METHANE de-NOX[®] for Utility PC Boilers
Quarterly Technical Progress Report
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ABSTRACT

During the current quarter, pilot scale testing was continued with the modified combustor and modified channel burner using the new PRB coal delivered in late December. Testing included benchmark testing to determine whether the system performance was comparable to that with the previous batch of PRB coal, baseline testing to characterize performance of the PC Burner without coal preheating, and parametric testing to evaluate the effect of various preheat combustor and PC burner operating variables, including reduced gas usage in the preheat combustor. A second version of the PC burner in which the secondary air channels were closed and replaced with six air nozzles was then tested with PRB coal.

Plans were developed with RPI for the next phase of testing at the 100 million Btu/h scale using RPI's Coal Burner Test Facility (CBTF). A cost estimate for preparation of the CBTF and preheat burner system design, installation and testing was then prepared by RPI.

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EXECUTIVE SUMMARY

Project Objectives: The overall project objective is the development and validation of an innovative combustion system, based on a novel coal preheating concept prior to combustion, that can reduce NO_x emissions to 0.15 lb/million Btu or less on utility pulverized coal (PC) boilers. This NO_x reduction should be achieved without loss of boiler efficiency or operating stability, and at more than 25% lower levelized cost than state-of-the-art SCR technology. A further objective is to make this technology ready for full-scale commercial deployment in order to meet an anticipated market demand for NO_x reduction technologies resulting from the EPA's NO_x SIP call.

Background: A novel pulverized coal-preheating approach for NO_x reduction was developed by the All Russian Thermal Engineering Institute (VTI), in Russia, for use on PC utility boilers. The approach consists of a burner modification that preheats pulverized coal to elevated temperatures (up to 1500°F) prior to coal combustion. This releases coal volatiles, including fuel-bound nitrogen compounds, into a reducing environment, which converts the coal-derived nitrogen compounds to molecular N₂. The quantity of natural gas fuel required for PC preheating is in the range of 3 to 5% of the total burner heat input. Basic combustion research and development of the preheat PC burner was conducted by VTI in the early 1980's. Following these promising laboratory results, commercial-scale PC preheating burners of 30 and 60 MW_t capacity were developed and demonstrated in field tests conducted in several Russian power stations.

The advanced PC preheating combustion system being developed in this project for direct-fired PC boilers combines the modified VTI preheat burner approach with elements of IGT's successful METHANE de-NO_x technology for NO_x reduction in stoker boilers. The new PC preheating system combines several NO_x reduction strategies into an integrated system, including a novel PC burner design using natural gas-fired coal preheating, and internal and external combustion staging in the primary and secondary combustion zones.

Design, installation, shakedown and initial PRB coal testing of a 3-million Btu/h pilot system at RPI's Pilot-Scale Combustion Facility (PSCF) in Worcester, MA has been completed and demonstrated that the PC Preheat process has a significant effect on final NO_x formation in the coal burner. It was found that the mechanism by which this occurs is not directly controlled by the equilibrium preheat temperature of the pyrolysis products after the gas-fired preheat combustor but rather by the residence time of the coal in the high temperature region within the preheat combustor. It was also determined that the PC burner design originally used was not optimal for low-NO_x combustion of the preheated char and pyrolysis products. Modifications were made to both the pilot system gas-fired combustor and the PC burner in order to test the full potential of the process for NO_x reduction. A series tests of the new combustor with PRB coal using the original PC burner showed that NO_x at the furnace exit was reduced to as low as 150 ppm with only 36 ppm CO (both corrected to 3% O₂). A modified PC burner was then fabricated, installed and tested on PRB coal with the modified gas combustor. NO_x reduction was demonstrated at levels below 100 ppmv with CO in the range of 35-112 ppmv without any furnace air staging.

EXPERIMENTAL

Fabrication, installation and initial testing of the pilot-scale PC PREHEAT system equipment were completed in the fall of 2001. The PC PREHEAT pilot system regulates pulverized coal flow with a gravimetric feeder, which drops the coal through a rotary airlock into the natural gas-fired PREHEAT combustor. The combustor produces hot combustion gases, which combine with the pulverized coal to produce a mixture of coal char and pyrolysis products at the desired test temperature. Two PREHEAT pipe sections after the combustor provide additional residence time for the coal at the preheated conditions. The hot char and pyrolysis products then enter the PC burner, which is designed for operation over a broad range of flow distributions between primary, secondary and tertiary burner combustion air streams.

During testing, real time operating data are collected at 1-second intervals and recorded by the personal computer-based data acquisition system (DAS). The concentrations of CO, CO₂, O₂, THC and NO/NO_x in the PC PREHEAT unit exhaust and the furnace exit are continuously monitored by on-line gas analyzers, including a Rosemount Analytical Model 880A infrared CO analyzer, a Rosemount Analytical Model 880A infrared CO₂ analyzer, a Rosemount Model 400 flame ionization total hydrocarbons (THC) analyzer, a Rosemount Analytical Model 755R paramagnetic O₂ analyzer, and a ThermoElectron Model 14A chemiluminescence NO_x analyzer.

The PREHEAT gas combustor temperatures are monitored by thermocouples installed on both the outer walls and inside of the combustion chamber. Temperature of the gas/air mixture is monitored in the gas/air plenum entering the combustor nozzles. Temperature are monitored downstream of the combustor by thermocouples installed in the PREHEAT pipe sections between the combustor and the PC burner.

RESULTS AND DISCUSSION

Project Status:

Task 1.1 Pilot-Scale Design

There was no activity in this task during the quarter.

Task 1.2 CFD Modeling

There was no activity in this task during the quarter.

Task 1.3 Pilot-Scale Equipment Fabrication and Installation

PCP Combustor Pretesting

All work in this task is complete.

Pilot Test Unit Installation at RPI

During the current quarter, following completion of PRB testing with the modified gas combustor and modified PC burner, fabrication and installation of a second modified version of the PC burner using air nozzles in place of air channels was completed. This air nozzle version of the burner more closely resembles GTI's gas-fired low NO_x burner designs, which may

produce a more distributed flame with the pyrolyzed coal containing a high proportion of gaseous fuel components and char that is already heated to 1200° - 1500°F.

Task 1.4 *Pilot-Scale Testing*

Air Channel Burner Testing

Pilot testing of the air channel version of the PC burner together with the modified gas combustor using PRB coal was completed during the quarter. A total of 37 tests were conducted with the air channel burner. Pilot testing of the air nozzle version of the burner was then completed with PRB coal.

A new 20-ton shipment of PRB coal was received for this testing from Hennepin Power Station in Illinois in late December. Testing with the air channel burner was therefore started with benchmark tests to determine whether performance with the new coal was comparable to that with the previous batch of PRB coal. Baseline testing was then performed to characterize performance of the PC Burner without coal preheating. Finally, parametric testing was performed to evaluate the effect of various preheat combustor and PC burner operating variables, including gas firing rate in the preheat combustor, combustor temperature, coal firing rate, furnace exit O₂, burner air flow and internal air distribution, and use of a low-swirl spreader in the burner coal nozzle.

A series of benchmark pilot tests were conducted with operating conditions similar to tests with the same system using the previous batch of PRB coal. A comparison of NO_x vs. furnace exit O₂ with the old and new coals is shown in Figure 1, which indicates very little performance difference between the two. All emissions results are given on a dry basis, corrected to 3 % O₂.

Figure 1. Benchmarking tests comparing pilot-scale preheating system performance with current and previous batches of PRB coal

A series of tests with PC preheating were conducted at furnace exit O_2 concentrations from 0.8% to 3.0 % by varying airflow to the outermost channel of the PC burner. The results of these tests without a coal spreader in the central coal tube are shown as the lower curve in Figure 2 relative to the project goal of 115 vppm. The upper curve in Figure 2 shows that addition of the coal spreader significantly increased NO_x production.

Figure 2. NO_x vs. exit O_2 curve for preheated PRB coal without coal spreader (lower curve) and with coal spreader (upper curve).

A series of baseline tests were conducted with the gas-fired coal preheater combustor shut off in order to assess the contribution of the combustor to NO_x reduction relative to that of the PC burner alone. Seven of the tests without the gas combustor used a PC burner configuration without a low-swirl spreader installed in central coal tube and one test was conducted with the spreader. Furnace exit NO_x readings with and without preheating in the gas combustor are shown Figure 3. Note that addition of the spreader again increased NO_x for the one point tested.

Two tests were conducted at a reduced coal-firing rate of 160 lb/h compared to the normal firing rate of 200 lb/h. The NO_x results for these tests are shown in Figure 4 vs. exit O_2 along with the same curve for operation at a 200-lb/h coal feed rate. The 20 % reduction in coal firing rate reduced NO_x at the furnace exit by about 20 % at 2.0 % exit O_2 .

The modified PC burner has 3 concentric air channels surrounding a central coal tube. A series of tests was conducted to determine the effect of varying the air distribution between these channels on NO_x formation. Air flow to the innermost air channel (drying agent air) was adjusted to 3 different levels and, over the range tested, showed little effect on NO_x production compared to the base air distribution (Figure 5). Increasing air distribution separately to the secondary and tertiary air channels, however, showed significant increases in NO_x formation.

Figure 3. Baseline comparison of pilot-scale system performance on PRB coal with and without gas firing in the preheat combustor.

Figure 4. Effect of reduced coal firing rate on NO_x at the furnace exit.

Figure 5. Effect of PC burner combustion air distribution on NO_x at the furnace exit

A series of tests was also conducted to determine the effect of reduced gas usage in the preheater combustor on NO_x formation. Gas usage was reduced to about 7 % of total thermal input from the 10-12% used for the base tests. NO_x formation at the reduced gas usage was essentially the same as for the base gas usage as shown in Figure 6. It is expected that when the process is scaled up to the 100 million Btu/h level that gas usage will be further reduced to the range of 3 to 5% of thermal input. The pilot unit includes a relatively long transfer pipe between the gas combustor and PC burner to allow variation of the residence time of preheated coal and pyrolysis products at the equilibrium preheat temperature before they enter the burner. It is expected that this transfer pipe, and the relatively high heat losses from it, will be eliminated in the scaled up design. The larger surface to volume ratio of the pilot-scale equipment also contributes to higher heat losses, and this ratio will be reduced in the larger burner.

Air Nozzle Burner Testing

An air nozzle version of the PC burner was also tested during the quarter. The secondary air channels were closed and 6 air nozzle installed in its place. Shakedown tests with the air nozzle burner showed that the initial design had poor flame stability. Several modifications were made to improve flame stability and attachment to the burner face. One modification to the coal tube improved stability enough that several test periods were achieved at a furnace load of 160 lb/h of coal feed (80% of full load). NO_x was measured at 110 vppm with about 120 vppm of CO. Several other approaches to improve flame attachment and stability were identified and will be tested in the next quarter. Performance of both burners will be compared with respect to flame stability, turndown, NO_x reduction, burnout, and gas usage requirements in the combustor. One of the two burner designs will then be selected for further development and testing with caking coals and scale-up to 100 million Btu/h.

Figure 6. Effect of reduced gas usage in the preheat combustor on NO_x at the furnace exit

Task 1.5 *Pilot-Scale Data Evaluation*

Data evaluation for the original pilot-scale system is complete. The data evaluation for the modified pilot-scale system is ongoing.

Task 1.6 Task 1 Management and Reporting

Babcock Borsig Power has restructured following its separation from its parent company in Germany. They have been renamed Riley Power Inc. (RPI), a subsidiary of Babcock Power Inc.

GTI and RPI completed a review of the project plans for 100 MMBtu/h PC Preheat burner fabrication, installation and testing and RPI developed an updated cost estimate for their portion of the workscope, including reactivation of their 100 MMBtu/h Coal Burner Test Facility (CBTF). GTI then initiated a third modification (M003) to RPI's subcontract to cover these changes. These changes will not increase DOE's costs under the prime contract with GTI. GTI will initiate a contract modification for the prime contract to reflect the increase in GTI cost sharing contribution once the subcontract modifications are finalized and approved.

Reactivation of the CBTF and design of the 100 million Btu/h Preheat system will begin next quarter with the goal of completing the large-scale testing by late fall of this year. Since the CBTF furnace is water cooled, testing cannot be conducted during the winter months.

Planning was also begun for completion of the pilot-scale tests with caking coals, which will be started as soon as the air nozzle burner testing is completed. It is intended that this testing will be conducted in parallel with reactivation and design work for large-scale testing, with the possibility that some design concepts can be tested at the pilot scale as they are developed.

Plans for Next Quarter:

- Complete parametric testing of the air nozzle version of the PC burner and select the design version (air channel or air nozzle) to be used for further development.
- Develop the test plans for pilot-scale testing with caking coals. Initially testing will be conducted with the Central Appalachian already on site, and will focus on evaluating the various methods for eliminating plugging in the preheater that were identified in the initial Central Appalachian coal testing. These include further lengthening the combustor, modifying the coal inlet nozzle to improve mixing, firing gas through the secondary combustor nozzles to increase heat input and mixing, and injecting steam into the preheat combustor.
- Continue pilot data evaluation and modeling as required.
- Execute subcontract modification M003 with RPI.
- Request a Contract modification for Cooperative Agreement DE-FC26-00NT40752 to reflect pending increases in GTI's cost sharing obligation.
- Begin reactivation of the 100 MMBtu/h Coal Burner Test Facility (CBTF).
- Begin design of the 100 MMBtu/h PC Preheat system.
- Complete the Task 1 Topical Report for Pilot-Scale testing.

CONCLUSIONS

The pilot-scale PC Preheat system has achieved the initial target for NO_x reduction to below 0.15-lb/MMBtu (115 ppmv) with PRB coal. NO_x reduction was demonstrated at levels below 100 ppmv with CO in the range of 35-112 ppmv without any furnace air staging and furnace exit oxygen levels of 2%. NO_x levels between 110 and 115 ppmv were achieved with natural gas usage equivalent to about 7% of the total thermal input. It is expected that when the process is scaled up to the 100 million Btu/h level that gas usage will be further reduced to the range of 3 to 5% of thermal input. Operation with furnace air staging can be expected to reduce NO_x emissions further.

While the pilot-scale results for PRB coal are important, the most important potential market for the PC Preheat technology is expected to be in the Eastern portion of the U.S. where PRB coal is generally not economic to use. This region includes the 22 states and the District of Columbia that are subject to the NO_x SIP call limit of 0.15 lb NO_x/MMBtu. The Eastern U.S. will be subject to an even more stringent limit of 0.11 lb NO_x/MMBtu when the NO_x provisions of the Clear Skies Initiative are fully implemented. For the PC Preheat technology development to be relevant in the Eastern U.S., it is necessary to develop and demonstrate the technology with Eastern caking coals. For this reason, upon completion of the PRB testing with the air nozzle version of the PC Burner, the most successful version of the PC Burner will be selected for additional pilot-scale testing with Central Appalachian caking coal. This testing will focus specifically on identifying the system configuration and operational changes necessary for successful operation with caking coal, for incorporation into the design and operation of the 100-MMBtu/h test unit for caking coals.

REFERENCES

None

Milestone Status Table: The planned completion dates for all project tasks and major milestones are currently be revised.

ID No.	Task / Milestone Description	Planned Completion	Actual Completion	Comments
◆	Kickoff Meeting	5/2/2000	5/2/2000	Complete
1.0	Technology Development			
1.1	Pilot-Scale Design	8/31/2000	12/31/2000	Complete
1.2	CFD Modeling-Pilot and Commercial Scale	6/30/2001		Modeling modified pilot-scale combustor and burner complete
1.3	Pilot-Scale Equipment Fabrication and Installation	11/30/2000	9/30/2001	Modified gas combustor & burner installation complete
1.4	Pilot-Scale Testing	3/31/2001		Full completion expected 6/2003
1.5	Pilot-Scale Data Evaluation	4/30/2001		Full completion expected 6/2003
1.6	Task 1 Management and Reporting	4/30/2001		Completion expected 6/2003
◆	Task 1 Report	4/30/2001		Completion expected 6/2003
2.0	Technology Validation			
2.1	Commercial Prototype Engineering Design	7/31/2001		Completion expected 7/2003
2.2	Baseline Data Review	7/31/2001		Completion expected 6/2003
2.3	Commercial Prototype Construction	10/31/2001		Completion expected 8/2003
2.4	Commercial Prototype Testing	2/15/2002		Completion expected 10/2003
2.5	Data Processing and Evaluation	3/31/2002		Completion expected 11/2003
2.6	Commercialization Plan Development	6/15/2002		Completion expected 1/2004
2.7	Design and Fabrication of Commercial Burner System	7/31/2002		Completion expected 2/2004
2.8	Task 2 Management and Reporting	8/10/2002		Completion expected 3/2004
◆	Final Report	8/10/2002		Completion expected 3/2004