Quarterly Progress Report

For: METHANE de-NOX® for Utility PC Boilers

Covering Period: April 1, 2000 to June 30, 2000

Date of Report: July 5, 2000

Recipient: Institute of Gas Technology (IGT)
1700 Mount Prospect Road
Des Plaines. IL 60018-1804

Award Number: DE-FC26-00NT40752

Subcontractors: DB Riley, Inc. (DBR)
Gas Research Institute (GRI)
All-Russian Thermal Engineering Institute (VTI)

Partners: IGT Sustaining Membership Program (SMP) will provide cash co-funding in the amount of $150,000. GRI will provide cash co-funding in the amount of $700,000. DB Riley will provide in-kind co-funding in the amount of $97,000.

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Project Objective: 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 by 2002-2003 in order to meet an anticipated market demand for NO_x reduction technologies resulting from the EPA's NO_x SIP call.

Background: Achieving NO_x emissions levels of 0.15 lb/million Btu requires NO_x reduction on the order of 90 %. Conventional measures for NO_x reduction in PC combustion processes primarily rely on combustion modifications and post combustion controls. In general, combustion modifications technologies try to reduce the formation of NO_x precursors while destroying already-formed NO_x. A variety of NO_x reduction technologies are in use today, including Low-NO_x Burners (LNB's), flue gas recirculation (FGR), and gas or other fuel reburning. Selective Non-Catalytic Reduction (SNCR) and Selective Catalytic Reduction (SCR) are post combustion techniques. NO_x reduction efficiencies from these technologies vary from 30 to 60%, with up to 90% for SCR.

A novel pulverized coal preheating approach for NO_x reduction has been developed by the All Russian Thermal Engineering Institute (VTI), in Russia, for use on PC utility boilers. The technology 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 coal preheat burners of 30 and 60 MW_t capacity were developed and demonstrated in field tests conducted in several Russian power stations:

The advanced pulverized coal (PC) preheat combustion system being developed in this project combines the VTI preheat burner together with elements of IGT's successful METHANE de-NOX technology for NO_x reduction. METHANE de-NOX has been commercially demonstrated on coal, MSW, and biomass-fired stoker boilers in the U.S. and Japan. Overall, the new PC preheat system combines several NO_x reduction strategies into an integrated, low-NO_x, PC combustion 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. This integrated system can achieve very low NO_x levels – down to 0.15 lb/million Btu – without the complications, limitations, and expense of SCR or SNCR technology.

Status:

Task 1.1 *Pilot-Scale Design*

Work during the quarter included selection of representative U.S. steam coals for comparison of properties to the Russian coals with which the preheat burner has already demonstrated. The selections were made with the assistance of the potential demonstration host site companies, Northern Indiana Public Service Company (NIPSCO) and Southern Company Services (SCS), and will help guide burner design modifications which might be necessary to optimize the burner design for U.S. coals. Also, IGT completed a review of the preheat burner technical information provided by VTI with the signing of a subcontract for VTI's assistance in the PC preheat technology development for U.S. coals. This support documentation details the major research findings and resulting design principles developed by VTI during approximately 20 years of research, development, and demonstration of the pulverized coal preheat technology. Finally, design basis information for the pilot-scale preheat burner and furnace information for DB Riley's burner test facility were forwarded to VTI to begin the pilot-scale burner design effort.

U.S. Utility Coal Selection

IGT, with help from two utility power generators, identified a total of 67 different coals that have historically been burned at PC combustion facilities. These generators pledged support of the preheated PC burner development and combined have offered 6 power stations as potential candidates to conduct commercial demonstrations of the technology. Popular coal choices for

PC boilers typically consist of high to medium–volatile bituminous and subbituminous coals because combustion is more stable. In 1997, utilities received a total of 881 million short tons of coal (reported by DOE's Energy Information Administration's "**1997 Electric Power Annual**") of which 524 million tons were high-volatile bituminous, 36 million tons were medium-volatile bituminous, and 320 million tons were subbituminous.

IGT's approach organized the 67 coals into producing regions. This breakdown resulted in five producing regions: Central Appalachia, Southern Appalachia, Illinois Basin, Western and foreign. From each region one coal type, excluding foreign, was selected to represent the wide range of coals fired at PC boiler power stations. Because burner design and performance is heavily dependent on coal properties such as volatile matter, IGT expanded the number of PC boiler coals considered for lab analysis up to a total of 6 instead of 4 to improve the thoroughness of the evaluation. In addition, coal samples from Russian test coals will be obtained and analyzed to confirm key properties based upon accepted U.S. testing procedures.

A table of the six representative U.S. coals selected is given below; and information about region, rank, moisture, and volatile matter is reported. IGT received two coal samples and is obtaining the remaining samples from the two utility power generators as well as samples of three Russian test coals. Also, a sample of pulverized coal was received for size analysis information.

Table 1. Representative U.S. Coals Fired in Utility PC Boiler Power Stations

Region	Western	Western	Central Appalachia	Southern Appalachia	Southern Appalachia	Illinois Basin
Rank	Subbit. A	Subbit. A	High-Vol. B bituminous	High-Vol. C bituminous	Low- to Med-Vol. C bituminous	High-Vol. C bituminous
Moisture %	24-28	8-12	6-9	3-10	3-10	7-14
Volatile Matter %	27-32	35-42	28-36	26-34	18-24	28-36

VTI Technical Information Review

IGT completed the negotiation of a cost reimbursement subcontract with VTI during the quarter. Under the Technology Transfer provisions of the subcontract, VTI provided its proprietary technical information, background data, and know-how for their preheated coal burner development work to-date. The information provided includes copies of patents, technical reports and papers, designs, drawings, materials of construction information, test data, operating and test procedures, and manuals related to the design, fabrication, operation, control, testing, and operation of the pilot- and commercial-scale preheated coal burners developed to-date. A complete listing of the technical documentation received from VTI is given in Attachment 1.

IGT has completed a review of the test data provided by VTI, covering the pilot-scale 1.1 MW_t testing as well as commercial scale burner demonstrations up to 60MW_t. The development and demonstration testing has been conducted with 20 different Russian coals, including coal ranks from subbituminous to anthracite. A summary of the characteristics for three Russian utility coals representative of the range of coals tested is presented in Table 2. Also shown in the table are the compositional ranges for the representative U.S. utility coals selected for the U.S. burner design basis.

Table 2. Comparison Of Russian and U.S. Utility Coal Compositions

	Selected Russian Utility Coals Tested by VTI			U.S. Utility Coals
Composition	Berezovo Subbit. B	Ekibastuz Subbit. C	Kuznetsk Semi Anthracite	Bituminous & Subbituminous
VM, wt % AR	40.27	23.68	9.28	22.9 – 42.0
C, wt%(dry)	66.03	53.13	71.6	74.0 – 86.5
H "	4.09	3.06	2.8	4.9 – 5.7
O "	21.49	8.31	3.12	6.0 – 19.4
N "	0.88	1.13	1.68	1.3 – 1.8
S "	0.5	0.86	0.8	0.5 – 2.8
Ash, wt% (dry)	7.00	33.5	20.0	6.0 – 13.9
HHV, Btu/lb	10820	9055	11859	11417-14288

From Table 2 it can be seen that, in general, the composition of U.S. coals falls within the range of compositions successfully demonstrated with Russian coals. The typical U.S. utility coal tends to be somewhat higher quality than the Russian coals, with lower ash content and higher volatile matter and heating value. The lower ash content of U.S. coals may simplify the preheat burner design and materials selection, although the increased sulfur content must be carefully evaluated with respect to materials selection. The most important (and favorable) compositional difference is the significantly higher level of volatile matter in most U.S. utility coals, the impact of which is discussed below.

The major findings of the VTI's investigation of NO_x formation in pulverized coal (PC) combustion were:

- most (80-90%) of the NO_x formed during PC combustion is fuel-bound NO_x - thermal NO_x formation is negligible
- most of the fuel-bound nitrogen contributing to NO_x formation is contained in the volatile matter, which is released and burned quickly as the coal particles are initially heated and partially pyrolyzed – the remaining char contributes very little to NO_x formation as it burns
- NO_x formation is strongly influenced by the concentration of oxygen in the flame region where the volatile matter is released, and the reaction of fuel-bound nitrogen with oxygen in this region is the primary mechanism for NO_x formation in PC combustion.

NO_x reduction in PC combustion is therefore favored when the nitrogen-bearing volatile matter is released into a zone of low excess oxygen content. This is the basis for the PC preheating approach to NO_x reduction. Provided the excess air in the pyrolysis zone is kept low, any factor which increases the amount of volatile matter released increases the efficiency of NO_x reduction. For a given coal, therefore, increasing the preheat temperature improves NO_x reduction efficiency by increasing the amount of volatile matter released during thermal pretreatment. For a given preheat temperature, increasing the volatile matter content of the coal increases NO_x reduction efficiency. This is the primary effect of coal type and composition on the NO_x reduction efficiency of the preheat process, and is illustrated in Figure 1, where it is clearly seen that coals with higher volatile matter require lower preheating temperatures to achieve a given level of NO_x reduction.

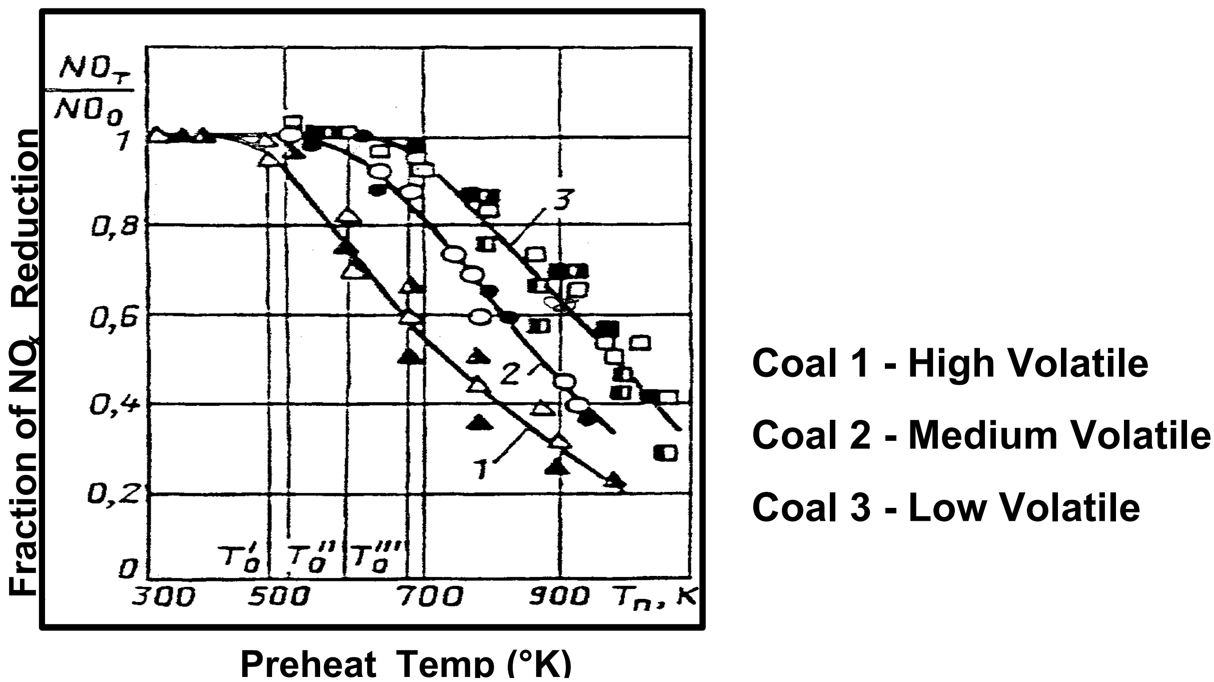

Figure 1. Effect of Preheat Temperature and Coal Volatile Matter Content on PC Preheat NO_x Reduction Efficiency

The implications of this for use of the preheat approach with U.S. coals are therefore quite favorable. In general, lower preheating temperatures will be required. This will result in reduced auxiliary fuel requirements and smaller, more compact preheater designs which can be more easily retrofitted on existing PC boilers.

Pilot-Scale Burner Design

IGT forwarded design basis information to VTI to facilitate the pilot-scale preheat PC burner design effort. Information was sent on the DB Riley Combustion Facility where the burner will be tested, including general arrangements, burner mounting details, and burner controls. A list of the information forwarded to-date is given in Attachment 2.

Task 1.6 *Task 1 Management and Reporting*

Work during the quarter included finalizing the project cofunding arrangements and execution of necessary subcontracts.

- A project kickoff meeting, attended by project personnel from IGT and DB Riley, was held with NETL representatives at NETL's offices in Pittsburgh, PA, on May 2nd.
- IGT proposal No. 18652-86 for GRI cofunding was accepted in principle and final contract negotiations are nearing completion.
- A subcontract was negotiated and signed with VTI for the preheat burner technology transfer and assistance with design and testing of the 3 MMBtu/h pilot-scale and 100 MMBtu/h commercial-scale preheat burners.
- Subcontract negotiations were continued with DB Riley for burner design, fabrication, and testing activities at their Worchester, MA research facility.

Plans for Next Quarter:

- IGT will receive and evaluate the 3 MMBtu/h pilot-scale preheat burner design documentation from VTI.
- IGT and VTI project personnel will visit DB Riley's burner test facility to review/complete the 3 MMBtu/h pilot-scale preheat burner design and review test facility requirements for the pilot-scale burner.
- IGT will complete the lab analysis and devolatilization studies for the U.S. utility coals and three (3) Russian utility coals.
- IGT will assemble the necessary burner design and furnace data required to begin CFD modeling of the preheat burner system and boiler for the pilot- and commercial-scale cases.

Milestone Status Table: The planned completion dates for all project tasks and major milestones are shown in the following table. As of this date, IGT expects the overall project to be completed on schedule in August, 2002.

ID No.	Task / Milestone Description	Planned Completion	Actual Completion	Comments
♦	Kickoff Meeting	5/2/2000	5/2/2000	
1.0	Technology Development			
1.1	Pilot-Scale Design	8/31/2000		Started
1.2	CFD Modeling	6/30/2001		
1.3	Pilot-Scale Equipment Fabrication and Installation	11/30/2000		
1.4	Pilot-Scale Testing	3/31/2001		
1.5	Pilot-Scale Data Evaluation	4/30/2001		
1.6	Task 1 Management and Reporting	4/30/2001		
♦	Task 1 Report	4/30/2001		
2.0	Technology Validation			
2.1	Commercial Prototype Engineering Design	7/31/2001		
2.2	Baseline Data Review	7/31/2001		
2.3	Commercial Prototype Construction	10/31/2001		
2.4	Commercial Prototype Testing	2/15/2002		
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		

ATTACHMENT 1

LIST OF SUBMITTED TECHNICAL INFORMATION

1. Verbovetsky E. Kh. "Investigation of the NO_x Reduction Method by Thermal Pulverized Coal Pretreatment. Design and Testing of the Pulverized Coal Burner." Moscow. VTI 1999.

2. Titov S. I., Babiy V. I., Barbarash V.M. "Investigations of NO formation from fuel nitrogen in firing Kuznetsk coal dust." Teploenergetika, No. 3, 1980, pp. 64-67.

3. Babiy V. I., Alaverdov P.I., Barbarash V.M., *et al*. The effect of coal dust pretreatment on fuel NO_x yield." Teploenergetika. 1983. #9. P. 10-13.

4. Babiy V. I., Imankulov E. R., Alaverdov P. I., *et al*. "Investigation of the fuel nitrogen oxide formation in the furnace chamber with coal dust thermal pretreatment." In: "Problems of effective burning of energetic coals". Moscow. ENIN. 1984. P. 49-55.

5. Imankulov E. R., Kanlybayev K. I., Babiy V. I., *et al*. "The effect of coal dust thermal pretreatment on the ignition of coal dust flame" Collected works: "Coal dust furnaces and burners (rig tests)". Moscow. ENIN. 1983. P. 31-35.

6. Enyakin Yu. P., Kotler V. R., Babiy V. I., *et al*. "VTI works on the NO_x emission reduction by technological methods." Teploenergetika. 1991. #6. P. 33-38.

7. Babiy V. I., Kotler V. R., Verbovetsky E. Kh. "Coal dust combustion in utility boilers." Collected works: "Developments in fuel preparation and combustion at power plants." Moscow. VTI. 1996. P. 46-57.

8. Ed.: V. R. Kotler. "Investigation and implementation of new technologies for fossil fuel combustion to reduce atmospheric emission of toxic NO_x from thermal power stations and boiler houses (analytical survey)." Moscow. VTI. 1997. P. 409, 12-18.

9. Babiy V. I., Kolodtsev K. I., Verbovetsky E. Kh., Serebryakova A. G. Author certification #243767 "A method of solid fuel combustion." Priority of 05. 02. 1968 Bulletin of Inventions 1969 #17.

10. Babiy V. I., Alaverdov P. I. Patent of the Russian Federation #1114115 "A method of preparing of pulverized fuel for combustion". Priority of 04. 03. 1983 Bulletin of Inventions 1991 #12.

11. Babiy V. I., Verbovetsky E. Kh., Artemyev Yu. P., Tumanovsky A. G. Patent application #99114725/06. "A method of reduction of nitrogen oxide formation in pulverized fuel combustion and low-NO_x burner " Priority of 07. 07. 1999.

12. Babiy V. I., Alaverdov P. I. "The effect of coal dust thermal pretreatment on the fuel NO_x yield in firing dust of Berezovo coal (report)." Moscow. VTI. 1981. (**CONFIDENTIAL**)

13. Babiy V. I., Alaverdov P. I. "The effect of coal dust thermal pretreatment on the fuel NO_x yield in firing dust of coals of various degree of metamorphism (report)." Moscow. VTI. 1983. (**CONFIDENTIAL**)

14. Babiy V. I., Alaverdov P. I. "Investigation of the effect of coal dust preheating on the formation of fuel NO_x (report)." Moscow. VTI. 1982 (**CONFIDENTIAL**)

15. Babiy V. I., Verbovetsky E. Kh., Tumanovsky A. G. *et al.* "The development and implementation of the thermal pretreated pulverized coal-fired burners on the Mosenergo Cogeneration plant-22 TPP-210A boiler (report)." Moscow. VTI. 1992 (**CONFIDENTIAL**)

16. Babiy V. I., Verbovetsky E. Kh., Pelipenko A. S. "Investigation of the processes in the burner in-built device for coal dust thermal pretreatment (report)." Moscow. VTI. 1998. (**CONFIDENTIAL**)

17. Babiy V. I., Verbovetsky E. Kh., Artemyev Yu. P. *et al.* "The development of the technology of coal dust combustion to reduce as low as two times the formation of nitrogen oxides by thermal pretreatment (report)." Moscow. VTI. 1999. (**CONFIDENTIAL**)

18. Drawings for installation of the device for coal dust thermal pretreatment in the burner of the TPP-210A boiler. (**CONFIDENTIAL**)

19. Drawings for installation of the device for coal dust thermal pretreatment in the burner of the P-50 boiler. (**CONFIDENTIAL**)

LIST OF SUBMITTED PATENTS

1. Babiy V. I., Kolodtsev K. I., Verbovetsky E. Kh., Serebryakova A. G. Author certificate #243767 "A method of solid fuel combustion." Priority of 05. 02. 1968. Bulletin of Inventions 1969 #17.

2. Babiy V. I., Alaverdov P. I. Patent of the Russian Federation #1114115 "A method of preparing of pulverized fuel for combustion." Priority of 04. 03. 1983. Bulletin of Inventions 1991 #12.

3. Babiy V. I., Verbovetsky E. Kh., Artemyev Yu, P., Tumanovsky A. G. Patent application #99114725/06. "A method of reduction of nitrogen oxide formation in pulverized fuel combustion and low-NO_x burner." Priority of 07. 07. 1999.

ATTACHMENT 2

Design Basis Information Sent to VTI for the 3 MMBtu/h Pilot-Scale Preheat PC Burner

1. DB Riley Pilot Scale Combustion Facility Diagram 3 MMBtu/h (~1 MW_{th}), IGT Drawing No. PC-B-0300-D, Rev. 0, dated 6-01-00 (two copies).
2. General Arrangement of Pilot Test Furnace - Front and Side Elevations, DB Riley Drawing No. 200000-7-2, Rev. 2, dated 1-11-85 (two copies)
3. General Arrangement of Pilot Test Furnace – Plan Views Elev's 0'-0", 24'-0" & 42'-0", DB Riley Drawing No. 200001-7-2, Rev. 2, dated 1-14-85 (two copies).
4. Test Furnace Burner Mount Details, IGT Drawing No. PC-A-0500-D, Sheet 1 of 2, Rev. 0, dated 5-26-00 (two copies)
5. Test Furnace Burner Mount Details, IGT Drawing No. PC-A-0500-D, Sheet 2 of 2, Rev. 0, dated 5-26-00 (two copies)
6. PC Coal Burner Simplified Piping and Instrumentation Diagram (P&ID), IGT Drawing No. PC-PI-1000-D, Rev. 0, dated 5-26-00 (two copies)
7. Solid Fuel Specification Table dated 6-06-00. The table lists coal properties for three (3) Russian coals and six (6) U.S. coals are given (two copies).
8. VTI Work Schedule and Cost Summary (revised) dated 6-06-00 (two copies).