MERCURY CONTROL USING COMBUSTION STAGING

Vitali Lissianski, Peter Maly, Randy Seeker, and Loc Ho

Energy and Environmental Research Corporation (EER)
18 Mason, Irvine, CA 92618

Introduction

In December 2000, the U.S. EPA reported that mercury (Hg) emissions from coal-fired power plants pose significant hazards to public health and must be reduced. The EPA is under court order to propose Hg regulations for coal-fired power plants in 2003 and finalize them in 2004. Present regulatory mechanisms require that such regulations be developed through Maximum Achievable Control Technology (MACT). Several other frameworks for Hg regulations have been proposed recently. The Clear Skies Initiative proposed by President Bush mandates dramatic reductions in power plant SO_2, NO_x, and Hg emissions over the next 15 years. Independent of the EPA's final decision regarding the required level of Hg control, important questions that need immediate answers are (1) what technologies can provide a significant level of Hg removal and (2) can a significant level of Hg removal be achieved for all coal types?

Many utilities are actively seeking effective and inexpensive technologies for controlling multiple pollutants emitted from power plants. Recent experimental data[1,2,3] obtained by EER demonstrated the reduction of Hg emissions through the use of fly ash with high carbon content formed *"in situ"* in the combustion process of coal-based power generating stations. High-carbon fly ash can be formed by low NO_x burners (LNB), overfire air (OFA) injection or in coal reburning. These commercial technologies are currently used to reduce NO_x emissions from coal-fired power plants.

This paper further investigates potential of using high carbon fly ash for Hg control. Objective of this work was to investigate effects of carbon in ash, coal composition, and temperature on the efficiency of Hg removal.

Experimental Facility

Tests on utilization of "in-situ" formed high-carbon fly ash to remove Hg from flue gas were conducted in Boiler Simulator Facility (BSF) described elsewhere[4]. The BSF has a full load firing capacity of 1×10^6 Btu/hr and is designed to provide an accurate sub-scale simulation of the flue gas temperatures and composition found in a full-scale boiler. A schematic of the BSF and setup for Hg sampling are shown in Figure 1. The BSF consists of a burner, vertically down–fired radiant furnace, horizontal convective pass, and ESP. A variable swirl diffusion burner with an axial fuel injector is used to simulate the approximate temperature and gas composition of a commercial burner in a full-scale boiler. Numerous ports located along the axis of the facility allow access for supplementary equipment such as reburning and OFA injectors, and sampling probes.

The cylindrical furnace section is constructed of eight modular refractory lined sections with an inside diameter of 22 inches. The convective pass is also refractory lined, and contains air cooled tube bundles to simulate the superheater and reheater sections of a utility boiler. Heat extraction in the radiant furnace and convective pass can be controlled such that the residence time-temperature profile matches that of a typical full-scale boiler. A suction pyrometer is used to measure furnace temperatures.

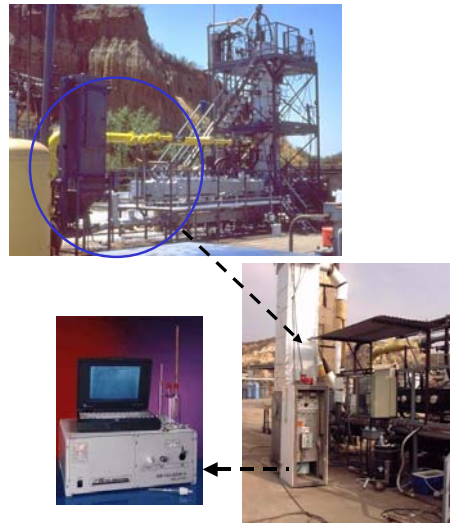

Figure 1. Boiler Simulator Facility.

High-carbon fly ash was formed using air staging. An online Hg analyzer from PS Analytical was used in these tests. The analyzer is capable measuring both total (Hg) and elemental (Hg^0) mercury in flue gas. Mercury concentration in flue gas was measured at ESP inlet and outlet. The ESP for the BSF is a single-field down-fired unit consisting of 12 tubes with axial corona electrodes. The ESP flue gas temperature was controlled by inserting or removing cooling rods situated in the convective pass.

Experimental Results

Objective of pilot-scale testing were to determine effects of combustion staging and ESP temperature on efficiency of Hg removal by fly ash. Tests were conducted with several bituminous coals. Carbon in fly ash (characterized as LOI) was adjusted by staging combustion. Two approaches to stage combustion were used – air staging (overfire air injection or OFA) and fuel staging (reburning). In air staging part of the combustion air is redirected from the main combustion zone into post-combustion zone (overfire zone). Because fuel combustion in air staging occurs in fuel-rich environment, fly ash tends to have higher carbon content than that at typical combustion conditions. Process variables in air staging tests included location of overfire air injection and stoichiometric ratio in the main combustion zone (SR_1). Stoichiometric ratio at the furnace exit (SR_3) in all tests was 1.16 which corresponded to about 3% excess air in flue gas.

In reburning part of the fuel (typically 10-30% of total) is injected above the existing burner zone to produce a slightly fuel-rich environment. Overfire air is injected downstream of the reburning zone to complete fuel combustion. Process variables in reburning tests were amount of the reburning fuel and the flue gas temperature T_{OFA} at which overfire air was injected (T_{OFA} was in the range of 1800-2500 ^oF). The latter was achieved by changing location of the overfire air injection port.

Figure 2 shows dependence of Hg removal efficiency (defined as a difference between Hg introduced with coal and Hg concentration in the gas phase at ESP outlet) as a function of LOI in air staging. Temperature of flue gas in ESP in these tests was 350 ^oF. Figure 2 demonstrates that mercury removal efficiency increases with LOI increase. Efficiency of Hg removal also depends on coal properties, especially for LOI up to 4%. Maximum Hg removal efficiency achieved in air staging tests was ~60%.

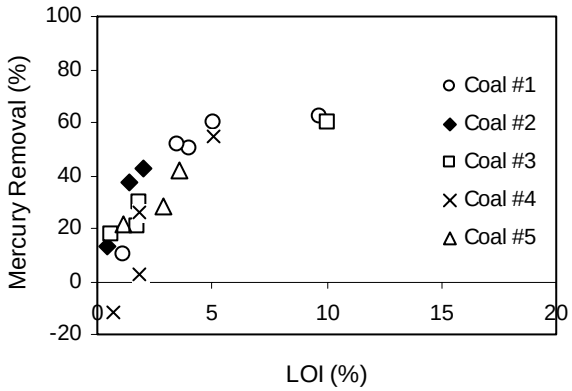

Figure 2. Effect of LOI on Hg removal in air staging.

Figure 3 shows effects of LOI and ESP temperature on Hg removal in reburning for coal#3. Figure 3 demonstrates that efficiency of Hg removal increases with increase in LOI and decrease in ESP temperature. Maximum Hg removal efficiency achieved in reburning tests was about 85%.

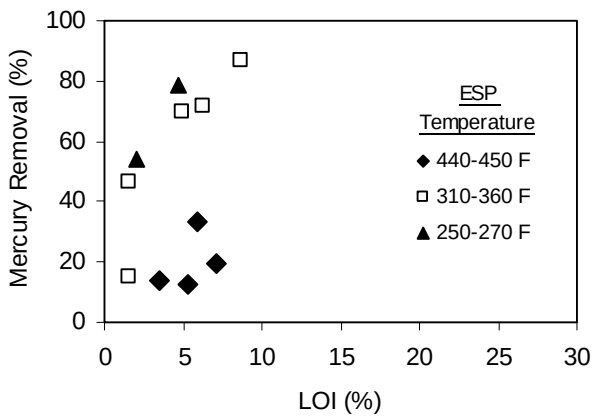

Figure 3. Effect of LOI on Hg removal in air staging for coal #3.

Consol studied[5] effect of ESP temperature on Hg removal on Hg adsorption on fly ash. In these tests high carbon fly ash generated by combustion of bituminous coal was re-injected into the duct of 1.5 MBtu/hr combustor. The flue gas temperature was controlled using both duct humidification and the pilot plant heat exchange. Amount of re-injected fly ash was similar to that generated by combustion of a bituminous coal. Results of the Consol study were combined with present data to determine dependence of Hg adsorption on temperature. Based on these data, transfer function was developed that predicted dependences of the efficiency of Hg adsorption on fly ash on LOI and temperature. Figure 4 shows results of the present and Consol studies (symbols) as well as predictions of the transfer function (lines). Figure 4 shows good agreement between experimental data and modeling predictions.

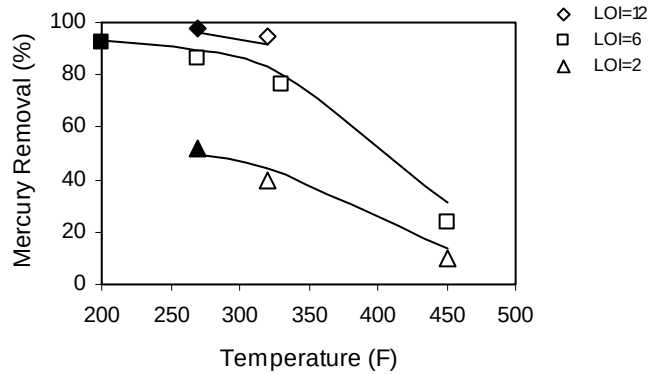

Figure 4. Experimental data (symbols) and modeling predictions (lines) on the effect of temperature on Hg adsorption of fly ash. Solid symbols represent Consol data, open symbols present study.

Figure 5 shows comparison of experimental data for reburning (Figure 3) adjusted to 350 ^{o}F using transfer function with predictions of the transfer function. Figure 5 demonstrates relatively small scatter of experimental data. It also demonstrates that about 80% Hg adsorption on fly ash can be expected at LOI 7-9% and ESP temperature of 350 ^{o}F.

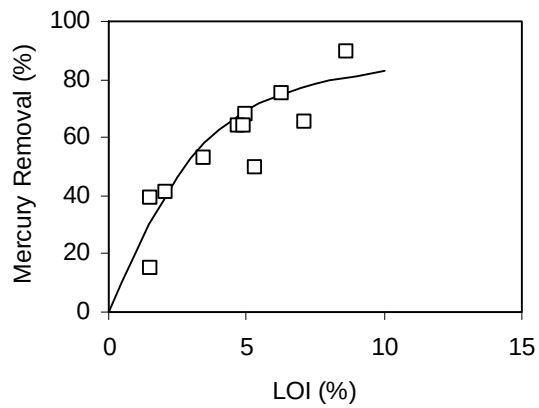

Figure 5. Comparison of experimental data and modeling predictions on the effect of LOI on Hg removal at 350 ^{o}F.

Figure 6 shows predicted by transfer function effect of temperature on Hg adsorption on fly ash. Figure 6 suggests that both temperature and LOI should be considered in selecting optimum conditions for Hg removal: LOI change in the range of 2-8% offers most significant effect on Hg removal. LOI increase to 12% gives only marginal improvement in Hg reduction efficiency. Temperature decrease below acid dew point can result in sulfuric acid condensation and duct corrosion. While acid dew point depends on a number of parameters including coal sulfur content, in most cases it is lower that 290 ^{o}F. Figure 6 suggests that Hg removal efficiency at LOI = 8-12% can be 80-90% at temperatures above 290 ^{o}F.

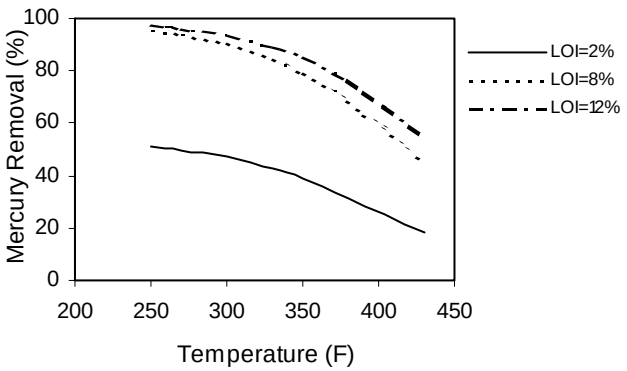

Figure 6. Predicted effect of temperature on Hg removal.

Conclusions

Experimental results confirmed that air staging and reburning could be used to control Hg emissions from coal-fired boilers. Pilot-scale testing demonstrated that this approach can provide 80-90% Hg removal across an ESP for bituminous coals at LOI = 8-12%. Lowering ESP temperatures can further improve Hg removal.

References

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(2) Lissianski, V.V., Zamansky, V.M., Maly, P.M., and Seeker, R.W. "Integration of Combustion Modifications with Mercury Control", *Air Quality III Conference*, Washington, DC, September 11, 2002.
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