Retrofitting ESP Equipped MWCs to Meet the 1995 Emission Guidelines Using Sensible Heat Exchanger Cooling and Dry Reagent Injection

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INTRODUCTION

Many municipal waste combustion (MWC) facilities are equipped with electrostatic precipitators (ESPs) and have no acid gas controls. Latent heat of vaporization (water spray) temperature control combined with Trona (sodium based acid gas control reagent) and powdered activated carbon (PAC) injection[1] met EPA's December 19, 1995 Emissions Guidelines for small plants[2]. A follow-up study to demonstrate similar performance using sensible heat removal (heat exchangers) for enhanced energy recovery along with powdered hydrated lime and activated carbon injection at an ESP equipped MWC was conducted to provide maximum flexibility to facilities needing to come into compliance with these regulations.

In 1995, the authors performed a proof-of-concept testing program at the Davis County Energy Recovery Facility in Layton, Utah under a subcontract from the National Renewable Energy Laboratory (NREL), a U. S. Department of Energy national laboratory to the American Society of Mechanical Engineers. That testing demonstrated that small MWCs equipped with ESPs could meet the EPA's small facility MWC emissions guidelines if the ESP inlet temperature was controlled and dry acid gas reagents and powdered activated carbon were added to the gas stream. Temperature control at the Davis County facility was accomplished by injecting water into the gas stream ahead of the ESP. This method of temperature control produced some operational problems, including particulate deposition in the gas ducts. Another test was conducted in 1996 in which temperature control was accomplished in a facility using extra heat exchangers to reduce the ESP inlet temperature to nearly 300°F from the 425°F traditionally found at MWCs. This testing was accomplished under an extension of the original arrangement with NREL.

Demonstration testing was conducted from December 1-11, 1996 at the 2x120 TPD, ESP equipped MWC at Energy Answers Corporation's Resource Recovery Facility in Pittsfield, MA (EAC/Pittsfield). The test plan was expanded to obtain duplicate metals (Cd, Pb and Hg), particulates, dioxin and acid gas runs at each condition.

Nine distinct emissions control conditions (two ESP operating temperatures, three levels of activated carbon addition and three levels of powdered hydrated lime acid gas control reagent) were planned to be tested during normal plant operations. The no acid gas reagent, no activated carbon (baseline) condition was replicated to provide a measure of reproducibility and experimental error.

During testing, selected plant operations, furnace conditions and Continuous Emissions Monitoring System (CEMS) data were continuously recorded by a digital data acquisition system. CEMS emissions data included NO_x, SO_2, CO, and O_2 both at the stack downstream of a tail-end wet scrubber and immediately after the electrostatic precipitator (ESP) as well as Continuous Opacity Monitoring System (COMS) data at the ESP outlet. The data covers periods of operation before, after testing and during each test run. It was used to demonstrate that the facility was operating normally during the proof-of-concept demonstration testing.

The operating conditions for each test day were established during the previous evening after all testing was completed. Testing activities commenced at dawn each day with sampling starting 3 to 4 hours later. The following emissions were measured at the ESP outlet:

- Front-half particulate matter, metals & mercury — Method 29
- Acid gas (HCl) — Method 26

- Dioxins and Furans (PCDD/F — 2,3,7,8 substituted isomers (congeners) plus homologue totals — Method 23
- Other combustion gases (CO, NO_x, and SO_2) — Methods 6c, 7 and 10 (CEMS)

To obtain replicates in the small rectangular duct leaving the ESP each day, a dual- or quad-probe sampling system had to be used. Duplicate Method 23 and 29 samples were obtained. The average of the duplicate results is used to characterize emissions for each test series. Method 26 used another port as did the Method 7 (CEMS) extractive probe.

For about six hours prior to and throughout sampling, the tested incinerator was run at its rated capacity of 30,000 lb/hr of 500 psig, 515°F steam. The specified ESP temperature (nominally 325 or 350°F) and targeted acid gas reagent (0, 12, 160 and 180 lb/hr of powdered hydrated lime —equivalent to stoichiometric ratios of 0:1, 2:1, 2.5:1 and 3:1) and activated carbon feed rates (0, 4 and 8 lb/hr — equivalent to 0, 100 mg/dsm^3 and 200 mg/dsm^3 were also maintained.

SITE SELECTION CRITERIA

While there is considerable evidence that reducing ESP operating temperature and adding reasonable amounts of acid gas sorbent and activated carbon to incinerator flue gas can theoretically allow existing ESP equipped MWCs to economically meet proposed guidelines; field experience has shown that it is difficult to reliably reduce ESP temperatures using evaporative (water spray) cooling techniques. Phase I testing under this program at Davis County, Utah Energy Recovery Facility demonstrated that dry acid gas sorbent and powdered activated carbon injection resulted in satisfactory performance of existing APCS. It was also demonstrated that the air or steam atomization system had to be carefully designed, located and operated to achieve reliable operation. The question remained, however, if similar emissions control performance could be achieved while recovering additional heat using heat exchangers without water sprays.

HOST FACILITY DESCRIPTION

Although built with three pre-engineered, refractory wall, excess air furnaces of the Enercon design, rated at 120 tons/day each, EAC/Pittsfield is only permitted to run with two of the furnaces on-line. Each furnace includes controlled overfire and underfire airflow, a large loading ram and water cooling of steel components. Dual fuel burners, gas or oil, located in the primary chambers provide initial ignition of refuse and at the exit of the trim economizer preheats the air pollution control system (APCS). These burners are turned off after the MSW fire is established. Primary chamber outlet and waste heat boiler (WHB) inlet temperatures are normally controlled using recirculated flue gas (RFG).

The manifold or tertiary chamber transports the hot gases from the furnaces to the WHBs. The normal gas flow is from both on-line furnaces to both Bigelow WHBs. Each WHB is rated at 30,000 lb/hr at 250 psi and 515°F. Flue gas temperature entering the boiler is maintained in the tertiary chamber with recirculated flue gas to 1,500°F. Boiling and trim economizers serve to heat boiler feed water before it enters the boilers, while reducing flue gas temperature to 350°F at the ESP inlet. Downstream of the ESP, a condensing heat exchanger is used to preheat the 100% boiler make-up and reduce the flue gas temperature below the acid gas saturation point before final flue gas cleaning in a packed bed scrubber.

The facility is equipped with a 4-field ESP designed to achieve particulate levels of 0.015 gr/dsft^3 @ 12% CO_2. Acid gas control is provided by a wet scrubber using a sodium carbonate scrubbing solution located downstream of the ESP and condensing heat exchanger (also called a "raining economizer"). Sampling access exists between the ESP outlet and raining economizer inlet. This is where most of the testing was conducted. Limited simultaneous sampling was conducted in the stack, after the wet scrubber, to provide an indication of the benefits of using a tail-end scrubber.

Figure 1 is a process flowchart of the facility. Table 1 is a heat balance for an individual combustion unit when the facility is burning 4,500 Btu/lb MSW at maximum continuous rating (MCR) conditions, or 120 TPD of MSW burned. The stoichiometric powdered hydrated lime addition rate (based on the plant's historical uncontrolled HCl and SO_2 concentrations) is 64 lb/hr.

Dry hydrated lime (Graybec Calc Inc.) and Powdered Activated Carbon (PAC) (Norit's FGD grade) were delivered to the site in nominal 1,000 kg supersacks. They were out-loaded using calibrated metering screws to a common eductor. The original temporary installation used compressed ambient air and a small commercial eductor. The system plugged rapidly when lime was added even though it was more than satisfactory for PAC-only injection. Air dryers were added and plant air was used on the system, but operating time only increased from 1 to 2 hours. The eductor was replaced by an entrainment device fabricated out of a 2", Schedule 40 cross connection (reagent falls into the top, pipe plug in the bottom to facilitate cleaning, ½" pipe nozzle in one side supplying nominal 10 psig dry air and a 2" pipe connected for exhaust flow from the other side of the entrainment box). This very inexpensive eductor substitute performed without difficulty throughout the balance of the test program.

PROGRAM OBJECTIVE

The objective of this program was to determine the emissions performance level achievable by a combination of ESP inlet temperature control, acid gas reagent injection and activated carbon addition. The target was to meet the emissions guideline requirements for small facilities and to determine if large facility guidelines can be met for particulates, dioxins, SO_2, HCl and mercury using dry sorbent injection technology in conjunction with sensible heat removal temperature control. The emitted concentrations and removal efficiencies are the numeric objectives shown in Table 2.

EXPERIMENTAL DESIGN

To accomplish the program objectives, a fractional 2x3x3 factorial test plan with one replicated test condition was developed. The order of testing was randomized using a 2x2x3 test matrix, but the no acid gas reagent condition was excluded from the overall randomization. To minimize the chance of lime carry-over effects from controlled test conditions to baseline, the baseline runs were scheduled to be conducted the day after a PAC-only run. Due to field exigencies, baseline testing was conducted at the beginning of the test program between the PAC-only and lime plus PAC test conditions to both maximize the applicability of baseline testing to other tests and to accommodate start-up difficulties with the dry powdered hydrated lime handling system.

The unbalanced experimental design provided in Table 3 makes maximum use of the available test runs. Data reduction is slightly complicated by this experimental design since traditional fractional factorial designs do not include partial replicates and utilize a different pattern. Mathematical tools do exist to interpret this data. The selected pattern enabled the fitting of a theoretically based predictive equation for dioxin and mercury control to the data so that interpolation (and limited extrapolation) to other conditions can be performed and the expected performance of a retrofit application determined.

RESULTS

The test matrix is provided in Table 3. The majority of the baseline runs were done under normal operating conditions where the flue gas temperature entering the ESP is less than 330°F. One high temperature run was performed with 4 lb/hr of PAC addition. Acid gas reagent (powdered hydrated lime obtained from Graybec Calc, Inc., Marbleton, Canada) was tested at three nominal temperatures in combination with two different PAC addition rates. A zero PAC, acid gas reagent test was not conducted because this condition provides neither baseline information nor was likely to produce operating conditions in compliance with EPA's December 19, 1995 Emission Guidelines for Existing Facilities.

The first question addressed was how much PAC and lime can be injected before the ESP and still maintain current emissions control performance.

Table 4 is a summary of the particulate and trace metal emissions test results. The particulate concentrations measured at the ESP outlet, the emissions likely to be seen by a MWC equipped with only this emissions control device, are unchanged regardless of the amount of lime or PAC injected. This is not particularly unusual given the comparatively large size of the dry sorbents being injected. Particles larger than 44 µm, those that pass a 325 mesh sieve are visually very fine, but are actually very coarse as far as an ESP designed to control sub-micron particles is concerned. Unfortunately, due to their large size and relative abundance compared to normal particulate loadings from the furnace, the residue take-away conveyors under the first hopper overfilled and plugged. Design modifications to overcome this problem are needed for a successful commercial installation.

As with the particulate results, lead and cadmium are unaffected by the dry injection of lime or PAC. This is the expected behavior since these pollutants are associated with the front-half particulates. Mercury was substantially reduced by the addition of PAC. Lime injection had a negligible effect on mercury emissions. Inspection of the data provides a strong indication that there is a temperature effect with lower temperatures enhancing mercury removal. The nominal 4 lb/h PAC injection rate is equivalent to 100 mg/dsm^3 7% O_2. Three-run average mercury emissions below 50 µg/dsm^3 @ 7% O_2 can be expected with this injection rate over the temperature range tested. This is as predicted by the extrapolated Davis County[3] results.

Dioxin concentrations shown in Table 5 are comparatively low at the ESP outlet due to the low flue gas temperature. With PAC addition, a factor of four reduction in dioxin emissions was observed. It is important to realize that the dioxin concentrations leaving the ESP were already in compliance with EPA's December 19, 1995 Emissions Guidelines for existing ESP equipped facilities. Simple inspection of the table indicates that the reduction is larger with lime injection. This could be real or simply a data artifact since the emitted concentrations are less than the Reference Method Practical Quantification Limit for Total and International Toxic Equivalent (ITEQ) dioxins established by the supplemental simultaneous results performed during this effort.

Other combustion condition related pollutant emissions (CO and NO_x) were unaffected by the addition of PAC.

Dry hydrated lime injection is expected to reduce sulfur dioxide and hydrogen chloride emissions. Reductions were observed in the data displayed in Table 6. Comparison of the results with and without lime injected indicates that using the calculation procedures in Method 19, better than the 50 percent HCl and SO_x removal needed to meet the 1995 Emissions Guidelines for Small Facilities was achieved.

The data in Table 7 include the results of three HCl tests conducted between the boiler and boiling economizer on the last day of testing (e.g. 301-3). This location is upstream of the lime/PAC injection point and represents uncontrolled emissions. Comparing these values to those obtained at the ESP outlet during conditions when no lime was being added to the system suggests that there is either a problem with Method 26 or relatively significant removal, on the order of 30 percent, is occurring across the economizer and ESP as a result of native alkalinity in the fly ash.

CONCLUSIONS

This performance demonstration test was successful. Dry acid gas and mercury reagent injection combined with ESP inlet temperature control are capable of bringing existing ESP equipped MWCs into compliance with EPA's December 19, 1995 Emissions Guidelines for small facilities. Large facility guidelines can be met for all pollutants except acid gases (SO_2 and HCl). Given the amount of acid gas reagent injected during some tests (almost a stoichiometric ratio of 3:1) and the results obtained, it is questionable if sufficient reagent could be injected to achieve the 95 percent HCl removal required by the large plant guidelines without causing particulate emissions exceedances.

Most importantly, ESP performance, while unchanged by dry injection, was not improved. This indicates that the addition of heat exchangers to reduce flue gas temperature while recovering more energy; hence, cover some of the costs of additional pollution control is prudent. However, using water sprays to accomplish part of the temperature reduction also improved ESP performance sufficiently that this effect might justify dealing with the difficulties described in the Davis County report.

Injection of either dry hydrated lime or Trona in combination with powdered activated carbon is capable of meeting the 1995 Small Plant Emissions Guidelines and all but the acid gas reduction requirements for large plants. Dry reagent injection in combination with temperature control is a viable method of extending the life of existing facilities at reasonable cost and seriously considered for plants that must be modified to comply with small plant standards.

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REFERENCES

1. H.G. Rigo and A.J. Chandler, “Retrofit of Waste-to-Energy Facilities Equipped with Electrostatic Precipitators,” (Davis County), an ASME Research Report, CRTD-Vol. 39, April 1996.
2. USEPA, Proposed Standards of Performance for Municipal Waste Combustors and Emission Guidelines for Existing Sources, 60 Fed. Reg. 65,387, December 19, 1995.
3. Op. Cit. Ref. 1, Figure 3.3.

Table 1. Boiler heat balance for EAC/Pittsfield (4,500 Btu/lb reference fuel).

MODIFIED October 21, 1996
Pittsfield Conditons – Individual Unit Balance

FUEL CHARACTERISTICS

C, % by weight	24.89
H2, % by weight	3.22
N2, % by weight	0.34
S, % by weight	0.13
O2, % by weight	19.38
Cl2, % by weight	0.24
H2O, % by weight	31.80
ASH, % by weight	20.00
HHV, Btu/lb	4,500
Fd, DSCF/MBtu	9,113
Fc, DSCF of CO2/MBtu	1,775
Fo, F ratio	1.08

SYSTEM CHARACTERISTICS

Main Steam Flow, lb/hr	30,000
S.H. outlet press.. psig	230
S.H. outlet temp.. deg F	525
S.H.outlet enthalpy, Btu/lb	1,278.0
Feedwater press.. psig	325
Feedwater temp.. deg F	240
F.W.inlet enthalpy, Btu/lb	208.3
Drum press.. psig	275
Drum temp.(sat.) deg F	414
Drum sat vapor enth.,Btu/lb	1,202.6
Drum sat liq. enth., Btu/lb	390.5
Blow Down	1.0%
Misc. Steam Leaks & Losses	1.5%
Fraction of Ash to Boiler	10%
Grate ash discharge temp, F	250
UBC in Fly ash	4%
UBC in Bottom Ash	5%
Residue, lb-residue/lb-fuel	21.0%
Avg temperature of residue, F	241
Unburned Comb. loss, %	2.2
UBC in residue , %	4.9
Gas temp lvg econimizer, F	160
Gas temp lvg air heater, F	160
U.F.A. Steam Heater Rise, F	0
Radiation loss, %	7.0
Sensible heat in residue, %	0.2
Unaccounted for loss, %	1.0
Reference Temperature, F	60
Ambient Air Temperture, F	60
Total Excess Air	80%
Fraction air under grate	70%
Excess Air Supplied by Fans, %	61.5
weight flue gas recirculation	40%
General Air leakage-% of Theo.	18.5%
deNOx Carrier air–% of Theo.	0.0%

MOLES/100 lbs FUEL actually burned
adjustment for UBC as proportion of
heat lost to unburned combustibles

C =	2.027
H2 =	1.563
S =	0.004
O2 =	0.592
N2 =	0.012
H2O =	1.765
Cl =	0.007

THERO. O2 REQ'D, MOL/100 LBS FUEL

For: C + O2 = CO2	2.027
For: 2H2 + O2= H2O	0.781
For: S + O2 = SO2	0.004
For: available O2 & Cl	-0.599
Theo. mols O2 to be supplied	2.213
Wet Theo. Air, lb air/lb fuel	3.082
Mols dry air./ mols O2	4.764
Moles Dry air /lb fuel	0.190
Lb. dry air req'd/lb fuel	5.476
Lb. H2O in air/lb fuel	0.071
Lb. Std. Air req'd/lb fuel	5.547

FLUE GAS ANALYSIS

Moles HCl/ lb fuel	0.00007
Moles CO2/ lb fuel	0.02027
Moles H2O/ lb fuel	0.03716
Moles SO2/ lb fuel	0.00004
Moles N2 / lb fuel	0.15008
Moles O2 / lb fuel	0.01771
Tot. Mols Flue gas/lb fuel	0.22533

FLUE GAS CHARACTERISTICS

Partial Pressures	
P(CO2)	1.322
P(H2O)	2.424
P(SO2)	0.003
Percent by Volume (Orsat)	
% CO2	10.8
% O2	9.4
PPM SO2	211
PPM HCl	352
Gas weights, lb gas/lb fuel	
Lb. HCl/lb fuel	0.002
Lb. CO2/lb fuel	0.892
Lb. H2O/lb fuel	0.669
Lb. SO2/lb fuel	0.003
Lb. N2/lb fuel	4.204
Lb. O2/lb fueL	0.567
Lb. Dry flu gas/lb fuel burnd	5.668
Lb. Wet flu gas/lb fuel burnd	6.337
Flue gas molecular weight	28.126
H2O in gas, % by weight	10.564

MOLECULAR WEIGHTS

Hydrochloric Acid (HCl)	36.46
Carbon (C)	12.01
Hydrogen (H2)	2.02
Sulfur (S)	32.06
Oxygen (O2)	32.00
Nitrogen (N2)	28.01
Water (H2O)	18.02
Chlorine (CL2)	70.91
Carbon Dioxide (CO2)	44.01
Sulfur Dioxide (SO2)	64.06
Carbon Monoxide (CO)	28.01

STANDARD AIR COMPOSITION

O2, % by volume	20.99
N2, % by volume	79.01
H2O, % by weight	1.30
Molecular weight dry air	28.85

ADJUSTMENTS TO HHV FOR DIFFERING CONDITIONS

Sensible Heat in Fuel	Btu/lb	0.0
Sensible Heat in Air	Btu/lb	0.0
Compression Heat	Btu/lb	6.4
Steam Air Heater Input	Btu/lb	0.0
Effective HHV	Btu/lb	4,506

BOILER EFFICIENCY -- ACTUAL	71.6
-- ADJUSTED TO AS-FIRED HHV	71.7%

HEAT LOSS ANALYSIS

Dry gas loss, %	3.0
Water from fuel loss, %	15.0
Moist. in air loss, %	0.1
Total losses, %	28.4

BOILER OUTPUTS

Feed Water Flow	30,303
Blowdown flow, lb/hr	303
High press. h/out-h/in, Btu/lb	1,070
Blowdown : h/out-h/in, Btu/lb	182
High press. duty, Btu/hour	32,089,050
Blowdown duty, Btu/hour	55,188
Total Boiler Output, Btu/hour	32,144,238
Lb-steam/Lb-fuel	3.01
Fraction of Combustibles Burned	97.86%

BOILER FUEL, AIR, & FLUE GAS FLOW RATES

Fuel flow rate–tons per day	120
Fuel heat input, Btu/hr	44,905,027
Fuel flow rate. lb/hr	9,965
Total air to boilers, lb/hr	55,273
Flue gas leaving boiler system, lb/hr	63,150
Air leakage, lb/hr	5,671
Thermal DeNox Carrier Air,lb/hr	0
undergrate air flow, lb/hr	34,722
overfire air flow, lb/hr	14,881
Flue gas recirculation, lb/hr	25,260
Flue gas leaving economizer, lb/hr	88,410
Total residue generation rate, lb/hr	2,096

Table 2. Target emissions control objectives for ESP equipped MWCs.

	Small Plant Guideline	Large Plant Guideline
Dioxins	125 ng/dsm^3	60 ng/dsm^3
Particulates	0.030 gr/dsft^3	0.012 gr/dsft^3
Mercury	80 mg/dsm^3 or 85% removal	80 mg/dsm^3 or 85% removal
SO_x	80 ppm or 50% removal	31 ppm or 75% removal
HCl	250 ppm or 50% removal	31 ppm or 95% removal

All emitted concentrations at 7% O_2, dry, standard conditions (68°F, 760 mm_{Hg}).

Table 3. Overall test matrix -- allocation runs conducted.

ALLOCATION OF TEST RUN CONDITIONS				
REAGENT FLOW		ELECTROSTATIC PRECIPITATOR TEMPERATURE		
LIME lb/hr	PAC lb/hr	<330°F	330-340°F	>340°F
0	0	T07 T08 T09 T10		
0	4	T01		T02
0	8	T03 T04 T05 T06		
120	4	T11	T17	
120	8		T18	T16
160	4		T12	T13
160	8			T14 T15
180	8	T19		

Table 4. Particulate, lead, and cadmium test results.

PARTICULATE CONCENTRATION gr/dsft^3 @ 7% O_2

REAGENT FLOW		ELECTROSTATIC PRECIPITATOR TEMPERATURE		
LIME lb/hr	PAC lb/hr	<330°F	330-340°F	>340°F
0	0	0.032 0.021 0.016 0.025		
0	4	0.030		0.024
0	8	0.017 0.025 0.015 0.011		
120	4	0.038	0.053	
120	8		0.031	0.032
160	4		0.018	0.024
160	8			0.021 0.033
180	8	0.027		

LEAD CONCENTRATION μg/dsm^3 @ 7% O_2

REAGENT FLOW		ELECTROSTATIC PRECIPITATOR TEMPERATURE		
LIME lb/hr	PAC lb/hr	<330°F	330-340°F	>340°F
0	0	1,591 1,718 1,161 2,108		
0	4	2,490		2,346
0	8	1,697 2,034 1,244 1,202		
120	4	2,515	2,456	
120	8		1,430	1,351
160	4		946	1,461
160	8			1,438 1,805
180	8	703		

CADMIUM CONCENTRATION μg/dsm^3 @ 7% O_2

REAGENT FLOW		ELECTROSTATIC PRECIPITATOR TEMPERATURE		
LIME lb/hr	PAC lb/hr	<330°F	330-340°F	>340°F
0	0	70 86 51 64		
0	4	73		60
0	8	50 54 48 58		
120	4	86	74	
120	8		51	40
160	4		28	42
160	8			37 59
180	8	32		

Table 5. Mercury test results and estimated removal efficiency.

MERCURY CONCENTRATION μg/dsm^3 @ 7% O_2

REAGENT FLOW		ELECTROSTATIC PRECIPITATOR TEMPERATURE		
LIME lb/hr	PAC lb/hr	<330°F	330-340°F	>340°F
0	0	13 239 240 151		
0	4	93		13
0	8	16 6 7 11		
120	4	45	26	
120	8		21	17
160	4		31	89
160	8			22 25
180	8	15		

MERCURY REMOVAL EFFICIENCY

REAGENT FLOW		ELECTROSTATIC PRECIPITATOR TEMPERATURE		
LIME lb/hr	PAC lb/hr	<330°F	330-340°F	>340°F
0	0			
0	4	65%		95%
0	8	94% 98% 97% 96%		
120	4	83%	90%	
120	8		92%	93%
160	4		88%	66%
160	8			92% 91%
180	8	94%		

Table 6. Dioxin, oxides of nitrogen and carbon monoxide test results.

TOTAL DIOXIN CONCENTRATION ng/dsm^3 @ 7% O_2

REAGENT FLOW		ELECTROSTATIC PRECIPITATOR TEMPERATURE		
LIME lb/hr	PAC lb/hr	<330°F	330-340°F	>340°F
0	0	20.9 36.6 22.2 17.6		
0	4	10.3		~~4.1~~
0	8	6.0 3.6 5.2 ~~1.8~~		
120	4	~~12.0~~	3.3	
120	8		1.5	1.9
160	4		2.5	2.7
160	8			1.6 2.0
180	8	1.2		

TOTAL DIOXIN REMOVAL EFFICIENCY

REAGENT FLOW		ELECTROSTATIC PRECIPITATOR TEMPERATURE		
LIME lb/hr	PAC lb/hr	<330°F	330-340°F	>340°F
0	0			
0	4	68%		~~87%~~
0	8	81% 89% 84% ~~94%~~		
120	4	~~62%~~	90%	
120	8		95%	94%
160	4		92%	92%
160	8			95% 94%
180	8	96%		

OXIDES OF NITROGEN CONCENTRATION ppm$_{dv}$ @ 7% O_2

REAGENT FLOW		ELECTROSTATIC PRECIPITATOR TEMPERATURE		
LIME lb/hr	PAC lb/hr	<330°F	330-340°F	>340°F
0	0	98 165		
0	4	152		100
0	8	162 90 99 86		
120	4	90	98	
120	8		91	93
160	4		89	86
160	8			94 98
180	8	157		

CARBON MONOXIDE CONCENTRATION ppm$_{dv}$ @ 7% O_2

REAGENT FLOW		ELECTROSTATIC PRECIPITATOR TEMPERATURE		
LIME lb/hr	PAC lb/hr	<330°F	330-340°F	>340°F
0	0	9.7 7.1		
0	4			8.9
0	8	5.2 3.1 7.5 2.2		
120	4	4.9	3.8	
120	8		7.6	6.9
160	4		3.2	6.9
160	8			5.3 4.0
180	8	6.4		

Table 7. Sulfur dioxide and hydrogen chloride test results.

SULFUR DIOXIDE CONCENTRATION ppm$_{dv}$ @ 7% O_2				
REAGENT FLOW		ELECTROSTATIC PRECIPITATOR TEMPERATURE		
LIME lb/hr	PAC lb/hr	<330°F	330-340°F	>340°F
0	0	101 121		
0	4	237		154
0	8	201 122 67 100		
120	4	101	57	
120	8		83	97
160	4		80	99
160	8			75 76
180	8	84		

SULFUR DIOXIDE REMOVAL EFFICIENCY				
REAGENT FLOW		ELECTROSTATIC PRECIPITATOR TEMPERATURE		
LIME lb/hr	PAC lb/hr	<330°F	330-340°F	>340°F
0	0			
0	4			
0	8			
120	4	48%	70%	
120	8		57%	50%
160	4		59%	49%
160	8			61% 61%
180	8	56%		

HYDROGEN CHLORIDE CONCENTRATION ppm$_{dv}$ @ 7% O_2				
REAGENT FLOW		ELECTROSTATIC PRECIPITATOR TEMPERATURE		
LIME lb/hr	PAC lb/hr	<330°F	330-340°F	>340°F
0	0	448 580 636 485		
0	4	402		463
0	8	285 398 420 457		
120	4	333	403	
120	8		259	502
160	4		118	165
160	8			124 151
180	8	237		

HYDROGEN CHLORIDE REMOVAL EFFICIENCY				
REAGENT FLOW		ELECTROSTATIC PRECIPITATOR TEMPERATURE		
LIME lb/hr	PAC lb/hr	<330°F	330-340°F	>340°F
0	0			
0	4			
0	8			
120	4	39%	26%	
120	8		53%	8%
160	4		78%	70%
160	8			77% 72%
180	8	57%		

Table 8. Test results data tabulation.

							Flue Gas								-- @7% O2 --				
Test Date	Run	lb/h		mg/dsm^3		°F	dsft^3/m	%	%	%	ppm	ppm	ppm	ppm	gr/dsft^3	ug/dsm^3	ug/dsm^3	ug/dsm^3	ng/dsm^3
YYMMDD	Identification	LIME	PAC	LIME	PAC	Stack Temp.	Flow	Moisture	Oxygen	Opacity	Carbon Monoxide	Sulfur Dioxide	Oxides of Nitrogen	Hydrogen Chloride	Front-Half Particulates	Lead	Cadmium	Mercury	Total Dioxin
961201	T01	0	4	0	94	328	18,685	12.1	12.4	3.5		~~237~~	152	402	0.030	2,490	72.7	~~93.0~~	10.3
961201	T02	0	4	0	91	345	17,803	12.1	11.7	3.6	8.9	154	100	463	0.024	2,346	59.7	~~12.5~~	~~4.1~~
961202	T03	0	8	0	205	318	18,598	11.3	13.1	2.6	5.2	~~201~~	162	285	0.017	1,697	49.9	16.5	6.0
961202	T04	0	8	0	199	326	18,532	12.8	12.8	3.1	3.1	122	90	398	0.025	2,034	54.2	~~5.7~~	3.6
961203	T05	0	8	0	175	326	18,870	12.9	11.9	3.7	7.5	67	99	420	0.015	1,244	48.1	6.8	5.2
961203	T06	0	8	0	195	327	19,601	10.8	13.1	4.5	2.2	100	86	457	0.011	1,202	57.8	11.5	1.8
961204	T07	0	0	0	0	324	18,922	11.9	12.0	4.0	9.7	101	98	448	0.032	1,591	70.3	~~13.0~~	20.9
961204	T08	0	0	0	0	328	18,999	11.7	13.0	5.1	7.1	121	165	580	0.021	1,718	85.9	238.7	36.6
961205	T09	0	0	0	0	314	20,028	12.0	14.7	3.8				636	0.016	1,161	51.5	239.6	22.2
961205	T10	0	0	0	0	328	19,626	10.8	13.9	5.8				485	0.025	2,108	64.3	151.3	17.6
961206	T11	120	4	3,358	112	323	19,073	10.5	13.9	1.1	4.9	101	90	333	0.038	2,515	85.6	44.8	~~12.0~~
961207	T12	160	4	3,298	82	339	19,571	12.2	11.7	1.2	3.2	80	89	118	0.018	~~946~~	27.8	30.6	2.5
961207	T13	160	4	3,772	94	348	18,465	11.1	12.4	1.6	6.9	99	86	165	0.024	1,461	42.5	~~88.9~~	2.7
961208	T14	160	8	3,765	188	353	18,607	11.8	12.4	2.8	5.3	75	94	124	0.021	1,438	36.8	21.9	1.6
961208	T15	160	8	3,850	192	351	19,394	10.5	12.9	2.5	4.0	76	98	151	0.033	1,805	59.4	24.8	2.0
961209	T16	120	8	2,913	194	351	18,529	11.8	12.7	4.2	6.9	97	93	502	0.032	1,351	39.8	17.2	1.9
961209	T17	120	4	2,996	100	340	18,994	11.5	13.1	3.5	3.8	57	98	403	0.053	2,456	73.9	26.2	3.3
961210	T18	120	8	2,859	191	335	19,288	11.4	12.8	3.0	7.6	83	91	259	0.031	1,430	50.6	20.5	1.5
961210	T19	180	8	4,252	189	327	19,215	12.5	12.7	2.9	6.4	84	157	237	0.027	~~703~~	32.3	15.0	1.2
961211	BO1	180	12	5,190	346		18,989	13.4	14.1					705					
961211	BO2	180	12	4,383	292		18,989	11.0	12.9					821					
961211	BO3	240	25	6,469	674		18,989	12.1	13.7					638					

Note: Lined through data points are statistical outliers; outlying individual data points are excluded from displayed pair averages displayed.

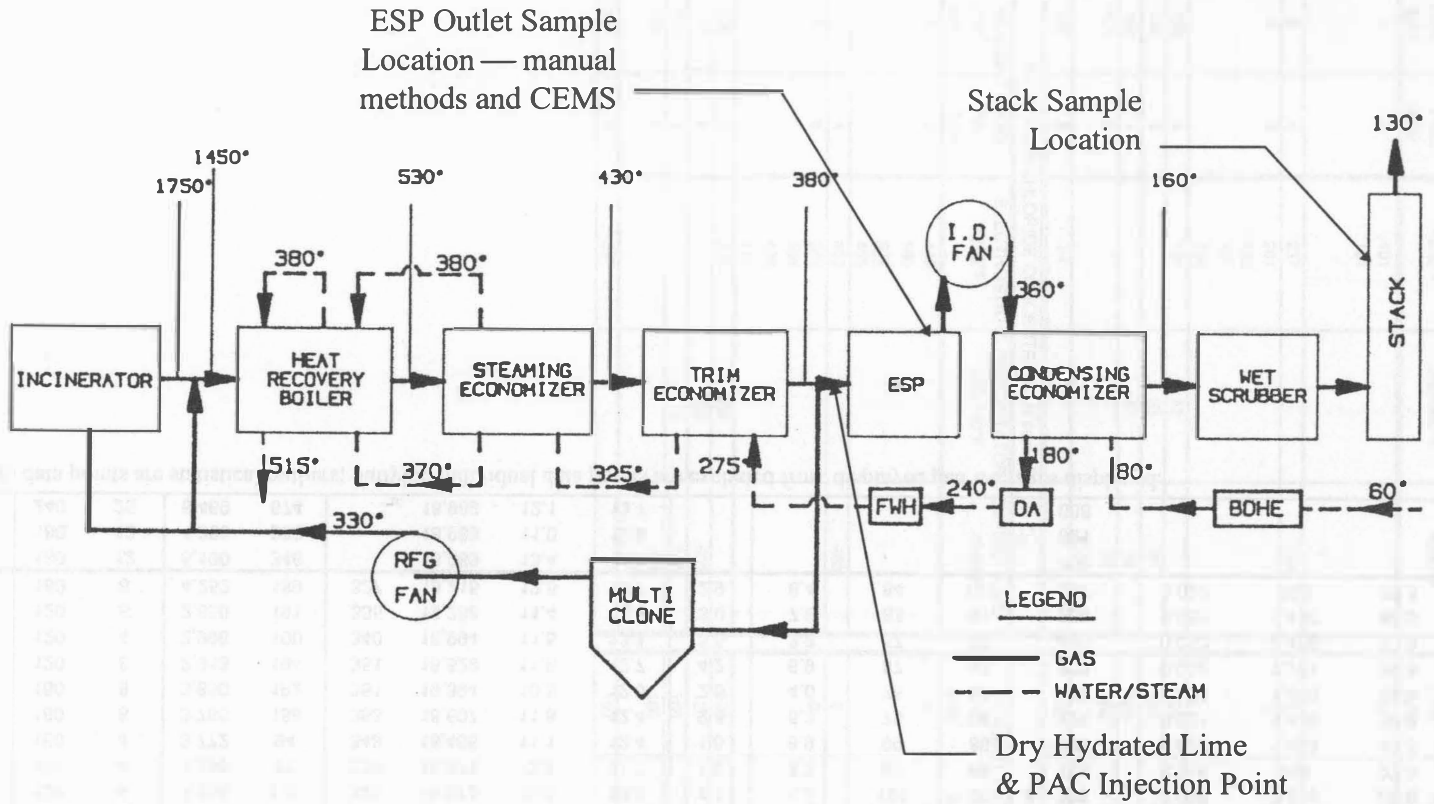

Figure 1. Process flow chart for EAC/Pittsfield.

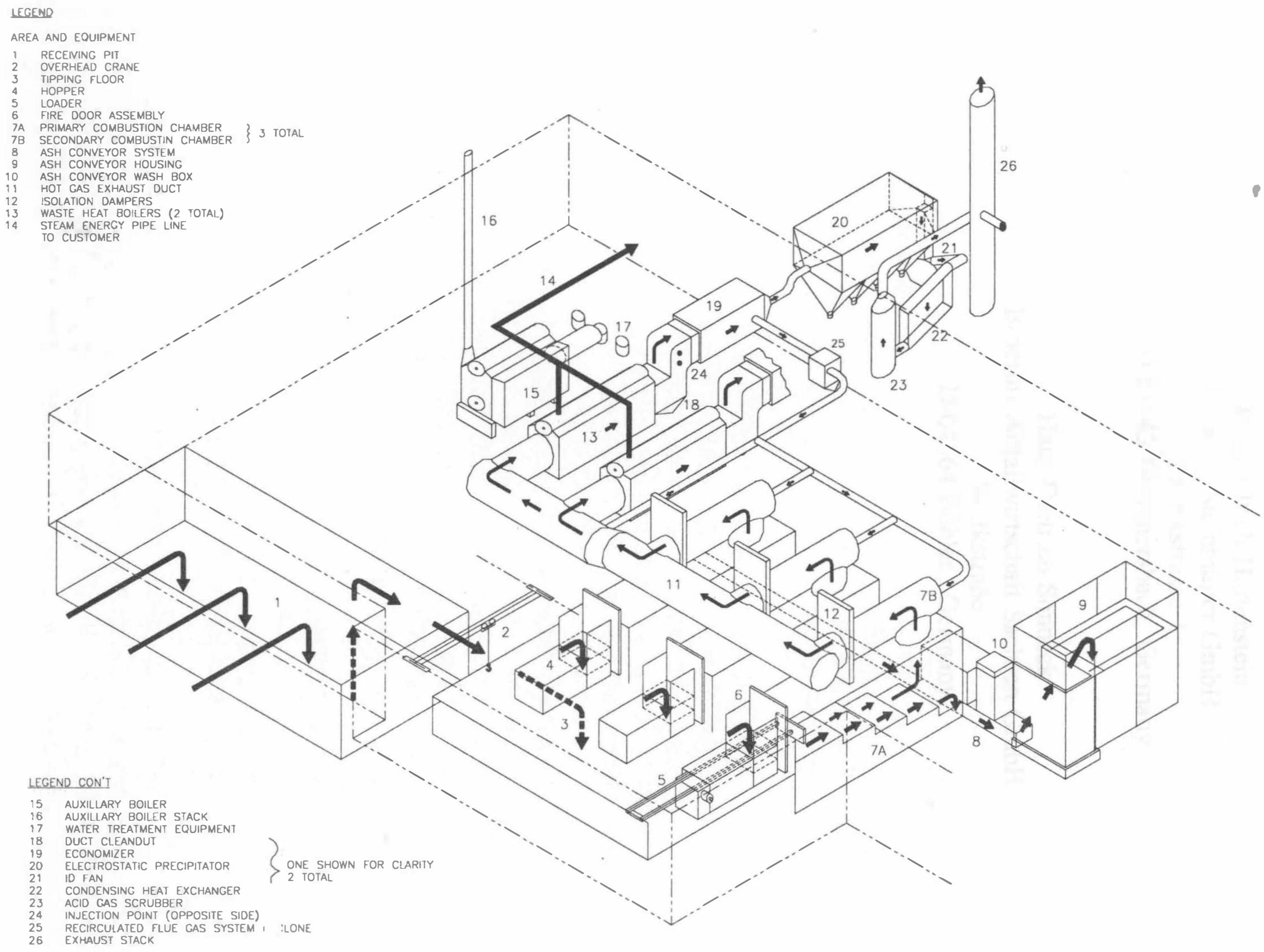

Figure 2. General isometric arrangement drawing of EAC/Pittsfield facility.