

METHANE de-NOX[®] for Utility PC Boilers
Quarterly Technical Progress Report
for the period ending December 31, 2003

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ABSTRACT

The primary focus for the project continues to be on developing a PC PREHEAT system design suitable for use with caking coals and readying the 100 MMBtu/h CBTF for testing with non-caking PRB coal.

During the current quarter, twenty-two pilot tests were conducted with Central Appalachian (CA) caking coal. The objective for these tests was to achieve continuous operation of the pilot system at its design coal feed rate of 156 lb/h, without plugging or agglomeration in the combustor. One combustor air distribution method tested achieved continuous operation at 110 lb/hr, and inspection of the combustor afterward indicated that this method has potential to solve the caking problem. The NO_x results from the pilot caking coal runs indicate that even greater NO_x reduction is possible with CA coal than with the PRB coal tested, to levels near 100 ppmv or lower at 4-6% exit oxygen. It was therefore decided to conduct additional pilot tests of the air distribution method to determine how to incorporate this into a workable CA combustor design. Based on current weather and manpower restrictions at the site, this pilot testing is expected to be started in February.

The design for the 100 MMBtu/h unit for PRB testing in the CBTF was completed and fabrication and installation started during the quarter. While significant progress has been made in the installation of the unit, weather and combustor fabrication delays are expected to move the start of large-scale testing with PRB coal into February, which will push the project completion date beyond the current 3/30/04 end date. GTI is in the process of developing a revised project schedule and estimated cost to 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 ready technology for full-scale commercial deployment to meet the 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) 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. Modifications to both the pilot system gas-fired combustor and the PC burner led to NO_x reduction with PRB coal to levels below 100 ppmv with CO in the range of 35-112 ppmv without any furnace air staging. Pilot testing with PRB coal is complete.

Initial pilot testing with caking coal resulted in deposition and plugging by caked material inside of the gas combustor. A series of modifications to the combustor configuration and operation were developed and tested during the quarter. One of these approaches was successful in sustaining operation with caking coal up to 126 lb/h, although some deposition and LOI issues remained. Additional pilot testing is planned with caking coal to test solutions to these problems. While not measured under steady-state operating conditions, NO_x results from the caking coal tests were promising, with NO_x levels approaching 100 ppmv with 6% oxygen in the flue gas at the furnace exit.

The design of a 100 MMBtu/h test unit for PRB coal is complete. Fabrication and installation of the test unit has encountered delays due to weather at the test site and RPI quality assurance issues with the gas combustor fabrication. These issues have been resolved and delivery of the PRB gas combustor is scheduled for the first week of February. Completion of the design for the 100 MMBtu/h PREHEAT combustor for caking coal is on hold pending completion of the

additional pilot testing, which has which has been delayed by weather and manpower availability until February.

EXPERIMENTAL

Pilot Unit

Fabrication, installation and initial testing of the pilot-scale PC PREHEAT system were completed in the fall of 2001. The unit is sized for operation with natural gas and pulverized coal at a total firing rate of approximately 3-million Btu/h and includes all equipment and controls necessary to operate and monitor energy and environmental performance of the system. A gravimetric feeder is used to regulate pulverized coal flow through a rotary airlock into a 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. In the original pilot system configuration, the combustor centerline was vertical and two PREHEAT pipe sections after the combustor provided additional residence time for the coal at the preheated conditions prior to entering the PC burner. However, pilot testing experience together with commercial design guidance from RPI 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 PREHEAT combustor was therefore relocated to a horizontal configuration with the combustor exit coupled directly to the PC burner inlet, eliminating the two PREHEAT pipe sections. In the modified pilot unit, the velocity of the devolatilization products in the combustor and burner is increased over previous pilot testing to minimize separation and impingement of coal on inner surfaces prior to reaching the burner face. The velocities utilized are consistent with standard design criteria developed by RPI for their commercial CCV burners.

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.

100 MMBtu/h Unit

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 one 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

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

Task 1.2 CFD Modeling

Pilot Unit

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

100 MMBtu/h Unit

Two modeling activities were conducted in support of the 100MMBtu/h design during the quarter. First, modeling of the PC burner was continued to evaluate the impact of various burner operational and geometry changes on near-burner aerodynamics with combustion in the preheater ahead of the burner.

As discussed in the last report, RPI performed 2-D axisymmetric aerodynamic CFD simulations without combustion to fix the major parameters of the burner design. During the current quarter,

GTI conducted 3-D simulations with combustion for the PREHEAT combustor. The output of the combustor simulations was then used as input to the burner simulation to simulate and evaluate the preheater combustor's effect on near-burner aerodynamics and predicted combustion and NO_x performance. Initial results showed that coupling the preheater output to the PC burner broke down the internal recirculation zones close to the burner discharge that are typical of low-NO_x burner operation. A series of modeling cases was therefore completed which varied the burner swirl, quarl and flow diverter angles until the desired burner exit flow patterns were restored.

The second modeling activity involved developing an appropriate gas/air mixing design for the preheater combustor. Several approaches were modeled and evaluated for mixing effectiveness vs. complexity and cost to fabricate. Based on this, the final mixer arrangement was defined and incorporated into the combustor design drawings.

Task 1.3 Pilot-Scale Equipment Fabrication and Installation

Based on the results of the previous quarter's scoping tests, a number of strategies were developed to improve operation of the 3 MMBtu/h pilot system at the design coal feed rate of 156 lb/h with caking coal. Fabrication and installation of the required components and modifications for testing these strategies were completed by RPI at the beginning of October.

Task 1.4 Pilot-Scale Testing

A total of 22 pilot tests were conducted during the quarter over a broad range of operating conditions with caking coal. The objective for these tests was to achieve continuous operation of the pilot system at its design coal feed rate of 156 lb/h, without plugging or agglomeration of the pulverized coal. The strategies tested were:

- Modification of the mixer air/N₂ injection pipe to avoid the potential for "clumping" of the pulverized coal prior to entering the Preheat combustor.
- Introduction of natural gas instead of air or N₂ to preheat the coal (and pass through the sticky phase) more rapidly in the combustor.
- Lengthening the coal pipe inside the combustor to slow the preheating and to shorten the residence time of preheated coal in the combustor.
- Installation of a Venturi insert at the end of the coal pipe to for the combustion gases and coal/char together in the center of the pipe for improved mixing/heating and to keep solids away from the combustor walls.
- Distributing a portion of the combustion air along the length of the combustion chamber.

As a result of this testing, all but the last approach have been abandoned as potential concepts for a workable caking coal design. Modification of the mixer/N₂ injection pipe and introduction of natural gas into the mixer ahead of the combustor did not reduce caking in the combustor. Lengthening of the coal pipe to effectively shorten the combustor and increase indirect heating of the coal resulted in plugging in the coal pipe, even when the coal pipe was insulated to reduce heat transfer. Installation of the Venturi was also unsuccessful at reducing plugging in the combustor. Finally, several brief tests with combustion air distributed further along the combustion chamber liner showed promise. Tests at 50 lb/h coal feed with air distributed in a 12-inch test section of the combustor resulted in no caking in the combustor and no evidence of agglomerated particles passing through the coal burner. When the coal feed rate was increased to 110 lb/h, small agglomerated particles were observed passing through the burner. However,

continuous operation was maintained up to 126 lb/h. The combustor eventually plugged when the firing rate was raised to 156 lb/h. However, the plugging was found to have occurred ahead of and after the test section of the combustor. The test section itself was completely clean.

Based on these results, the 3 MMBtu/h pilot combustor will be further modified and tested with the new air distribution method applied over various portions of the combustor length.

Task 1.5 Pilot-Scale Data Evaluation

While not measured under steady-state operating conditions, NO_x results from these caking coal tests were promising. Figure 1 shows a plot of NO_x vs. the oxygen concentration at the furnace exit for selected pilot tests in which the coal firing rate was able to be increased enough to allow the furnace's 1 MMBtu/h gas-fired ignitor to be shut off. These data points cover a broad range of operating conditions in the pilot unit. Taken together, they show the expected trend of declining NO_x emissions as the furnace excess air is reduced. It should be noted that NO_x readings approach 100 ppmv at about 6% O₂ in the furnace exit gas. This is considerably lower than the NO_x results at this oxygen level with PRB coal, which did not approach 100 ppmv until exit O₂ was around 2 %. This indicates a potential for NO_x emissions below 100 ppmv with caking coal and furnace exit oxygen in the 2-4% range, provided a satisfactory method is found to eliminate plugging in the gas-fired combustor.

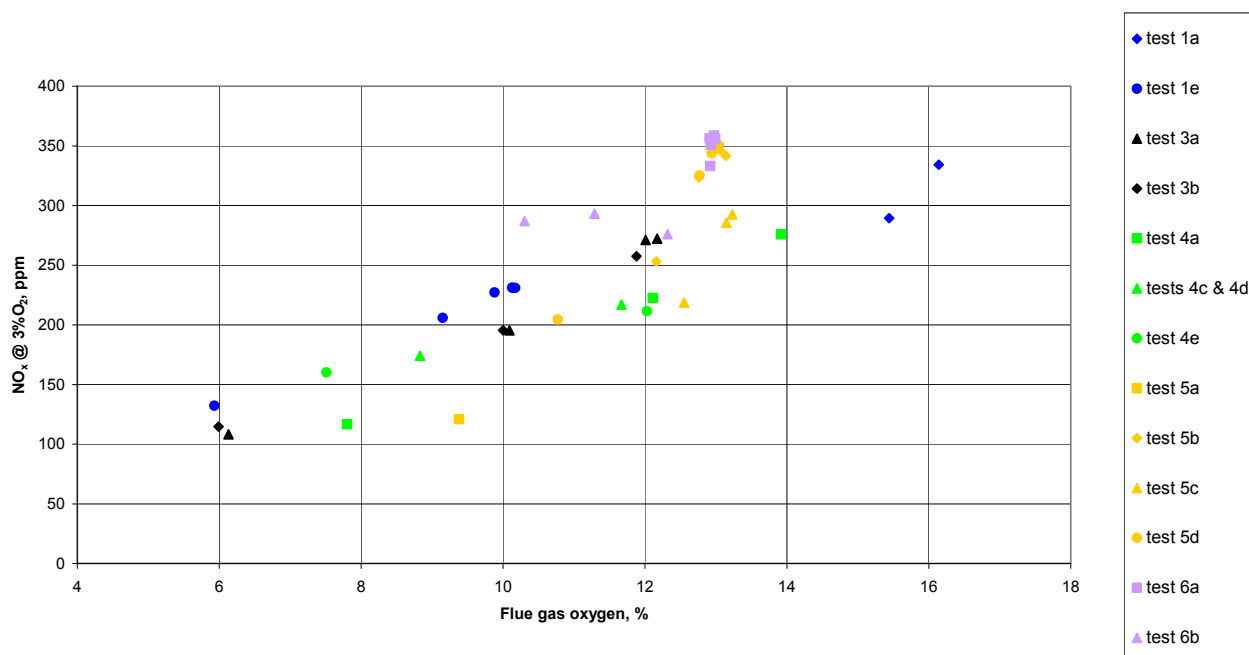


Figure 1. NO_x vs. O₂ Results for 3 MMBtu/h tests with Central Appalachian caking coal

Task 2.1 Commercial Prototype Engineering Design

The 100 MMBtu/h CCV-based Burner modification drawings were completed and checked. Burner drawings include details for both PRB and Caking coal. The burner drawings were released for quotes. The 100 MMBtu/h PRB combustor component drawings, including the Mixer, Compensator and Spool Piece, were completed, reviewed and released for fabrication. The 100 MMBtu/h PRB combustor drawings were completed and released for quotes. Structural

drawings for the 100 MMBtu/h PRB system were completed along with fabrication of the cyclone support tower. The 100 MMBtu/h system P&ID was completed, reviewed and approved.

Task 2.2 Baseline Data Review

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

Task 2.3 Commercial Prototype Construction

Inspection and repairs to the CBTF test facility are complete. The cyclone support tower and cyclone installation is complete. Fabrication of the 100 MMBtu/h PRB combustor components, including the Combustor, Mixer, Compensator and Spool Piece was started. The PRB combustor is expected to ship in mid-January, at which time all necessary components for the 100 MMBtu/h PRB are expected be on site. RPI estimates that the earliest that the installation of all equipment and instrumentation can be completed is the first week of February, which may delay the start of testing until March due to weather conditions at the site.



Figures 1-4. *Clockwise from upper left:* 1. CCV burner during PREHEAT modifications. 2. PREHEAT combustor shell during fabrication. 3. Cyclone support tower being set on the CBTF burner deck. 4. The cyclone and inlet pipe support installed on the burner deck.

Task 2.4 Commercial Prototype Testing

Arrangements were completed for procurement and shipping of 6 truckloads of PRB coal from Dynegy's Hennepin Power Station to the CBTF test site for the 100 MMBtu/h PRB testing.

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

A presentation was given for the project at DOE/NETL's 2003 Conference on Selective Catalytic and Non-Catalytic Reduction for NO_x Control, on October 29th in Pittsburgh.

RPI developed a Press Release regarding the project for review by GTI and DOE. GTI coordinated the review and approval by NETL, and the PR was released by RPI in November.

Approval was received for a proposal submitted to GTI's SMP program to fund the balance (\$75,000) of their \$150,000 cost share commitment for the project.

A fourth modification (M004) to RPI's subcontract was executed to increase their spending limit to the full subcontract value. The differences in PREHEAT system design and operation for processing PRB and caking coal have significantly increased project scope, schedule and cost. In addition to the additional pilot modifications and testing, both completed and planned to deal with caking coal, it is now apparent that two separate 100 MMBtu/h PREHEAT combustors will also have to be fabricated to accommodate differences in processing these two coal types. GTI has absorbed all of the cost increases to date, increasing our original obligation of \$ 850,000 by \$644,923 to a total of \$1,494,923. It is clear that the weather- and equipment fabrication-related delays encountered in the last quarter will push project completion beyond the current 3/30/04 end date. GTI is in the process of developing a revised project schedule and estimated cost to complete.

Plans for Next Quarter:

- Complete pilot testing with caking coals in the horizontal combustor configuration.
- Continue pilot data evaluation and modeling as required.
- Start the Task 1 Topical Report for Pilot-Scale testing.
- Complete the 100 MMBtu/h unit design for caking coal.
- Complete fabrication and installation of the 100 MMBtu/h PC Preheat system for PRB coal.
- Weather permitting, initiate 100 MMBtu/h testing with PRB coal
- Review and revise project schedule and initiate contract and subcontract extensions as necessary.
- Re-evaluate project cost to complete and secure additional funding as necessary.

CONCLUSIONS

The primary focus for the project continues to be on developing a PC PREHEAT system design suitable for use with caking coals and readying the 100 MMBtu/h CBTF for testing with PRB coal.

Twenty-two pilot tests were conducted during the quarter with caking coal. The objective for these tests was to achieve continuous operation of the pilot system at its design coal feed rate of 156 lb/h, without plugging or agglomeration of the pulverized coal. One combustor air distribution method tested achieved continuous operation at 126 lb/hr, and inspection of the combustor afterward indicated that this method has potential to solve the caking problem. The NO_x results from the pilot caking coal runs indicate that even greater NO_x reduction is possible than with the PRB coal tested, to levels near 100 ppmv or lower. It was therefore concluded additional pilot tests of the air distribution method to try to incorporate this into a workable combustor design are warranted.

The design for the 100 MMBtu/h unit for PRB testing in the CBTF was completed and fabrication started during the quarter. As a result of weather- and equipment fabrication-related delays, testing with PRB coal is now scheduled to start in February. This will push project completion beyond the current 3/30/04 end date, and GTI is in the process of developing a revised project schedule and estimated cost to complete.

REFERENCES

N/A

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 2/2004 |
| 1.5 | Pilot-Scale Data Evaluation | 4/30/2001 | | Completion expected 4/2004 |
| 1.6 | Task 1 Management and Reporting | 4/30/2001 | | Completion expected 5/2004 |
| ◆ | Task 1 Report | 4/30/2001 | | Completion expected 5/2004 |
| 2.0 | Technology Validation | | | |
| 2.1 | Commercial Prototype Engineering Design | 7/31/2001 | | Completion expected 3/2004 |
| 2.2 | Baseline Data Review | 7/31/2001 | | Completion expected 3/2004 |
| 2.3 | Commercial Prototype Construction | 10/31/2001 | | Completion expected 2/2004 |
| 2.4 | Commercial Prototype Testing | 2/15/2002 | | Expected to start 3/2004 |
| 2.5 | Data Processing and Evaluation | 3/31/2002 | | * |
| 2.6 | Commercialization Plan Development | 6/15/2002 | | * |
| 2.7 | Design and Fabrication of Commercial Burner System | 7/31/2002 | | * |
| 2.8 | Task 2 Management and Reporting | 8/10/2002 | | * |
| ◆ | Final Report | 8/10/2002 | | * |

*Revised schedule under development by GTI and RPI.