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# MINIMIZING EMISSIONS FROM EXISTING ESP EQUIPPED MWCs

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## ABSTRACT

A number of municipal waste combustors [MWCs] built before the mid-1980's, when local permitting processes resulted in the application of acid gas control technology, were equipped with electrostatic precipitators to minimize particulate emissions and comply with the then applicable New Source Performance Standards for Municipal Waste Incinerators (40 CFR 60, Subpart C). Polychlorinated dibenzo-p-dioxins and dibenzofurans [PCDD/F] emissions can be minimized from these facilities by improving combustion to minimize furnace carryover and flame formation. Unfortunately, this can do nothing about the gas and particle phase formation of PCDD/F when the products of combustion are held in the "dioxin formation window"--250 to 400°C or 482 to 752°F.

A proof-of-concept demonstration test program was conducted under the direction of the ASME Research Committee on Municipal and Industrial Waste by the ASME Center for Research and Technology Development. The work was supported by the United States Department of Energy's [DOE] National Renewable Energy Laboratory [NREL] and several electrostatic precipitator [ESP] equipped facilities. The purpose of this program is to demonstrate that flue gas temperature entering existing ESPs can be practically reduced below 175°C (350°F) to minimize PCDD/F formation in the air pollution control system [APCS]. At the same time, the performance of powdered activated carbon [PAC] and dry acid gas control reagent injection are demonstrated to establish the practicality of bringing existing ESP-equipped MWCs into compliance with the USEPA's Emissions Guidelines without scrapping the sunk investment in functional, high efficiency ESPs. The practical difficulties to be overcome include avoiding surface wetting (which leads to plugging and accelerated wastage) while reducing the APCS inlet temperature enough to minimize PCDD/F formation and enable the PAC to polish the effluent.

The test program includes baseline testing to establish as-is conditions as well as an extensive battery of tests at different APCS operating temperatures, with and without acid gas reagent and PAC injection. Emissions testing utilizes Methods 23, 26 and 29. CEMS are employed to monitor routine combustion parameters, $SO_x$ and $NO_x$. Plant operating data are captured for the test period.

## INTRODUCTION

On December 19, 1995, the USEPA promulgated final air standards for municipal waste combustors [MWCs]. These standards regulate the emitted concentration of criteria and hazardous air pollutants listed in Section 129 of the Clean Air Act. These regulations have taken a long time to develop and along the way many stakeholders have become involved. As a result of this effort, requirements to control PCDD/Fs, mercury and acid gases (HCl and $SO_2$) to very low levels have emerged.

There are at least 54 existing MWC units in 25 plants that are jeopardized by the new regulations. These facilities were built before dry scrubbers and ultra-high efficiency electrostatic precipitators [ESPs] or fabric filters became the ***de facto*** standard for MWCs in the mid-1980's prompted by state environmental impact hearing processes and national carryover via Federal Prevention of Significant Deterioration regulations. These facilities, which serve a useful function in their communities, are equipped with ESPs and need to find an economical way to meet the new standards without wasting the residual value in the APCS that exceeded regulatory requirements when they were built. The problem is particularly acute for the large waste-to-energy plants with MWC units smaller than 250 TPD that are currently equipped with dry (duct) sorbent injection [DSI] and ESPs. These plants have already made a significant investment that achieves much of the new emissions limitations. The incremental cost effectiveness of retrofitting these facilities is much worse than ESP-only plants because a nominal 50% acid gas control is already being achieved.

In an effort to assist communities operating ESP-equipped MWCs, 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 to conduct a proof-of-concept demonstration test on an innovative method of achieving the Emissions Standards in these facilities. This program is intended to demonstrate the technical performance and viability of flue gas temperature control in combination with dry acid gas reagent and activated carbon injection at an existing MWC equipped with an ESP.

## APPROACH TO PROGRAM

*The Facility*

This experimental program was conducted at the Davis County Energy Recovery Facility [Davis ERF] in Layton, Utah between November 17 and 28, 1995. The Davis ERF is a nominal 420 TPD (2 by 210 TPD) MWC that uses a back pressure turbine to generate electricity and export steam to neighboring Hill AFB. The facility has refractory wall Seghers (combination rocking and sliding grate) furnaces and Zurn waterwall waste heat recovery boilers rated to raise 51,344 lb/hr of 500°F, 500 psig steam.

The Davis ERF was built with a powdered limestone furnace injection system. After much experimenting with injection location and reagent, Trona (a natural sodium reagent--sodium sesquacarbonate--used for acid gas control and as a cattle feed supplement) is now injected between the boiler outlet and economizer through a rapid dispersion lance system that achieves virtually full duct coverage in a few feet. Particulate emissions are controlled by a three-field Environmental Elements ESP with a specific collector area of about 400 $ft^2$/1000 acfm when operating at MCR steam flow and 430°F. The facility has a Foxboro DCS and a DEC Micro VAX data historian.

**Temperature Control**

While dioxin formation is not yet well understood, there is considerable phenomenological evidence that once good combustion has been achieved, the predominant mechanism is *de novo* synthesis. This synthesis may take place in the gas phase, on catalyzed surfaces, or within the bulk of particulate. Regardless of the actual mechanism, laboratory data indicates that a formation window exists. Below 250°C (482°F or a standardized inverse absolute temperature of 1.91), the formation reaction is slow; above 400°C (752°F or a standardized inverse absolute temperature of 1.49), the destruction reaction overwhelms formation. Between 250 and 400°C, the two reactions compete and laboratory tests point towards a maximum net formation around 325°C (617°F) or a standardized inverse absolute temperature of 1.67. Figure 1 shows the relationship exhibited between PCDD/F concentration and APCS outlet temperature at 75 MWCs. While the data are noisy, indicating that phenomena other than temperature are important, the effect of temperature on PCDD/F concentration is clear.

Water spray humidification is successfully used to reduce flue gas temperatures at several North American MWC facilities, including the Greater Vancouver Regional District Facility in Burnaby, British Columbia; Peel Resource Recovery Inc. [PRRI] near Toronto, Ontario; and Quebec City, Province of Quebec, Canada. Each of these facilities have large reaction vessels where the water is evaporated and dry acid gas control reagents are subsequently added. Fabric filters are used for particulate control. Residual, unevaporated water droplets in the gas stream led to early operating problems in the Burnaby installation. Water spray nozzle selection was considered an important design aspect for both the Quebec City and PRRI installations. Even so, at PRRI, poor sprays in combination with inadequate attention to vessel insulation and access hatch sealing led to rapid wall failures that have now been resolved.

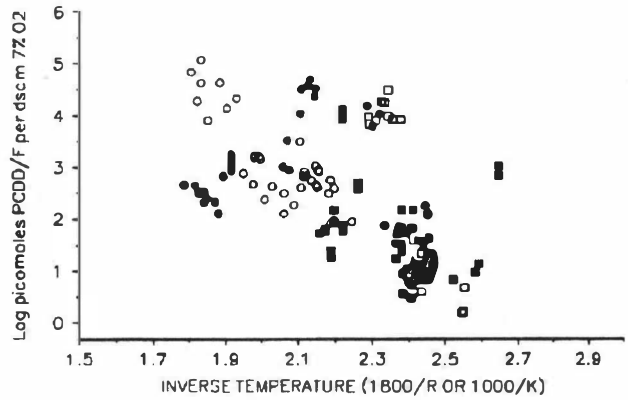


Figure 1. Relationship between dioxin concentration and inverse flue gas temperature.

Water injection has not proven to be reliable at ESP equipped facilities. Jones (1993) reports that SPSA (Portsmouth, VA) experienced ESP plugging when pressure sprays were used to reduce the flue gas temperature entering the precipitator. At the Davis ERF, the economizer outlet plugged after 10 to 14 days of operation with pressure water spray injection into the duct downstream of the economizer. The problems in both cases appear to be related to both the location where the water must be injected and the time available for the water to vaporize. Both installations have relatively closely coupled ESPs that limit the time for the water to evaporate. The Davis ERF may have also experienced problems with the spray nozzles becoming plugged on the inside or blinded from the outside. Such conditions would allow water to stream and drip if undetected.

To overcome these known problems, an atomization system that economically and reliably delivers a very fine water spray is required. The atomizer design criteria, based on gas retention time and the system geometry shown in Figure 2, requires a spray system that produces a 25 micron Sauter mean diameter droplet. This size droplet is expected to evaporate within 0.4 seconds, about 7 feet. Sufficient water addition is needed to reduce the flue gas temperature from 430°F to 285°F, without wall impingement.

To produce droplets of the required size, bi-fluid atomizers were selected. Both air and steam atomization were investigated and found to be potentially suitable. Air atomizers require large compressors; steam atomizers require code piping.

The Davis ERF demonstration test employed air atomization to meet installation time requirements and to minimize the demonstration cost. 150 scfm of air was delivered at 100 psig through a spiral wrapped BARRACUDA hose rated at 150 psig at 450°F.

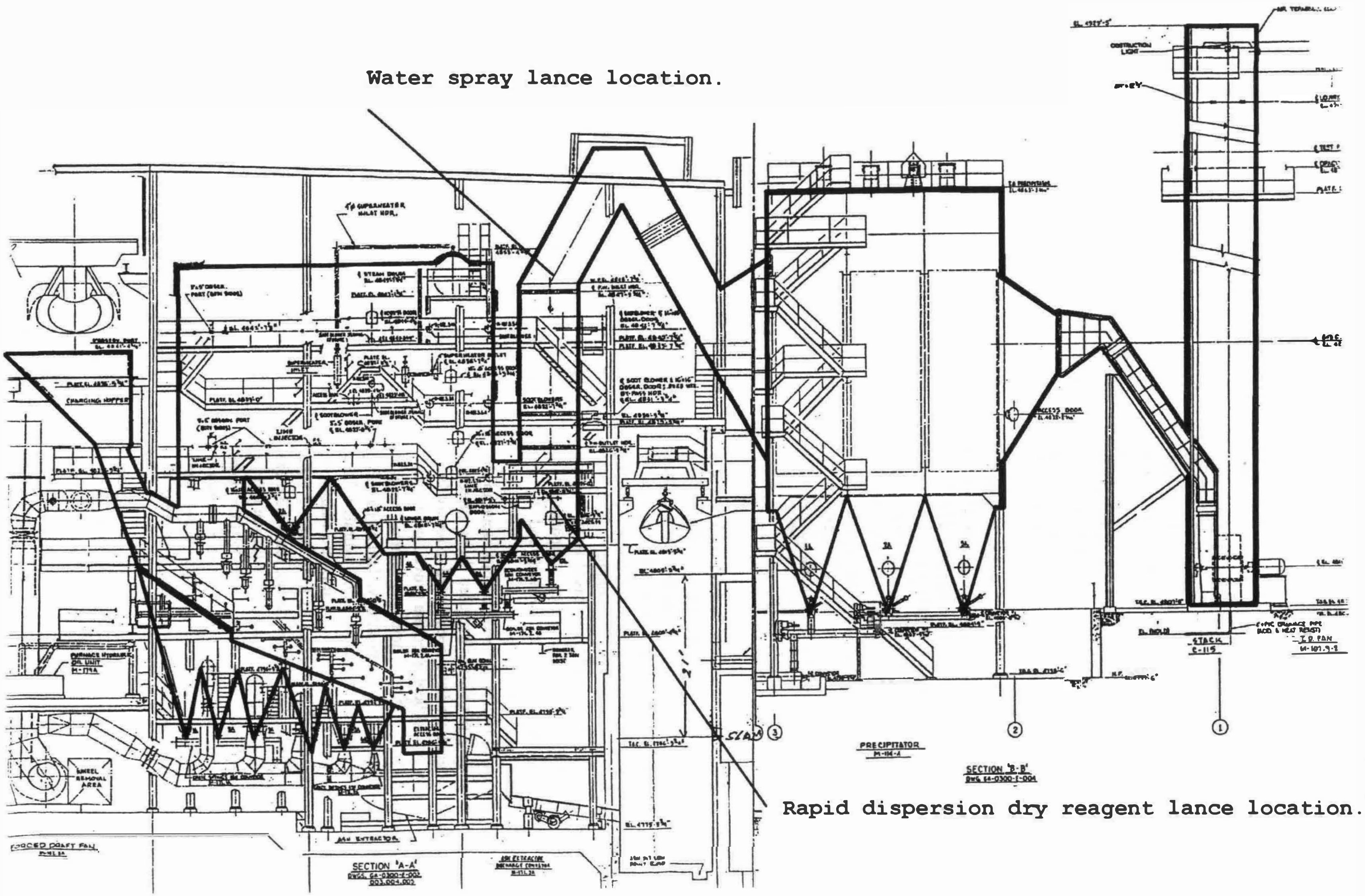


Figure 2. Plant cross section for Davis Co. E R F.

The spray lance shown in Figure 3 is built around a 3" Schedule 40 steel supply pipe with a ½" Schedule 40 water supply pipe. The air supply pipe diameter was selected so that no branch connection to the atomizer nozzle would exceed 10 percent of the air duct diameter. A smaller pipe could be used, but flow balancing could become a problem and careful design employing velocity regain methods would be required. Three Bete Fog Nozzles, Inc. nozzles are used. The outer two nozzles produce a 60° spray angle (BETE SA308) and the center nozzle a 90° spray angle (BETE SA310).

A digital vortex flow meter is installed in the ½" water supply line to monitor flow. It is also used to provide an alarm signal if a nozzle head is lost and too much flow occurs. An automatic control valve is used to modulate water flow and maintain a set gas temperature at the ESP exit.

Thermodynamic calculations indicate that about 9 gpm of water is needed to reduce the flue gas temperature from 430°F to 285°F for each of the Davis ERF MWCs burning 210 TPD. Nominal stack flow is on the order of 35,000 dsft$^3$. To ensure the required atomization, the water is preheated to about 175°F via a water heating loop. Heated water has a lower viscosity, hence, finer spray for the same atomizing conditions. Field results indicate that about 1 gpm achieved a 20°F temperature reduction at this plant, right in line with the calculated result.

**Sorbent Addition**

The Davis ERF is equipped with a dry sorbent injection system to add acid gas reagent to the flue gas stream. The sorbent of choice at Davis is Trona, sodium sesquacarbonate, a natural sodium based acid gas control reagent that is used as a cattle feed supplement. It is available locally at much more favorable pricing than either lime or sodium bicarbonate. The stochiometric Trona addition rate is 155 lb/hr based upon historic uncontrolled HCl and $SO_2$ concentrations. For comparison, the stochiometric sodium bicarbonate rate is 110 lb/hr and the stochiometric hydrated lime rate is 76 lb/hr.

While originally designed to inject powdered limestone in the furnace throat, Trona and powdered hydrated lime injection before and after the economizer have been tested extensively at the Davis ERF after furnace sorbent injection proved ineffectual. Trona was found to be an effective acid gas control reagent during testing conducted in 1993. Interestingly, Trona proved to be more effective on HCl than hydrated lime; hydrated lime proved more effective on $SO_2$ than Trona. A mixture cannot be used since Trona and hydrated lime react to form caustic soda which solidifies in the system. On balance, Trona removed more total acid gas than the hydrated lime at the tested addition rates.

The Trona must be calcined--$CO_2$ driven off--to maximize effectiveness. Hence, it is injected at the inlet to the economizer downstream of the boiler, before the location of the water spray lance discussed above. At this point, the flue gas temperature is about 620°F.

Carbon injection has been successfully tested for mercury reduction at MWCs. Several reports also suggest that improved PCDD/F emission reductions in dry sorbent injection equipped MWCs occur with the injection of powdered activated carbon [PAC]. Analysis of available test data suggest that for this ESP equipped facility the PAC addition rate needs to be in the range of 15 lb/hr for optimal PCDD/F removal. There is a knee in the removal efficiency curve for both PCDD/F and mercury removal. Adding PAC above the amount indicated by the inflection point is much less economically efficient. However, since the purpose of this test is to demonstrate that an existing ESP-equipped MWC can be relatively easily modified to meet the proposed NSPS for PCDD/F and mercury, a second addition rate of 30 lb/hr was selected to provide an injection rate that should definitely meet the promulgated regulatory requirements.

PAC can either be obtained separately or pre-mixed with the acid gas sorbent of choice. If the correct mixture is known, pre-mixed versus separate feed systems is a facility specific economic decision. For test purposes, however, the ability to adjust the mixture to alter experimental conditions dictates that separate systems be used.

Further, there are indications that sulfur or iodine impregnated PAC can perform better than ordinary PAC in some applications. Based on the lack of significant overall performance differences reported by Richman, et al. (1993) for MWCs using ordinary and sulfur augmented PAC, finely divided ordinary activated carbon was chosen for this demonstration. Again, site-specific experience and economics may dictate a different choice.

The PAC supplied by NORIT (DARCO FGD) was made from bituminous coal and pulverized to pass a 325 mesh screen. 900 pound bags of PAC were metered through a PortaPAC dosing unit equipped with a calibrated Acrison, Inc. (Model FHMO1262) screw feeder. The PAC was dropped onto an enclosed, rubber peg belt CAMBELT conveyor with side skirts and conveyed to the suction side of the Trona injection system eductor. The conveyor has a 12° up-angle. The discharge hopper sides were between 50° and 65° from the horizontal to minimize bridging.

The Trona and the PAC were combined at the eductor in the plant's 10 psig DSI pneumatic conveying system. It was injected into the duct below the economizer through the rapid dispersion lance displayed in Figure 2.

**Experimental Design**

The program objectives were:

- to determine the actual emissions reduction achievable by a combination of ESP inlet temperature control, acid gas reagent injection and activated carbon addition; and
- to demonstrate that ESP inlet temperature control can be reliably accomplished during the test program and the 2 months immediately following.

To accomplish the program objectives, a fractional factorial (3 x 4) test plan with one designed replicated test condition was developed. Since the purpose of this test is to demonstrate achievement of 40 CFR 60 Subpart Cb emissions guidelines, the replicate was assigned on engineering grounds to the operating configuration judged most likely to reliably achieve the program objective.

The order of testing was developed by randomizing a 3 x 3 matrix that excluded the no acid gas reagent condition. The high temperature, low activated carbon addition test was assigned to the high temperature, no reagent or activated carbon test

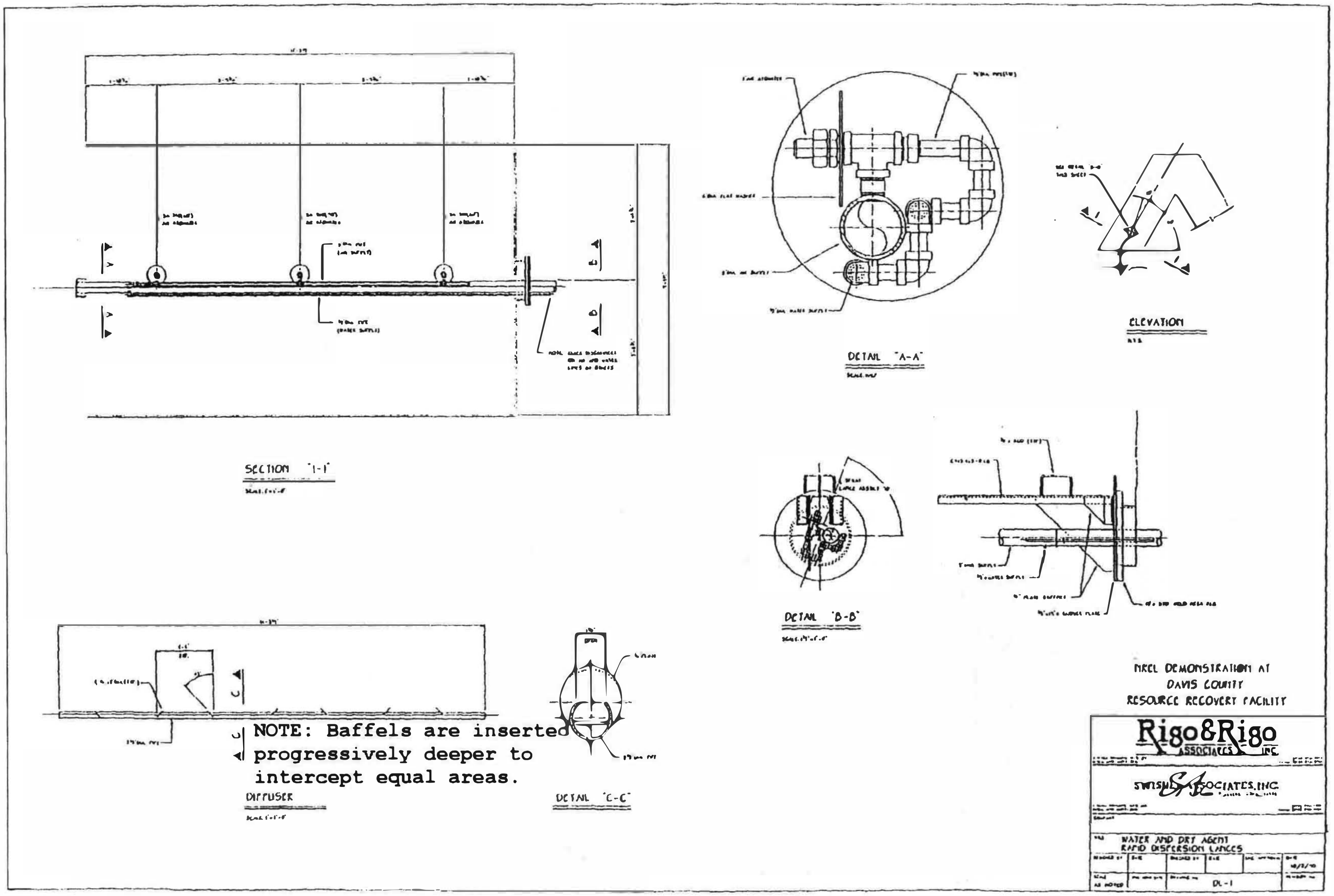


Figure 3. Water spray cooling and rapid dispersion dust lance designs.

condition to provide additional uncontrolled baseline data. This test condition is designed to determine what effect acid gas reagent addition alone has on PCDD/F emissions in this facility. The test matrix is provided in Table 1.

This is an unbalanced experimental design that makes maximum use of the available test runs. Data reduction is slightly complicated because traditional fractional factorial designs do not include partial replicates and utilize different patterns. Mathematical tools exist to interpret this data. The selected pattern enables the fitting of a theoretically based predictive equation to the data so that interpolation to other conditions can be performed.

Table 1. Test plan matrix showing test conditions by day.

| TEST CONDITION | TEST DAY | | |
|---|---|---|---|
| TEMPERATURE of ESP / REAGENT ADDITION | Normal Ops 430°F | Intermediate 350°F | minimum 300°F |
| No AG reagent or PAC | 3 | -- | -- |
| AG reagent only | 1 | 9 | 6 |
| AG reagent + low PAC | -- | 8 | 10 |
| AG reagent + high PAC | 2 | 4, 7 | 5, 11 |

**Test Regime**

The same daily schedule was followed throughout testing. After setup was completed, the test conditions for the next day were established early in the evening. Setup for the day's testing commenced early in the morning, with the PCDD/F testing commencing first, followed about one hour later by the start of metals testing, once the first port was cleared, non-traversing acid gas testing commenced. At the completion of the acid gas run, the sampling trains were turned around and the process was repeated with testing completed about 6 p.m. each night.

Sampling included:

- PCDD/F utilizing Method 23;
- Particulate and Trace Metals utilizing Method 29 with ICAP analysis for Cd and Pb in particular and CVAA for Hg determinations;
- Hydrogen Chloride using Method 26A and determinations for both HCl and $Cl_2$;
- Sulfur dioxide using Method 6C; and
- Oxides of Nitrogen using Method 7E.

Test runs were of two hours in duration to allow two complete sets of runs each day. This duration was considered adequate to demonstrate that the total PCDD/F concentration was below the 60 ng/dscm @ 7% $O_2$ standard. Duplicate runs enable inconsistent and aberrant data to be identified.

During the test period, plant operating conditions were monitored and recorded continuously using the process monitors and the data historian. These results were translated into Excel files for analysis. 15 minute average process data were collected for the week prior to testing, throughout testing, and for the week following testing.

Ash samples were collected from the ESP along with combined bottom ash and APCS residue following the plant's residue sampling protocol.

**Data Handling and Analysis**

The plant operating data, including the APCS parameters such as water and Trona flow rates and PAC dosing rate, were entered into a master data spreadsheet along with the sampling test information and the results of all laboratory analyses. Using one master spreadsheet avoided the possibility of correcting field or laboratory data in one place in the report but overlooking the same problem in other parts of the report. The summary statistics for each test were generated within the spreadsheet. Commercial statistical analysis packages (SPSS\PC+ and SYSTAT) were used for detailed analysis and exploration of the data.

To evaluate the overall performance of each test condition, multiple linear regression based Analysis of Variance [ANOVA] were conducted (Draper & Smith, 1987). Adsorption performance models (PAC effects) were based on Langmuir adsorption isotherms for mercury and dioxin removal. Activated carbon feed rate was included as a pair of binary variables to indicate whether 0, 15 or 30 lb/hr were being added. Trona injection rate was treated as a binary variable since all tests with Trona injection were conducted with a nominal 150 lb/hr addition rate. Binary variables were used instead of normalized feed rates in $mg/dsm^3$ @ 7% $O_2$ since real time feed back is not required at the Davis ERF and normal operations call for injecting a minimum amount of reagent. As the flue gas flow fluctuates with changing excess air and steam flow, so does the reagent concentration. Normalized inverse absolute temperature (1800/°R which equals 1000/°K) was used to account for temperature effects.

It is important that operations be normal during testing since continuous compliance is the objective. The similarity of normal operations and test conditions was established using box plots to compare the range of 15 minute readings obtained outside test periods to those collected during tests. Based on statistics developed for The WASTE Program (1993) from Gabriel (1985), as long as the boxes which represent ±1 standard deviations from the median overlap, there is a 95 percent probability that the operating conditions are the same.

## FINDINGS AND CONCLUSIONS

At this time, the field data have not been returned from the laboratory. Consequently, only a few observations can be made.

The water spray lance worked well. The 6" washer around the spray nozzles could be increased on future lances to minimize fly ash build-up around the nozzle head. The heads themselves were free of ash, but the washers were caked with a soft covering after three days of operation. The final water connection was made using a rubber hose with Chicago fittings and seems satisfactory. The final air connection used 3" rubber hose with a compression fitting. Special clamps were required to keep the hose connected to the quick-disconnect. Lighter 150 psig rated hose was originally tried; but it failed explosively at the joints. The 150 psig, 450°F BARRACUDA spiral wrap was finally employed. A plug valve was used to control the water flow from the 230 psig pumps to the nozzle. Due to the back pressure, the plug valve opened at 3.5 gpm of flow and was wide open at 12 gpm. A different control valve type is indicated.

The ESP performed well. To avoid confounding the experiment, the controllers on each of the three fields were not adjusted. Under normal operation, the first two fields display a spark rate around 230 sparks per minute and 23 kV potential differences; the third field ranges between 0 and 100 sparks per minute. This was not affected when PAC was introduced at 30 lb/hr or when the Trona addition was stopped. With the water spray atomization system in use, the spark rate in the first two fields dropped dramatically (averaging 30 and 120 sparks per minute) and the third field stayed mostly in the 0 to 40 spark per minute range. The potential difference rose to 25 to 30 kV and exhibited much less variability. Further, the opacity--usually less than 2 percent--fell below 1 percent with the water sprays in use regardless of the amount of PAC added.

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