VI.2 Key Accomplishments

(Nothing new to report.)