

REDUCING MERCURY EMISSION FROM MUNICIPAL WASTE COMBUSTION WITH CARBON INJECTION INTO FLUE GAS

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Abstract

The Clean Air Act Amendments of 1990 require the U.S. Environmental Protection Agency (EPA) to set emission limits for cadmium (Cd), lead (Pb), and mercury (Hg) for municipal waste combustors (MWCs). To aid developing Hg emission rules, tests were conducted in July and August 1991 on a 360-tonne (400-ton)/day mass burn MWC at the Ogden Martin Systems of Stanislaus, Inc. (OMSS) facility near Crows Landing, CA. The primary objective was to evaluate the effectiveness of powdered activated carbon (C) in controlling Hg emission. The C was injected into flue gas at both the economizer outlet and spray dryer absorber (SDA) inlet, as well as into the lime slurry fed to the SDA, during separate test conditions.

Secondary test objectives were to evaluate (1) the impact of ammonia (NH₃) slip from the selective noncatalytic reduction (SNCR) system on Hg control, (2) the effect of lime stoichiometry in the SDA/fabric filter (FF) system on Hg emission, (3) the effect of FF gas temperature on Hg emission, and (4) the time/temperature stability of Hg residing with the ash (residue) collected at several locations from the unit tested (Unit 2).

Results of the tests indicated that C addition was effective in improving Hg removal, the removal increasing with increasing C feed rate. Hg removal improved from about 30% without C addition to over 90% at the highest C feed rate tested. The test data obtained for evaluation of the secondary test objectives suggested that (1) NH₃ addition (which occurred with low slip) had no apparent adverse effect on Hg control, (2) lime stoichiometry had no effect on Hg emissions over the narrow range studied, (3) the FF gas temperature over the range tested did not affect Hg control, and (4) the Hg content of ash/residue stream samples remained relatively constant over a period of 28 days in samples held at 54°C (130°F).

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INTRODUCTION

Section 129 of the 1990 Clean Air Act Amendments requires the U.S. Environmental Protection Agency to set emission limits for mercury (Hg) for municipal waste combustors (MWCs).¹ Data collected during the regulatory development process for MWCs show highly variable Hg emissions. Tests of recently built MWCs, frequently equipped with spray dryer absorber (SDA) and fabric filter (FF) flue gas cleaning systems to control air pollutant emissions, have indicated Hg removals ranging from zero to over 95%.² Modern mass burn waterwall (energy recovery) MWCs having high combustion efficiencies [and also low carbon (C) content in their flyash] appear prone to low Hg removals even when equipped with SDA/FF systems. Thus, the C content of the flyash is suspected of having a key role in the control of Hg emissions from MWCs.

MWCs with dry scrubbing systems [dry sorbent injection (DSI) or SDA followed by particulate matter (PM) collection] in Canada and Europe have injected either sodium sulfide (Na_2S) or activated powdered C before sorbent addition for acid gas control to supplement Hg control.²⁻⁴ The products of the Na_2S -Hg or -Hg-compound reactions or the Hg or Hg compounds physically or chemically absorbed on the C particles were subsequently removed with the PM. Hg removals exceeding 80% were reported using these supplemental control technologies.²⁻⁴

Many recently built MWCs in the U.S. (and those being planned) have lime SDA/FF systems for flue gas cleaning. Few MWCs employ DSI/FF systems in the U.S., and use of these systems has been restricted to units with capacities under 225 tonnes (250 tons)/day. Outside of the U.S., activated C for supplemental Hg control has been successfully used with SDAs coupled with either FFs or electrostatic precipitators (ESPs), whereas Na_2S injection has normally been used in conjunction with DSI/FF or ESP systems. Safety considerations [since crystalline Na_2S is frequently mixed with water on-site to the desired Na_2S concentration (for injection into flue gas) with potential liberation of hydrogen sulfide (H_2S) as a consequence] and the trend in the U.S. of using SDA/FF systems were advantages considered by EPA in choosing to evaluate activated C instead of Na_2S for supplemental Hg control. EPA also determined that its evaluation should be on a modern mass burn waterwall MWC equipped with a lime SDA/FF system because of its history of low Hg removal but high control of other air pollutant emissions.

EPA's Air and Energy Engineering Research Laboratory (AEERL) selected the Ogden Martin Systems of Stanislaus, Inc. (OMSS) facility near Crows Landing, CA, as meeting the criteria for its supplemental Hg control study. This facility, which began operation in 1988, has two identically designed Martin GmbH mass burn waterwall MWCs with selective noncatalytic reduction (SNCR) and lime SDA/FF

systems for flue gas cleaning. Each unit has a capacity of 360 tonnes (400 tons)/day and normally operates continuously at full capacity.

AEERL developed the test plan in coordination with OMSS. The major objective of the test project was to evaluate the addition of activated powdered C to flue gas on reducing stack Hg emission. Secondary objectives included investigating the effect on Hg emission from the stack of (1) ammonia (NH₃) addition in the furnace (SNCR) which is used to control nitrogen oxide (NO_x) emissions, (2) lime stoichiometry in the SDA, and (3) gas temperature into the FF. Earlier tests at the OMSS facility had indicated that increasing NH₃ and lime feed rates correlated with increasing Hg emission,⁶ and tests elsewhere noted increasing Hg emission with increasing lime stoichiometry.⁷ Another objective was to determine the stability of Hg collected with ash* over time.

Prior to the test program, AEERL coordinated the proposed test plan with EPA Region 9 (San Francisco) and the Stanislaus County (Modesto) air pollution control authorities. Since some test conditions (e.g., operation without NH₃ injection) would or could result in exceeding emission limits for the unit being tested, the test program conducted conformed to agreements with these regulatory authorities.

Hg was sampled using EPA Method 101A. This method was modified to include Hg collected on the laboratory filter in determining Hg collected in each sample. [EPA is expected to modify this method to include analysis of the laboratory (analytical) filter for Hg in 1992].**

DESCRIPTION OF UNIT TESTED

The test program was performed using Unit 2 of the OMSS facility. A schematic diagram of the 360-tonne/day unit is shown in Figure 1, with the NH₃ injection in the furnace corresponding to the SNCR (Exxon Thermal DeNO_x®) system and the lime SDA/FF (ABB Flakt) system being the flue gas cleaning system.

Flue gas with a design flow rate of 1890 standard cubic meters per minute (scmm) [66,700 standard cubic feet per minute (scfm)]*** leaves the economizer. It is divided into three equal streams at the SDA inlet before contacting atomized lime slurry from the SDA's two-fluid nozzles. The lime slurry feed rate is regulated according to the sulfur dioxide (SO₂) concentration in the stack, while the dilution

* The term "ash" is used here for "residue," which consists of flyash, reaction products, and unreacted sorbent.

** Hg sampling validation studies and comparison of Hg data obtained using EPA Methods 101A and 29 (multiple metals train) were also performed in conjunction with this program. This work is reported in "Evaluation of Two Methods for the Measurement of Mercury Emissions in Exhaust Gases from Municipal Waste Combustors," EPA-450/4-92-013, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

*** Standard conditions correspond to 20°C (68°F) and 101.3 kPa (14.7 psi).

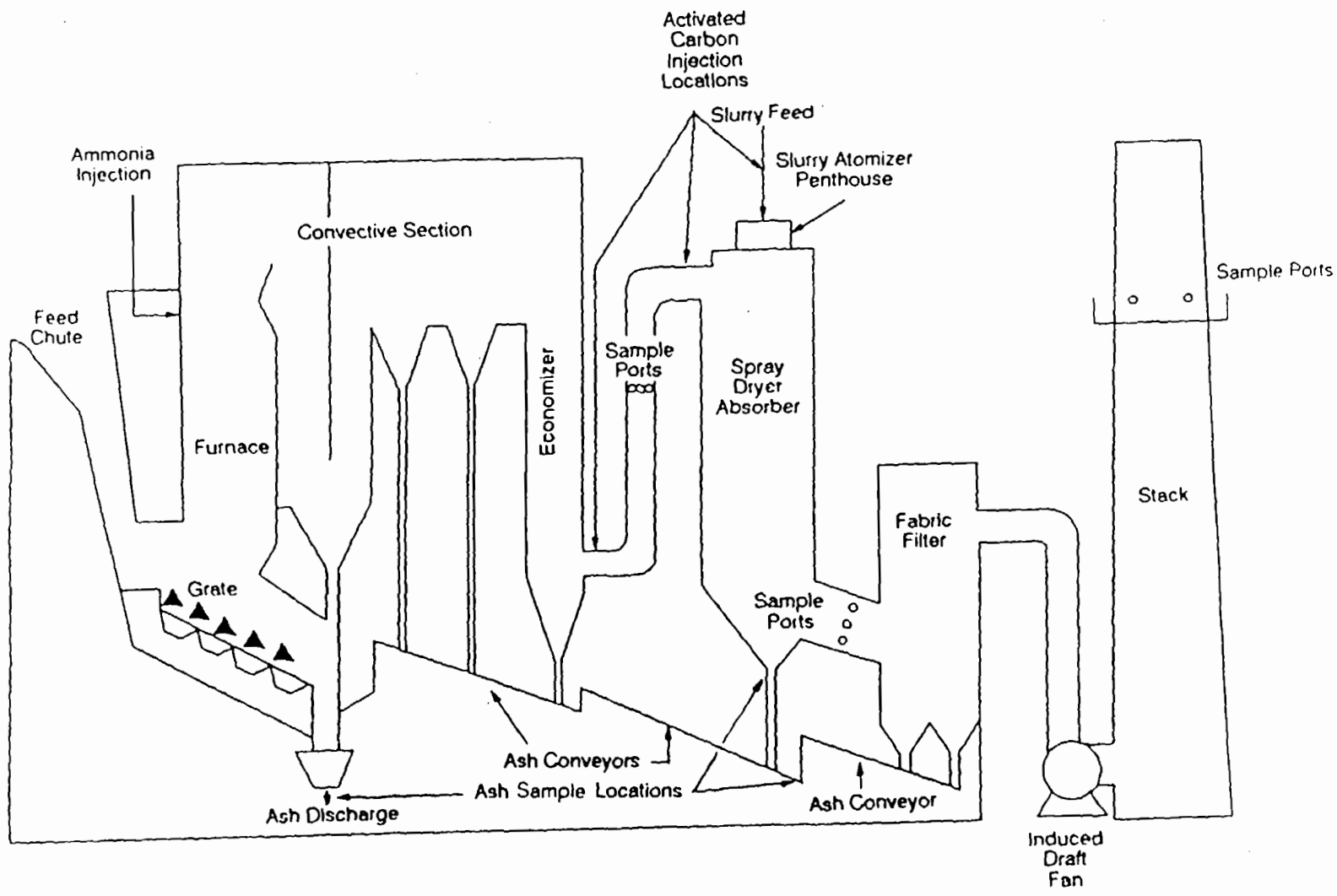


Figure 1. Schematic Diagram for a Unit of the Ogdan Martin Systems of Stanislaus, Inc. (OMSS) Facility.

water added to slaked lime in the slurry feed tank is controlled by the gas temperature leaving the SDA. The flue gas transit time through the SDA is about 15 seconds. The FF has a net air-to-cloth ratio of $0.98 \text{ m}^3/\text{min}\cdot\text{m}^2$ ($3.2 \text{ cfm}/\text{ft}^2$) and six compartments of Teflon™-coated glass fiber bags. The pulse-jet cleaning is continuous, and the cleaning cycle is about 2 minutes per compartment, or approximately 12 minutes for the entire baghouse.

A covered conveyor carries ash from the FF to the SDA where ash from the SDA is added. Flyash from the convective section of the boiler is added to the SDA and FF ashes and transported for combination with bottom ash. After quenching with water, the combined ash is discharged to a shaker conveyor which carries the ash to a large-material separator. Ash from this separator moves on a belt conveyor to a magnetic separator where ferrous materials are removed. The ferrous materials and remaining ash are retained in their separation building until they are removed for recycling and landfilling, respectively.

TEST PROGRAM

Table I summarizes the test parameters for the 16 conditions evaluated. The activated C type, feed rate, and feed location (see also Figure 1) were the primary independent variables. Secondary variables evaluated for their effect on Hg emission in the stack were NH₃ injection (either zero or at rates corresponding to normal unit operation), flue gas temperature in the FF [136 to 151°C (277 to 303°F)], and acid gas control efficiency [using SO₂ outlet concentration (up to about 30 ppmv)* as a surrogate]. With the exception of Condition 15 where two 1-hour tests were run, three 1-hour tests were normally conducted for all conditions. During Conditions 4, 5, 6, 8, and 9, dual Method 101A sampling trains were operated in the stack. Thus, two stack Hg concentrations were obtained for each test run for these conditions, except for Runs 2 and 3 of Condition 4.

Conditions 4 and 5 were performed without C addition to establish baseline conditions. Condition 4 corresponded to normal unit operation, while no NH₃ injection occurred during Condition 5 so that results for these conditions could be used to evaluate the effect of NH₃ on Hg removal by the SDA/FF system. Condition 7 was conducted to study the impact of C injection without NH₃ addition and followed Condition 4 to minimize the time without operation of the SNCR system. To allow time for the combustor and SDA/FF system to be purged of NH₃, the injection of NH₃ was terminated (with regulatory approval) 12 hours prior to starting the Condition 5 tests. NH₃ injection was resumed immediately after completion of the third (final) test at Condition 7. Hg was also sampled at the SDA outlet for Conditions 5 and 7 to study Hg control in the SDA and FF separately.

* Unless otherwise noted, all concentrations are referenced to 7% O₂ in dry gas.

TABLE I. MERCURY EMISSIONS CONTROL FIELD TEST PARAMETERS FOR THE OMSS MWC FACILITY

CONDITION NUMBER	TEST DATE	NUMBER OF TEST RUNS	OPERATING PARAMETERS					
			THERMAL DENO _x	CARBON FEED RATE ^a kg/hr(lb/hr)	CARBON ^b (Raw Material)	FABRIC FILTER TEMPERATURE	CARBON INJECTION LOCATION ^c	LIME FEED RATE
1	7/22/91 ^d	3	Normal	1.3 (2.8)	Coal	Normal	EO	Normal
2	7/23/91	3	Normal	5.4 (12)	Coal	Normal	EO	Normal
3	7/24/91	3	Normal	1.3 (2.8)	Coal	Normal	SDAI	Normal
4 (BL) ^e	7/25/91	3	Normal	Off	None	Normal	None	Normal
5 (BL)	7/29/91	3	Off	Off	None	Normal	None	Normal
6	7/26/91	3	Normal	5.5 (12.1)	Coal	Normal	SDAI	Normal
7	7/30/91	3	Off	1.3 (2.9)	Coal	Normal	SDAI	Normal
8	7/31/91	3	Normal	2.8 (6.1)	Coal	Normal	SDAI	Normal
9	8/1/91	3	Normal	1.3 (2.8)	Lignite	Normal	SDAI	Normal
10	8/7/91	3	Normal	5.6 (12.3)	Lignite	Normal	SDAI	Normal
11	8/5/91 ^f	3	Normal	1.3 (2.9)	Coal	Low	SDAI	Normal
12	8/5/91 ^g	3	Normal	1.3 (2.8)	Coal	Normal	SDAI	Low
13	8/2/91	3	Normal	1.5 (3.2)	Wood	Normal	SDAI	Normal
14	8/6/91 ^h	3	Normal	3.0 (6.6)	Wood	Normal	SDAI	Normal
15	8/10/91	2	Normal	8.3 (18.3)	Coal	Normal	w/lime slurry	Normal
16	8/10/91	3	Normal	5.5 (12.2)	Coal	Normal	w/lime slurry	Normal

^a Numbers may not agree because of rounding of English units to two significant (metric) figures.

^b Lignite = Darco FGD, Surface Area = 600 m²/g, Average Pore Radius = 3.0 nm, Tamped Density = 475 kg/m³
 Coal = Darco PC-100, Surface Area = 950 m²/g, Average Pore Radius = 1.5 nm, Tamped Density = 685 kg/m³
 Wood = Darco KB, Surface Area = 1500 m²/g, Average Pore Radius = 2.5 nm, Tamped Density = 450 kg/m³

^c EO = Economizer Outlet, SDAI = Spray Dryer Absorber Inlet

^d One run conducted on 7/23/91

^e BL = Baseline

^f One run conducted on 8/6/91

^g One run conducted on 8/2/91

^h One run conducted on 8/7/91

The remaining test conditions examined Hg removal as a function of C type, feed rate, or feed location. C from coal was used in 10 test conditions, for three feed rates, and three feed locations (see Figure 1). C from lignite and wood was studied at two feed rates and two feed locations, both into the flue gas duct. All C types were injected at the low feed rate [1.3 kg/hr (2.8 lb/hr)] into the flue gas entering the SDA. Table I describes the three C types tested.

During Conditions 3, 6, and 8, the effect of C feed rate with coal-based C was studied with the C injected into the SDA inlet duct. As shown in Figure 1, this injection site was downstream of the SDA inlet sample ports. Condition 3 had an average C feed rate of 1.3 kg/hr (2.8 lb/hr); the feed rates for Conditions 6 and 8 averaged 5.5 and 2.8 kg/hr (12.1 and 6.1 lb/hr), respectively. These feed rates corresponded to C concentrations in flue gas of about 17, 73, and 37 mg/dscm (0.0074, 0.032, and 0.016 gr/dscf).

The effect of injecting C at different locations was also investigated. Injecting the C at the economizer outlet provided about a second longer contact time between the C and flue gas compared to C injection at the SDA inlet. When the C was mixed in the lime slurry and injected with the slurry, the C flue gas contact time was slightly less than when the C was injected in the SDA inlet duct; however, the major factors expected to influence Hg removal by C carried in the slurry were the wetting of the C, the potential agglomeration of particles, and reduction in carbon surface area through coating of the C particles with lime. Since these factors were expected to decrease the effectiveness of the C in capturing Hg, the C feed rate for Condition 15 was increased by about 50% over the high rate for powdered C injection into flue gas.

The effect of reduced gas temperature in the FF was examined during Condition 11. Because the SDA/FF system was designed to shut off the lime slurry feed pump when the flue gas temperature at the FF reached 135°C (275°F), this bag protection feature limited the minimum temperature for the tests.

Condition 12 was performed to investigate the effect of lime stoichiometry on Hg emission. Since the maximum permitted stack SO₂ emission was 30 ppmv, the tests at this condition were run with manual slurry feed control. Because of varying SO₂ concentration with time at the SDA inlet and the finite response time required for the changed slurry flow to counter the change in inlet SO₂ concentration, controlling the stack SO₂ steadily at a set point over a 1-hour test was not possible.

Ash samples collected daily for each test location and condition were aggregated and thoroughly mixed before obtaining a representative sample for analysis. In addition to determining Hg retention in the combined ash over time, FF ash samples were analyzed for moisture, C, and loss-on-ignition (LOI).

DISCUSSION OF RESULTS

Effect of Carbon

Coal-based C was studied in 10 test conditions encompassing three feed rates and three feed locations. The effect of feed location at the high and low feed rates on Hg removal by the lime SDA/FF system is shown in Figure 2. The data scatter is greater at the low feed than at the high feed rate, and the Hg reduction values for the feed locations overlap. At the low feed rate, Hg reductions were 66-85% with C fed at the economizer outlet (Condition 1) and 53-77% for C fed at the SDA inlet (Condition 3). With the high feed rate, Hg reductions were 88-92% (Condition 2) and 91-98% (Condition 6) with C fed at the economizer outlet and SDA inlet, respectively. During conditions when the C was fed at the medium rate of approximately 2.8 kg/hr (6 lb/hr) at the SDA inlet, Hg reductions were 73-92% (not shown in Figure 2).

The differences in Hg reductions as a function of C feed location were not statistically significant. The C feed rate (or C concentration in flue gas) did have a significant effect on Hg reduction, and this result is consistent with that reported earlier.⁴

The trend of increasing Hg reduction with increasing C feed rate, regardless of C type, is indicated in Figure 3. This figure also suggests that the type of C had no effect on Hg reduction for the three types investigated.

The data points in Figure 4 show that Hg reduction generally increased with increasing Hg concentration in flue gas entering the SDA as well as with increasing C feed rate. The curves on this figure are plotted using Equation 1, which is discussed below.

Considering 57 valid data points for Hg reduction and 60 points for outlet (stack) Hg concentrations, these variables were correlated with C feed rate raised to the 0.5, 0.7, and 1.0 power, respectively, using multiple regression analysis.⁸ The best predictive equations for Hg reduction (PRED) and outlet Hg concentration (HGOUT) were:

$$\ln(100-\text{PRED}) = 4.81 - 0.948 (\text{CFR})^{0.5} - 0.000776 (\text{HGIN}) \quad (1)$$

and

$$\ln(\text{HGOUT}) = 5.66 - 0.963 (\text{CFR})^{0.5} + 0.000724 (\text{HGIN}) \quad (2)$$

where: \ln is the natural (Naperian) logarithm, PRED is the Hg reduction in percent, CFR is the C feed rate in kg/hr, and HGIN and HGOUT are Hg concentrations in $\mu\text{g}/\text{dscm}$ at the SDA inlet and in the stack, respectively. The "goodness of fit" for these predictive models for PRED and HGOUT given by Equations 1 and 2 are 0.762 and 0.777, respectively.

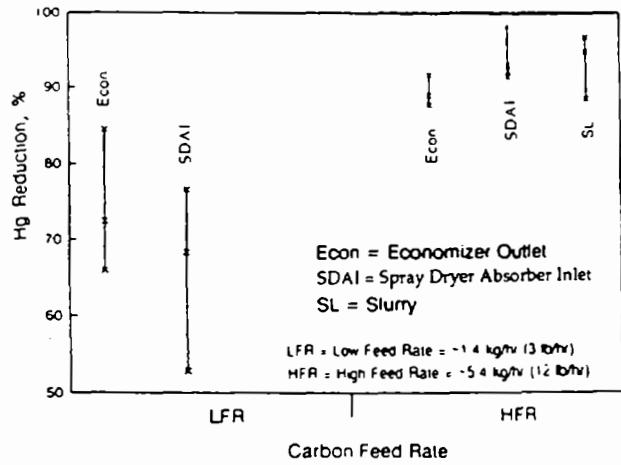


Figure 2. Effect of Carbon (Darco PC-100) Feed Location on Mercury Reduction.

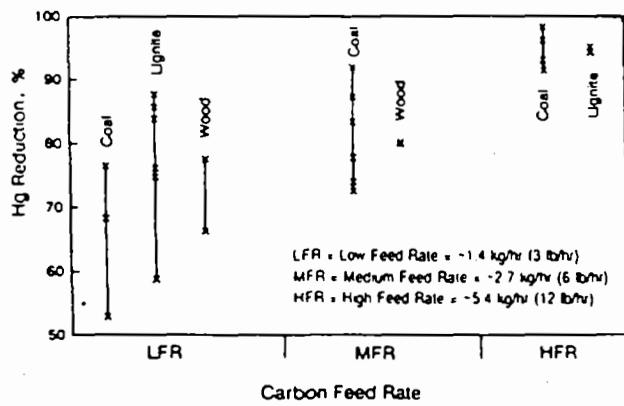


Figure 3. Dependence of Mercury Reduction on Carbon Type Under Normal Operation and Carbon Injection at the Spray Dryer Absorber Inlet.

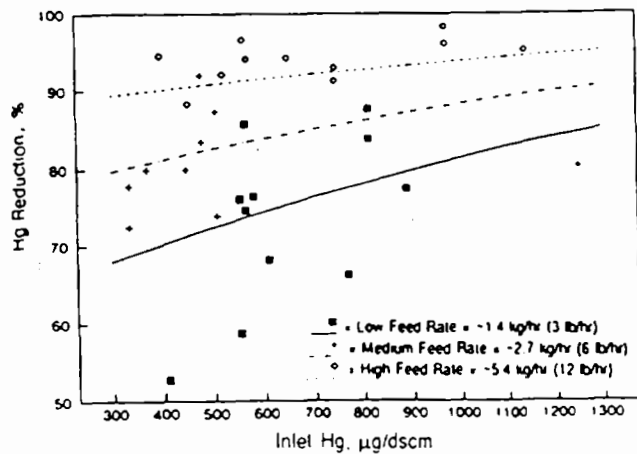


Figure 4. Effect of Carbon Feed Rate on Mercury Reduction.

The curves (from Equation 1) shown in Figure 4 show that Hg reduction increases with C feed rate and inlet Hg concentration. As noted earlier, the data scatter is greater at the low than at the high C feed rate. At the high feed rate, Equation 1 predicts Hg reductions of 90% or more for inlet Hg concentrations above 300 $\mu\text{g}/\text{dscm}$. The slope of each curve decreases slightly with increasing Hg concentration and suggests that C utilization for adsorption of Hg decreases as the Hg concentration rises. The convergence of the curves indicates that increasing the C feed rate to reduce Hg emission becomes less effective as the inlet Hg concentration increases.

Using statistical methods and all data for the high C feed rate, it has been estimated that about 95% of individual tests will attain Hg reductions of at least 80%.⁸ Using similar procedures, approximately 95% of individual tests would be expected to yield outlet Hg concentrations of 112 $\mu\text{g}/\text{dscm}$ or less.

Hg reductions across the SDA and FF individually were obtained during Conditions 3 and 7, both conditions with the low C feed rate at the SDA inlet. With NH_3 injection during Condition 3, the Hg removal in the SDA averaged 17%. However without NH_3 injection during Condition 7, the average Hg concentration in the flue gas increased by 19% (a negative Hg reduction) in the SDA. Noting that the Hg reduction between the SDA outlet (FF inlet) and the stack averaged 60% for both conditions, the cause for this apparent anomaly has not yet been determined. While the average overall Hg reduction of 66% (53-77% range) for Condition 3 is consistent with the 74% (66-85% range) obtained at Condition 1 (noting that injection location did not significantly impact Hg reduction), the average Hg reduction for Condition 7 with two valid data sets was 52% (average of 48 and 56%). While greater Hg removal was expected in the FF than in the SDA because of the greater sorbent residence time in the FF, an increase in Hg concentration across the SDA was unexpected. More on this finding will be said later in discussing the effect of NH_3 on Hg emission.

Effect of NH_3 on Hg Control

As noted earlier, Conditions 4 and 5 were conducted to determine if NH_3 had an impact on Hg emission in the absence of C addition. The results of tests at Condition 4 (normal NH_3 feed) gave an average Hg removal of 28% in the SDA/FF system and those at Condition 5 (no NH_3 feed) indicated an average removal of 31%. For both conditions dual (Method 101A) trains were used in the stack. The average Hg removals were based on four valid stack values (16-36%) for Condition 4 and six values (18-39%) for Condition 5. Thus, these Hg reductions are comparable.

The NH_3 concentrations in the flue gas entering the SDA (NH_3 slips)* were below 5 ppmv for all but two runs (9.4 ppmv for Run 2 of Condition 3 and 23 ppmv

* NH_3 slip is defined as NH_3 which does not react with NO_x in the SNCR process.

for Run 2 of Condition 12) and included the runs (Conditions 3 and 7) without NH₃ feed. These low values of NH₃ slip suggest that the SNCR system and NH₃ injection rates were "well-tuned," which may not have been the case for the 1988 tests on Unit 2 when Hg emissions appeared to increase with increasing NH₃ feed rate (no NH₃ slip data were reported).⁶

Earlier it was stated that Hg concentration increased in the SDA for both runs during Condition 7, which was conducted as the last of three consecutive test conditions without NH₃ feed. Thus, no residual effects of NH₃ were expected. The Hg concentration at the SDA inlet for Condition 7 averaged 389 µg/dscm, the lowest average obtained for all 16 test conditions and 50 µg/dscm lower than the next lowest average value (Condition 8). However, no basis has yet been found for invalidating these data of Condition 7. As noted earlier, the Hg removals in the FF were equal for both Conditions 3 and 7 and the Hg concentrations entering the FF and in the stack were reasonably consistent relative to similar tests.

In view of the above discussion, no firm conclusion can be made regarding the impact of NH₃ concentration in flue gas on Hg removal. The low NH₃ slip values measured suggest that the NH₃ concentrations in flue gas entering the SDA were independent of whether the SNCR system was or was not operated during this test program. The small difference (10%) between the average Hg reductions for Conditions 3 and 7 indicates that NH₃ had a minor, if any, effect on Hg removal in these tests.

Effect of Gas Temperature

Temperature can affect Hg removal from flue gas in several ways. Decreasing temperature supports condensation of vapors of Hg and Hg compounds present in flue gas and their adsorption on PM. Gas temperature can affect the reaction rate between Hg species and chemical reactants in flue gas.

The temperatures of flue gas leaving the SDA and entering the FF were 136-151°C (277-303°F) and about 1-3°C (2-5°F) lower in the stack. Since the Hg removal from flue gas in the FF will usually require the Hg species to be in PM form, gas temperature entering the FF was selected as the appropriate temperature for study.

Because the vapor pressure (or concentration)/temperature data for Hg components expected in flue gas of MWCs equipped with lime SDA/FF systems show that these components [e.g., elemental Hg, mercuric chloride (HgCl₂), mercurous chloride (HgCl), and mercuric oxide (HgO)] are predominantly in the vapor phase even below operating temperatures [about 140-145°C (284-293°F)], removal of these vapors through condensation is not expected to be significant. The average Hg removal for Condition 3 was 66% when the temperature was 147°C (297°F), while Hg removal for Condition 11 was 64% when the temperature averaged 140°C (284°F) for otherwise equivalent MWC operating conditions. This

finding suggests that the SDA outlet temperature over the limited range permitted for this test program did not affect Hg removal.

Effect of Lime Stoichiometry

Earlier tests on Unit 2 showed a linear correlation between lime slurry feed rate (proportional to stoichiometry) and Hg emission, with emission increasing with feed rate.⁶ This increasing Hg emission may have resulted from the reduction of HgCl₂ solids through reaction of calcium hydroxide [Ca(OH)₂] to form HgO and calcium chloride (CaCl₂), and subsequent conversion of HgO yielding Hg vapor.

Since the lime stoichiometry could not be measured directly, the SO₂ outlet concentration provided a continuously measured surrogate for lime stoichiometry and was controlled manually in the attempt to maintain a set point of 30 ppmv over each 1-hour test at Condition 12.* Because of the varying SO₂ concentration at the SDA inlet and the finite response time required to adjust lime feed slurry flow and lime solids concentration in the slurry, maintaining the desired SO₂ set point continuously was not possible. With both inlet and outlet SO₂ concentrations measured continuously, the corresponding SO₂ removal was calculated, with high removal suggesting high lime stoichiometry. With Equation 3 defining stoichiometric ratio (SR), which is the ratio of the actual to the stoichiometric lime requirement for flue gas entering the SDA, it is seen that the lime supplied is inversely proportional to both the SO₂ and hydrogen chloride (HCl) present in the flue gas to be cleaned.

$$SR = \frac{[\text{mol lime supplied}]}{[\text{mol SO}_2 + 0.5 (\text{mol HCl})] \text{ in flue gas into SDA}} \quad (3)$$

If removal efficiencies for SO₂ (E_{SO₂}) and HCl (E_{HCl}) are expressed as fractions, Equation 3 becomes Equation 3a.

$$SR = \frac{[\text{mol lime supplied}]}{[E_{SO_2} (\text{mol SO}_2) + 0.5 (E_{HCl})(\text{mol HCl})]_{\text{into SDA}} + \{(\text{mol SO}_2) + 0.5 (\text{mol HCl})\}_{\text{from SDA}}} \quad (3a)$$

The average SO₂ removal during Condition 12 was 73% (66-77% range), when the SO₂ inlet concentration averaged 82 ppmv. The average HCl reduction was 97% and the inlet HCl concentration averaged 661 ppmv at this condition. An average Hg reduction of 59% was obtained during Condition 12 when the inlet Hg concentration averaged 682 µg/dscm. Condition 3 was similar to Condition 12 except normal SO₂ control yielded an average SO₂ removal of 92% when the inlet SO₂ concentration averaged 108 ppmv. The average HCl inlet concentration and

* The SO₂ outlet concentration is normally controlled so that either 80% SO₂ removal or an outlet SO₂ concentration of 30 ppmv at 12% CO₂, whichever is less restrictive, is maintained. Although regulatory concurrence was received to vary SO₂ concentration, an effort was made to stay within the 30 ppmv limit during Condition 12.

removal were 517 ppmv and 98%, respectively. The average Hg reduction for Condition 3 was 66% for removals in the 53-77% range when the Hg concentration averaged 534 $\mu\text{g}/\text{dscm}$. Comparison of the HCl and Hg reductions for Condition 12 and 3 indicates similar control levels, while the lower SO₂ removal during Condition 12 relative to Condition 3 suggests a lower lime stoichiometry. However, the different acid gas concentrations and removals during these conditions do not permit assessing the related lime stoichiometries for these conditions (see Equation 3a). Thus, the limited test data appear inconclusive regarding the existence of a correlation between SO₂ control efficiency and Hg emission control.

Ash Characteristics and Retention of Hg by Ash

It was noted earlier that the C content of flyash is believed to impact control of Hg emission, and the temperature at which combined ash is held may affect Hg retention in this ash over time. Several studies were made to study these factors.

Flyash samples collected from flue gas entering the SDA were analyzed for dry C content using a modification of ASTM Method D3174 for an additional weight measurement at an intermediate temperature to account for the water of hydration associated with calcium chloride hydrate. The LOI was the percent weight lost between samples heated and held for given periods first at the intermediate temperature of 210°C (410°F) and then at the final temperature of 750°C (1380°F). Ten of the 11 samples analyzed had a dry C content of 1% or less by weight. The other samples had a dry C value of 2.2%. The highest dry C value (2.2%) occurred during Condition 2 when C powder was injected at 5.4 kg/hr at the economizer outlet, just upstream of the flyash sampling ports. Thus, C injection was believed responsible for this high dry C value. All LOIs exceeded 4% but were below 6.5%.

As noted earlier, the average Hg removal for tests without C injection was about 30%. This corresponded to a flyash carbon content of 1% or less. Tests at the Mid-Connecticut facility showed Hg removals exceeding 95% and probable flyash C contents of several percent.⁷ This comparison supports the premise that the C content of flyash affects Hg emission control.

Time stability of Hg retention in ash was studied for the fabric filter and combined ashes. The samples evaluated for Hg content were weighed initially and after 14 and 28 days in storage, respectively, in an oven at 54°C (130°F), a refrigerator at 7°C (45°F), and room air at 16°C (60°F). At the highest temperature, the change in weight in five samples (one without C addition, two with coal-based C, and one each with lignite- and wood-based C addition to flue gas) indicated a maximum weight change of about 10% (one coal-based C sample after 14 days) and values below 10% for the other samples. However, the highly hygroscopic nature of the samples stored at the lower temperatures led to absorption of water when weighed in air. Laboratory analysts noted while weighing these samples that the samples gained weight so rapidly it was difficult to record a weight. Whether the gain of weight via

absorption of water by the sample during its weighing accounts for all the differences in weights over time cannot be determined, but a method is being developed to study this effect.

The combined ash samples are representative of the ash being landfilled. The Hg concentrations before storing the ash samples in the three temperature environments noted above (oven, refrigerator, and room air) were less than 2 µg/g for Condition 4 (no C injection) and about 9 µg/g for Condition 6. The results indicate that Hg was not volatilized from the combined ash after its capture over the 28-day period of this study. The highest ash exposure temperature [54°C (130°F)] was greater than expected in combined ash landfills and was expected to result in greater Hg emission than at the lower temperatures tested.

SUMMARY

The field evaluation on Unit 2 of the OMSS MWC facility near Crows Landing, CA, showed that C feed rate affected the control of Hg emission but C type and feed location did not. Increasing the feed rate from zero to 5.4 kg/hr improved Hg reduction from about 30% to over 90% and, correspondingly, lowered Hg emission in the stack. The low C feed rate (1.3 kg/hr) resulted in lower Hg reductions and greater variability in the reductions than did the medium (2.8 kg/hr) and high (5.4 kg/hr) feed rates when comparing test runs.

NH₃ injection in the SNCR system appeared to have little or no effect on Hg removal: the NH₃ concentration (NH₃ slip) in flue gas entering the SDA seemed to be independent of whether the SNCR was operated or not. Additional data are needed to verify if NH₃ injection negatively impacts Hg emission control because the limited test data preclude a firm conclusion. No correlation between Hg removal and lime feed rate (or SO₂ removal) was possible with the limited test data obtained. Gas temperature entering the FF over the temperature range studied (136-151°C) did not affect Hg emission control.

Test data indicated that the dry C content of flyash entering the SDA was 1% or less and that the LOI of the flyash was under 7%. The low C content of the flyash was consistent with the low Hg removal obtained without C injection. The time stability study of combined ash which is landfilled indicated that Hg captured with this ash did not volatilize from this ash even when held in an oven at 54°C for the 28-day study.

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16. ABSTRACT The paper gives results of tests (to aid in developing emission rules) in July and August 1991 on a 360-tonne/day mass burn municipal waste combustor (MWC) at the Ogden Martin Systems of Stanislaus, Inc. facility near Crows Landing, CA. Test results indicated that carbon (C) addition was effective in improving mercury (Hg) removal: removal increased with increasing C feed rate. Hg removal improved from about 30% without C addition to over 90% at the highest C feed rate tested. The test data obtained for evaluation of the secondary test objectives suggested that (1) ammonia (NH3) addition (which occurred with low slip) had no apparent adverse effect on Hg control, (2) lime stoichiometry had no effect on Hg emissions over the narrow range studied, (3) the fabric filter (FF) gas temperature over the range tested did not affect Hg control, and (4) the Hg content of ash/residue stream samples remained relatively constant over a period of 28 days in samples held at 54 C.		
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