METHANE de-NOX[®] for Utility PC Boilers
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ABSTRACT

During the current quarter, pilot-scale testing with the modified air nozzle version of the PC burner was completed with PRB coal at the Riley Power Inc. (RPI) test facility. A total of 8 different burner configurations were tested utilizing various burner air nozzle arrangements in place of the burner air channels. It was found that with the arrangements tested, a stable flame could not be maintained at coal feed rates above 100 lb/h. While it is felt that the air nozzle approach can ultimately be used effectively, in the interest of holding to the current project schedule it was decided to proceed with the balance of the project using the air channel design.

The pilot-scale PC burner was therefore restored to the air-channel configuration and benchmark testing with PRB coal to confirmed previous operating results. A series of tests was then conducted with PRB and West Virginia caking coal to evaluate modifications to the gas combustor configuration and operation for improved performance with caking coal. Continuous operation was achieved with caking coal up to 50 lb/h vs. the full load target of 150 lb/h. Impingement and deposition of partially devolatilized coal occurred at various points within the combustor when the caking coal feed was increased above 50 lb/h.

The 100 MMBtu/h commercial-scale prototype design was started with coal burner design input from both RPI and VTI. Based on typical burner installation layout considerations, it was that the preheat combustor should be oriented horizontally on the axial centerline of the coal burner. Accordingly, work was begun to relocate the pilot gas combustor to this orientation so that the pilot results with caking coal will be directly applicable to the preferred 100 MMBtu design.

Inspection and repair of the 100 MMBtu/h Coal Burner Test Facility (CBTF) was initiated by RPI and as of 6/30, this activity was 70% complete.

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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-NOX 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 demonstrated that the PC Preheat process has a significant effect on final NO_x formation in the coal burner. Various 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. NO_x reduction was demonstrated with PRB coal at levels below 100 ppmv with CO in the range of 35-112 ppmv without any furnace air staging.

Initial pilot testing with caking coal resulted in deposition and plugging by caked material inside of the gas combustor. Modifications to the combustor configuration and operation were developed that achieved sustained operation with caking coal up to 50 lb/h vs. the full load target of 150 lb/h. Further modifications will be tested to achieve full load operation in the pilot unit on caking coal. Design of the 100 MMBtu/h system is underway and is based on the preheat combustor oriented horizontally on the axial centerline of the coal burner. The pilot unit is being modified to this horizontal configuration so that pilot results will be directly applicable to the 100 MMBtu/h design.

EXPERIMENTAL

Pilot Unit

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.

100 MMBtu/h Unit

Inspection and repair of the Coal Burner Test Facility (CBTF) was begun by RPI in preparation for testing of the 100 MMBtu commercial prototype PC PREHEAT system. The CBTF comprises a large horizontally fired dry bottom furnace capable of testing full-scale burner systems with firing capacities up to 100 MMBtu/h. The furnace is fully integrated with coal storage, grinding and feeding, emissions control, and continuous flue gas sampling and analytical subsystems.

Coal is pulverized and dried in a DB Riley Model 350 Atrita pulverizer, which is fed from a 40-ton bunker by a weigh-belt feeder and rotary valve. The mill's air supply system includes a Venturi air flow meter, fan and natural gas direct-fired heater to supply a measured amount of hot air to the pulverizer to dry and transport the coal. The CBTF is capable of firing in both the direct fire mode and from an intermediate storage bin (indirect fire). All testing will be conducted in the direct fire mode to simulate the most common firing method in the U.S market. Drying and transport air will be separated from coal stream immediately ahead of the PC PREHEAT combustor inlet. The separated air will be directed to on of the three air channels in the coal burner. Secondary air will be preheated to 600 °F by a separate fan and heater and routed to the coal burner. Air can be routed to the burner through an integral windbox plenum or through separate external ducts. Flow to each burner air channel can be regulated independently. Ports are also available at several locations for furnace air staging.

Flue gas composition will be monitored continuously. A multiple-probe sampling grid consisting of sintered Hasteloy filters is mounted in the CBTF exit duct, just upstream of the flue gas scrubber. The in-duct filters remove the majority of particulate, and the flue gas is drawn through stainless steel tubing, ice-bath conditioners, and a final filter by individual sample pumps. A rotameter at the outlet of each pump is used to admit equal flow of clean, dry sample from each grid probe to a manifold. The proper flow of sample for each continuous analyzer is supplied from the manifold.

Continuous monitors are used to measure O₂, CO₂, CO, NO/NO_x and SO₂. In addition to the gas sampling grid, a separate water-cooled probe is used to withdraw particulate samples at the CBTF outlet for determination of carbon burnout. A high velocity thermocouple probe monitors furnace outlet temperature.

The CBTF is fully instrumented to allow continuous measurement and recording of all relevant flow, pressure and temperature readings to allow complete material and energy balances to be developed for each testing period.

RESULTS AND DISCUSSION

Project Status:

Task 1.1 Pilot-Scale Design

Design work was completed to relocate the pilot gas combustor to a horizontal orientation along the centerline of coal burner so that the pilot results with caking coal will be directly applicable to the preferred 100 MMBtu design. Other pilot design changes to accommodate caking coal include lengthening the combustor and reducing its diameter to match the coal burner. This eliminates the diameter reduction at the combustor outlet that has been a source of plugging with caking coal, while slightly increasing the residence time for char and devolatilization product within the combustor. Design documents were prepared and forwarded to RPI for fabrication and installation.

Task 1.2 CFD Modeling

Plans were developed to begin modeling activities for the 100 MMBtu/h unit and to restart modeling for the pilot unit. 3D modeling will be done for the horizontal PC PREHEAT pilot combustor arrangement at two different gas phase inlet velocities to evaluate the impact of the new configuration on particle and volatile matter contours and comparisons of temperature, density and velocity magnitudes. Of particular interest is the extent to which char particles may settle out on the bottom of the horizontal combustor.

Plans were made to initiate modeling in support of the 100MMBtu/h design. It was decided that RPI would perform 2D axisymmetric aerodynamics CFD simulations to fix the burner design while GTI will conduct 3D modeling including combustion modeling.

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

The pilot-scale PC burner was restored to the air-channel configuration following completion of testing with the air nozzle version of the PC burner. An additional flame scanner was mounted on the gas-fired ignitor to monitor the coal flame through the ignitor pipe to improve flame sensing and reduce nuisance trips during startup and transition periods. New and replacement skin thermocouples for the Preheat Combustor body were also specified, procured and installed.

Task 1.4 Pilot-Scale Testing

Air Nozzle Burner Testing

Pilot testing of the air nozzle version of the PC burner with PRB coal was concluded during the quarter. Initial testing of this burner design in the previous quarter revealed problems with pressure pulsations, flame stability and flame attachment at the burner face. A number of modifications were made to the burner during testing conducted in April to eliminate these problems. Changes to the air nozzle diameter eliminated the pressure pulsations. Other changes to the burner and burner operating conditions tested included:

- Length of the coal nozzle
- Addition of various flame holders at the end of the coal nozzle
- Addition of several different coal swirlers in the coal nozzle
- Adjustment of relative velocity of primary, secondary and tertiary air streams

The best NO_x result measured during this testing was 110 vppm corrected to 3% O₂, with 120 vppm CO. In general, problems of flame stability continued throughout the testing and were not satisfactorily resolved by the various modifications to the burner and its operating conditions. It was therefore decided to return the burner to its previous air channel configuration for the balance of the pilot testing.

Air Channel Burner Testing

GTI continued pilot testing in June with air channel version of the coal burner. The goal of the testing was to evaluate several new approaches to operation with caking coal to eliminate deposition and plugging in the gas combustor chamber. The technical approach used was to intensify heat transfer between coal and natural gas flame through combustor design and operating changes such that all of the char and devolatilization products would pass through the sticky mesophase before reaching the diameter reduction at the exit of the combustor. Four baseline tests with PRB coal were conducted using the previously tested gas combustor design. During those tests, radial profiles of temperature in the combustor were measured at two locations, 7 and 17 inches from the combustor front wall. The temperature profile at 17 inches for this combustor configuration is shown in Figure 1. In general, temperatures in the devolatilization product stream near the centerline of the combustor were found to be near or below the minimum temperature (about 900 °F) expected to be necessary to avoid sticking with caking coal.

Two modifications of the coal injection nozzle were then tested with PRB coal to determine their effect on heat transfer between the coal stream and the natural gas flame. The modifications included increasing the diameter of the coal injection nozzle, adding perforations through the nozzle walls and adding a small cross-section bluff body at the bottom. The resulting temperature profile at the same location 17 inches from the combustor front wall is shown in Figure 2. Comparison of the temperature profiles in Figure 2 (modified coal nozzles) to the

Figure 1. Radial temperature distribution at 17 inches from combustor front wall shows relatively low devolatilization product temperatures for the baseline combustor

profiles in Figure 1 (straight nozzle) shows that both modifications provide faster heat transfer from the natural gas flame to the coal stream than coal injection through the straight nozzle. Temperatures are significantly higher and more uniform at the 17-inch point, which is 3 inches from the combustor exit.

Figure 2. Modifications to gas combustor coal nozzle significantly increase heat transfer to coal devolatilization products

Based on the favorable results with PRB coal, four versions of the modified coal injection nozzles were tested with caking bituminous Central Appalachian (CA) coal. Continuous operation was achieved with a perforated coal nozzle at a CA coal-feeding rate of 50 lb/h (30% of full firing rate). However, plugging of the combustor with caked material occurred when the rate was increased above this level. Several different preheat regimes were tested, including high, medium, and low temperature preheat regimes, and preheat with both lean and rich natural gas flames. Inspection of the preheater after plugging showed that accumulation occurs wherever there was direct wall impingement by preheated coal particles. The coal nozzle modifications tested greatly improved mixing and heat transfer between the coal and combustion gases, but did so at the expense of increased coal particle impingement on the walls of the combustor in the immediate vicinity of the coal nozzle. This approach to nozzle design appears promising for non-caking coals like PRB, since it can significantly shorten the required combustor length by improving mixing and heat transfer. For caking coals, however, a different approach will be necessary.

Based on these results, development of further pilot combustor modifications was started, including reducing the combustor diameter to increase velocity and eliminate the diameter reduction at the combustor outlet, and increasing the combustor length to maintain coal residence time. Also, RPI's initial guidance on the 100 MMBtu commercial burner design based on typical-installation layout considerations is that the preheat combustor should be oriented horizontally on the axial centerline of the coal burner. Accordingly, it was decided that the pilot gas combustor would be relocated to this orientation during the current changes so that the pilot results will be directly applicable to the preferred 100 MMBtu design.

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 2.1 Commercial Prototype Engineering Design

Development of the commercial prototype burner design basis was begun by GTI with collaboration from RPI and VTI. It was agreed that the starting basis for design for the coal burner to be utilized in the PC PREHEAT system would be RPI's commercial CCV[®] burner. It was further decided, based on RPI's experience with PC burner installations in the U.S., that a horizontal configuration for the preheat combustor along the same centerline as the coal burner would be the easiest to retrofit in most installations. Since all pilot testing to date has been conducted with the preheat combustor in the vertical orientation, it was decided to modify the pilot unit immediately to the horizontal configuration for the balance of pilot testing with caking coal. In this way all operating experience and performance data from the pilot unit will be more readily applicable to the commercial burner development effort.

Task 2.2 Baseline Data Review

RPI will provide and review combustion and emissions test results obtained with their commercial CCV burners for a wide variety of coals, including both bituminous caking and non-bituminous non-caking coals from both the CBTF and field-testing programs. This analysis will

be used to guide the commercial burner development in the CBTF such that the resulting burner will perform satisfactorily in actual field applications.

Task 2.3 Commercial Prototype Construction

Inspection of the CBTF revealed that the facility requires repairs to the furnace backend and scrubber outlet since the facility has not been in operation since 2001. The entire facility's operational and emissions monitoring systems is being put through a complete maintenance checkout. In addition, the existing coal pipe routing is being changed to accommodate coal separation from the primary air stream using an existing cyclone on site. The cyclone is being relocated and ductwork added to route the separated primary air to a separate air channel in the modified PC burner. As of the end of June 2003, this work was approximately 70 % complete.

Task 2.4 Commercial Prototype Testing

No work was performed on this task during the reporting period.

Task 2.5 Data Processing and Evaluation

No work was performed on this task during the reporting period.

Task 2.6 Commercialization Plan Development

No work was performed on this task during the reporting period.

Task 2.7 Design and Fabrication of Commercial Burner System

No work was performed on this task during the reporting period.

Tasks 1.6 & 2.8 Management and Reporting

The third modification (M003) to RPI's subcontract was executed to cover revised project plans for the 100 MMBtu/h PC Preheat burner fabrication, installation and testing and reactivation of the CBTF. GTI initiated contract amendment A006 for the prime contract with DOE to reflect an increase in GTI's cost share contribution to cover the additional program costs.

GTI prepared and presented a technical paper titled "Current Status of Development and Testing of a Novel Coal Preheating Technology for NO_x Reduction from Pulverized Coal-Fired Boilers" at the 2003 MEGA Symposium in Washington D.C. in May. A copy of the paper and presentation materials was forwarded to DOE. An abstract was submitted and accepted for a presentation on the project at DOE/NETL's 2003 Conference on Selective Catalytic and Non-Catalytic Reduction for NO_x Control, to be held October 29 and 30 in Pittsburgh.

Reactivation of the CBTF will be completed next quarter. Completion of the design of the 100 million Btu/h Preheat system is targeted for the end of July so that fabrication and installation of the system can be completed in time to allow startup of the CBTF by mid-October at the latest. The CBTF furnace is water cooled and testing cannot be conducted during the winter months.

Pilot testing will be conducted in parallel with reactivation and design work for large-scale testing. Modifications to the pilot unit for testing with the horizontal combustor configuration will be completed in July with testing to be resumed in early August.

Plans for Next Quarter:

- Complete modifications to the pilot unit for testing with the horizontal combustor configuration.

Complete pilot testing with caking coals in the horizontal combustor configuration.

- Continue pilot data evaluation and modeling as required.

Complete the Task 1 Topical Report for Pilot-Scale testing.

- Complete 2D and 3D CFD modeling in support of the pilot modifications and 100 MMBtu design.

Complete reactivation of the 100 MMBtu/h Coal Burner Test Facility (CBTF) and design and installation of the 100 MMBtu/h PC Preheat system.

CONCLUSIONS

The primary focus for the project is now on developing a PC PREHEAT system design suitable for use with caking coals. The most important potential market for the technology is expected to be in the Eastern portion of the U.S. where non-caking PRB coals are generally not economic to use. Initial efforts to modify the pilot unit for caking coals centered on improving mixing and heat transfer between the gas combustion products and the coal stream in order to more rapidly traverse the coal's sticky mesophase before impingement and deposition on an interior surface of the combustor. It was found that the methods employed significantly increased both mixing and heat transfer, but at the expense of significantly increased coal impingement and plugging in the combustor. While these methods may be useful to develop shorter combustor designs for non-caking coals like PRB, they will not be useful for caking coals.

The pilot experience, together with commercial design guidance from RPI that favors a horizontal orientation for the combustor, has redirected the development of both the pilot and commercial units toward a horizontal combustor design with no diameter change between the combustor and burner. The velocity of the devolatilization products in the combustor and burner will be increased over previous pilot testing to minimize separation and impingement of coal on inner surfaces prior to reaching the burner face. The velocities utilized will be consistent with standard design criteria developed by RPI for their commercial CCV burners. The pilot unit will be operated in parallel with the 100 MMBtu commercial prototype design in order to be able to test various design alternatives as they are developed. While it is expected that some plugging may always occur in the pilot unit due to its relatively small size, it will still provide valuable insight on both caking and emissions performance in a much more economical and timely manner than testing a large number of design alternatives at the 100 MMBtu scale.

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		Completion expected 9/2003
1.5	Pilot-Scale Data Evaluation	4/30/2001		Completion expected 9/2003
1.6	Task 1 Management and Reporting	4/30/2001		Completion expected 9/2003
◆	Task 1 Report	4/30/2001		Completion expected 9/2003
2.0	Technology Validation			
2.1	Commercial Prototype Engineering Design	7/31/2001		Completion expected 8/2003
2.2	Baseline Data Review	7/31/2001		Completion expected 8/2003
2.3	Commercial Prototype Construction	10/31/2001		Completion expected 9/2003
2.4	Commercial Prototype Testing	2/15/2002		Completion expected 12/2003
2.5	Data Processing and Evaluation	3/31/2002		Completion expected 1/2004
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