

OXYGEN ENHANCED COMBUSTION **FOR NO_x CONTROL**

QUARTERLY TECHNICAL PROGRESS REPORT

For Reporting Period Starting October 1, 2002 and Ending Dec. 31, 2002

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Report Issue Date: February 2003

DOE AWARD NO. DE-FC26-00NT40756

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ABSTRACT:

This quarterly technical progress report will summarize work accomplished for the Program through the eleventh quarter, October-December 2002, in the following task areas: Task 1 - Oxygen Enhanced Combustion, Task 2 - Oxygen Transport Membranes, Task 3 - Economic Evaluation and Task 4 - Program Management.

The program is proceeding in accordance with the objectives for the third year. Pilot scale experiments conducted at the University of Utah were aimed at confirming the importance of oxygen injection strategy for different types of burners. CFD modeling at REI was used to better understand the potential for increased corrosion under oxygen enhanced combustion conditions. Data from a full-scale demonstration test in Springfield, MO were analyzed.

OTM element development continued with preliminary investigation of an alternative method of fabrication of PSO1d elements. OTM process development continued with long-term testing of a PSO1d element.

Economic evaluation has confirmed the advantage of oxygen-enhanced combustion. Proposals have been submitted for two additional beta test sites. A first commercial proposal has been submitted. Economic analysis of a beta site test performance was conducted.

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A. Executive Summary

The objective of this program is to demonstrate the use of oxygen enhanced combustion as a technical and economical method of meeting the EPA State Implementation Plan for NO_x reduction to less than that of 0.15lb/MMBtu for boilers and coal. This program will develop both oxygen based low NO_x technology and the new low cost oxygen transport membrane (OTM) oxygen production technology.

The breakdown of the program work consists of the following four major tasks:

- Task 1.0 Oxygen enhanced combustion
- Task 2.0 Oxygen transport membranes
- Task 3.0 Economic evaluation
- Task 4.0 Program management

Task 1 work focused on three areas: CFD modeling results from REI (Task 1.1.1) suggest that oxygen reduces corrosion concerns from operating a boiler under deeply staged conditions compared to operating without oxygen; Data from pilot-scale testing (Task 1.3) at the University of Utah indicate that the burner design has a very strong impact on the degree of NO_x reduction achievable with oxygen enhanced combustion; Results from full-scale testing (Task 1.4) at the City Utilities' James River Power Station demonstrate that oxygen enhanced combustion can substantially reduce NO_x emissions from coal-fired power plants.

Task 2 efforts this quarter focused on OTM element development (Task 2.2) of an alternative fabrication technique for PSO1d elements. A long-term test with a PSO1d element was successfully completed under Task 2.3, OTM process development.

Task 3 work confirmed the economic advantages of oxygen enhancement based on beta site test results. Target boiler utilities were identified. Test proposals were submitted to two additional utilities. A commercial proposal was also submitted this quarter.

Program management (Task 4) continued on track during the eleventh quarter. All subcontracts and amendments to subcontracts have been negotiated and executed. Project documentation has been prepared and delivered to the US DOE in accordance with the cooperative agreement.

B. Experimental Methods

B.1. Combustion Modeling (Task 1.1.1) Experimental Methods

One of the concerns utilities have with operating their units under deeply staged conditions is increased waterwall wastage. To better understand the potential for increased corrosion under oxygen enhanced combustion conditions REI (Reaction Engineering International) used the computational fluid dynamic (CFD) model developed earlier¹ to explore oxygen enhanced staging for NO_x control and coupled the output with corrosion correlations available from the literature. First the corrosion based on H₂S and the corrosion rates associated with deposition of unburned carbon and FeS were estimated for the 'as found' staged combustion condition. These

corrosion rates were then calculated based on the deeply staged condition with and without oxygen.

B.2. Pilot-Scale Testing (Task 1.3) Experimental Methods

The objective of this task is to explore the effect of various oxygen injection strategies on NO_x emissions from a typical wall fired burner². Experiments performed at the University of Utah during the reporting period were aimed at confirming the importance of oxygen injection strategy for different types of burners. A wide range of burner configurations were evaluated, including evaluating the effect of coal pipe relative dimensions and coal spreaders on the effectiveness of oxygen enhanced combustion.

B.3. Full-Scale Testing (Task 1.4) Experimental Methods

Full-scale experiments were previously performed in ALSTOM Power's Industrial Scale Burner Facility (ISBF) in Windsor, CT using a 25 MMBtu/h commercially available Radially Stratified Flame Core (RSFCTM) burner as discussed in the 8th quarterly Technical Progress Report³. A wide range of burner parameters were evaluated, as were the first stage stoichiometric ratio and residence time. Several methods were explored to introduce the oxygen into the first stage.

The main driver for the development of oxygen enhanced combustion for NO_x control is to not only allow utility operators to control NO_x emissions but to also avoid or minimize many of the detrimental side effects common to alternative control strategies. The successful demonstration of the concept at the pilot and full-scale single burner levels led to an agreement between Praxair and City Utilities of Springfield, Missouri to test oxygen enhanced combustion at full scale. The demonstration project (separately funded) utilized Unit 3 at the James River Power Station to evaluate the effect of O₂ addition during staged combustion on NO_x emissions, residual carbon in ash, opacity and plant operation.

B.4. OTM Element Development (Task 2.2) Experimental Methods

The objective of this task is to fabricate elements from OTM materials for testing. Powder characterization techniques and element manufacturing equipment were described in the first quarter technical progress report⁴. An alternative proprietary fabrication technique for PSO1d elements was studied. This fabrication method was developed outside this program.

B.5. OTM Process Development (Task 2.3) Experimental Methods

The objective of this task is to design, build and operate a single tube reactor for high-pressure operation that can demonstrate at least 75% of the commercial target flux. Details of the design and operation of the single tube high-pressure permeation test facility can be found in the second⁵ and third¹ quarterly reports.

This quarter long-term testing of a dense PSO1d element in the single tube high-pressure permeation reactor was completed.

C. Results and Discussion

C.1. Combustion Modeling (Task 1.1.1) Results and Discussion

Overall, the model results indicate that corrosion rates for deeply staged oxygen enhanced systems are comparable to mildly staged air cases. The model results do suggest that small increases in H_2S based corrosion are possible with oxygen enhanced staging due to elevated tube temperatures compared to deep staging with air alone. However, this mechanism is predicted to comprise a very small fraction of the maximum corrosion rate, so small increases are not likely to significantly increase the waterwall wastage. Experience has suggested that FeS based corrosion can have a much larger impact on waterwall wastage. The data suggest that below the OFA ports, deeper staging alone (no oxygen added) is predicted to cause an increase in the area susceptible to FeS based corrosion. However, in combination with oxygen enrichment, the susceptible water wall area is predicted to decrease significantly. In fact, in many furnace zones the susceptible water wall area is predicted to be lower than or comparable to the baseline case (SR=0.90). The peak corrosion rate is estimated to increase slightly due to the higher tube temperatures, but the average rate (based on affected areas) does not change from the baseline case.

The results obtained through the modeling suggest that there is cause for concern to operate a boiler under deeply staged conditions without oxygen injection. However, when oxygen enhanced combustion is used there is little or no impact on the expected waterwall wastage.

C.2. Pilot-Scale Testing (Task 1.3) Results and Discussion

The data from the University of Utah experiments indicate that the burner design has a very strong impact on the degree of NO_x reduction achievable with oxygen enhanced combustion, particularly under typical air preheat conditions found in utility boilers. For example, a given injection strategy can be fairly successful at reducing NO_x emissions with high burner swirl and actually increase NO_x at low swirl with all else being comparable.

Figure 1 shows a typical NO_x vs. staging curve developed during this testing. As indicated NO_x formation is significantly reduced as the burner zone stoichiometric ratio decreases. This reduction in NO_x is evident in both the air-based case and the oxygen enriched cases. These data indicate that the oxygen enriched combustion provides additional NO_x reduction beyond that available from simple air-based staging.

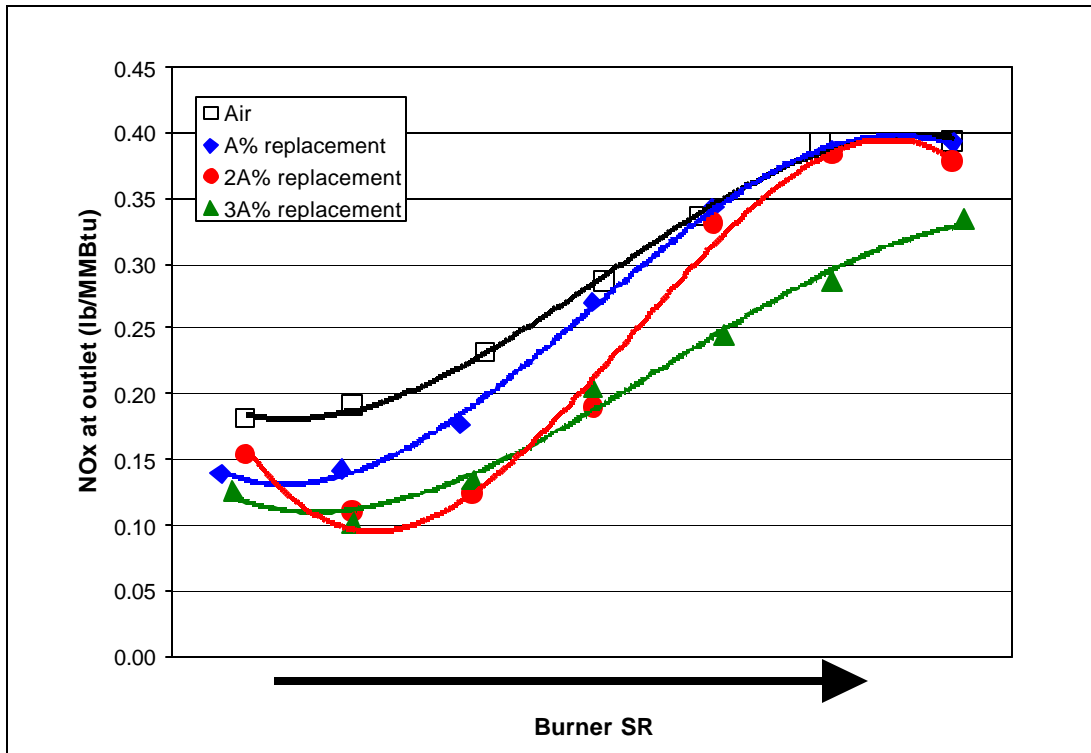


Figure 1. Pilot-scale results – University of Utah

The pilot-scale data was used to define some of the mixing strategies tested during the subsequent full-scale testing at the City Utilities' James River Power Station.

C.3. Full-Scale Testing (Task 1.4) Results and Discussion

Full-scale single burner testing at Alstom was completed. Figure 2 shows the effect of oxygen replacement under deeply staged conditions. These data further support that under fuel rich conditions oxygen enhanced combustion can significantly reduce NO_x formation even with very low oxygen replacement rates⁶. Similar data demonstrated that oxygen can enhance staging for NO_x control over a wide range of conditions, and that the method for oxygen introduction is critical to the NO_x reduction achieved⁶.

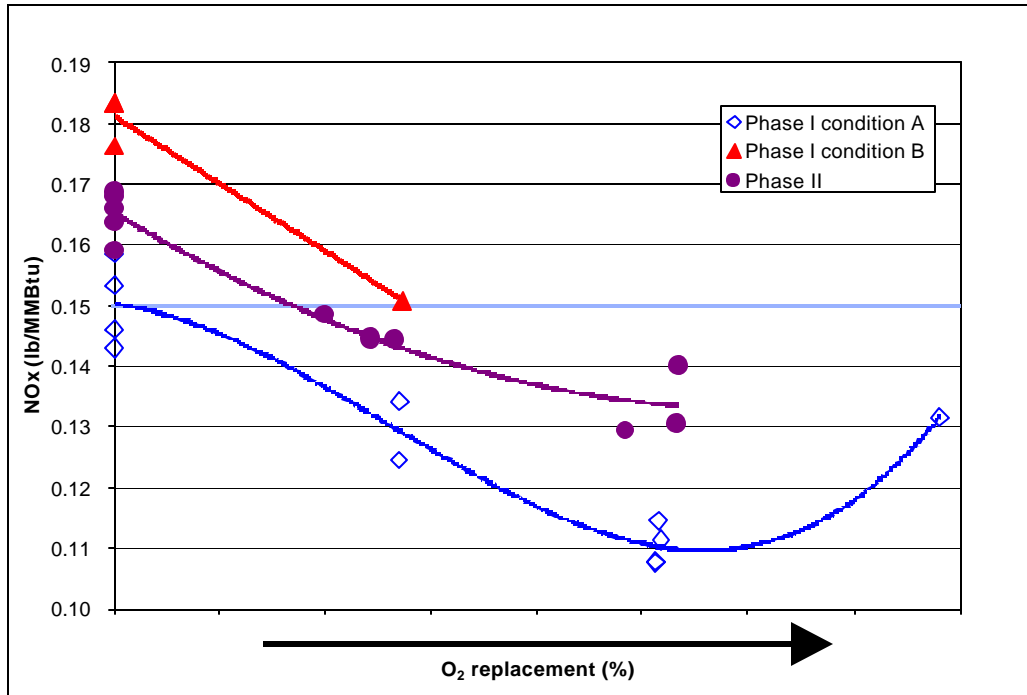


Figure 2. Full-scale single burner results – Alstom Power

This single burner work demonstrated that oxygen enhanced combustion can substantially reduce NO_x emissions from coal-fired power plants.

Data analysis of the demonstration project at James River Unit 3 also indicated that oxygen enhanced combustion can substantially reduce NO_x emissions from coal-fired power plants. The burner observations indicate that flame stability was dramatically improved with oxygen addition. The use of oxygen also *reduced* LOI and opacity as compared to the air- alone staging, with measured LOI and opacity being comparable or only slightly higher than the unstaged air-only condition. Therefore, this project demonstrated that oxygen enhanced combustion leads to significant reductions in NO_x emissions *without* many of the problems typically associated with staged combustion systems.

C.4. OTM Element Development (Task 2.2) Results and Discussion

An alternative proprietary element fabrication method, which may result in lower processing costs, was investigated using PSO1d composition. Straight green elements were successfully prepared. Future work will focus on sintering optimization and alternative element architecture.

C.5. OTM Process Development (Task 2.3) Results and Discussion

The long-term PSO1d element test in the NO_x reactor was completed. The element did not experience any dimensional changes after >1500 hours of continuous operation. This lack of deformation is an important milestone in the long-term development of this technology. Elements with alternative architecture will be tested next quarter.

C.6. Economic Evaluation (Task 3) Results and Discussion

Oxygen enhancement advantage versus SCR/SNCR was confirmed with utilities. Based on pilot-scales tests, commercial burner performance tests, and the beta site test results, the economic advantage of oxygen enhancement was confirmed.

The market segmentation was completed with target boiler utilities identified. Potential host sites have also been identified and test proposals submitted.

C.7. Program Management (Task 4) Results and Discussion

The Program Management highlights for the US DOE NO_x program are as follows:

- Teleconferences were held among combustion team members throughout the year.
- Monitoring of accounts established within the Praxair accounting system to track labor hours and costs was ongoing.
- Project documentation has been prepared and delivered to the US DOE in accordance with the cooperative agreement including quarterly technical progress reports and financial status reports.

D. Conclusion

Progress was made in all tasks toward achieving the DOE NO_x program objectives.

Oxygen Enhanced Combustion Tasks:

CFD modeling experiments at REI explored oxygen enhanced staging for NO_x control and coupled the output with corrosion correlations. Results suggest that when oxygen enhanced combustion is used there is little or no impact on the expected waterwall wastage compared with a conventionally staged air case. Pilot-scale testing at the University of Utah demonstrated that the burner design has a very strong impact on the degree of NO_x reduction achievable with oxygen enhanced combustion, particularly under typical air preheat conditions found in utility boilers. The successful demonstration of oxygen enhanced combustion for NO_x control at the pilot and full-scale single burner levels led to an agreement between Praxair and City Utilities of Springfield, Missouri to test oxygen enhanced combustion at full scale (separately funded). The results from the full-scale demonstration project at the James River Power Station indicated that oxygen enhanced combustion can substantially reduce NO_x emissions from coal-fired power plants.

Oxygen Transport Membrane Tasks:

Straight PSO1d elements were successfully prepared using an alternative fabrication method. Sintering optimization will continue and alternative element architecture will be investigated next quarter. A long-term test (>1500 hours) of a dense PSO1d element in the single tube high-pressure permeation reactor was completed, resulting in no element deformation.

Economic Evaluation:

The advantage of oxygen enhancement versus SCR/SNCR was confirmed with utilities. Based on pilot-scales tests, commercial burner and beta site performance tests, the economic advantage of oxygen enhancement was confirmed. Also, market segmentation was completed with target utilities and boilers identified. Discussions were held during this quarter with utilities to confirm economics and identify issues limiting the commercialization of the technology. Two additional beta site proposals and a commercial proposal have been submitted. Commercialization activity is expected to accelerate during the first quarter of 2003.

E. References

1. Thompson et. al, "Oxygen Enhanced Combustion for NO_x Control", Quarterly Technical Progress Report for US DOE Award No. DE-FC26-00NT40756, January 2001.
2. Thompson et. al, "Oxygen Enhanced Combustion for NO_x Control", Quarterly Technical Progress Report for US DOE Award No. DE-FC26-00NT40756, July 2001.
3. Thompson et. al, "Oxygen Enhanced Combustion for NO_x Control", Quarterly Technical Progress Report for US DOE Award No. DE-FC26-00NT40756, April 2002.
4. Thompson et. al, "Oxygen Enhanced Combustion for NO_x Control", Quarterly Technical Progress Report for US DOE Award No. DE-FC26-00NT40756, July 2000.
5. Thompson et. al, "Oxygen Enhanced Combustion for NO_x Control", Quarterly Technical Progress Report for US DOE Award No. DE-FC26-00NT40756, October 2000.
6. Patents pending