MINIMIZATION OF CARBON LOSS IN COAL REBURNING

Semiannual Report No. 3 for Period

August 11, 2001 – February 10, 2002

Prepared by:

Vitali V. Lissianski, Loc Ho, Peter M. Maly, and Vladimir M. Zamansky

March 8, 2002

DOE Contract No. DE-FC26-00NT40912

Submitted by:

General Electric Energy and Environmental Research Corporation

(GE EER)

18 Mason, Irvine, CA 92618

Disclaimer

Abstract

This project develops Fuel-Flexible Reburning (FFR), which combines conventional reburning and Advanced Reburning (AR) technologies with an innovative method of delivering coal as the reburning fuel. The FFR can be retrofit to existing boilers and can be configured in several ways depending on the boiler, coal characteristics, and NO_x control requirements. Fly ash generated by the technology will be a saleable byproduct for use in the cement and construction industries. FFR can also reduce NO_x by 60%-70%, achieving an emissions level of 0.15 lb/10^6 Btu in many coal-fired boilers equipped with Low NO_x Burners. Total process cost is expected to be one third to one half of that for Selective Catalytic Reduction (SCR).

Activities during reporting period included design, manufacture, assembly, and shake down of the coal gasifier and pilot-scale testing of the efficiency of coal gasification products in FFR. Tests were performed in a 300 kW Boiler Simulator Facility. Several coals with different volatiles content were tested. Data suggested that incremental increase in the efficiency of NO_x reduction due to the gasification was more significant for less reactive coals with low volatiles content.

Experimental results also suggested that the efficiency of NO_x reduction in FFR was higher when air was used as a transport media. Up to 14% increase in the efficiency of NO_x reduction in comparison with that of basic reburning was achieved with air transport. Temperature and residence time in the gasification zone also affected the efficiency of NO_x reduction.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AR	-	Advanced Reburning
BSF	-	Boiler Simulator Facility
DOE	-	Department of Energy
FFR	-	Fuel-Flexible Reburning
GE EER	-	General Electric Energy and Environmental Research Corp.
HFID	-	Hydrocarbon Flame Ionization Detector
OFA	-	Overfire Air
SCR	-	Selective Catalytic Reduction
SR	-	Stoichiometric Ratio
UBC	-	Unburned Carbon

Executive Summary

This project develops Fuel-Flexible Reburning (FFR), which combines conventional reburning and Advanced Reburning (AR) technologies with an innovative method of delivering coal as the reburning fuel. The FFR can be retrofit to existing boilers and can be configured in several ways depending on the boiler, coal characteristics, and NO_x control requirements. Fly ash generated by the technology will be a saleable byproduct for use in the cement and construction industries. FFR can also reduce NO_x by 60-70%, achieving an emissions level of 0.15 lb/10^6 Btu in many coal-fired boilers equipped with Low NO_x Burners. Total process cost is expected to be one third to one half of that for Selective Catalytic Reduction (SCR).

The overall objective of this project is to develop engineering and scientific information and know-how needed to improve the cost of reburning via increased efficiency and minimized carbon in ash and move the FFR technology to the demonstration and commercialization stage. Specifically, the project entails: (1) optimizing FFR with injection of gasified and partially gasified fuels with respect to NO_x and carbon in ash reduction; (2) characterizing flue gas emissions; (3) developing a process model to predict FFR performance; (4) completing an engineering and economic analysis of FFR as compared to conventional reburning and other commercial NO_x control technologies, and (5) developing a full-scale FFR design methodology.

Activities during reporting period included design, manufacture, assembly, and shake down of the coal gasifier and pilot-scale testing of the efficiency of coal gasification products in FFR. Tests were performed in a 300 kW Boiler Simulator Facility. Tests demonstrated that partial coal gasification prior to the injection into reburning zone resulted in an increase in NO_x reduction. Several coals with different volatiles content were tested. Data suggested that incremental increase in the efficiency of NO_x reduction due to the gasification was more significant for less reactive coals with low volatiles content. Coals with low volatiles content are usually less reactive in basic reburning. Coal gasification improves their reactivity by producing gas-phase combustible species prior to the injection into reburning zone. Coals with high volatile content are easily gasified in the reburning zone and thus benefit less from gasification prior to the injection.

Experimental results suggested that the efficiency of NO_x reduction in FFR was higher when air was used as a transport media. Up to 14% increase in the efficiency of NO_x reduction in

comparison with that of basic reburning was achieved with air transport. The extent of coal gasification was more significant in the presence of air since temperatures in the gasification zone were higher. Residence time in the gasification zone also affected the efficiency of NO_x reduction in FFR. Coal gasification in the temperature range of 1000 – 1200 ^oF resulted in the production of hydrocarbons, CO, H_2, and char. Tests demonstrated that NO_x reduction was maximum at residence time of about 1 s.

Future work will continue pilot-scale tests and develop tools required to move the technology to a demonstration stage. More pilot-scale tests will be conducted to characterize and optimize FFR. In particularly, tests will be conducted to characterize the effect of coal gasification on carbon content in fly ash. Tests with different biomass fuels will be also conducted to determine potential benefits of the FFR technology for these fuels. Efforts to develop a predictive model for Coal Reburn will continue. An engineering and economic analysis of FFR will be conducted to confirm economic benefits of the FFR technology as compared to conventional reburning and other commercial NO_x control technologies, and to develop a full-scale FFR design methodology.

1.0 INTRODUCTION

This project develops Fuel-Flexible Reburning (FFR) technology that combines conventional reburning and Advanced Reburning (AR) technologies with an innovative method of delivering coal as the reburning fuel. In FFR solid fuel is partially gasified before injection into reburning zone of a boiler. To achieve gasification, fuel can be transported and injected by recycled flue gas stream at 1000 – 1200 K. This allows the fuel to be preheated and partially pyrolyzed and gasified in the duct and then injected into the boiler as a mixture of coal, gaseous products, and char (Option No. 1). Gasification increases coal reactivity and may result in lower unburned carbon (UBC) levels. In other option (Option No. 2), the gaseous and solid products can be split using cyclone separation. Indeed, coal typically consists of approximately equal fractions of volatile matter and fixed carbon. Splitting the reburning fuel stream will allow the volatile matter to be used for reburning and the fixed carbon to be injected into the high-temperature flame zone. Option No. 2 has two benefits. First, since reburning performance directly correlates with volatile matter content, this approach allows reburning to be performed with the volatile matter alone. Second, fixed carbon is primarily responsible for high UBC levels during coal reburning. Splitting off the char fraction and conveying it to the main burner zone will provide high carbon combustion efficiency. The N-agent can be injected into one or several zones of a boiler to increase the efficiency of NO_x reduction.

The project started in August 2000 and is being conducted over a two-year period. This report summarizes work performed during third six-months period of the project. *Section 2* describes the GE EER approach to technology development. *Section 3* gives summary of work conducted prior to the reporting period. *Section 4* describes experimental facilities and *Section 5* presents results of pilot-scale evaluation of FFR. Summary of the third six-months period of work and plans for the last six months of the project are discussed in *Sections 6* and *7*.

2.0 APPROACH TO THE FFR DEVELOPMENT

This section describes the GE EER approach to the development of the FFR technology. Table 1 presents milestone schedule for the project.

The steps of the technical approach for this project include (1) updating chemistry-mixing reburning model developed by GE EER in previous R&D projects to include soot reactions (Task # 4) and (2) applying this model to predicting the performance of coal gasification products as a reburning fuel (Task #2). Based on previous experience with reburning modeling, such a model could predict process performance for the Option No. 2 of FFR. The chemistry-mixing model assists in FFR optimization during the second year. Modeling also provides a scientific understanding of the FFR process.

Table 1. Milestone schedule.

Task	Project Tasks	2000				2001				2002			
No.	*Calendar Quarters*	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
1	Management and Reporting												
2	Reburning with Coal Gasification Products												
3	Reburning with Partial Coal Gasification Products												
4	Process Model Development												
5	Economics and Design Methodology												
Current Reporting Period													

Pilot scale tests (Task #3) are designed to provide key engineering data required for FFR demonstration. These tests are currently in progress. Pilot-scale experiments are being conducted at the GE EER test site in Irvine, California. The 300 kW Boiler Simulator Facility (BSF) described in the First Semiannual Report[1] is used in tests. Coal was gasified in a gasifier which was designed, assembled and tested during the reporting period.

Task #5 will be conducted during the last six months of the project and will upgrade GE EER's reburning design methodology developed in previous studies with natural gas and coal reburning (Coal Reburn) to include the FFR system. In addition, a conceptual process design will be prepared for the full-scale demonstration of FFR.

3.0 SUMMARY OF PREVIOUS EFFORTS

Activities during first 18 months of the projects included experimental and modeling studies. The experimental part of the program was performed in conjunction with a commercial coal reburning (Coal Reburn) project that GE EER performed for a commercial client. In that project GE EER investigated the potential to apply Coal Reburn technology to achieve substantial reductions in power plant NO_x emissions. The client expressed interest in FFR demonstration at a 200 MW plant if the study showed economic advantages of Coal Reburn over

1. Zamansky, V.M. and Lissianski, V.V. *Minimization of Carbon Loss in Coal Reburning*, Semiannual Report No. 1, Report to U.S. DOE, DOE Contract No. DE-FC26-00NT40912, 2001.

other approaches to control NO_x emissions. The FFR pilot-scale tests utilized the same coals that were tested for the commercial client.

Tests were performed in the BSF with two coals referred to here as coal A and coal B. Coal A had lower volatile matter content and higher sulfur content than coal B. Tests showed that better performance in Coal Reburn was obtained with the coal B. More volatile fuels tend to release the bound-nitrogen species and fuel fragments faster. This allows the reburning chemistry more time to occur, and enables nitrogen-bound species to be processed in an environment where they can be reduced to molecular nitrogen. Other factor that can affect reburning performance is the nitrogen content of the coal that is higher for coal A. Higher nitrogen concentrations result in poorer reburning performance.

The objective of the combined chemistry-mixing modeling was to develop a FFR model for predicting the NO_x control performance and carbon in ash. This model was used to predict composition of coal gasification products and to optimize FFR for achieving most effective NO_x reduction at lowest carbon in ash.

Modeling activities concentrated on the development of Coal Reburn model and on the prediction of NO_x reduction in reburning by coal gasification products. The model was first applied to bituminous coals. Modeling predicted that composition of coal gasification products depended on gasification temperature. At lower temperatures yield of hydrocarbons was high which resulted in higher efficiency of gasification products as a reburning fuel. As temperature increased, yield of hydrocarbons decreased and CO and H_2 yields increased.

4.0 EXPERIMENTAL FACILITIES

Two test facilities were utilized in the experimental work: the BSF and a gasifier. The schematic of experimental setup is shown in Figure 1. Coal was injected in the gasifier and partially gasified. Gas-phase products of the gasification and char were delivered to the BSF through stainless still duct and then injected into the BSF reburning zone through a water-cooled injector.

The following sub-sections describe coal gasifier and its shake down. The BSF was described elseweher[1].

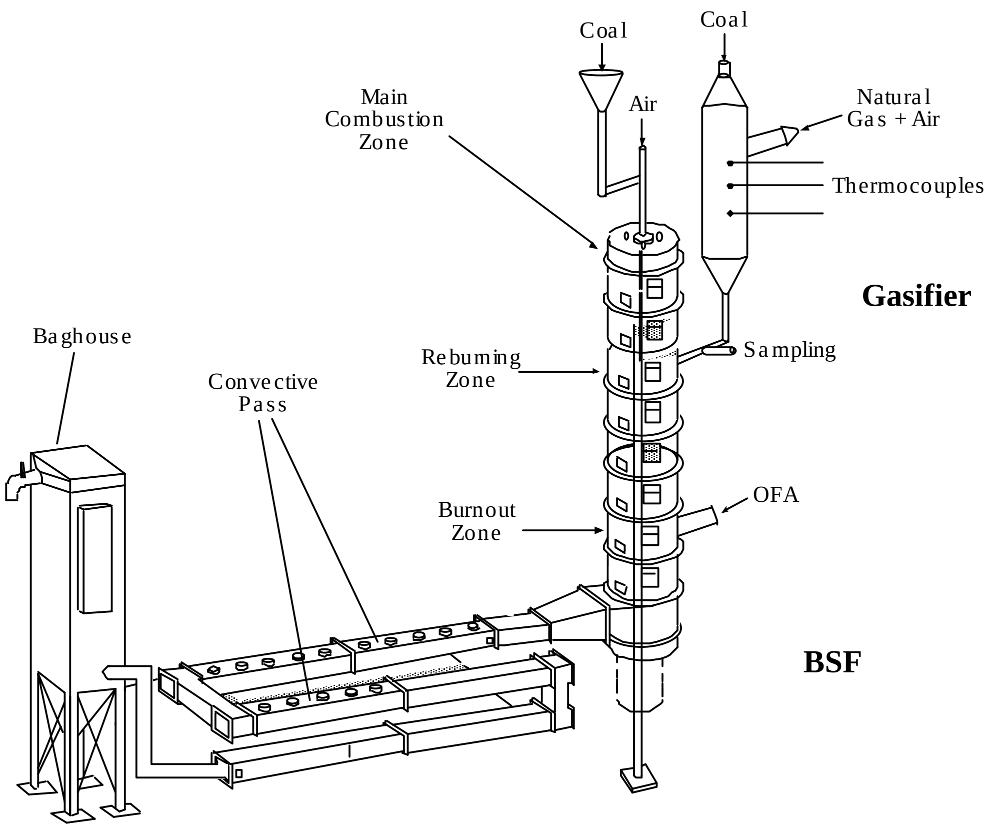

Figure 1. Experimental setup.

4.1 Coal Gasifier

Schematic of the coal gasifier is shown in Figure 2. The gasifier was constructed from stainless steel and its inner walls were refractory lined. Heat required for coal gasification was supplied by the combustion of natural gas in air. The auxiliary section of the gasifier had an internal diameter of 8 inch. Coal was injected into the gasification section that had an internal diameter of 12 inch. Nitrogen or air were used as a transport media for coal. Temperature profile in the gasification zone was measured using several thermocouples located along the zone. Port located near the exit of the gasifier allowed gas and solid samples to be taken and analyzed.

4.2 Gasifier Shake Down

After the gasifier was manufactured, assembled and installed, shake down tests were conducted to characterize its performance. Goals of these tests were to determine the dependence of the extent of coal gasification on the value of auxiliary heat, coal transport media, temperature and residence time in the gasifier. During shake down tests, the auxiliary natural gas burner heat input varied from 70,000 to 80,000 Btu/hr. Kittanning coal (see Table 2, p. 10 for coal composition) was used in shake down tests. Figure 3 shows measured temperature profile in the gasification zone at 70,000 Btu/hr auxiliary heat input at different heat inputs of the reburning fuel (coal). Here heat input of the reburning fuel is defined as percent from the total BSF heat input.

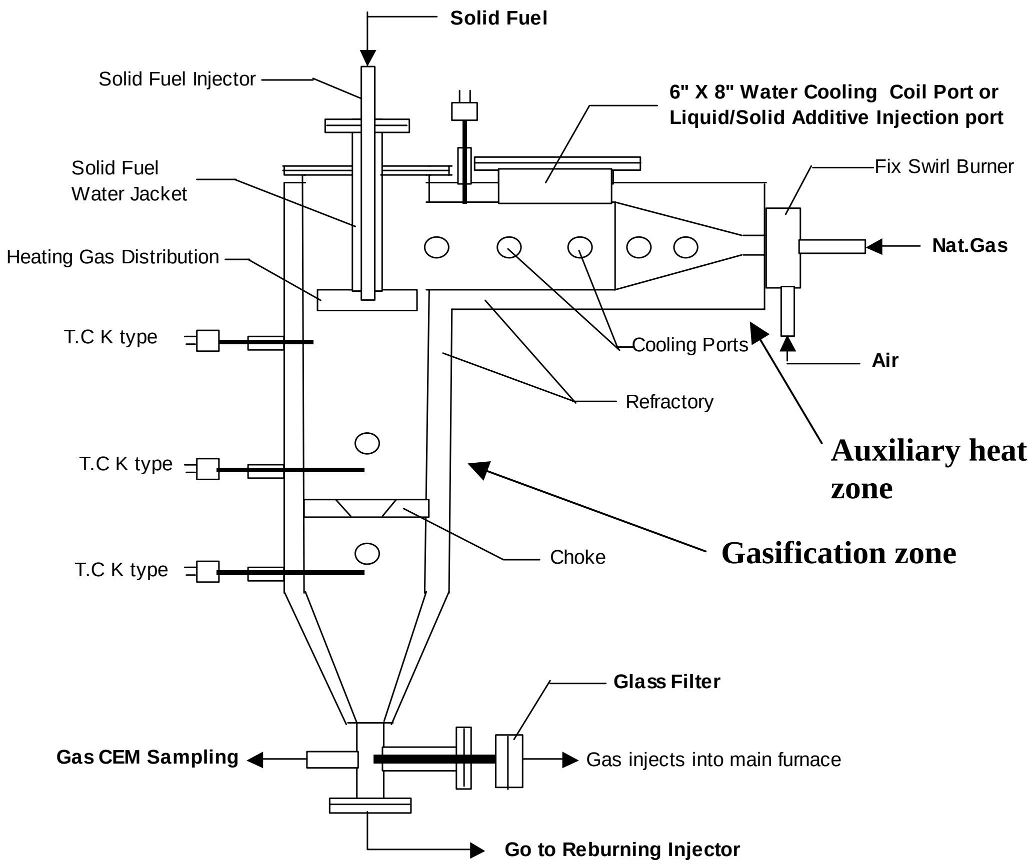

Figure 2. Coal gasifier.

Figure 3 demonstrates that temperature in the middle of the gasification zone is about 1100 K without coal injection and decreases when nitrogen is used as a transport media for coal injection. The decrease is most likely coursed by coal gasification which is an endothermic process. This conclusion is supported by the observation that the temperature decrease becomes more significant when a larger amount of coal is injected into gasification zone. When air is used as a coal transport media, temperature in the gasification zone increases probably due to the partial coal gasification by oxygen from air. This temperature increase is more significant for larger amount of coal injected.

Figure 4 shows temperature profiles in the gasification zone at 80,000 Btu/hr auxiliary heat input and different heat inputs of the reburning fuel. As for 70,000 Btu/hr auxiliary heat input, the temperature in the gasifier decreases with nitrogen transport and increases with air transport. Comparison of Figures 3 and 4 demonstrates that temperature in the gasification zone increases as auxiliary heat input increases. During the test program, auxiliary heat was set at 80,000 Btu/hr.

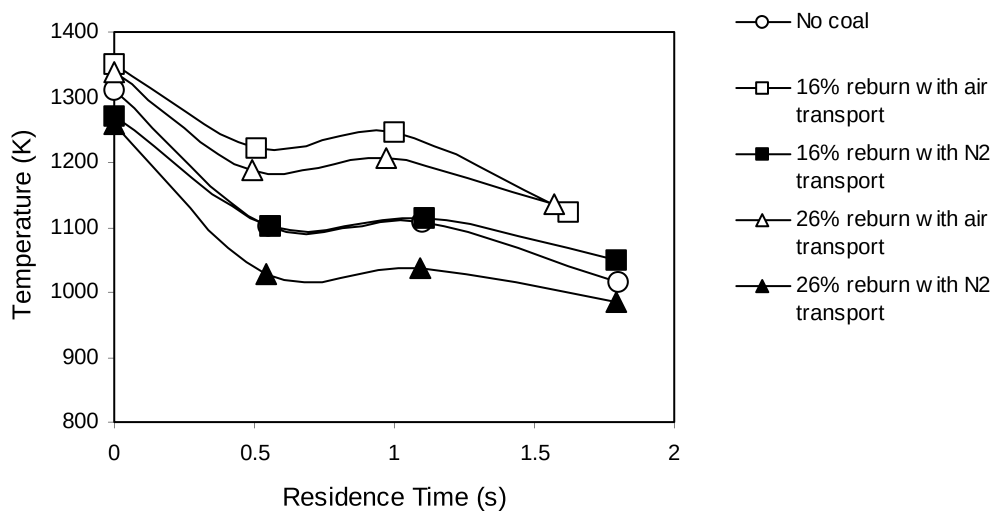

Figure 3. Temperature profiles in the gasification zone at different heat inputs of the reburning fuel. Auxiliary heat input is 70,000 Btu/hr.

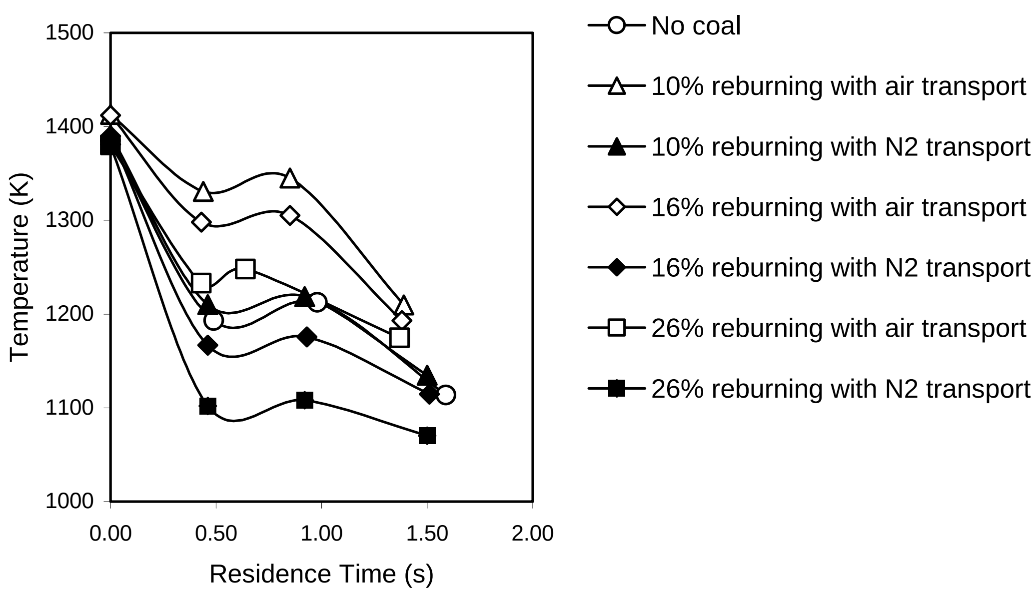

Figure 4. Temperature profiles in the gasification zone at different heat inputs of the reburning fuel. Auxiliary heat input is 80,000 Btu/hr.

To determine the extent of coal gasification, gas and solid samples were taken at the gasifier exit. Gas samples were analyzed on hydrocarbon content using hydrocarbon analyzer 300-HFID manufactured by California Analytical Instruments. Gas samples were also sent to an outside lab. Solid samples were analyzed to determine UBC.

Figures 5 and 6 show the effect of the residence time and stoichiometric ratio (SR) in the gasification zone on UBC. Gasifier SR was varied by varying the amount of coal and by changing gas carrier from air to nitrogen. Residence time was varied by moving coal injector deeper into the gasification zone. Figures 5 and 6 demonstrate that the extent of gasification increases as residence time and SR increase.

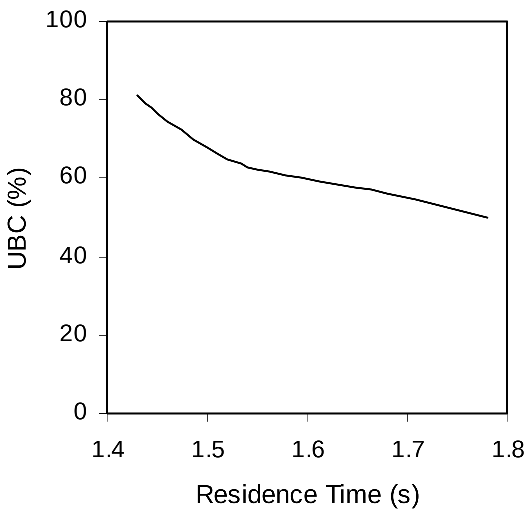

Figure 5. Effect of the gasifier residence time on solid carbon content in gasification products.

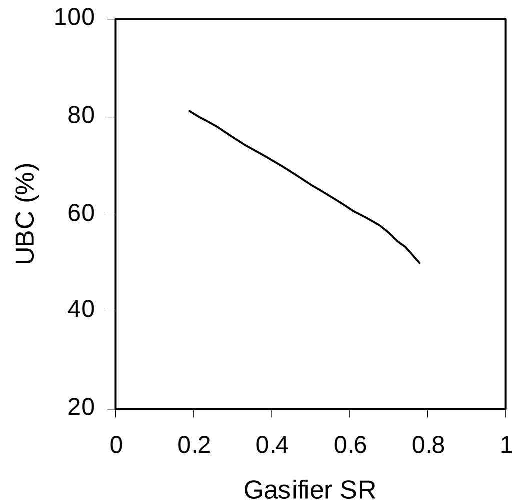

Figure 6. Effect of the stoichiometric ratio in the gasification zone on solid carbon content in gasification products.

Figure 7 shows composition of gasification products as measured by the hydrocarbon analyzer and determined from samples sent to an outside lab. Samples were collected only for nitrogen as a transport media while measurements using hydrocarbon analyzer were made for both nitrogen and air. Sample analysis did not show heavy hydrocarbons, most likely because they condensed in the sampling line which was maintained at room temperature. Data presented in Figure 7 were obtained at 10% and 20% of the reburning fuel heat input. First two groups of bars compare compositions of gasification products at 10% reburning fuel heat input with nitrogen and air as a transport media. Concentrations of combustible species in gasification products are higher when nitrogen is used as transport media. Most likely this is coursed by partial oxidation of gasification products by oxygen from air. Comparison of first and third groups of bars shows that concentrations of combustible species increase as the amount of coal increases. Methane concentration in the third group of bars (20% reburning with N_2 transport) as measured by the analyzer could not de quantified because detector signal was larger than the analyzer was calibrated to measure. Estimates show that CH_4 concentration was on the level of 6-8%.

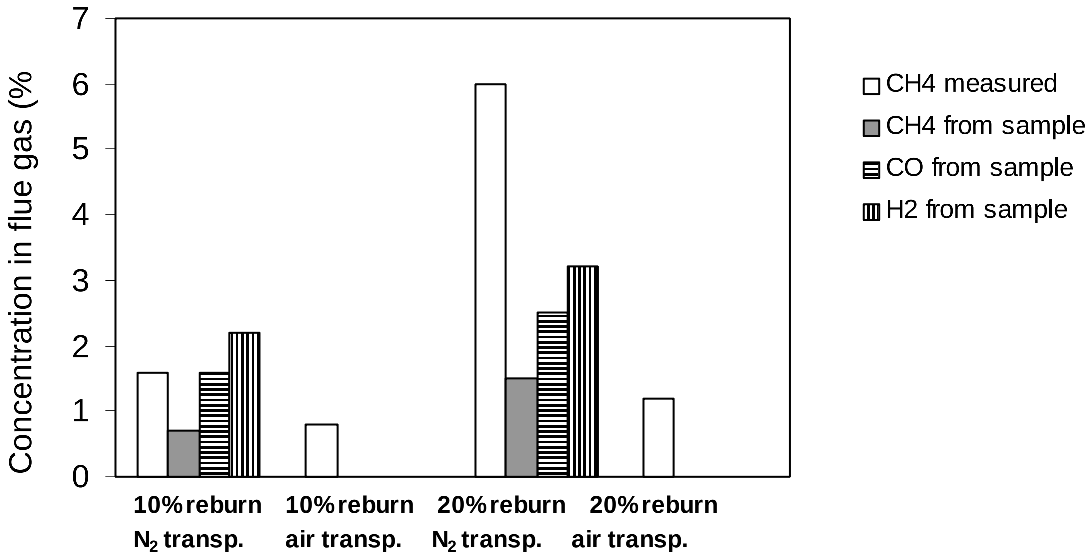

Figure 7. Composition of gasification products as measured by the hydrocarbon analyzer (measured) and determined by an outside lab (from sample).

Figure 7 also demonstrates that results of measurements using hydrocarbon analyzer measurements always gave a higher concentration of methane than that measured in samples. A reason for this disagreement is not clear, and tests are planned to clarify this issue.

5.0 EXPERIMENTAL RESULTS

Tests were conducted to determine the effect of partial coal gasification on the efficiency of NO_x reduction in FFR. Figure 8 shows schematic of the injector that was used to inject gasification products into the BSF reburning zone. Walls of the injector were water-cooled to prevent their damage by hot gases coming from the BSF main combustion zone. Walls of the injector were also refractory lined from inside to maintain high temperature of gasification products and prevent condensation of heavy hydrocarbons.

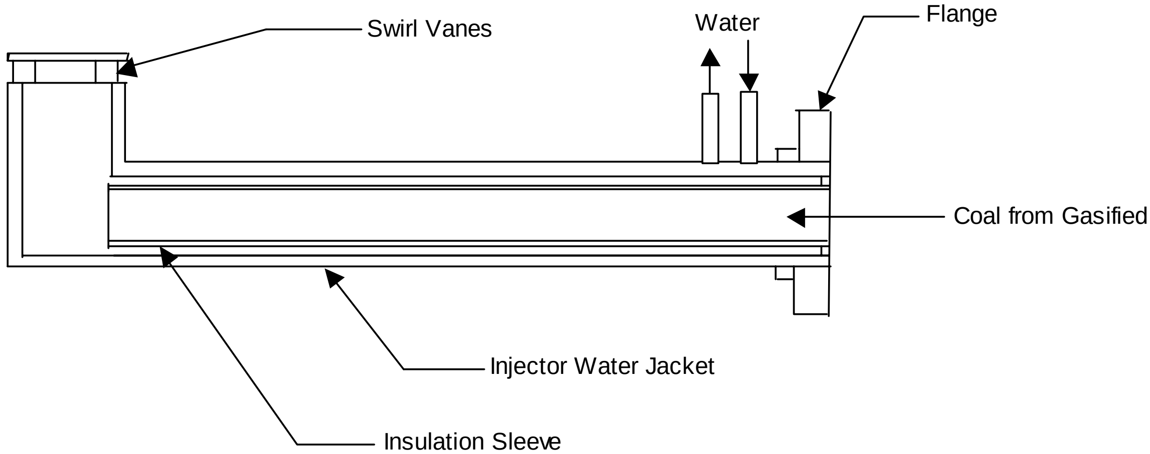

Figure 8. Schematic of coal injector.

Section 5.1 describes coal screening tests and *Section 5.2* describes optimization tests conducted with Kittanning coal.

5.1 Coal Screening Tests

Tests were first conducted with several coals to determine the effect of coal composition on the efficiency of NO_x reduction in FFR. Compositions of tested coals are presented in Table 2.

Figure 9 compares efficiencies of NO_x reduction of coals and gasified coals. The amount of the reburning fuel was 20% from total heat input, residence time in the reburning zone was 0.6 s. Reburning fuel was injected at the flue gas temperature T_{RF} of 1750 K and overfire air (OFA) was injected at flue gas temperature T_{OFA} of 1640 K. Initial NO_x (NO_i) was 370 ppm at 0%O_2. Figure 9 demonstrates that coal gasification improved the efficiency of NO_x reduction for all three tested fuels. The largest improvement in the efficiency of NO_x reduction was achieved for Kittanning coal.

Figure 10 demonstrates the dependence of the relative NO_x reduction on coal volatiles content. Relative NO_x reduction is defined as a difference between NO_x reduction by gasified and un-gasified coal. In other words, it is an incremental increase in NO_x reduction due to coal gasification. With both air and nitrogen transport, relative NO_x reduction decreases when volatiles content increases above 45%.

Table 2. Composition of tested coals.

Parameter	Units	Coal		
	wt%	Kittanning	Utah	WKE-C
C		64.98	66.94	66.77
H		3.65	4.74	4.35
N		1.14	1.32	1.49
S		1.21	0.63	3.15
Ash		13.73	7.17	9.17
O		6.33	10.52	5.10
H_2O		8.96	8.68	9.97
Wet HV	Btu/lb	11183	11806	11848
Dry Analysis	wt %			100.00
C		71.38	73.30	74.16
H		4.01	5.19	4.83
N		1.25	1.45	1.66
S		1.33	0.69	3.50
Ash		15.08	7.85	10.19
O		6.95	11.52	5.66
Dry HV	Btu/lb	12284	12928	13160
Volatiles	wt% (DAF)	30.66	46.44	44.13
Fixed C	wt% (DAF)	69.34	53.56	55.87
Na_2O in ash	wt% dry	0.33	1.71	0.18
K_2O in ash	wt% dry	2.81	1.03	1.39
Cl in coal	wt%dry			0.007

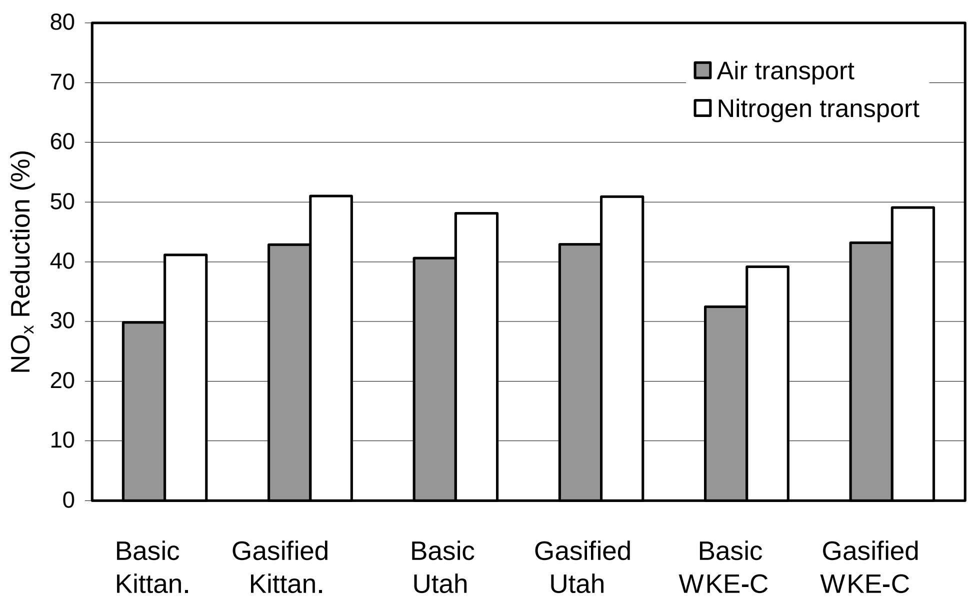

Figure 9. Efficiency of NO_x reduction for different coals.

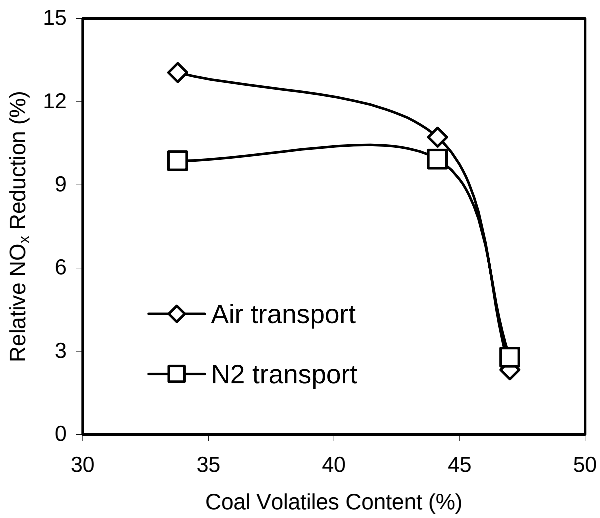

Figure 10. Effect of coal volatiles content on relative NO_x reduction.

Figure 11 demonstrates the effect of fuel-N content on relative NO_x reduction. Relative NO_x reduction first decreased and then increased with an increase in fuel-N. Possible explanation is that the range of fuel-N content of tested coals was relatively narrow, and the effect of fuel-N was masked by more significant effect of volatiles content and some other unknown factors.

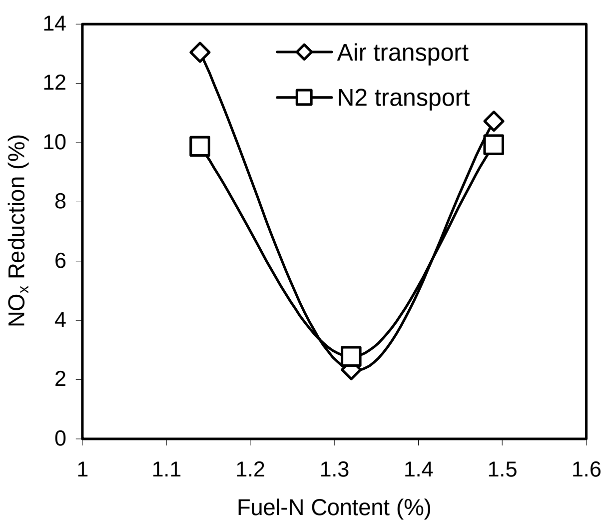

Figure 11. Effect of fuel-N content on relative NO_x reduction.

Based on the results of screening tests, Kittanning coal was selected for optimization tests.

5.2 FFR Optimization Tests

Optimization tests were conducted with Kittanning coal to determine the effect of process parameters on the efficiency of NO_x reduction in FFR. Process parameters varied in these tests included T_{RF}, initial NO_x, and residence times in the reburning and gasification zones.

Figure 12 compares performances of natural gas, coal and gasified coal in reburning. It is known that the efficiency of NO_x reduction can be affected by mixing conditions in the reburning zone. Precautions were taken to preserve the same mixing conditions in the reburning zone for all three fuels. In basic reburning tests natural gas or coal were injected into BSF reburning zone through the duct connecting gasifier with the BSF. Gasifier auxiliary natural gas flame in basic reburning tests was operating at the same conditions as in gasification tests. The same injector that was used in gasification tests was used to inject natural gas and coal. This allowed direct comparison of NO_x reduction by different fuels under the same mixing conditions in the reburning zone. The auxiliary natural gas was fired at 80,000 Btu/hr, main fuel in BSF was natural gas. Initial NO_i was 370 ppm at 0%O_2 and was controlled by adding ammonia to the air in the main combustion zone. Reburning fuel was injected at T_{RF} of 1640 K and the residence time in the reburning zone was 0.7 s.

Figure 12a demonstrates that reburning efficiencies of coal, natural gas and coal gasification products are similar. Differences in performances of these fuels were more significant when air was used as a transport media (Figure 12b). Efficiency of NO_x reduction by coal gasification products was almost the same as that of natural gas and was 5-12% higher than that of coal. Differences in the performances of coal and gasification products were less significant at large heat inputs of the reburning fuel possibly because of the decrease in the temperature in the gasification zone at large heat input of the reburning fuel (Figure 4).

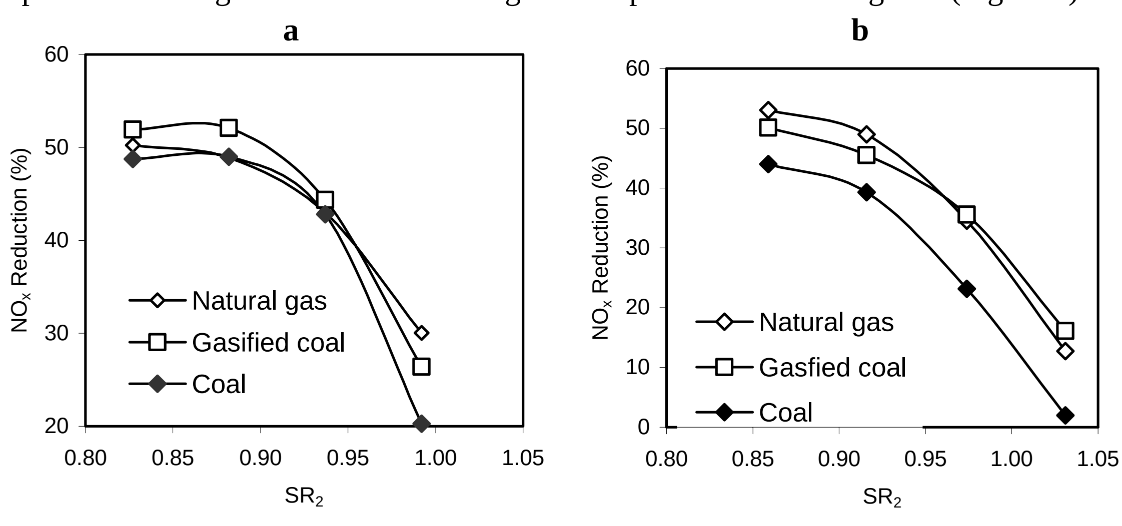

Figure 12. Effect of fuel type and SR in the reburning zone on NO_x reduction with nitrogen (a) and air (b) transport.

Figures 13 and 14 show the effect of the residence time in the reburning zone on NO_x reduction at 20% reburning fuel heat input. Initial NO_i concentration was 370 ppm at 0%O_2 and T_{RF} was 1640 K. Figures 13 and 14 demonstrate that benefits of coal gasification are more significant when reburning fuel has less time to react in the reburning zone. This is because gasification products contain gas-phase combustible species which are more reactive than char. Efficiency of NO_x reduction by coal decreases as the residence time in the reburning zone decreases since coal requires more time to react.

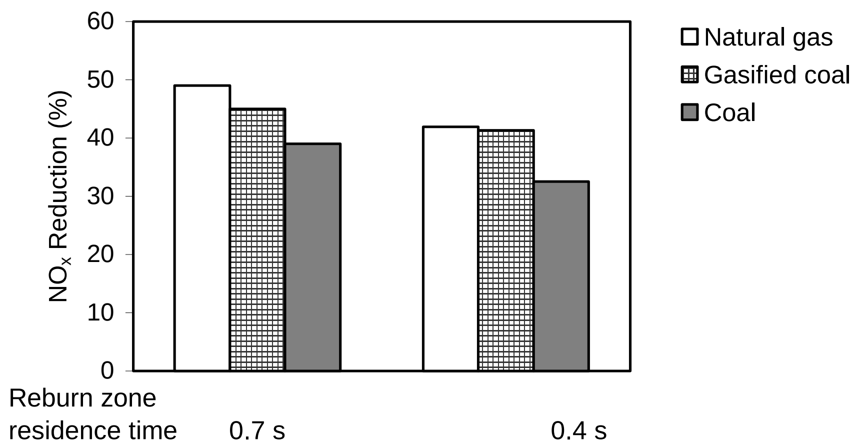

Figure 13. Effect of the residence time in the reburning zone on NO_x reduction with air transport.

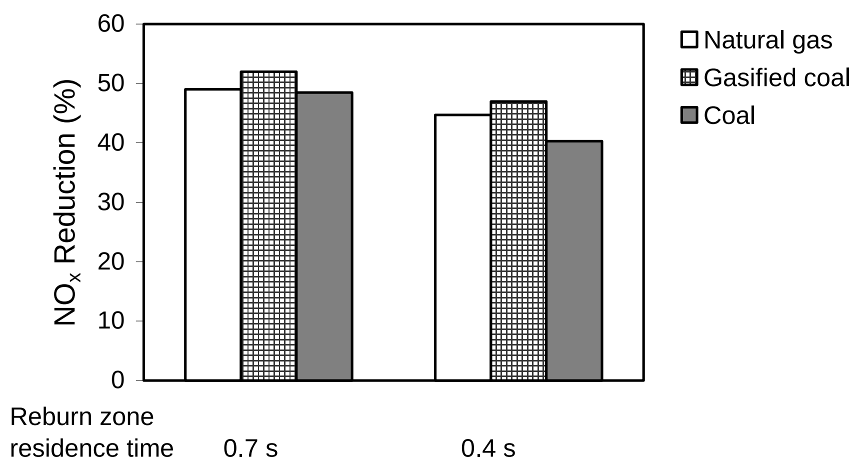

Figure 14. Effect of the residence time in the reburning zone on NO_x reduction with nitrogen transport.

Figures 15 and 16 demonstrate the effect of NO_i on NO_x reduction with air and nitrogen transport. Reburning fuel was injected at T_{RF} of 1750 K, residence time in the reburning zone was 0.6 s. The amount of the reburning fuel was 20% from total heat input. Figures 15 and 16 demonstrate that efficiencies of NO_x reduction for all fuels decrease to about the same extend with a decrease in NO_i. Figures 15 and 16 also demonstrate that gasification products were more effective reburning fuel than coal when air was used as a transport media.

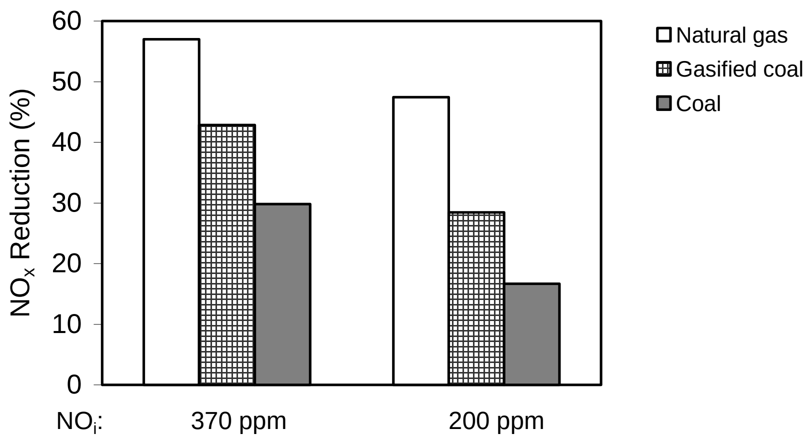

Figure 15. Effect of NO_i on NO_x reduction with air transport.

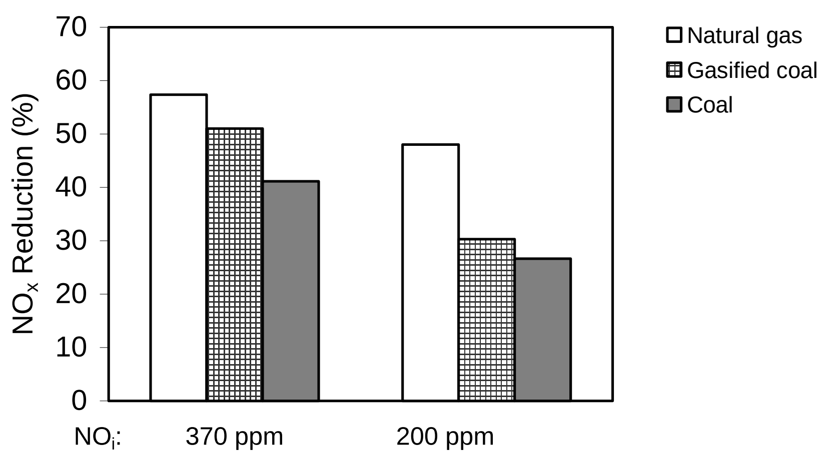

Figure 16. Effect of NO_i on NO_x reduction with nitrogen transport.

Coal residence time in the gasification zone is an important parameter that can affect the FFR efficiency. On the one hand, long residence time gives more time for coal to be gasified thus producing more gas-phase products. On the other hand, hydrocarbons which are more desirable gasification products that CO and H_2, can be partially converted to CO and H_2 at long residence times. Figure 17 shows the effect of the residence time in the gasification zone on the efficiency of NO_x reduction. The amount of the reburning fuel was 20% from total heat input, T_{RF} and T_{OFA} were 1750 K and 1640 K, respectively. Residence time in the reburning zone was 0.6 s. Figure 17 demonstrates that efficiency of NO_x reduction improves as residence time decreases from 1.6 s to 1 s. Physical limitations in the gasifier did not allow to decrease residence time to below 1 s. However, data presented in Figure 17 indicate that a decrease in the residence time to below 1 s will unlikely result in significant further improvement of NO_x reduction.

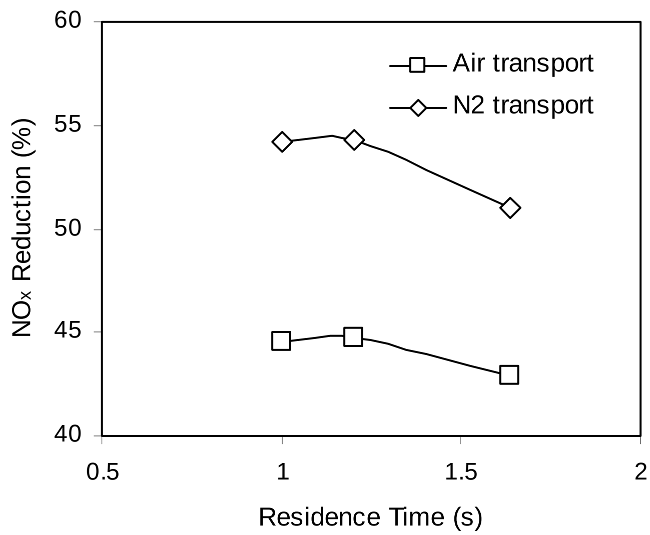

Figure 17. Effect of the residence time in the gasification zone on NO_x reduction.

6.0 SUMMARY AND CONCLUSIONS

Activities during the reporting period included design, manufacture, assembly, and shake down of coal gasifier and pilot-scale testing of the efficiency of coal gasification products for NO_x reduction in FFR. Tests demonstrated that partial coal gasification prior to injection into the reburning zone improved the efficiency of NO_x reduction. The following conclusions can be made from the analysis of experimental data:

- Several coals with different volatiles content were tested. Data suggested that incremental increase in the efficiency of NO_x reduction due to coal gasification was more significant for coals with low volatiles content. Coals with low volatiles content are usually less reactive in basic reburning. Coal gasification improves their reactivity by producing gas-phase combustible species prior to injection into the reburning zone. Coals with high volatile content are easily gasified in the reburning zone and thus benefit less from gasification prior to the injection.

- Efficiency of NO_x reduction in FFR was more significant when air was used as a transport media. Up to 14% increase in the efficiency of NO_x reduction in comparison with basic reburning was achieved with air transport. The extent of coal gasification was more significant in the presence of air since temperatures in the gasification zone were high when air was used as a transport media.
- Efficiency of NO_x reduction in FFR depended on the residence time in the reburning zone. It appears that benefits of using FFR over basic reburning become more significant at smaller residence times when coal does not have enough time to react.
- Temperature and residence time in the gasification zone affected the efficiency of NO_x reduction in FFR. Coal gasification in the temperature range of 1000 – 1150 K resulted in production of hydrocarbons, CO, H_2, and char. Tests demonstrated that NO_x reduction was maximum at residence time of about 1 s.

7.0 FUTURE WORK

Work during the last six-months period of the project, the work will focus on the development of the following elements of the FFR technology:

- More pilot-scale tests will be conducted to characterize and optimize FFR. In particularly, tests will be conducted to characterize the effect of coal gasification on UBC content in fly ash. Tests with different biomass fuels will be also conducted to determine potential benefits of the FFR technology for these fuels.
- Model of Coal Reburn will be refined and applied to subbituminous coals. Model of Coal Reburn will be validated against experimental data and then used to optimize FFR. The FFR performance will be optimized against such parameters as temperature and residence time in the gasification zone, T_{RF}, the amount of the reburning fuel, and reburning fuel transport media.
- An engineering and economic analysis of FFR will be conducted to confirm economic benefits of the FFR technology as compared to conventional reburning and other commercial

NO_x control technologies, and to develop a full-scale FFR design methodology.