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Project Summary

Emission Test Report: OMSS Field Test on Carbon Injection for Mercury Control

K. L. Nebel, D. M. White, C. R. Parrish, T. G. Zirkle, M. A. Palazzolo, and M. W. Hartman

In 1991, the U.S. Environmental Protection Agency conducted a parametric evaluation of powdered activated carbon for control of mercury (Hg) emission from a municipal waste combustor (MWC) equipped with a lime spray dryer absorber/fabric filter (SD/FF). The primary test objectives were to evaluate the effect of carbon type, feed rate, and feed location on Hg emissions and control efficiency. Secondary process parameters studied included the impact of ammonia injection for nitrogen oxides control, SD outlet temperature, and SD/FF acid gas control efficiency on Hg removal. The time stability of Hg collected with ash was also studied. Conducted at the Odgen Martin Systems of Stanislaus, Inc. MWC, near Modesto, CA, testing covered 16 system operating conditions, including normal unit operation (no carbon injection) and operation without ammonia injection.

Test results showed that the two primary variables affecting both Hg emission and control efficiency were carbon feed rate and uncontrolled Hg levels. The results also indicated that Hg emissions were reduced by over 80% at high carbon addition rates. At low carbon feed rates, both the average Hg emissions rate and the variability in Hg levels during individual tests were significantly higher. The secondary parameters did not affect Hg control over the range of values tested, nor did the mass of Hg collected with ash change over a 28-day period.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Section 129 of the 1990 Clean Air Act requires the U.S. Environmental Protection Agency (EPA) to promulgate mercury (Hg) emission limits for municipal waste combustors (MWCs). Data from existing MWCs equipped with lime spray dryer absorber (SD) and fabric filter (FF) emissions control systems indicate highly variable Hg collection efficiencies ranging from zero to over 95%. To help develop a better understanding of factors influencing the control of Hg emissions from MWCs, EPA's Air and Energy Engineering Research Laboratory (AEERL) contracted with Radian Corporation to conduct a series of tests to evaluate the injection of powdered activated carbon as a Hg control technique. These tests were conducted during the Summer of 1991 on Unit 2 of the Ogden Martin Systems of Stanislaus, Inc. (OMSS) MWC facility near Modesto, California. The objectives of these tests were to evaluate:

- the effectiveness of injecting activated carbon into the flue gas upstream of an SD/FF system and into the lime slurry feed to the SD to control Hg emissions;
- the impact of ammonia (NH_3) injection in the Thermal DeNO$_x$® process on the control of Hg emissions;
- the effect of SD/FF system operating conditions on Hg control and emissions; and

- the stability (permanence of capture) of Hg collected on ash/residue over time.

Facility Description

The OMSS MWC consists of two identical Martin GmbH mass burn waterwall (MB/WW) combustors, each capable of combusting 400 tons* per day (tpd) of municipal solid waste. Each unit is equipped with an Exxon Thermal DeNO$_x$® NH_3 injection system for reducing emissions of nitrogen oxides (NO_x) and a Fläkt SD/FF system for reducing emissions of acid gases, particulate matter (PM), metals, and organics.

Test Matrix

Table 1 is the test matrix for the 16 conditions examined. Primary variables examined were carbon type, carbon feed rate, and carbon feed location. Secondary variables were NH_3 injection, FF gas temperature, and acid gas control efficiency. Most of the conditions consisted of three 1-hr test runs. During Condition 15, only two 1-hr test runs were conducted.

To evaluate baseline Hg levels, Conditions 4 and 5 runs were conducted without activated carbon injection. The remaining tests examined Hg removal efficiency when injecting activated carbon. To examine the effect of injecting carbon in the absence of NH_3 injection, Condition 7 was run with the Thermal DeNO$_x$® system off while injecting carbon at the SD inlet.

Three carbon types were used to investigate the impact of carbon characteristics on Hg control. Activated carbon made from coal was used in 10 of the test conditions. During two test conditions, a lignite-based carbon was used. The third carbon type, which was also used during two test conditions, was wood-based. The wood carbon was chemically activated, while the coal and lignite carbons were thermally activated. Of these three, the lignite-based carbon had the lowest specific surface area and average particle size, and the highest average pore radius. The wood-based carbon had the highest specific surface area, and the coal-based carbon had the smallest average pore radius and tamped density.

The effect of carbon feed rate using the coal-based carbon was examined during Conditions 3, 6, and 8. During these tests, carbon was injected at the SD inlet, downstream of the inlet sampling location. During these three conditions, the average feed rates were 2.8, 12.1, and 6.1 lb/hr, respectively, corresponding to approximately 17, 73, and 37 mg/dscm corrected to 7% oxygen (O_2). Additional testing examining the effect of carbon feed rate was conducted at the SD inlet during Conditions 9 and 10 while injecting lignite-based carbon and during Conditions 13 and 14 while injecting wood-based carbon.

The effect of injecting carbon at alternate locations was also examined. During Conditions 1 and 2, carbon was injected through three ports in the horizontal duct just downstream of the economizer outlet, but upstream of the sampling location for the SD inlet. Conditions 15 and 16 examined the effect of mixing carbon with the lime slurry used in the SD.

Condition 11 was conducted to assess the effect of reduced FF temperature. Condition 12 was conducted to study the effect of reduced lime stoichiometry (i.e., reduced sulfur dioxide [SO_2] and hydrogen chloride [HCl] control) on Hg emissions.

Impact of Carbon Feed Location, Type, and Feed Rate on Mercury Emissions

Carbon Feed Location

Figure 1 shows the relationship between carbon injection location and Hg removal for the low and high feed rates of the coal-based carbon. At the low feed rate of approximately 3 lb/hr, removal efficiencies were 66-85% with carbon injection at the economizer outlet feed location (Condition 1), and 53-77% with carbon injection at the SD inlet feed location (Condition 3). At the high feed rate of approximately 12 lb/hr, Hg removal was 88-92% with carbon injection at the economizer outlet feed location (Condition 2) and 91-98% with carbon injection at the SD inlet feed location (Condition 6). When the carbon was injected into the SD with the lime slurry, Hg removal was 88-96% (Condition 16). At both carbon feed rates, statistical analysis using the t-statistic at the 95% confidence level indicated that the differences in Hg reductions as a function of feed location were not statistically significant.

Carbon Type

Figure 2 presents Hg removal efficiency as a function of carbon type for the low, medium, and high carbon feed rates. Based on statistical analysis of the data, carbon type did not significantly influence Hg emissions or Hg removal at any of the feed rates.

Carbon Feed Rate

As indicated by Figures 1 and 2, carbon feed rate had a significant impact on Hg removal for all carbon feed locations and types. To better define the impact of carbon feed rate on Hg reduction efficiency and outlet concentration, stepwise multivariate regression analysis was used. In this analysis, Hg reduction efficiency and outlet concentration were the dependent variables, and uncontrolled Hg levels, carbon feed rate, carbon type, carbon feed location, and NH_3 injection rate were the independent variables.

For the analysis, Hg reduction efficiency values were converted to emissivity values (100 minus percent reduction). Both the actual values and natural log transform of Hg emissivity and outlet Hg concentrations were evaluated as dependent variables. Because of the tendency of sorbent to have diminishing effectiveness as carbon feed rate increases (i.e., decreasing sorbent utilization), three formats for carbon feed rate were examined: the feed rate as measured, the measured feed rate raised to the 0.5 power (i.e., square root), and the feed rate raised to the 0.7 power.

The best predictive model identified for Hg percent reduction was based on the square root of the carbon feed rate and the uncontrolled Hg level. The regression equation was:

$$\ln(100\text{-PRED}) = 4.81 - 0.639*(\text{CFR})^{0.5} - 0.000776*\text{HGIN} \quad (1)$$

where PRED is Hg percent reduction, CFR is carbon feed rate (in lb/hr), and HGIN is the uncontrolled (inlet) Hg level (in µg/dscm at 7% O_2). The "goodness of fit" (R^2) of this model is 0.762. Figure 3 shows the measured and predicted values of Hg reduction versus inlet Hg level. The three curves for predicted reduction are based on carbon feed rates of 3, 6, and 12 lb/hr. These carbon mass feed rates correspond to roughly 18, 36, and 72 mg of carbon per dscm of flue gas at 7% O_2. Although there is significant scatter in the data, particularly at the low carbon feed rates, the model predicts the expected increase in Hg reduction at both higher carbon feed rates and higher uncontrolled Hg levels. Based on this model, a carbon feed rate of 12 lb/hr would achieve an average Hg reduction of at least 90% over the entire range of uncontrolled Hg levels shown in Figure 3. However, note that, because of scatter in inlet and outlet Hg concentrations caused by variations in process operation and measurement imprecision, calculated Hg reductions during individual runs will be higher and lower than the levels indicated by the predicted curves.

The best predictive model for outlet Hg concentration was also based on the square root of carbon feed rate and uncontrolled Hg level. This regression equation was:

*1 ton = 907 kg.

Table 1. *Test Matrix for OMSS Emissions Control Field Test (1991)*

Condition No.	Test Date (1991)	Number of Test Runs	Operating Parameters: Thermal $DeNO_x$	Carbon Feed Rate (lb/hr)	Carbon [a] (Raw Material)	Fabric Filter Temperature	Carbon [b] Injection Location	Lime
1	7/22[c]	3	Normal	2.8	Coal	Normal	Econ. Outlet	Normal
2	7/23	3	Normal	12.0	Coal	Normal	Econ. Outlet	Normal
3	7/24	3	Normal	2.8	Coal	Normal	S.D. Inlet	Normal
4 (BL)[d]	7/25	3	Normal	0	None	Normal	None	Normal
5 (BL)	7/29	3	Off	0	None	Normal	None	Normal
6	7/26	3	Normal	12.1	Coal	Normal	S.D. Inlet	Normal
7	7/30	3	Off	2.9	Coal	Normal	S.D. Inlet	Normal
8	7/31	3	Normal	6.1	Coal	Normal	S.D. Inlet	Normal
9	8/1	3	Normal	2.8	Lignite	Normal	S.D. Inlet	Normal
10	8/7	3	Normal	12.3	Lignite	Normal	S.D. Inlet	Normal
11	8/5 [e]	3	Normal	2.9	Coal	Low	S.D. Inlet	Normal
12	8/5 [f]	3	Normal	2.8	Coal	Normal	S.D. Inlet	Low
13	8/2	3	Normal	3.2	Wood	Normal	S.D. Inlet	Normal
14	8/6 [g]	3	Normal	6.6	Wood	Normal	S.D. Inlet	Normal
15	8/10	2	Normal	18.3	Coal	Normal	w/lime slurry	Normal
16	8/10	3	Normal	12.2	Coal	Normal	w/lime slurry	Normal

[a] Lignite Raw Material = DARCO FGD, Surface Area = 600 m^2/g.
Coal Raw Material = DARCO PC100, Surface Area = 950 m^2/g.
Wood Raw Material = DARCO KB, Surface Area = 1500 m^2/g.
[b] S.D. Inlet = Spray Dryer Inlet, Econ. Outlet = Economizer Outlet.
[c] One run conducted on 7/23/91.
[d] BL = Baseline
[e] One run conducted on 8/6/91.
[f] One run conducted on 8/2/91.
[g] One run conducted on 8/7/91.

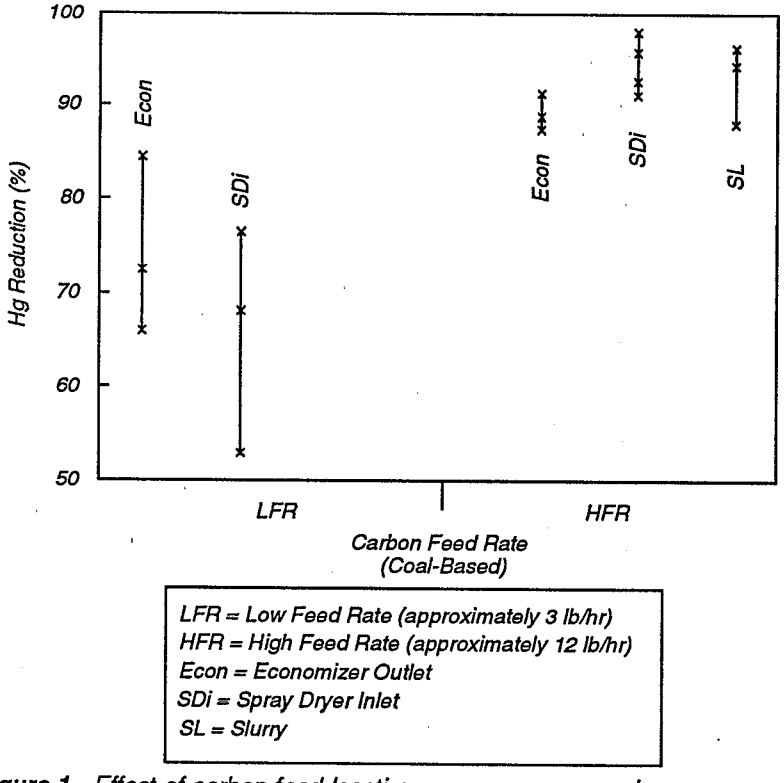

Figure 1. *Effect of carbon feed location on mercury removal.*

$$\ln(HGOUT) = 5.66 - 0.649*(CFR)^{0.5} + 0.000724*HGIN \quad (2)$$

where HGOUT is outlet Hg concentration in µg/dscm at 7% O_2, and CFR and HGIN are as defined in Equation 1. The "goodness of fit" of this model is 0.777. Figure 4 shows the measured values of outlet Hg level versus inlet Hg level, and the regression model curves at carbon feed rates of 3, 6, and 12 lb/hr. As with percent reduction, there is significant scatter in the data at low carbon feed rates. As expected, the modeled regression curves indicate that Hg outlet levels increase with increased uncontrolled Hg levels and decreased carbon feed rate. The increased slope of the regression curves at high uncontrolled Hg levels indicates a tendency toward decreased carbon utilization. This suggests greater saturation of individual carbon-to-Hg adsorption sites. Based on this model, a carbon feed rate of 12 lb/hr is predicted to achieve an average outlet Hg concentration of less than 80 µg/dscm at 7% O_2 over the entire range of uncontrolled Hg levels. Again, however, because of the variability in outlet Hg levels caused by changes in process opera-

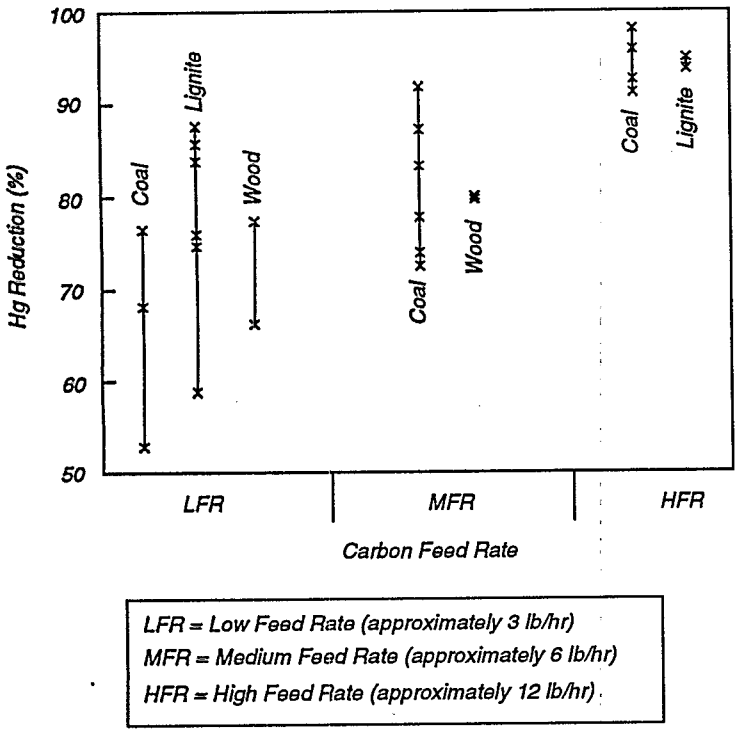

Figure 2. Effect of carbon type on mercury removal.

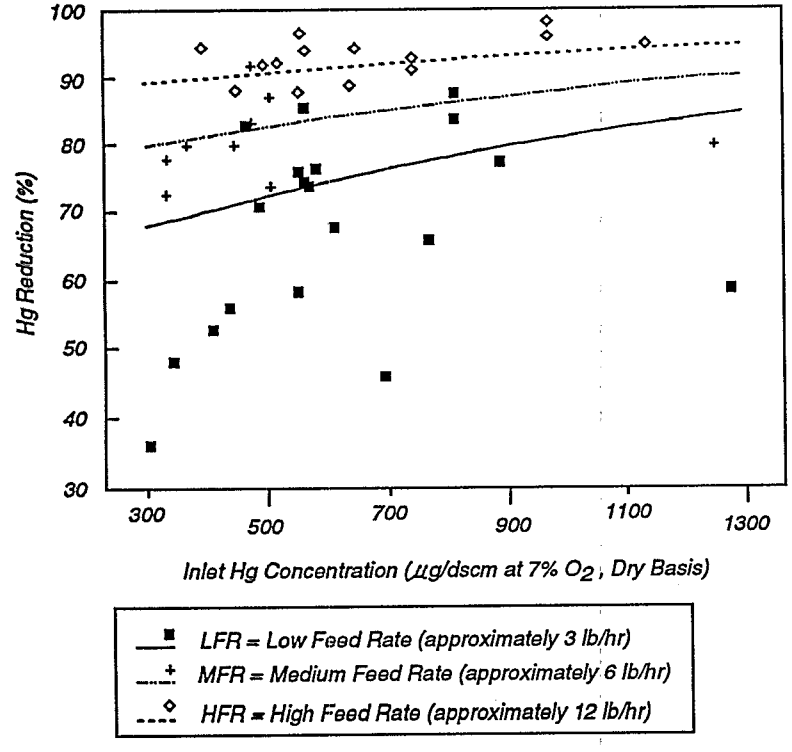

Figure 3. Effect of carbon feed rate on mercury removal.

tion and measurement imprecision, individual measurements of stack Hg levels will be higher and lower than the levels indicated by the curves in Figure 4.

Impact of Other Operating Parameters on Mercury Emissions

Ammonia Injection

To study the effect of NH_3 injection on Hg removal, NH_3 injection was shut off during Conditions 5 and 7. In addition, during Condition 5, no carbon was injected. Condition 4 was the baseline condition without carbon injection, but with NH_3 injection. As shown on the left half of Figure 5, Hg removal during Conditions 4 and 5 are comparable, with removal efficiencies of 15-36% for Condition 4 and 18-46% for Condition 5.

The effect of NH_3 injection on Hg removal while injecting carbon can be examined by comparing Conditions 3 and 7. During both conditions, coal-based carbon was injected at the SD inlet at an average rate of approximately 2.8 lb/hr. During Condition 3, NH_3 was injected, while during Condition 7, no NH_3 was fed. As shown on the right half of Figure 5, Hg removals were 53-77% during Condition 3, and 48-56% during Condition 7. Given the limited number of samples, it is not possible to conclude that the values measured at these two conditions are statistically different.

It is noteworthy, however, that the NH_3 levels in the flue gas measured at the SD inlet were consistently low (less than 5 ppmv) during all but two runs and were not significantly affected by the Thermal DeNO$_x$® system's being on or off. As a result, it is not possible to clearly establish the impact of NH_3 level in the flue gas on Hg collection efficiency.

Lime Feed Rate/Acid Gas Removal

A potential concern identified with Hg control was whether the conversion of vaporous elemental Hg (Hg°) to particulate mercuric chloride ($HgCl_2$) could be reduced at high lime feed rates. To examine this potential, the lime feed rate was lowered during Condition 12. Because of problems with direct measurement of lime feed rate, SO_2 control efficiency was used as a surrogate indicator. The SO_2 removal during Condition 12 was 66-77%, and averaged 73%. The average SO_2 removal during most other conditions was at least 90%.

Condition 3 was similar to Condition 12, but with normal SO_2 control. Comparing the results from Conditions 3 and 12, the range of Hg removals is similar — Condi-

tion 3 at 53-77% (average 66%) and Condition 12 at 36-83% (average 59%). As shown in Figure 6, there does not appear to be a correlation between Hg and SO_2 control efficiency over the limited SO_2 range of these tests. During both test conditions, HCl control efficiencies were greater than 96%.

Fabric Filter Temperature

Unlike most other metals (e.g., cadmium, lead), Hg can exist as a vapor at normal SD/FF temperatures and, therefore, does not readily condense onto PM as do other metals. During the testing, average stack temperatures generally were 275-295°F.* The stack temperatures during Condition 11 averaged 282°F. By comparison, FF temperatures during Condition 3 averaged 294°F. For both conditions, coal-based carbon was injected at the SD inlet at an average rate of roughly 2.8 lb/hr. Comparing average Hg removal levels, there is essentially no difference between Conditions 3 (66%) and 11 (64%).

Mercury Stability in Ash Streams

The stability of Hg captured in ash has important consequences with regard to storage, transport, and disposal of the ash. Therefore, studies were conducted to determine the stability of Hg on combined fly ash and bottom ash and on FF ash as a function of time and temperature. (Moisture, carbon, and loss on ignition analyses were also conducted on FF and SD ash samples.)

The results of the combined ash time stability study indicate that Hg did not volatilize from the ash over the 28-day period of study. The samples were held in a heated environment, in a refrigerated environment, and at room temperature. These results are of significant importance since these samples represent the ash that is normally landfilled, and concern had been raised over the fate and stability of Hg in the landfilled ash over time.

The results of the studies on the FF ash samples are somewhat inconclusive. All of the FF ash was collected dry, prior to the usual quenching the FF ash experiences. The dry FF ash is extremely hygroscopic and, because of the difficulty of removing hydrated water from the samples and the rapid rehydration of ash when the samples were removed from the oven, precise measurements were not possible. The data for the samples held in the re-

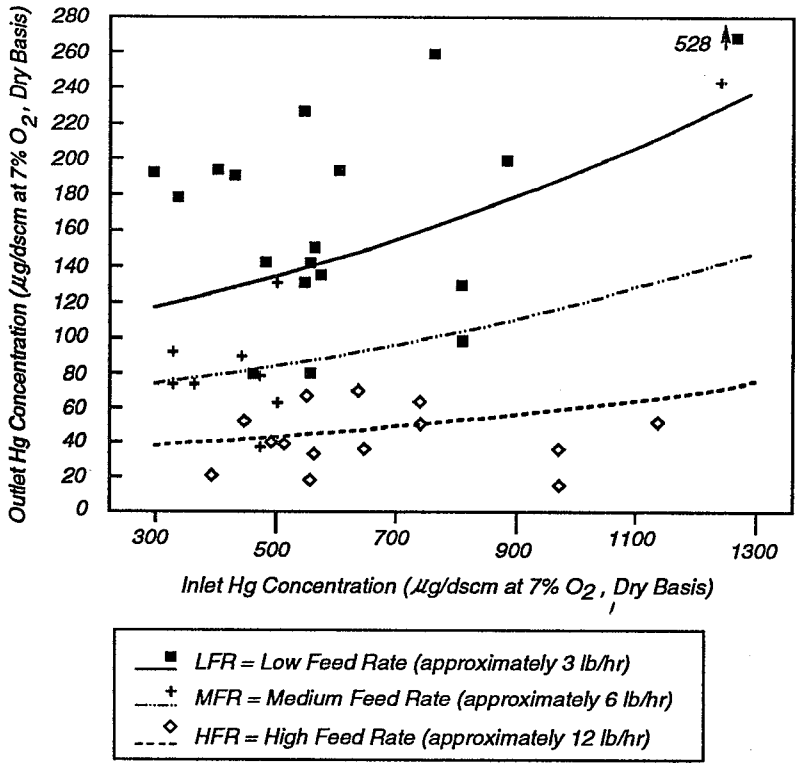

Figure 4. *Effect of carbon feed rate on outlet mercury emissions.*

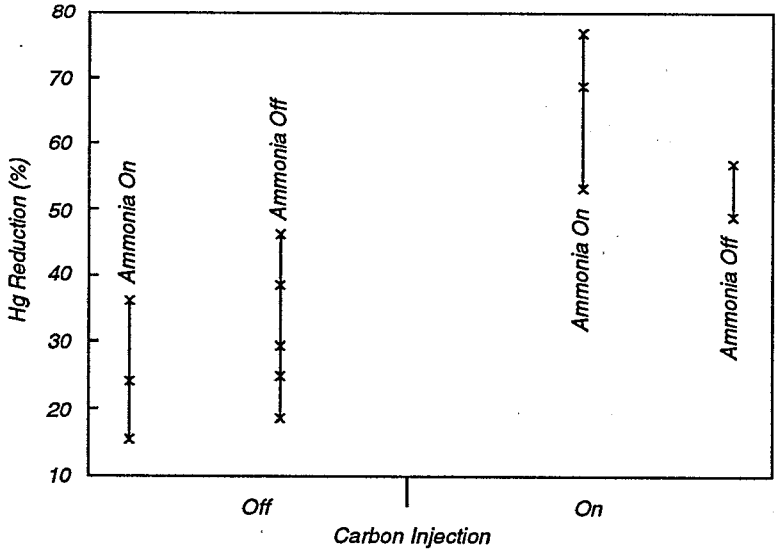

Figure 5. *Effect of ammonia injection on mercury removal.*

*°C = 5/9 (°F-32)

K. L. Nebel, D. M. White, C. R. Parrish, T. G. Zirkle, M. A. Palazzolo, and M. W. Hartman are with Radian Corp., Research Triangle Park, NC 27709.
***Theodore G. Brna** is the EPA Project Officer (see below).*
The complete report, entitled "Emission Test Report: OMSS Field Test on Carbon Injection for Mercury Control" (Order No. PB93-105518/AS; Cost: $27.00, subject to change) will be available only from:
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