Biomass Reburning - Modeling/Engineering Studies

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ABSTRACT

This project is designed to develop engineering and modeling tools for a family of NO_x control technologies utilizing biomass as a reburning fuel. The sixth reporting period (January 1 – March 31, 1999) included CFD modeling and assessment of available experimental and modeling data on biomass reburning.

Experimental and modeling data obtained within scope of this and Phase II SBIR USDA projects were reviewed and analyzed. This work was necessary to summarize available data and to make decision about additional efforts that are necessary for successful completion of the DOE FETC project. These efforts resulted in preparation of the paper entitled “Kinetic Study of Biomass Reburning” which was presented at the 1999 Joint Meeting of the United States Sections of the Combustion Institute. The paper is included in Attachment A.

No patentable subject matter is disclosed in the report.

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Description of Project Activities

This report describes project activities during the period from January 1 to March 31, 1999. Tasks to be conducted during the sixth reporting period included (1) CFD and (2) physical modeling, and (3) evaluation of slagging and fouling in biomass reburning. The purpose of the CFD modeling is to determine the effect of mixing on the chemistry of the biomass reburning process. This task as well as task on experimental analysis of slagging and fouling in biomass reburning were performed by DOE FETC research staff. Contribution of FETC R&D group during this reporting period will be send to DOE at a later date.

The physical modeling will be done at EER. In this task, EER will construct a subscale isothermal flow model of the host boiler to be used for demonstrating the biomass reburning technology. When project started in October 1997, Niagara Mohawk Power Corporation (NMPC, a potential partner for commercialization of the biomass reburning technology), offered one of its power plants as the host boiler in the demonstration project. EER has planned to construct a flow model of that boiler. However, the target unit has been recently sold. The new owner will now make a decision about the demonstration program. Because of the current uncertainty, EER has not started physical modeling pending NMPC decision.

During the reporting period, previous experimental and modeling data obtained within the scope of this and Phase II SBIR USDA projects were reviewed and analyzed. This work was necessary to summarize available data and to make decision about additional efforts that are necessary for successful completion of the R&D program. These efforts resulted in preparation of the paper entitled "Kinetic Study of Biomass Reburning" which was presented at the 1999 Joint Meeting of the United States Sections of the Combustion Institute. The meeting was held in March 15-18, 1999 in Washington, DC. The paper describes a series of pilot scale tests that were conducted in EER's 300 kW (1×10^6 Btu/hr) Boiler Simulator Facility to characterize biomass reburning performance as a function of key process variables. Fuels under investigation included natural gas, furniture waste, willow wood and walnut shells. Tests showed that some biomass fuels at small heat inputs of the reburning fuel are as effective as natural gas. The experimental data showed that the efficiency of biomass is affected by its composition. The paper also described kinetic model developed within the scope of the DOE FETC project. The biomass fuels were represented by a mixture of decomposition products, thus assuming rapid breakdown of the fuel. The model took into account such features of the mixing process as not uniform mixture composition in the reburning zone and not instantaneous mixing of reagents. Modeling showed that nitrogen and mineral content of biomass determine its efficiency as the reburning fuel.

A copy of the paper is attached.

2.0 Future Work

This report describes continuous efforts to evaluate performance of biomass fuels in the reburning process. Future activities will include continuation of CFD and kinetic modeling. Kinetic model will be improved to give better representation of biomass mineral composition and the effect of additives on advanced biomass reburning (biomass reburning in the presence of N-agent).

Kinetic Study of Biomass Reburning

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Abstract

This paper presents results of combustion experiments and modeling studies on NO reduction in the reburning process with different reburning fuels. Fuels under investigation include natural gas, furniture waste, willow wood and walnut shells. Tests showed that some biomass fuels at small heat inputs of the reburning fuel are as effective as natural gas. Efficiency of biomass is affected by its composition. The kinetic model agrees with experimental data for a wide range of initial conditions and thus can be used for process optimization.

Introduction

An environmental problem faced by the power generation industry involves controlling flue gas emissions from coal fired boilers. Reburning is a commercial two-stage fuel injection technology which is currently most promising for low-cost NO_x control. In this firing method, the main fuel is coal or oil (80-90% of the total) and the remaining fuel (reburning fuel) might be natural gas or other combustibles. Basic natural gas reburning can achieve 60-65% NO_x control.

Energy and Environmental Research Corp. (EER) is currently working on development of basic and advanced biomass reburning technologies that utilize biomass as a reburning fuel. Advanced biomass reburning is a combination of basic reburning with N-agent injection (Zamansky *et al.* 1996, 1997, 1998a). Biomass which may include wastewood, straw, agricultural waste, etc. can be inexpensive and may have a potential for lower cost NO_x reduction with sometimes even higher performance than that of gas and coal reburning. This concept presents a means for utilizing both energy content of biomass and its chemical constituents which can promote the chemical reactions of NO removal from combustion flue gas.

This paper describes experimental and modeling studies conducted in an effort to better understand the chemical base for the influence of biomass on NO removal.

Experimental Results

A series of pilot scale tests was conducted in EER's 300 kW (1×10^6 Btu/hr) Boiler Simulator Facility (BSF) to characterize biomass reburning performance as a function of key process variables. The BSF is designed to provide subscale simulation of the flue gas temperatures and compositions found in conventional utility boilers and is described elsewhere (Zamansky *et al.* 1998b). Pelletized furniture waste, willow wood, and walnut shells were used as reburning fuels. For comparison, several tests were also conducted with natural gas. Natural gas was used as the primary fuel.

All solid fuels were pulverized for the tests in a hammer mill. Size distribution was varied by installing different screens in the hammer mill and by running samples through the mill multiple times. The 48% < 200 mesh grind was used for most of the tests. The walnut shells were more brittle than the

furniture waste pellets and provided a finer size distribution. For the walnut shells a grind of 55% < 200 mesh was tested.

It was found that the willow wood was fibrous and considerably more difficult to process than other biomass samples. The willow wood was difficult to convey through the hammer mill and it provided larger size particles than those obtained with other biomass samples. The baseline size fraction for the willow wood reburn tests was 23% less than 200 mesh.

Reburning fuel was injected at 1700 K, and burnout air was injected at 1450 K. The initial amount of NO in flue gas was 400 ppm.

Figure 1 shows NO_x control performance for willow wood, furniture waste, walnut shells and natural gas as a function of reburning heat input. NO reduction provided by the furniture waste was better than natural gas at 10% and 15% reburning. For furniture waste, maximum NO reduction was 66%, achieved at 15% reburning heat input. The walnut shells provided a maximum of 65% NO reduction at 20% reburning. Willow wood gave a maximum of 61% NO reduction at 20% reburning. Walnut shell performance was slightly better than that of natural gas at lower reburning heat inputs, and worse than natural gas at higher reburning heat inputs. Performance of willow wood was worse than natural gas at all reburning heat inputs. Difference in the performance of biomass fuels are due to their different compositions: walnut shells have high volatiles, low nitrogen, and very high potassium content. The willow wood has high volatiles and low ash. The ash from the willow wood has low sodium and notably high P₂O₅.

Modeling and Discussion

The model includes 447 reactions of 65 chemical species (*Glarborg et al. 1998*). Since the adopted kinetic mechanism extends to only C₁ and C₂ hydrocarbons, biomass was represented by a mixture of decomposition products, thus assuming rapid breakdown of the fuel. The fuel oxygen was assumed to form CO in the substoichiometric environment. The remaining hydrocarbon component was represented by a mixture of C₂H₆, C₂H₄ and C₂H₂. Fuel-N was represented as HCN. The composition of decomposition products corresponds to the biomass ultimate analysis.

The EER chemical kinetic code ODF, for “One Dimensional Flame” (*Kau and Tyson 1987*) was employed to model experimental data. ODF treats a system as a series of one-dimensional reactors. Each reactor may be perfectly mixed (well-stirred) or unmixed (plug flow). Each ODF reactor may be assigned a variety of thermodynamic characteristics, including adiabatic, isothermal, or specified profiles of temperature or heat flux, and/or pressure. Process streams may be added over any interval of the plug flow reactor, with arbitrary mixing profiles along the reactor length. The flexibility in model setup allows for many different chemical processes to be simulated under a wide variety of mixing conditions.

The reburning process was treated as series of four reactors. Each reactor described one of the physical and chemical processes occurring in a boiler: addition of the reburning fuel, NO_x reduction as a result of the reaction with the reburning fuel, addition of overfire air (OFA), and oxidation of partially oxidized products.

The following features of the mixing process were addressed in the modeling:

- Injected gases are available for the reaction over certain period of time (mixing time) rather than instantaneously.
- Injection of reburning fuel results in mixture stratification such that mixture composition in the mixing area is not uniform.

For the reburning fuel jet, the mixing time was adopted to be 200 ms for all biomass fuels. This time is considerably longer than mixing time for natural gas injection (100 ms) estimated using a model of single jet in cross flow. This increase in mixing time was introduced to allow to take into account longer heating and decomposition times of biomass particles. For the overfire air jet, the mixing time was 100 ms.

Mixture stratification in the reburning zone, or existence of local fuel rich zones in which concentration of fuel is higher than average, is an important factor that affects efficiency of the reburning process. This factor is believed (*Luan et al. 1996, Miller et al. 1998*) to be mainly responsible for high levels of NO reduction (40-50%) at slightly fuel rich and even at fuel lean reburning conditions observed in experiments (*Kokkinos 1992, Folsom et al. 1991*). The mixing process in the reburning zone was described in modeling by addition of flue gas to the stream of natural gas over mixing time (so-called

inverse mixing). Inverse addition of reagents partially addresses the issue of mixture stratification in the mixing area: at first moments of mixing the reaction occurs in a fuel-rich environment and then progresses gradually to the final composition determined by the amount of the injected fuel. This approach was found (Luan *et al.* 1996, Glarborg *et al.* 1998, Zamansky *et al.* 1998b) to be most effective in description of the mixing process in one dimensional approximation. Additional fuel stratification in modeling was introduced by assuming that within the reburning zone there is one zone with 25% larger and one zone with 25% smaller concentration of fuel than average. NO reduction was calculated as average of that for these two zones. This approach showed in the past to be effective in description of natural gas reburning.

Figures 2, 3 and 4 show comparison of modeling predictions with experimental data for different reburning fuels. The model quantitatively agrees with experiments within scatter of experimental data for walnut shells and willow wood and qualitatively agrees with experimental data on furniture waste reburning. High efficiency of furniture waste at low heat inputs of the reburning fuel is well predicted, even though maximum efficiency in the modeling is smaller than that in experiments. A decrease in efficiency at large heat inputs is also predicted.

Modeling shows that there are several factors that determine the efficiency of biomass as the reburning fuel. At low heat inputs, fuels with high concentration of minerals (furniture waste and walnut shells) show NO reduction efficiencies similar or better than that of natural gas. At high heat inputs, fuels with high fuel-N content (furniture waste) show degradation in the reburning efficiency. Willow wood has high nitrogen and low mineral content and as a result is less effective than natural gas at all heat inputs of the reburning fuel.

The fact that the model agrees with experimental data suggests that contribution of heterogeneous reactions to NO reduction is not very significant and NO reduction is mainly determined by reactions in the gas phase.

Conclusions

1. Furniture waste and walnut shells provided similar or better NO_x control as that of natural gas at low heat inputs and performed worse at high ones. Performance of willow wood was worse than that of natural gas at all heat inputs.
2. The kinetic model of basic reburning agrees with experimental data for a wide range of initial conditions and thus correctly represents main features of the reburning process.

Acknowledgment

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References

- Folsom, B.A., Sommer, T.M., and Roynes. (1991) *AFRC-JFRC International Conference on Environmental Control of Combustion Process*, Paper 16.
- Glarborg, P., Alzueta, M.U., Dam-Johansen, K., and Miller, J.A. (1998) *Combust. Flame* 115, 1.
- Kau, C.J., and Tyson, T.J. (1987) A Computer Program for General Flame Analysis. U.S. Environmental Protection Agency Report No. EPA-6000/7-87-027.
- Kokkinos, A. (1992) *EPRI Journal* 8, Vol. 17, p. 36.
- Luan, T., Liu, H., Gibbs, B.M., and Hampartsoumian, E. (1996) *The 9th International Symposium on Transport Phenomena in Thermal-Fluids Engineering*, p. 268.
- Miller, C.A., Touati, A.D., Becker, J., and Wendt, J.O.L. (1998) *27th Symposium (International) on Combustion*, Abstracts of Accepted Papers, p. 122, The Combustion Institute, Pittsburgh.
- Zamansky, V.M., Ho, L., Maly, P.M., and Seeker, W.R. (1996) *26th Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, p. 2075
- Zamansky, V.M., Maly, P.M., and Ho, L. (1997) *Proceedings of ASME International Joint Power Generation Conference*, Denver, CO.
- Zamansky, V.M., Sheldon, M.S., and Maly, P.M. (1998a) *27th Symposium (International) on Combustion*, Abstracts of Accepted Papers, p. 78, The Combustion Institute, Pittsburgh.
- Zamansky, V.M., Lissianski, V.V., Maly, P.M., Ho, L., Rusli, D., and Gardiner, W.C., Jr. (1998b) *Combust. Flame*, accepted.

Figure 1. Performance comparison of different reburning fuels. ● natural gas, ■ walnut shells, □ willow wood, △ furniture waste.

Figure 3. Performance of walnut shells reburning. Symbols are experiments, line represents calculations.

Figure 2. Performance of furniture waste reburning. Symbols are experiments, line represents calculations.

Figure 4. Performance of willow wood reburning. Symbols are experiments, line represents calculations.