Heterogeneous Reburning by Mixed Fuels

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Rationale and Objectives

A multi-functional, mixed fuel containing natural gas for NO reduction, and lignite fly ash for reducing the reburning intermediate, HCN, has demonstrated remarkably high efficiency in reburning (*AIChE J.*, 47, 2781 (2001); *Fuel*, 85, 1781 (2006)). Because the price of natural gas has increased and fluctuated significantly in the last five years and the amounts of lignite fly ash required are unreasonably large, there is an incentive to find their substitutes.

Several combinations of hydrocarbon substances and minerals have been chosen as the main reburning fuel and the HCN reducing agent, respectively, in a reburning apparatus. Results, indeed, show that a wide range of mixed-fuels possess remarkably high overall NO reduction efficiency, up to 85%, from the two-stage experiments at reburning stoichiometric ratio, 0.90.

About 60 to 200 metric ton of this catalyst is needed for a 172 MW bituminous coal-fired power plant, depending on the main constituent in the reburning fuel. Furthermore, this catalyst does not cause fouling or slagging problems in the coal-fired boilers.

Both components of these substitutes are widely available at low costs. For the fuels showing low overall NO reduction efficiencies, char-nitrogen conversion to NO in the burnout zone is a limiting factor.

Prior Contributions

- Design of mixed fuel for heterogeneous reburning using lignite-fired power plant ashes, biomass fly ash and methane – Paper published (Chen and Gathitu, 2006) and patent application filed.
- Effective reduction of nitric oxide in post-combustion zone – manuscript prepared and invention disclosure in progress.

Experimental

- The test apparatus used is the same one as that described by (Chen and Gathitu, 2006). However, in order to conduct two-stage experiments that include a simulated reburning zone and a burnout zone, another furnace was added in series with the previous one; this second furnace is a Lindberg Model 54494-V with the associated controller Model 58256-P-B-COM (Figure 1). To quantify nitrogen speciation during reburning (single-stage tests), the top furnace temperature was set at 1150 °C and the bottom one at 200 °C to avoid condensation. To conduct two-stage tests, the reburning furnace was set at 1250 °C and the burnout furnace at 1150 °C. Residence time in the reburning furnace flat zone is approximately 0.2 sec; in the burnout zone, this varies with the amount of burnout air added and can range from approximately 0.14 to 0.16 sec.
- To investigate the nitrogen speciation in reburning zone, a set of single-stage experiments were conducted. For these simulated reburning tests, the simulated flue gas had a composition of 16.8% CO_2, 1.95% O_2, and 0.05% NO in a helium base.
- Two-stage experiments were carried out to expand our knowledge about the chemistry in the burnout zone. For most of the two-stage tests, the reburning furnace temperature was increased to 1250 °C and water was added into the simulated flue gas at a concentration similar to that produced during combustion of Pittsburg #8 bituminous coal in the primary stage. This altered the composition of the flue gas to 16% CO_2, 1.8% O_2, 0.05% NO and 6.35% H_2O. Vapor is introduced into the feed stream by passing He through from the bottom of a water bottle maintained at a desired temperature.

Figure 1. Experimental Apparatus

Results

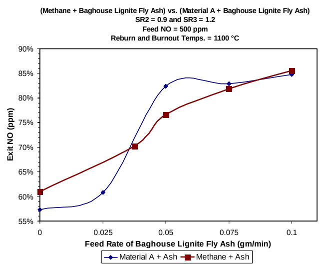

Figure 2. Reburning and burnout using material A and methane with baghouse lignite fly ash added to reduce HCN to N_2.

- The heterogeneous reburning mechanisms proposed by Chen and Tang (2001) and the mixed fuel work of Chen and Gathitu (2006) suggested the promising technological potential of using a wide range of industrial by-products.
- At the outset of the current project, a combination of material A and lignite ash was chosen for two-stage tests. Figure 2 illustrates that the NO reductions from these tests are comparable to those from reburning with methane and lignite ash, and 85% NO reduction is achievable.
- The cost for the former approach, however, will be much lower due to the low cost for material A. Moreover, it is not expected to cause problems to the operation of boiler. This finding also gave us incentives to compare the nitrogen speciation in reburning and to test other industrial by-products, as discussed below.

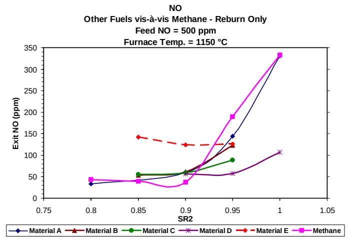

Figure 3. Exit NO concentration from single-stage reburning with different fuels at different SR2 (no lignite ash is added into the feed).

- For a comprehensive evaluation of the effectiveness of different fuels without lignite ash, nitrogen speciation in single-stage reburning tests was measured.
- As shown in Figure 3, the optimal SR2 (stoichiometric ratio of the reburning zone) for NO reduction is between 0.9 and 0.95 and four of the five fuels are as effective as methane.

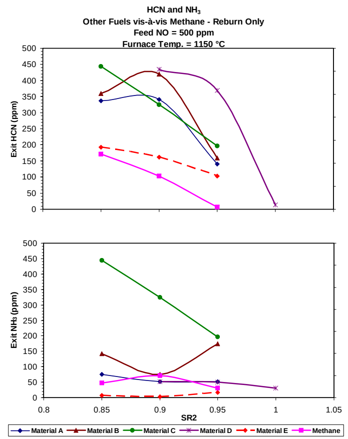

Figure 4. Exit HCN and NH_3 concentration from single-stage reburning with different fuels at different SR2 (no lignite ash is added into the feed).

- HCN and NH_3 yields (Figure 4) are much higher than those of methane because of their high contents of fuel-nitrogen. The high HCN yields from reburning zone reflect the need for finding a substitute for lignite fly ash. It is interesting to note that, since material A produces higher yield of HCN than methane in reburning zone, it results in a lower overall NO reduction efficiency from the two-stage experiments, see the data at the left end of Figure 2.

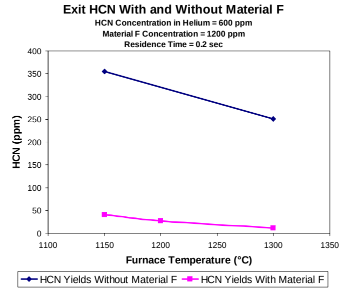

Figure 5. Conversion of HCN by material F in He at different temperatures.

- Based on our review of literature data, material F was selected and tested for reducing HCN to N_2.
- As illustrated in Figure 5, addition of material F indeed effectively converts HCN over a wide range of temperatures.
- Due to the long residence time in our reactor, in comparison to the actual boiler, HCN thermal decomposes and this could somewhat obscure the effect of material F at HCN reduction at boiler temperatures (up to 1400 °C). Nevertheless, the effectiveness of material F is obviously positive.

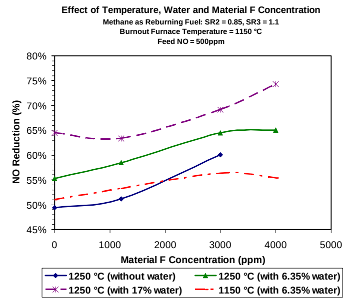

Figure 6. Effects of water and temperature on the activity of material F towards HCN conversion.

- Reburning is fuel rich and the activity of material F is diminished in this environment. Nevertheless, the presence of water vapour and high temperatures enhance its activity.
- A temperature of 1250 °C is suitable in both regards i.e. thermal decomposition of HCN is minimal (Figure 5) and material F is active at HCN reduction during reburning (Figure 6).
- Although larger concentrations of water enhance NO reduction, it was added at an amount typical to that in a coal-fired boiler (6.35%).

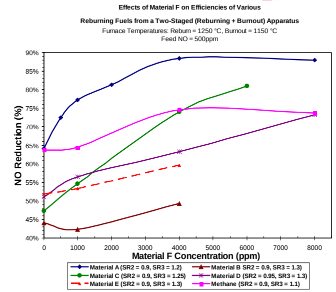

Figure 7. NO reductions by several combinations of mixed fuels (material A through E and material F) from two-stage tests.

- Results show that the combination of material A and material F forms an excellent substitute for natural gas (Figure 7).
- Material A can achieve up to 88% NO reduction when 4000 ppm of material F is added into the reactor. This feed rate is equivalent to 185 metric tons of material F per day for a 172 MW bituminous coal-fired boiler, which is much more efficient than lignite fly ash.
- Material F does not cause known problems in boilers, such as fouling or slagging on the heat transfer surfaces. For the other fuels, char-N conversion to NO in the burnout stage is limiting the overall NO reduction efficiency.

Work in Progress

- An economic analysis of the use of mixed fuel reburning using materials A and F is being conducted. Preliminary results indicate that while Material A is widely available and efficient at NO reduction, more efficient fuel processing technology has to be developed so that it can successfully compete with established NO_X control technologies such as SCR.
- We are developing a novel technology to minimize char-N conversion to NO in the burnout zone.

Conclusions

This reburning technology will meet the Environmental Protection Agency's regulation of removing 85%, or up to 0.15 lb/MillionBtu, of NO_X in boilers. This technology utilizes widely available wastes and, when fully developed, its cost effectiveness and simplicity will make it more competitive than currently preferred technologies such as SCR. An invention disclosure will be prepared for patent consideration.

References

Chen, W. Y., and Gathitu, B. B, Fuel, 85, 1781-1793 (2006).

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Acknowledgement

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