

OXYGEN ENHANCED COMBUSTION **FOR NO_x CONTROL**

QUARTERLY TECHNICAL PROGRESS REPORT

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ABSTRACT:

This quarterly technical progress report will summarize work accomplished for the Program through the ninth quarter April-June 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. Full-scale testing using the Industrial Boiler Simulation Facility (ISBF) at Alstom Power was completed.

The pilot scale experiments to evaluate the effect of air preheat and transport air stoichiometric ratio (SR) on NO_x emissions were conducted at the University of Utah.

Combustion modeling activities continued with full-scale combustion test furnace simulations.

An OTM element was tested in Praxair's single tube high-pressure test facility and two thermal cycles were completed. PS01d elements of new dimension were tested resulting in a lower flux than previous PS01d elements of different dimensions, however, no element deformation was observed.

Economic evaluation has confirmed the advantage of oxygen-enhanced combustion. Two potential host beta sites have been identified and proposals submitted.

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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 this quarter consisted of pilot-scale and full-scale testing and computer modeling used to better understand the fundamentals of oxygen for NO_x emissions control and to illustrate the benefit of oxygen addition to low NO_x coal firing systems. Computational fluid dynamic (CFD) simulations (Task 1.1.1) performed by Reaction Engineering International (REI) were designed to evaluate the effectiveness of oxygen enhanced low NO_x burners in a full-scale unit. Data from pilot-scale testing (Task 1.3) at the University of Utah suggest there is a relatively small effect of air preheat temperature on NO_x. Experiments with two coals were completed at the full-scale testing facility at Alstom Power (Task 1.4) with data that show significant reductions are available with oxygen use.

Task 2 work focused on the optimization and testing of an OTM system for use with the proposed technologies. OTM element development (Task 2.2) efforts this quarter focused on a new element fabrication process and dimension using PSO1d, and sintering optimization. OTM process development (Task 2.3) experiments include thermal cycling of an OTM element and testing of PSO1d elements of new dimension. No element deformation was observed after 350 hours at 900°C, however flux results were lower.

Task 3 work confirmed the advantages of oxygen enhancement and identified target boiler utilities.

Program management (Task 4) continued on track during the ninth 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

During the last reporting period computational fluid dynamic (CFD) modeling activities were performed by Reaction Engineering International (REI) for Praxair's United States Department of Energy (US DOE) program entitled "Oxygen Enhanced Coal Combustion for NO_x Control". The objective of this work was to illustrate the benefit of oxygen addition to low NO_x coal firing systems. Simulations performed during the last quarter were designed to evaluate the effectiveness of oxygen enhanced low NO_x burners in a full-scale unit.

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 burner. Pilot-scale testing activities were performed at the University of Utah during the last quarter. The activities performed included both baseline air optimization and oxygen testing with air preheat and different transport air stoichiometric ratios.

B.4. Full-Scale Testing (Task 1.4) Experimental Methods

Experimental work was performed using the Industrial Boiler Simulation Facility (ISBF) at Alstom Power's Power Plant Laboratory in Windsor, CT. The experiments were designed to demonstrate the concept of oxygen enhanced low combustion system can meet the emissions target of 0.15 lb/MMBtu with minimal impact on CO emissions and furnace performance. Two coals were evaluated with oxygen enhanced combustion using Alstom Power's ISBF. The ISBF is a water-cooled tunnel furnace designed to test burners up to 50 MMBtu/h in firing rate with time-temperature histories similar to PC-fired boilers. The unit has two locations for separated over-fire air (SOFA) injection. An 'off the shelf' RSFC burner, Alstom's commercial wallfired low NO_x burner, was used in these experiments. The burner was designed for a firing rate of 26 MMBtu/h and was typically fired at 24 MMBtu/h for these tests.

B.5. 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 report ¹. A new dense PSOfd fabrication process was investigated. Sintering optimization continued on PSOfd elements.

B.7. 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 in year 2 of the program. Details of the design and operation of the single tube high-pressure permeation test facility can be found in the second and third quarterly reports ^{2,3}.

An element of new OTM composition and dense PSOfd elements of a new dimension were tested in the single tube high-pressure permeation reactor this quarter. The maximum operating temperature for these tests was 900°C.

C. Results and Discussion

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

During the last quarter REI used one of their existing coal fired utility boiler models to explore the effect of oxygen injection on NO_x and LOI emissions. The boiler was assumed to fire with air alone at a stoichiometric ratio of 0.90 in the main burner zone. These results indicate that both NO_x and LOI are significantly reduced when the main burner zone stoichiometric ratio is reduced *and* oxygen is added.

In the next quarter REI will continue modeling other burners and boilers to explore the effect of oxygen injection on NO_x formation, and LOI.

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

One of the primary goals of these experiments was to evaluate the effect of air preheat and transport air stoichiometric ratio on NO_x emissions. These data suggest there is a relatively small effect of air preheat temperature on NO_x.

A series of experiments were also performed to evaluate the effect of oxygen enhanced combustion on NO_x. These data show that oxygen enhanced combustion under deep staging significantly reduces NO_x emissions. Additional data was collected using a coal spreader design similar to that available in commercial burners. Analysis of these data is ongoing.

Additional experiments are planned for the next quarter to further evaluate the effect of coal spreader on NO_x emissions. Experiments are also scheduled to evaluate oxygen enhanced combustion with the PRB coal utilized at Alstom Power.

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

Two coals were evaluated with oxygen enhanced combustion using Alstom's ISBF. The first coal tests was an eastern bituminous coal, the Mingo Logan. These data were used to evaluate the performance of two new oxygen injection methods and to check for reproducibility of the previous data with this coal. These data show significant reductions are available with oxygen use.

The next set of experiments utilized the Cordero Rojo PRB coal. These data were mixed, but for at least one stoichiometric ratio and transport air to fuel ratio combination adding oxygen did lead to a significant reduction in NO_x. Additional work is planned for the University of Utah to better understand these results. No additional testing is scheduled for the Large-scale facility.

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

A new fabrication method was investigated using PSO1d composition. Elements of 2ft length were successfully prepared. Sintering optimization of OTM elements was ongoing, and progress was made in the ovality of the elements. Future work will focus on element straightness and process optimization.

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

An element of new OTM composition survived two thermal cycles to 900°C, and failed during the heatup of the third thermal cycle. The flux observed was significantly lower than the flux of previously tested elements of different compositions.

Dense PSO1d elements of a new dimension were tested at 900°C in the single tube high-pressure permeation reactor this quarter. There was no element deformation after 350 hours at 900°C however, the flux measured was half the value observed with previously tested PSO1d elements with the same wall thickness, different dimension.

Future OTM process development work will continue to focus on element thermal cycling and enhancement of oxygen flux by architecture modifications.

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

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

The market segmentation was completed with target boiler utilities identified. Two potential host sites have also been identified.

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

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

- Project review meeting was held on May 15, 2002 at the US DOE.
- 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.
- A paper entitled "O₂ Enhanced Combustion for NO_x Control" was presented by Dr. Lawrence Bool of Praxair at the 2002 Conference on SCR and SNCR for NO_x Control, Pittsburgh, PA, May 15-16, 2002.

D. Conclusion

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

Oxygen Enhanced Combustion Tasks:

CFD results from REI indicate that both NO_x and LOI are significantly reduced when the main burner zone SR is reduced and oxygen is added.

Pilot scale testing continued at the University of Utah to evaluate the effect of preheat and transport air SR on NO_x emissions. These experimental data suggest there is a relatively small effect of air preheat temperature on NO_x emissions. Another experiment shows that oxygen enhanced combustion under deep staging can significantly lower NO_x emissions. Additional data was collected using a coal spreader design and analysis of this data will continue next quarter.

The final test campaign for the full-scale test facility was completed this quarter. Two new oxygen injection methods were evaluated using the Mingo Logan bituminous coal. Significant reductions with oxygen use were observed. Another experiment used the Cordero Rojo PRB coal. The data was mixed and to better understand these results, additional work is planned next quarter at the University of Utah.

Oxygen Transport Membrane Tasks:

PSO1d elements of 2ft length were successfully prepared using a new fabrication method. Sintering optimization of OTM elements was ongoing, and progress was made in the ovality of the elements. Process optimization will continue next quarter.

An element of new OTM composition survived two thermal cycles to 900°C, however, the flux observed was much lower than the flux of previously tested elements of different compositions. Dense PSO1d elements of a new dimension were tested at 900°C resulting in flux half the value observed with previously tested PSO1d elements with the same wall thickness, different dimension. No element deformation was observed after 350 hours at 900°C. Future work will focus on element thermal cycling and enhancement of oxygen flux by architecture modifications.

Economic Evaluation:

The advantage of oxygen enhancement versus SCR/SNCR was confirmed with utilities. Based on pilot-scales tests and commercial burner 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 11 utilities to confirm economics and identify issues limiting the commercialization of the technology. Two host sites have been identified and proposals submitted.

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