

## EXECUTIVE SUMMARY

### Retrofit of Waste-To-Energy Facilities Equipped with Electrostatic Precipitators

#### INTRODUCTION

On December 19, 1995, the USEPA promulgated New Source Performance Standards [NSPS] and Emissions Guidelines for municipal waste combustors [MWCs]. These guidelines restrict the emitted concentration of both criteria and hazardous air pollutants listed in Section 129 of the Clean Air Act. There are 135 electrostatic precipitator [ESP] equipped units in 54 facilities, representing more than 43,000 tons per day [TPD] (39,000 Mg/d) of municipal solid waste [MSW] disposal capacity; 5,200,000 lb/hr of congenerated and direct steam sales; and 640 MW of electrical generating capacity that are significantly affected by these guidelines. Particularly affected are ESP-equipped MWCs smaller than 250 TPD. This category contains at least 54 units in 25 facilities. These small MWCs provide more than 5,300 TPD of MSW disposal capacity; 70 MW of electrical generating capacity; 860,000 lb/hr of steam sales; and more than 700 jobs. Many of these affected installations were built before dry scrubbers and ultra-high efficiency ESPs or fabric filters became the *de facto* standard in the mid-1980s. These older ESP-equipped facilities still provide useful services to the communities that invested in them. But, an economical way must be found to meet the guideline emissions limitations, otherwise, the residual economic value in these ESPs or, in extreme cases, the entire facility will be lost.

The Department of Energy's [DOE] National Renewable Energy Laboratory [NREL] supported an American Society of Mechanical Engineers' [ASME] Center for Research and Technology Development [CRTD] project directed by the electrostatic precipitator retrofit subcommittee of the ASME Research Committee on Industrial and Municipal Waste [RCIMW]. This work was instigated to assist communities operating ESP-equipped MWCs. A proof-of-concept demonstration test of an emissions control technique for these facilities was conducted to help keep these valuable investments operating and contributing to our nation's energy future. This program demonstrated the ability of an existing ESP-equipped MWC using flue gas temperature control, dry acid gas reagent injection and activated carbon addition to meet the emissions guidelines for small (<250 TPD) MWCs.

#### OBJECTIVES

The overall program objectives were:

- to determine the controlled emissions after applying a combination of reduced ESP operating temperature, acid gas reagent injection, and activated carbon addition; and,
- to demonstrate that ESP temperature reduction can be reliably accomplished.

The purpose of this test was to demonstrate achievement of the final 40 CFR 60 Subpart Cb emission guidelines,

summarized in Table ES-I for PCDDIF , mercury, HCl and SO<sub>2</sub>. The proposed emissions guidelines (September 20, 1994) for small facilities shown in Table ES-1 served as a design basis for this effort.

Table ES-1 Emissions guidelines for existing facilities

	<u>September 20, 1994 Proposed</u>		<u>December 19, 1995 Guidelines</u>	
	Large Plants	Small Plants	Large Plants	Small Plants
PCDD/F (ng/dsm <sup>3</sup> )	30	60	30 60 w/ESP	125
Particulates (mg/dsm <sup>3</sup> )	27	69	27	70
Cadmium (µg/dsm <sup>3</sup> )	40	100	40	100
Lead (µg/dsm <sup>3</sup> )	50	1,600	49	1,600
Mercury (µg/dsm <sup>3</sup> )	80	80	80	80
Sulfur Dioxide				
Efficiency	75%	50%	75%	50%
Concentration (ppmdv)	35	80	31	80
Hydrogen Chloride				
Efficiency	95%	50%	95%	50%
Concentration (ppmdv)	35	250	31	250

Note: All concentrations at regulatory standard conditions (20°C & 760 mm<sub>Hg</sub>) and 7% O<sub>2</sub>.

## APPROACH

It was imperative that the project be completed as soon as possible after contracts were signed on August 24, 1995 so facilities could include the results in their assessment of how to best meet the then pending emissions guidelines. To meet the expedited project schedule equipped host facilities had to have suitable operating permits or variances to conduct the testing and a dry sorbent injection system operational by the end of September 1995. Technology transfer issues required close coupling between the incinerator outlet and ESP inlet. An existing distributive control system, data logger and plant continuous emissions monitoring system [CEMS] for criteria pollutants (CO, NO<sub>x</sub> and SO<sub>x</sub>), and a continuous opacity monitoring system [COMS] were beneficial enhancements for the test. Selection of the Davis County Energy Recovery Facility [DCERF], Layton, Utah was approved by the Subcommittee, Advisory Committee and sponsors on August 30, 1995. As part of that approval, one advisor recommended, and all concurred, that a sodium-based reagent should be used to maximize the chance of meeting the then proposed acid gas emissions limitations. The final test protocol was approved on September 23, 1995.

The Facility

The demonstration test was conducted between November 17 and 28, 1995. The DCERF is a nominal 420 TPD (2 by 210 TPD) MWC. A back pressure turbine is used to generate electricity before the steam raised from burning waste is sent to the neighboring Hill Air Force Base district heating system. The facility has refractory wall Seghers (combination rocking and sliding grate) furnaces and Zurn waterwall waste heat recovery steam generators which produce 51,344 lb/hr of 500°F, 500 psig steam when operating at maximum continuous rating [MCR].

The DCERF was built with a powdered limestone furnace injection system. After much experimenting with injection location and reagent, trona (a natural ore-sodium sesquicarbonate-used for acid gas control and as a cattle feed supplement) has been injected between the boiler outlet and economizer inlet since July 1993. Particulate emissions are controlled by a three-field Environmental Elements ESP with a specific collector area [SCA]of about 400 ft<sup>2</sup>-/1000acfm.

### Temperature Control

There is considerable experimental evidence that, once good combustion has been achieved, the predominant source of PCDD/Fs in MWCs is formation downstream of the active combustion zone (Kilgroe & Licata, 1996). Formation may take place in the gas phase, on particulate surfaces, or inside the particulate matter itself (Wilson, et al., 1995). Regardless of the actual mechanism, laboratory data indicate that temperature plays a significant role in the reaction. Figure ES-1 brings together much of the available PCDDIF and air pollution control system [APCS] temperature data. While the data are variable and system design and operating characteristics clearly affect PCDDIF stack concentrations, the effect of temperature is evident. Lower gas temperatures in the APCS are associated with lower PCDDIF concentrations in the stack gas. Furthermore, available data indicates that acid gas removal is enhanced at lower temperatures. For comparison, typical spray dryer absorbers have a practical lower temperature limit of 350°F.

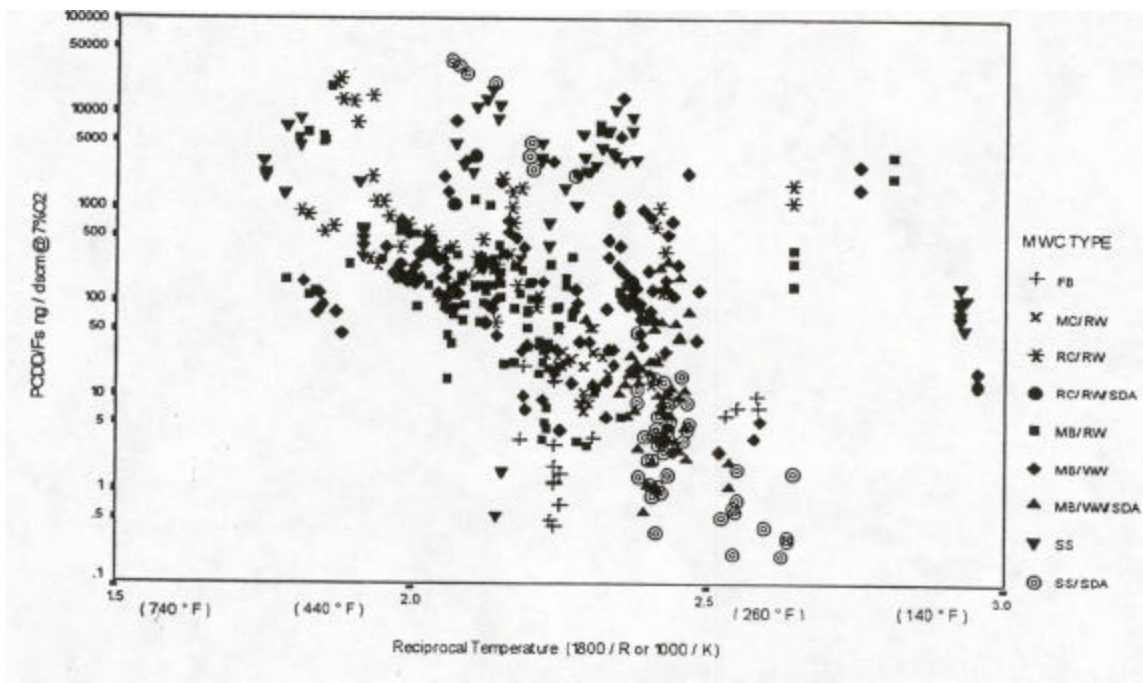


Figure ES-1 Relationship between stack concentrations of PCDD/Fs and reciprocal APCS inlet temperature.

Thermodynamic calculations indicate that each of the 210 TPD DCERF MWCs require about 9 gpm of water to reduce the temperature of their nominal 35,000 dsft<sup>2</sup>/hr stack flow from the normal economizer outlet temperature of 420°F to 300°F. These calculations were corroborated by field data during the test period when the 300°F temperature target required the addition of 8.5 to 9.5 gpm of water.

A temperature-reducing water spray atomization system that economically and reliably delivers a very fine water spray was required due to the short distance for evaporation between the economizer outlet and ESP inlet. The bi-fluid atomizer based spray system was designed to produce 25 micron Sauter mean diameter water droplets. Such fine droplets theoretically evaporate within 0.4 seconds. This should minimize wall impingement. The DCERF demonstration test employed air atomization to meet installation time requirements and to minimize the cost. Steam driven bi-fluid atomizers are an alternative. To help achieve fine atomization, the water was preheated to about 170°F via an integral water heating loop designed into the lance. Preheating reduces the water's viscosity and produces a finer droplet for the same atomizing conditions.

The lance itself was fabricated from carbon steel pipe and three bi-fluid nozzles were employed. A 90° spray angle nozzle was placed in the middle and 60° spray angle nozzles were located on the quarter points. The nozzles were oriented to spray 10° above the duct centerline so that gravity would not cause wall impingement prior to droplet evaporation.

#### Sorbent Addition

Both trona and powdered hydrated lime were injected before and after the economizer during extensive tests at the facility between 1988 and 1993. Trona proved to be more effective on HCl than hydrated lime. Trona, ground to pass a 325 mesh sieve (<44 μm), is a locally available natural ore and its pricing is much more favorable than either lime or sodium bicarbonate at DCERF. Previous testing (Solvay, 1993) indicates that between 75 and 100 percent of stoichiometric<sup>1</sup> addition rates produce 50 percent acid gas reductions. If particulate emissions limitations are to be simultaneously met, reagent addition rate is limited by the particulate removal capability of the ESP. DCERF typically operates at a nominal stoichiometric ratio of 0.8: 1. The baseline runs indicate that the actual stoichiometric ratio achieved during testing was between 66 and 97 percent.

Several reports suggest that powdered activated carbon [PAC] injection reduces PCDD/F emissions (Heath 1995; Licata, et al., 1994; and Sierhuis, et al. 1994). While sulfur or iodine impregnated PAC have been suggested to perform better than ordinary PAC in

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<sup>1</sup> The stoichiometric trona addition rate – the amount needed to just neutralize all of HCl and SO<sub>2</sub> (110 ppm<sub>dv</sub> @ 7% O<sub>2</sub>) concentrations at DCERF. For comparison, the stoichiometric sodium bicarbonate rate is 110 lb/hr/unit and the stoichiometric hydrated lime rate is 96 lb/hr/unit.

some applications. Richman (1993) reported a lack of significant performance differences for a MWC using ordinary and sulfur augmented PAC. Based on this finding, ordinary PAC was chosen.

PAC can be obtained either pre-mixed with acid gas sorbent or packaged separately. If the correct mixture is known, the selection of pre-mixed versus separate feed systems is a facility-specific decision. For test purposes, however, the ability to independently control the reagent and PAC feed rates to alter experimental conditions required that separate systems be used. Analyses of the available data suggested that a 15 lb/hr PAC addition rate ( $200 \text{ mg/dsm}^3 @ 7\% \text{ O}_2$ ) should provide the necessary PCDD/F removal. The limited data suggested that less would be needed to meet mercury removal requirements. Since a purpose of this test was to demonstrate that an existing ESP-equipped MWC can be relatively inexpensively modified to meet the proposed PCDD/F and mercury Emissions Guidelines for Small Plants (<250 TPD), a second addition rate of 30 lb/hr ( $400 \text{ mg/dsm}^3 @ 7\% \text{ O}_2$ ) was selected to provide a safe fall-back position.

The PAC was Norit DARCO FGD made from lignite coal and pulverized so that 95 percent passed a 325 mesh screen (<44  $\mu\text{m}$ ). This is the same type of PAC used in USEPA testing at Stanislaus County, CA (1993) and Camden, NJ (1993) thereby eliminating a potential difference (confounding factor) between the test programs. It must be recognized, however, that both Stanislaus and Camden are equipped with spray dry absorbers and Stanislaus has a fabric filter rather than ~ ESP. As a result, the data sets cannot necessarily be directly merged and analyzed as a single experiment. Testing at DCERF; however, was conducted at an ESP inlet temperature about 100°F (55°C) higher than previous tests. Thus, this work extends the range of published information.

The trona and the PAC were combined in the feed chute to the plant's 10 psig trona injection system eductor and injected below the economizer through a specially designed rapid dispersion dry sorbent injection lance that visually achieves full duct coverage within 3 to 5 feet. The lance is the bottom 2/3 of a piece of 2-inch diameter Schedule 40 pipe with progressively deeper 45° baffles inserted every 18 inches to disperse the reagent.

## FINDINGS AND CONCLUSIONS

### Emissions Control Performance

Performance models for PCDD/F, Hg, HCl and SO<sub>2</sub> removal (PAC and trona effects), developed using Langmuir isotherms as a theoretical construct, were used to calculate routinely achievable emissions limitations (95 percent statistical confidence level upper prediction limits designed to contain the next five 3-run average test results) from the data. Overall, the results indicate that the DCERF and other facilities using dry sorbent injection, PAC addition and APCS inlet temperature control can meet the small MWC category emissions limitations for all pollutants and would likely meet the large facility guidelines for all regulated pollutants except for the acid gases. NO<sub>x</sub> control is required at large, non-refractory wall MWC facilities, but demonstrating such a retrofit was outside the scope of this effort.

The PAC performance results indicated that 11.25 lb/hr ( $300 \text{ mg/dsm}^3 @ 7\% \text{ O}_2$ ) should be able to meet the large plant emissions limitations for PCDD/F and mercury from ESP-equipped MWCs. To provide a safety margin, some temperature control is indicated but

there is little apparent value in dropping the APCS inlet temperature below 350°F for PCDD/F and mercury control.

Injecting reagents increased particulate emissions slightly compared to zero reagent injection rate measurements at normal ESP operating temperatures. When coupled with water spray temperature control, sorbent injection had no effect on particulate emissions. 3-run average cadmium and lead concentrations remained below small and large plant regulatory limits, but spikes (individual high runs) are evident.

The acid gas control results for trona injection only incorporate the feed rate variability induced by changes in stack gas flow and nominal trona feed fluctuations because the experiment did not call for adjusting this feed rate. The results indicate that feed rates above 1,700 mg/dsm<sup>3</sup> @ 7% O<sub>2</sub> (125 lb/hr) should keep the HCl and SO<sub>2</sub> removal efficiency safely above the mandated 50 percent removal level for small MWC facilities. It does not appear that dry acid gas sorbent injection/ESP systems can meet the 75 percent SO<sub>2</sub> and 95 percent HCl reductions required for large facilities without causing exceedances of the particulate emissions limitations; however, specific facilities with very efficient ESPs may be successful. Also, other sodium based reagents (nacolite and sodium bicarbonate, for example) and calcium based reagents (hydrated lime, for example), could provide technically equivalent, but economically superior performance depending on site-specific factors. This proof-of-concept demonstration test, however, shows which emissions limitations can be met by DSI/ESP retrofit and provides a basis for moving ahead. Economic optimization can follow at specific sites since the same equipment is involved regardless of the dry powdered reagent employed.

The effect of temperature reductions alone on PCDD/F and mercury removal was not very significant between the 420°F nominal operating temperature and the 300°F lowest tested temperature. However, reducing temperature had a favorable effect when combined with the addition of PAC. HCl and SO<sub>2</sub> removal also benefited from reduced temperature operation.

#### Field Observations

Comparison of plant operating data before testing commenced, during each test series and during non-test times between runs and after testing, indicates that the plant was operating normally during the demonstration test.

The water spray lance performed as expected. Water flow rates and temperature drops corresponded to the values calculated using elementary thermodynamics. A 6-inch diameter washer was used to minimize fly ash build up around each nozzle head. Inspection after 3 days showed the heads to be free of ash, but the washers were caked with a soft covering. After a further 8 days of operation with the spray heads and washers reoriented from 10° above the duct centerline to 35° below the duct centerline, harder material was caked on and about the nozzle faces. This coating may have accounted for the inability to achieve the desired temperature reduction during the last two days of testing.

A plug valve was used to control the water flow from the 230 psig pumps to the nozzle. Flow commenced at 55 percent of the valve-wide-open position (3.5 gpm of flow)

because there was too much valve resistance to overcome the atomizing air back pressure at lower flows. The valve-wide-open flow was 12 gpm. A different control valve type or variable air pressure operation will be needed at facilities requiring a greater operating range.

Lowering the gas temperature from 420°F to 300°F also reduced the gas velocity by about 10 percent. Lower velocities induce more particulate settling than the plant experiences at higher temperatures with their inherently higher gas velocities. Theoretical calculations and stack gas flow measurements indicate that the average gas velocity dropped to about 90 percent of design when the temperature was reduced from 420°F to 350°F using water sprays. The reduced velocity effect was probably exacerbated by particle agglomeration. As the fly ash, PAC and trona laden flue gases pass through the spray zone, the water can cause some of the particulates to combine into larger aggregates. Such agglomerates settle faster than the individual particles. The resulting sedimentation and build-up can lead to plugging of the economizer. Accumulated particulate can slough off the bottom of the 60° inclined breaching leaving the economizer and slide back on top of the economizer. To solve this problem, at least an intercepting hopper is required. Installation of a separate, custom designed contact chamber is a more robust solution that should be investigated and employed when room is available.

The high efficiency ESP performed well. To avoid confounding the experiment, the spark rate and secondary voltage controllers were not adjusted. Normally, the first two fields spark rate is around 230 sparks per minute and the fields operate with 23 kV potential differences; the third field ranges between 0 and 100 sparks per minute and a similar applied voltage. These characteristics did not change when either 15 or 30 lb/hr of PAC was introduced or when the trona addition was stopped. With the water sprays, however, the spark rate dropped dramatically in the first two fields to less than 10 and 50 sparks per minute respectively. The third field was rarely above the 10 sparks per minute range. The secondary voltage applied to all three fields also rose to between 30 and 32 kV and exhibited much less variability. These changes are all beneficial. The secondary voltage can be increased farther than the automatic adjustment took it. This would improve the particulate control system performance.

## TEST PROGRAM

A fractional factorial<sup>1</sup> test plan-three operating temperatures, two trona feed rates and three PAC feed rates- with one designed replicated test condition was used. The order of testing was random. The replicate was assigned to the low temperature, low PAC feed, because the information available prior to the start of testing indicated that this was the one most likely to reliably and economically achieve the program objective.

The project plan had 10 days of scheduled testing, with two additional testing days allowed for field difficulties. Because the field work proceeded with few problems after the first day, an extra day of testing was available. The 30 lb/hr PAC, 150 lb/hr trona and 300°F ESP inlet temperature condition was replicated because contemporaneous field observations indicated that the PAC feed was not uniform. The target temperatures were

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<sup>1</sup> A factorial plan test all possible combinations and permutations of the factor levels in the design; a fractional factorial plan only tests a selected subset.

not achieved on the last two days of testing due to economizer fouling that raised the flue gas temperature entering the water spray zone. The temperature on these days was in the range of 325°F, so an extra, unplanned temperature condition was achieved.

Plant operating conditions and reagent injection rates were established the evening before to help ensure that steady-state operating conditions were achieved before testing began. Sampling equipment setup commenced at dawn. Simultaneous metals Method 29 and PCDD/F Method 23 test runs were conducted on opposite traverses in the stack. Following completion of these tests, a non-traversing HCl (Method 26) test run was performed. At the completion of the HCl run, the testing sequence was repeated. Two complete sets of runs were finished about 6 p.m. each night.

Plant operating data were collected for the week prior to testing, throughout testing, and for the week following testing using the plant's process monitors. The data historian was used to continuously record plant operating conditions. Combined residue (bottom ash and APCS) was sampled following the plant's residue sampling protocol.