METHANE de-NOX® for Utility PC Boilers

Quarterly Technical Progress Report
for the period ending September 30, 2004

Covering Period: July 1 – September 30, 2004

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Date of Report: October 30, 2004

Award Number: DE-FC26-00NT40752

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ABSTRACT

Large-scale PRB testing during the current quarter was cut short due to the inability of the coal mill to meet the 85 MMBtu/h design firing rate. The project was therefore redirected toward design, installation and testing of the 85-million Btu/h preheater for bituminous coal. Based on extensive pilot-scale testing completed earlier in the project, 2-D modeling and preliminary design activities were started based on the use of staged, annular protective air films to control temperature and prevent deposition on the preheater walls. A total of 14 2-D modeling cases were completed for the modified preheater for bituminous coal. The preheater concept modeled was based on an expanding preheater chamber where the diameter of the chamber is increased in steps along its length and annular cooling/protective air is introduced at each step. A process flow diagram for the bituminous coal preheating system and a preliminary preheater design drawing were developed based on the modeling results. A project schedule to complete design, installation and testing of the 85 MMBtu/h bituminous coal preheating system before the end of December was also developed.

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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 N_2. 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 have been developed and tested during previous quarters, and testing of several more versions was continued in the current quarter. One of these approaches using a stainless steel liner indirectly cooled with air was successful in sustaining operation with caking coal up to 150 lb/h.

The installation of the large-scale prototype coal preheater for PRB testing in the CBTF was completed and shakedown testing with natural gas and PRB coal started during the previous quarter. Large-scale testing during the current quarter was cut short due to the inability of the coal mill to meet the 85 MMBtu/h design firing rate. The project was therefore redirected toward design, installation and testing of the 85-million Btu/h preheater for bituminous coal. Based on extensive pilot-scale testing completed earlier in the project, 2-D modeling and preliminary design activities were started based on the use of staged, annular protective air films to control temperature and prevent deposition on the preheater walls.

EXPERIMENTAL

Pilot Unit

Fabrication, installation and initial testing of the pilot-scale coal preheating 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 preheater 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 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 preheater combustor was therefore relocated to a horizontal configuration with the combustor exit coupled directly to the PC burner inlet, eliminating the two 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 higher velocities are more consistent with standard design criteria developed by RPI for their commercial CCV burners. The higher combustor velocities were achieved by inserting a liner in the combustor to reduce its internal diameter. The liner also facilitates testing of various designs and operating approaches to eliminate plugging of the combustor with caking coals. Various liner materials, including metal and ceramic, and liner cooling methods are being developed and tested to determine their effect on wall deposition and plugging.

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, CO_2, O_2, THC and NO/NO_x in the pilot 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 CO_2 analyzer, a Rosemount Model 400 flame ionization total hydrocarbons (THC) analyzer, a Rosemount Analytical Model 755R paramagnetic O_2 analyzer, and a ThermoElectron Model 14A chemiluminescence NO_x analyzer.

The preheater 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.

Large-Scale Prototype 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 preheater 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 ºF 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 O_2, CO_2, CO, NO/NO_x and SO_2. 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 or 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.

Pilot-scale testing conducted earlier in the project determined that the process variables affecting coal deposition on the preheater combustor walls include velocity in the preheater, the mixing pattern of the coal particles with products of natural gas combustion, combustion air distribution in the preheater and the surface temperature of the combustor walls. Testing also demonstrated that plugging is initiated by agglomeration of coal particles on the preheater inner walls with no contribution of volumetric agglomeration detected in all tested regimes. This indicates that adequate local protection of the combustor walls against deposition of coal volatiles would resolve the issue. Based on these results, the technical approaches incorporated into the large-scale bituminous coal preheater design during the quarter include (i) creation of a thin oxidizing film over the preheater inner wall and (ii) use of indirect cooling of the preheater inner wall.

Task 1.2 CFD Modeling

Pilot Unit

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

Large-Scale Prototype Unit

A total of 14 2-D modeling cases were completed for the modified preheater for bituminous coal. The preheater concept modeled was based on an expanding preheater chamber where the diameter of the chamber is increased in steps along its length and annular cooling/protective air is introduced at each step. This design approach was developed based on favorable results in the pilot testing when protective air was introduced through annular ports next to the inner wall of the preheater chamber to cool the wall and oxidize sticky volatile matter that approached the wall. In this design, the preheater chamber is positioned inside the burner in place of the burner coal tube. This results in only the cyclone and combustor plenum having to be mounted in front of the PC burner, greatly reducing the space required for the system. Several versions of this design were modeled and a version with three steps for annular air introduction provided the best compromise between protection of the wall and design complexity.

It was found that when the hot combustion products from the natural gas burner nozzles around the outside of the coal feed pipe were used, the tendency for coal particles to migrate to the preheater wall was minimized, but the extent of coal heating and devolatilization was limited by poor heat transfer between the hot gas and coal streams. For this reason, a small gas burner was added inside the coal feed pipe to increase coal heating. Coal flows around this burner through the annular space between the burner pipe the coal pipe. Heat transfer to the coal stream is greatly improved by this approach with a corresponding improvement in the degree of devolatilization of the coal at the preheater exit. Adjusting the firing rates of the coal pipe and annular gas burners will be used to achieve the maximum degree of devolatilization consistent with minimizing the migration of coal particles and sticky devolatilization products to the preheater walls. The firing balance between these burners can also be varied to improve startup and turndown capabilities of the system. A process diagram for the new preheater configuration is shown in Figure 1. The yellow arrows in Figure 1 represent the velocity vectors for the annular gas burners and red arrows for the coal pipe gas burner. The arrow colors correspond to the magnitude of the velocity for each stream.

Figure 2 shows the static temperature profiles inside the preheater resulting from this dual-firing configuration together with the corresponding wall temperatures along the preheater's length. The effectiveness of annular air introduction on reducing the preheater wall temperature is also clearly shown in Figure 2.

Figure 3 shows the concentration (mole fraction) profiles of devolatilization products released from coal in the preheater. Red areas in Figure 3 indicate the highest concentration of devolatilization products corresponding to overall devolatilization of 70 percent at the preheater exit.

Figure 4 shows predicted particle tracks in the preheater colored by particle residence time in the preheater. Note that impingement of particles is minimal in this case, with the exception of a small particle recirculation zone at the entrance to the preheater chamber. It is expected that this zone can be minimized by further adjustment of the annular burner firing rate and the position of the coal pipe relative to the preheater chamber inlet.

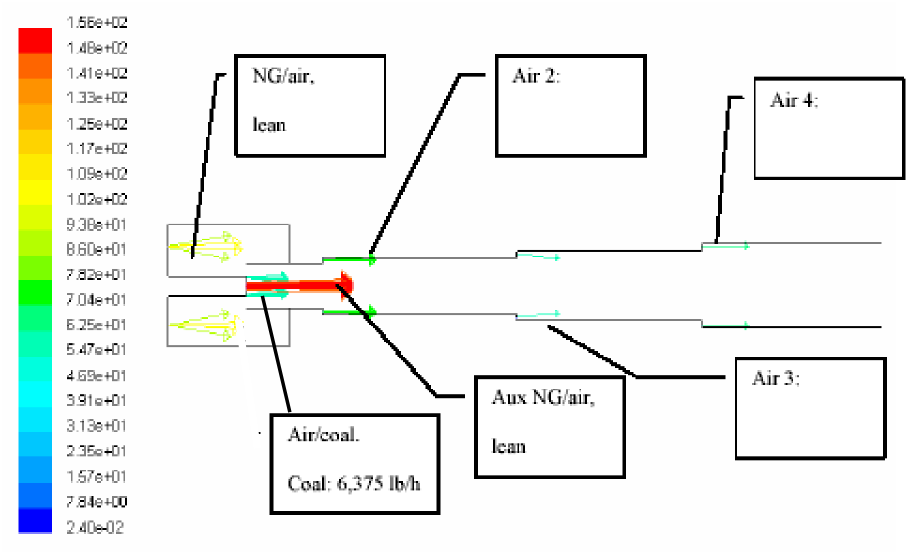

Figure 1. Process schematic for the bituminous coal preheater

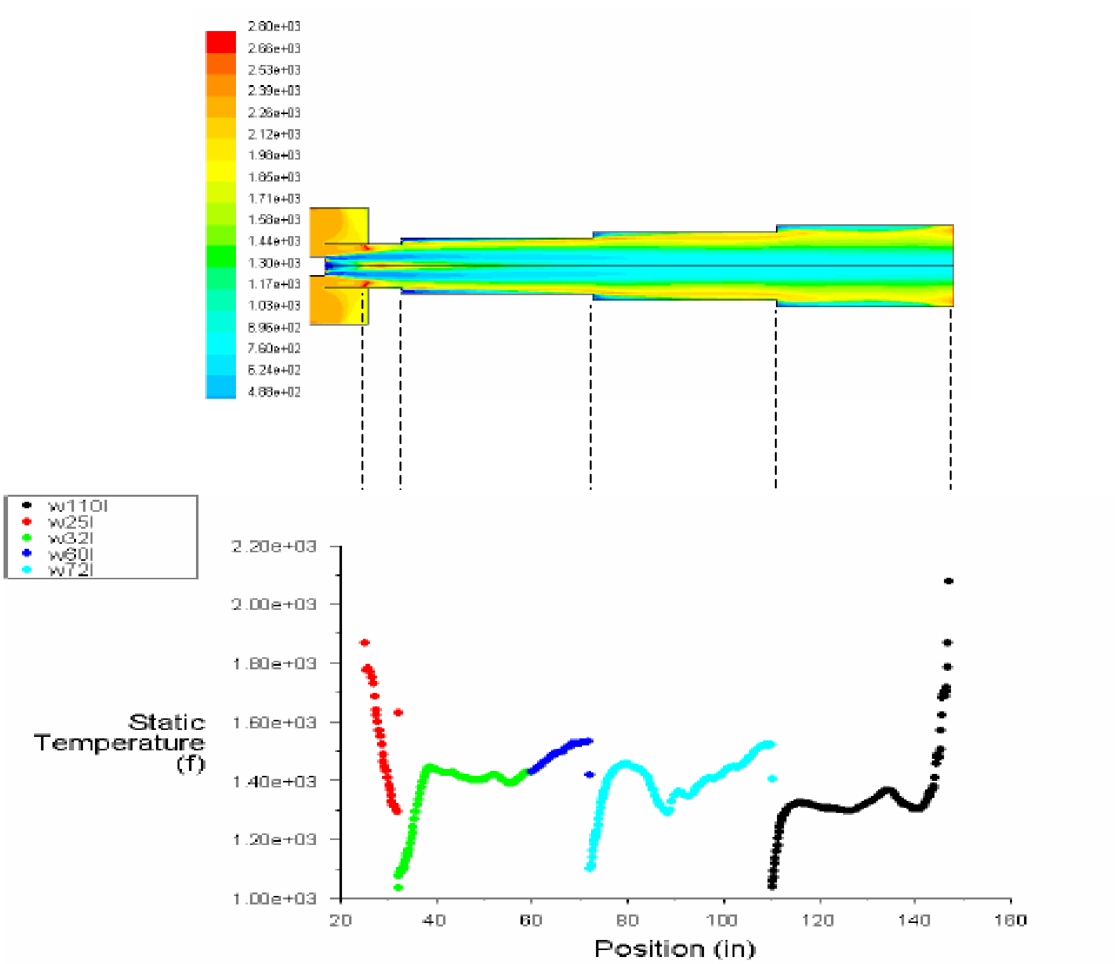

Figure 2. Preheater static temperature contours (top) and corresponding wall temperatures (bottom)

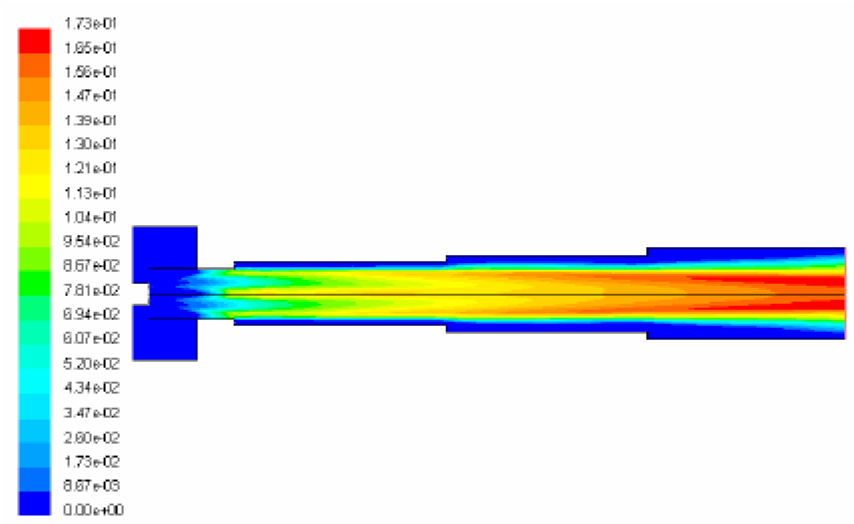

Figure 3. Contours of devolatilization products resulting from the dual-firing system

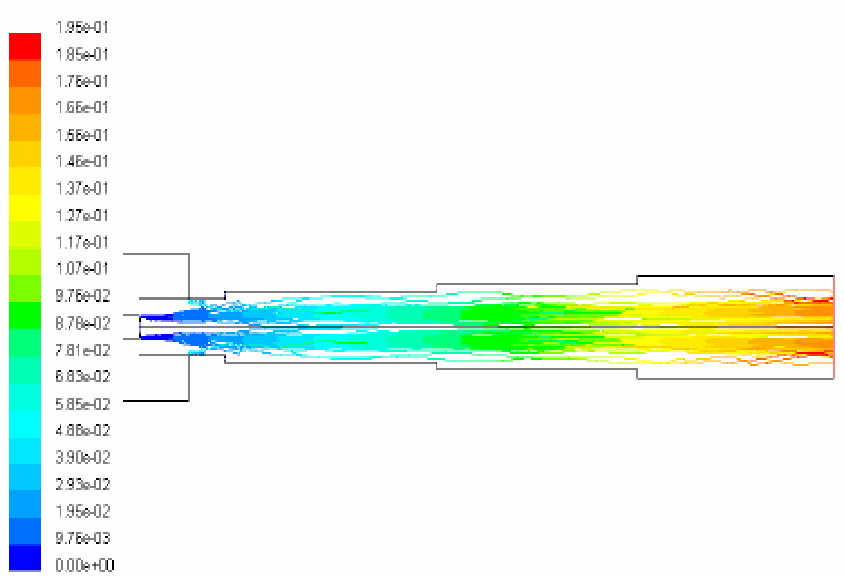

Figure 4. Particle tracks colored by particle residence time in the preheater

Task 1.3 Pilot-Scale Equipment Fabrication and Installation

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

Task 1.4 Pilot-Scale Testing

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

Task 1.5 Pilot-Scale Data Evaluation

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

Task 2.1 Commercial Prototype Engineering Design

The following bituminous coal specification was developed for 85 MMBtu/h preheater testing and a supplier was identified.

Coal characteristics:
- HHV=13,000 Btu/lb
- HGI=43-45
- Moisture=6-8%
- Size=2"
- Ash=8%
- Sulfur=1%

Calculations were performed using the design standards for the RPI R&D Center's 350s Atrita pulverizer with the above coal specification. In any pulverizer the quality of the product (fineness) is dependent on the coal and air throughput. An Air/Coal (A/C) ratio of 1.36 is the original value used in the early standards for this machine. The following table illustrates the relationship between mill A/C ratio and the fineness and throughput of the machine.

HHV BTU/lb	%<200 Mesh	Air/Coal Ratio	Capacity MMBtu/hr
13,000	70	1.50	81
13,000	70	1.36	85
13,000	65	1.36	94

The design basis for the bituminous coal preheater was therefore selected as 85 MMBtu/h with a minimum coal HHV of 13000 Btu/lb and an A/C ratio of 1.36 requiring 6500 lb/h of coal from the mill. Previous testing with PRB coal having a similar HGI of 45 achieved over 7500 lb/h of coal through the mill with an A/C ratio of 1.35.

A process flow diagram (PFD) was developed for the bituminous preheater system specifying the normal and maximum flows for all coal, gas and airflows together with the corresponding stream conditions.

Based on the above design basis information, a preliminary design drawing for the bituminous coal preheater was prepared and released for comments.

Task 2.2 Baseline Data Review

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

Task 2.3 Commercial Prototype Construction

Modifications to the large-scale prototype coal preheating combustor for PRB coal resulting from the findings of the initial shakedown tests are discussed under Task 2.4 below.

Task 2.4 Commercial Prototype Testing

Final commissioning and shakedown testing of the large-scale prototype unit firing natural gas in the preheat combustor was completed during the previous quarter. The objectives for this testing were:

- Develop and test a startup procedure for the combustor firing natural gas
- Confirm mechanical integrity of the combustor including adequacy of thermal expansion provisions
- Confirm functionality of all instruments and controls
- Confirm combustor operation over the full design firing range
- Confirm ability to produce accurate heat and mass balances around the combustor/furnace
- Develop a final punchlist for necessary repairs and changes prior to testing with PRB coal

In the initial shakedown tests, stable operation of the coal system, combustor and burner were achieved for the first time with coal feed rates up to 6000 lb/h (about 50 MMBtu/h). However, attempts to increase the firing rate to the design level of 85 MMBtu/h were prevented by a high-amp condition in the coal mill. Reduced gas velocities in the preheater due to reduced firing rates resulted in some accumulation of coal in the bottom of the preheater chamber.

Inspection of the combustor following the shakedown showed no remaining accumulation of coal on the bottom of the combustor, indicating that all accumulation was burned out during the shutdown procedure. Evaluation of the combustor supports after coal testing resulted in the installation of two additional spring hangers at the ends of the combustor to better carry the weight of the combustor during hot operation when it lifts off of its support stand. A toothed ring was also designed and fabricated in accordance with RPI standards and installed at the burner face on the central coal tube to improve coal flame attachment.

Various instrument repairs and calibration checks identified during the shakedown coal testing were completed and two additional thermocouples were installed in the bottom (5 o'clock position) of the combustor to monitor coal accumulation.

An internal inspection of the burner windbox was conducted to determine the cause of high-pressure drops measured across the secondary and tertiary air channels during the coal testing. These pressure drops were on the order of 9-10 in. wc. vs. the expected 3-4 in. wc. It was determined that the high pressure drops were the result of improper settings of the secondary air vanes and the tertiary air shroud that control air flow from the windbox to the air channels. It was also found that the swirl vanes for the secondary air were set to 0° (no swirl) and they were therefore adjusted to the correct setting of 30°.

The pressure drop across the reagent air channel was also on the order of 10 in. wc, which, together with the 8-10 in wc drop across the cyclone resulted in a backpressure of over 20 in. wc on the coal mill. This restricted air flow through the mill and was one of the causes for reduced mill capacity during the shakedown tests. Tests were conducted with the auxiliary air blower downstream of the mill shut off, which resulted in increased primary air flow through the mill. It was also noted that the reagent air enters the reagent air channel tangentially in a direction opposite to the reagent air channel swirl vanes, and this is increased the pressure drop in the reagent air line by several in. wc.

Evaluation of previous mill performance data indicated that the reduction in auxiliary air and increase in primary air should result in increased mill capacity. Investigation of the feasibility and cost of reactivating an existing bin-firing system to supplement coal feed from the mill determined that the system was difficult to operate and had significant safety issues relative to storage of highly reactive pulverized PRB coal in the intermediate storage bin.
Additional testing was conducted at the R&D center in Worcester, MA in order to determine whether the coal mill capacity with PRB coal could be increased to 85 MMBtu/h. The objective

of the tests was to increase the coal output from the mill from 6000 lb/h (wet) previously achieved to 9700 lb/h (wet) required to meet the preheater system design basis. After evaluating the previous results and comparing them to historical mill data, it was that the mill had not been operated at the correct air to coal ratio. Strategies for increasing coal output included reducing the introduction of auxiliary air to the coal line after the mill, reducing and backpressure on the mill by reducing the pressure drop through the cyclone and reagent air piping.

A total of 6 test periods were conducted at the beginning of August to improve mill performance. During these tests it was necessary to fire the preheat combustor and burner as there was nowhere else to discharge the coal. This amounted to costly full-scale testing of the system even though the objective was only to verify and improve the mill performance. The results were that coal throughput was increased to about 7550 lb/h (wet) at an air/coal ration of 1.35. Coal fineness met the mill spec of 70% passing 200 mesh but coal drying was less than expected at 18 to 22% vs. 12-15% expected. This mill performance was not close enough to the required performance to warrant further testing with PRB. The high cost of operating the entire system precluded operation of the preheat system for mill testing and optimization. A decision was therefore made to stop the work with PRB and proceed with preheater design, installation and testing with bituminous coal, which would meet the required 85 MMBtu/h capacity at the reduced coal throughput due to the higher heating value of bituminous coal.

Task 2.5 Data Processing and Evaluation

This activity is on going and results from the shakedown testing are given under Task 2.4 above.

Task 2.6 Commercialization Plan Development

This task has been deleted from the project workscope.

Task 2.7 Design and Fabrication of Commercial Burner System

This task has been deleted from the project workscope.

Tasks 1.6 & 2.8 Management and Reporting

Modifications to RPI's subcontract were completed to extend the period of performance through 3/31/05 and to add additional funds to complete the large-scale testing.

Testing of the 85 MMBtu/h unit for PRB coal was cut short due to schedule and funding constraints, which dictated that PRB testing be stopped August in order to complete modifications and testing with bituminous coal by the end of the year.

A project schedule to complete design, installation and testing of the 85 MMBtu/h bituminous coal preheating system before the end of December was developed and is shown in Figure 5. The primary schedule constraint is the inability to conduct testing in the CBTF during freezing weather, which generally corresponds to the period between the end of December and the end of March.

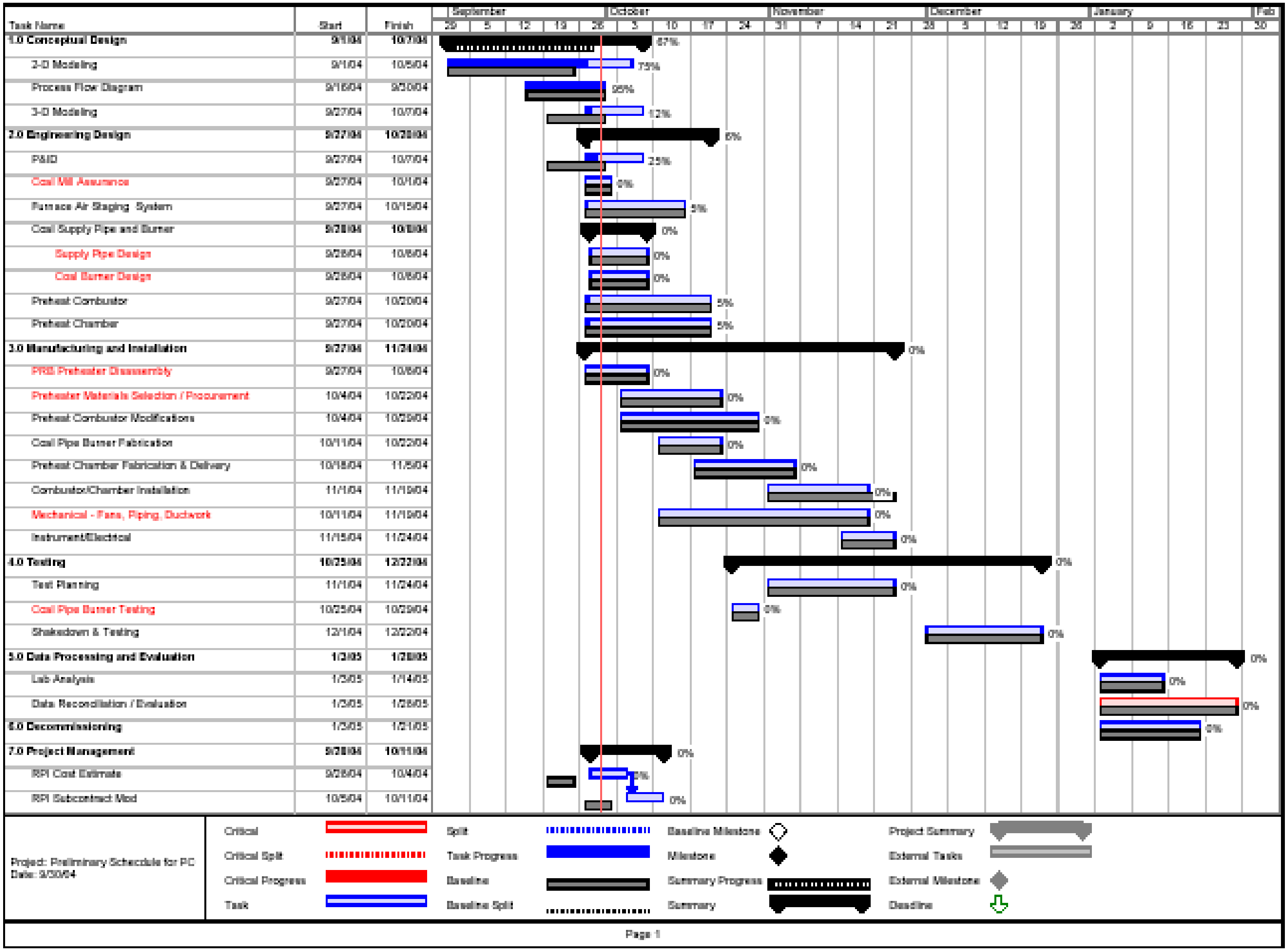

Figure 5. Project schedule for completion of bituminous coal testing by December 2004.

Plans for Next Quarter:

- Complete design and modification of the large-scale test unit for bituminous coal
- Complete testing in the large-scale unit with bituminous coal.
- Continue securing additional funding from cost share sources sufficient to complete the remaining work scope.

CONCLUSIONS

Efforts to increase the coal mill throughput to the design capacity of the PRB preheating system fell significantly short of the required 85-million Btu/h. The time and cost required modify the PRB preheater or upgrade the mill was judged to be unacceptable by the project team. The project was therefore redirected toward design, installation and testing of the 85-million Btu/h preheater for bituminous coal. Based on extensive pilot-scale testing completed earlier in the project, 2-D modeling and preliminary design activities were started based on the use of staged, annular protective air films to control temperature and prevent deposition on the preheater walls.

REFERENCES

N/A

Milestone Status Table: The proposed revised completion dates for all project tasks and major milestones are shown below.

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		Pilot-scale modeling complete
1.3	Pilot-Scale Equipment Fabrication and Installation	11/30/2000	9/30/2001	Pilot Scale complete
1.4	Pilot-Scale Testing – Caking Coal	6/15/2004		Hold
1.5	Pilot-Scale Data Evaluation – Caking Coal	6/15/2004		Hold
1.6	Task 1 Management and Reporting	7/15/2004		
♦	Task 1 Report	8/15/2004		Hold
2.0	Technology Validation			
2.1a	Commercial Prototype Engineering Design - PRB Coal	4/15/2004	6/30/2004	Complete
2.1b	Commercial Prototype Engineering Design - Caking Coal	8/30/2004		
2.2	Baseline Data Review	4/15/2004	4/15/2004	Complete
2.3a	Commercial Prototype Construction - PRB Coal	4/15/2004	6/15/2004	Complete
2.3b	Commercial Prototype Construction - Caking Coal	9/30/2004		
2.4a	Commercial Prototype Testing - PRB Coal	6/30/2004	8/30/2004	Discontinued
2.4b	Commercial Prototype Testing - Caking Coal	11/30/2004		New Date: 12/15/04
2.5a	Data Processing and Evaluation - PRB Coal	7/30/2004	8/30/2004	Complete
2.5b	Data Processing and Evaluation - Caking Coal	12/31/2004		
2.6	Commercialization Plan Development	--	--	Task Eliminated
2.7	Design and Fabrication of Commercial Burner System	--	--	Task Eliminated
2.8	Task 2 Management and Reporting	5/31/2005		
♦	Final Report	5/31/2005		