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CONTROL OF PCDD/PCDF EMISSIONS FROM REFUSE-DERIVED FUEL COMBUSTORS

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ABSTRACT

This paper presents preliminary results of performance tests conducted at the Mid-Connecticut Refuse-Derived Fuel Facility in February 1989. The objectives of these performance tests were to evaluate the effects of combustion and flue gas cleaning process conditions on air pollution emissions and residue properties.

INTRODUCTION

From January through February 1989, Environment Canada (EC) and the U.S. Environmental Protection Agency (EPA) jointly conducted a comprehensive field test project at the Mid-Connecticut (Mid-Conn) Resource Recovery Facility in Hartford, Connecticut. The primary objective of the Mid-Conn project is to study the relationship of combustion conditions and furnace emissions in refuse-derived fuel (RDF) combustors. Adjunct objectives include the development of correlations between flue gas cleaning (FGC) process conditions and emissions, and the characterization of residue properties. This paper presents a summary of process conditions and polychlorinated dibenzo-p-dioxin and dibenzo-furan (PCDD/PCDF) emissions from 13 performance tests. Some preliminary interpretations of the data are also provided.

TEST FACILITY DESCRIPTION

The Mid-Conn facility is owned by the Connecticut Resource Recovery Authority and operated by Combustion Engineering (CE). The facility contains a processing plant and a RDF power plant.[1] The power plant contains three CE steam generating units, each consisting of a RDF spreader stoker, a natural circulation welded-wall boiler, a superheater, an economizer, and a tubular combustion air preheater. All tests were conducted on Unit 11, which is designed to produce 105 tonnes/h of steam at full load.

The fuel burning system for each unit consists of a RDF injection system, a traveling grate stoker, and a combustion air system (Fig. 1). RDF is pneumatically injected through four ports in the front face of each combustor. The lighter fraction burns "in-suspension" and the heavier falls onto the stoker where combustion is completed. Underfire air is provided at controlled rates to ten zones under the grate. There are two separate overfire air (OFA) systems: a tangential system and a wall system. The tangential system consists of four tangential overfire air (TOFA) windbox assemblies located in the furnace corners. Each TOFA assembly contains three elevations of nozzles which can

be manually adjusted in the horizontal plane. The wall system contains one row of overfire air ports on the front wall and two rows on the rear wall.

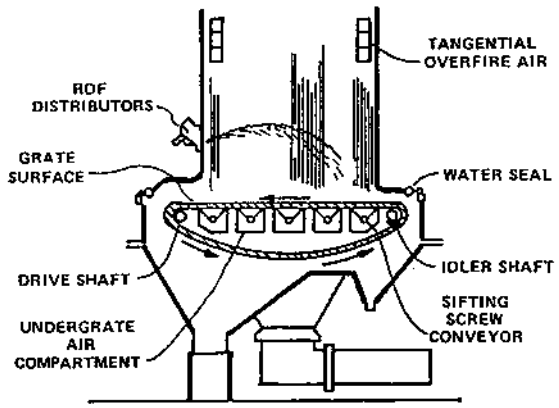

FIGURE 1 COMBUSTION ENGINEERING RDF STOKER BOILER

The flue gas cleaning (FGC) system consists of a lime-based spray dryer absorber (SDA) followed by a reverse air-cleaned fabric filter (FF) or baghouse. The SDA is capable of controlling the temperature at the FF inlet and the sulfur dioxide (SO_2) concentration at the FF outlet. The FF inlet temperature is controlled by the lime slurry flow rate. The SO_2 removal rate is controlled by adjusting the lime concentration in the feed. Each baghouse has 12 compartments, each with 168 Teflon-coated glass fiber bags.

MEASUREMENT METHODS, TEST CONDITIONS, AND TEST RESULTS

All tests were run at slightly de-rated load conditions because of problems with wet RDF and performance of the induced draft fan.[2] Combustion and FGC process test conditions for the performance tests were based on the results of 28 characterization tests conducted in January 1989.[2,3] During the performance tests, a computerized data acquisition system was used to continuously record combustion and FGC process conditions. Continuous emission monitors (CEMs) were used to measure the concentration of oxygen (O_2), carbon monoxide (CO), carbon dioxide (CO_2), total hydrocarbons (THC), hydrogen chloride (HCl), SO_2, and nitrogen oxides (NO_x) at the SDA inlet and FF outlet. CEMs were also used to measure the concentration of CO, HCl, and SO_2 at the "mid-point" between the SDA and FF. Modified Method 5 (MM-5) sampling trains were used to collect organic samples at the SDA inlet and FF outlet during all tests. Organic samples were also collected at the air heater inlet during four tests (PT07, PT08, PT09, and PT10) Method 5 (M-5) sampling trains were used to collect total particulate samples at the SDA inlet and FF outlet. All sampling and analysis was done in accordance with protocols approved by EC and EPA.

The duration of each test was from 4 to 6 hours. Combustion and FGC process conditions were set and the test was begun after stable operating conditions were obtained. The tests were terminated after sufficient volumes of samples had passed through the MM-5 sampling trains.

All PCDD/PCDF, CO, SO_2, and HCl data presented in this paper have been corrected to 12 percent CO_2. All PCDD/PCDF data are given in nanograms per standard cubic meter [25°C, 101.3 kPa(77°F, 1 atm)] as noted by ng/Sm^3.

A total of 14 performance tests were conducted. However, performance test 1 (PT01) did not meet all sampling requirements and the results are not given. Combustion and FGC process conditions were varied independently. The combustion tests were structured to evaluate the effects of good and poor combustion conditions on organic concentrations at the SDA inlet.

The primary combustion test variables were boiler steam load, underfire-to-overfire air ratio, and overfire air distribution. During testing, the criterion for judging good or poor combustion conditions was the CO concentration at the SDA inlet. The effects of load were evaluated by conducting tests at low (L), intermediate (I), normal (N), and high (H) boiler steam flow rates. Underfire-to-overfire air ratios, which influence the relative amount of RDF burned in suspension and the entrainment of particulate matter in the flue gases (particulate matter carryover), were controlled by changing the number of levels of overfire air. Distributional mixing effects were evaluated by changes in the underfire-to-overfire air ratio and by using rear wall overfire air (ROFA) in combination with different levels of TOFA.

Combustion test conditions, in order of increasing load, and the resultant average CO and PCDD/PCDF concentrations are summarized in Table 1. The CO values are averages based on measured values at the SDA inlet and FF outlet. The PCDD/PCDF values are from the SDA inlet.

TABLE 1. COMBUSTION CONDITIONS AND RESULTS

Test No.	Load	Comb.	Overfire Air			CO,	PCDD/PCDF
(PT)	1000 kg/h	Cond.[a]	TOFA[b]	ROFA[c]	OFA%[d]	ppmv	ng/Sm^3 [e]
13	71 (L)	G	2	nil	47	158	599
14	74 (L)	G	2	nil	49	70	428
10	87 (I)	G	2	nil	52	77	667
02	88 (I)	G	2	nil	52	108	946
05	84 (I)	P	1	65	38	903	1861
09	95 (N)	G	2	65	51	92	449
08	96 (N)	G	2	65	48	89	1162
11	96 (N)	G	2	65	52	68	536
07	101 (N)	P	3	nil	51	387	1003
04	98 (N)	P	3	nil	54	214	774
03	99 (N)	P	1	65	44	432	1008
12	117 (H)	G	2	65	53	116	282
06	118 (H)	P	2	nil	57	397	1202

[a] Good (G) or poor (P) combustion conditions
[b] Number of levels of TOFA
[c] Pressure in ROFA plenum, mm Hg
[d] Overfire air as a percentage of total combustion air
[e] Standard conditions: 25°C, 101.3 kPa

The independent FGC test variables (gas temperature at the SDA outlet and SO_2 concentration at the FF outlet) were each held constant at values defined as high (H), medium (M), or low (L) during each test. Combustion and FGC test conditions and the resulting acid gas (SO_2 and HCl) and PCDD/PCDF concentrations at the SDA inlet and FF outlet are presented in Table 2. These tests are listed in the order of improving conditions (poor to good) for acid gas control.

TABLE 2. COMBUSTION AND FGC CONDITIONS AND RESULTS

Test No. (PT)	Combustion Load/Cond.[a]	FGC Cond. Temp./SO_2[b]	SO_2, ppm In	SO_2, ppm Out	HCl, ppm In	HCl, ppm Out	PCDD/PCDF ng/Sm^3 In	PCDD/PCDF ng/Sm^3 Out
09	N/G	H/H	178	189	432	98	449	1.08
04	N/P	H/M	186	44	471	31	774	0.85
03	N/P	H/L	200	13	419	18	1008	0.94
11	N/G	H/L	174	20	413	23	536	0.33
08	N/G	M/H	184	126	538	41	1162	0.75
13	L/G	M/M	175	29	421	18	599	0.38
14	L/G	M/M	189	85	442	20	428	0.03
12	H/G	M/M	198	63	470	17	282	0.14
06	H/P	M/L	192	32	404	10	1202	0.51
02	I/G	L/H	177	110	472	20	946	0.20
05	I/P	L/H	169	132	469	21	1861	1.50
10	I/G	L/M	194	74	429	19	667	0.28
07	N/P	L/L	183	17	399	8	1003	0.31

[a] High (H), normal (N), intermediate (I), or low (L) load. Good (G) or poor (P) combustion.
[b] High temperatures ranged from 166 to 171°C, medium from 141 to 142°C, and low from 122 to 124°C.

INTERPRETATION OF RESULTS

The results of the laboratory PCDD/PCDF analyses were received just prior to the preparation of this paper. The test results have not been fully evaluated and the interpretation of data must be considered as preliminary and incomplete.

Combustion Tests

To minimize furnace emission of PCDD/PCDF, it is postulated that combustion conditions must maximize furnace destruction of organics and minimize the amount of particulate matter (PM) which is carried out of the furnace with flue gases.[4] Maximizing furnace destruction of organics will limit the amount of organic precursors available for PCDD/PCDF formation. Minimizing PM carryover will limit the number of reaction sites (surface area) for surface catalyzed de novo synthesis of PCDD/PCDF which is postulated to occur on the surface of MWC flyash.[5,6]

Furnace emission of CO is a good indicator of combustion conditions. In general high concentrations of CO are associated with high concentrations of organics; low concentrations of CO are associated with low concentrations of organics. High emissions of CO may be due to: intermittent or abnormal RDF feed conditions, insufficient overall amounts of combustion air, excessive overall amounts of combustion air which may lead to low combustion temperatures and increased PM carryover, poor mixing resulting in fuel-rich regions or excessive air levels which quench reactions, and excessive carryover of particulate-bound organics into colder regions of the combustion system before burning is complete.[4]

The highest furnace emission of PCDD/PCDF (1861 ng/Sm^3) was observed during the test (PT05) with the highest furnace emission of CO (903 ppmv). With the exceptions of PT02 and PT08, the furnace emissions of PCDD/PCDF were higher for poor combustion conditions than for good combustion conditions. The high PCDD/PCDF emissions associated with the moderately low CO concentration during PT02 and PT08 are possibly related to higher than normal HCl concentrations and PM carryover rates. The correlation between furnace emission of PCDD/PCDF and CO are

moderately strong (R^2 = 0.704) as shown in Figure 2. This correlation is interpreted to indicate that combustion conditions which lead to high furnace emission of CO also lead to increased formation of PCDD/PCDF. While the emission of CO and PCDD/PCDF is associated with combustion conditions which lead to increased flue gas concentration of organics, a direct causal relationship between CO and PCDD/PCDF emissions is not apparent.

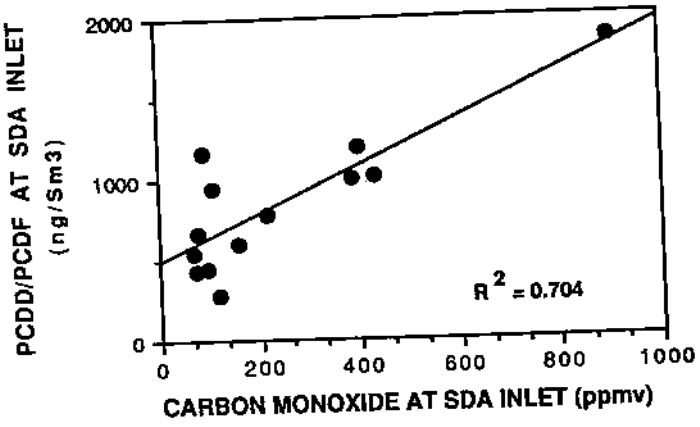

FIGURE 2 PCDD/PCDF VS CO AT SDA INLET

High furnace emission of CO is interpreted to result from poor mixing, or inadequate excess air margins. Poor mixing may result from insufficient overfire air (PT03 and PT05) or from improper distribution of overfire air (PT04, PT06, and PT07). Inadequate excess air margins result when the combustion air demand, which changes with varying RDF feed conditions, exceeds the local supply of combustion air.[2]

It has been reported that PCDD/PCDF furnace emission concentrations are strongly related to the level of PM carryover.[4] Although the Mid-Conn test data show an upward trend in PCDD/PCDF concentrations with increasing PM carryover, there was not a statistically significant correlation (see Figure 3). This is probably because of the rather narrow range of particulate loading for which data were obtained and the effects of other combustion variables which affect PCDD/PCDF emissions.

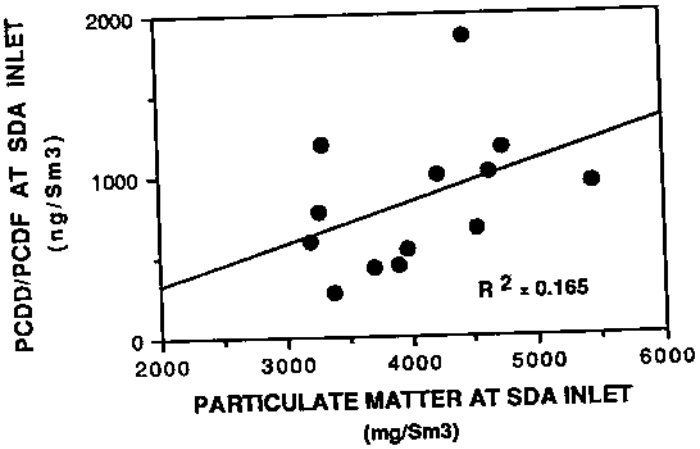

FIGURE 3 PCDD/PCDF CONCENTRATION VS PM CARRYOVER

A substantial increase in PCDD/PCDF concentrations at the air heater outlet (SDA inlet) was expected because gas temperatures in the air heater corresponded to those favoring de novo synthesis of these compounds. The temperature at the economizer outlet (which approximates that at the air heater inlet) typically ranges from 340 to 370°C, while the flue gas temperature at the outlet of the air heater ranges from 175 to 205°C. Contrary to expectations, measurements at the inlet and outlet of the air heater indicated a reduction of PCDD/PCDF concentrations (see Figure 4). This unexpected result may possibly be due to deposition of PCDD/PCDF-laden particulate matter within the air heater, but could not be verified with available data.

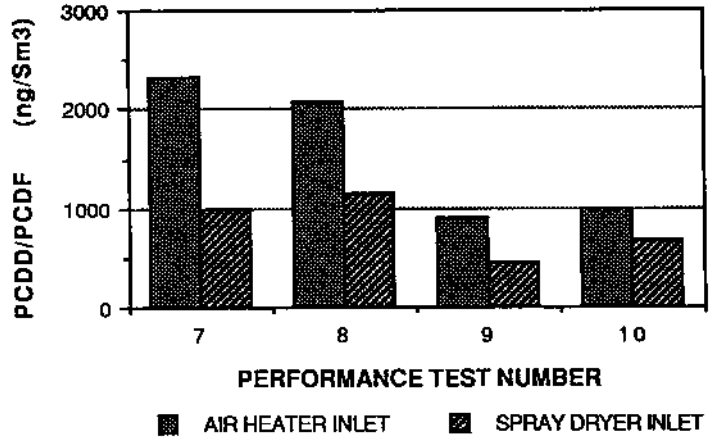

FIGURE 4 CHANGE IN PCDD/PCDF ACROSS THE AIR HEATER

A more complete evaluation of these and other results are needed to provide rational interpretations of the relationships between combustion conditions and furnace emission of PCDD/PCDF.

Flue Gas Cleaning Tests

PCDD/PCDF concentrations at the FF outlet (stack emissions) ranged from 0.03 to 1.50 ng/Sm^3. The PCDD/PCDF emissions were dependent on PCDD/PCDF inlet concentration (combustion conditions), load, SDA outlet temperature, and SDA lime-slurry usage rate (SDA outlet SO_2 concentration). The two highest PCDD/PCDF concentrations were recorded for tests PT05 (which had the worst combustion condition as defined by SDA inlet CO concentration) and PT09 (which had the worst FGC conditions - high temperature and high SO_2 concentration).

Excluding poor combustion conditions, the lowest emissions were obtained when the SDA outlet temperature was less than 145°C and when the SDA lime-slurry flow rate was sufficient to maintain a FF outlet SO_2 concentration less than 85 ppmv. If good FGC conditions are defined as those for which both the SDA outlet temperature and SO_2 outlet concentration are maintained at medium or lower values, then the PCDD/PCDF emissions for all tests with good combustion and good FGC conditions were always less than 0.40 ng/Sm^3.

While the combination of combustion and FGC test conditions leading to low PCDD/PCDF emissions can be identified by this preliminary evaluation, additional analyses must be made to determine the relative effects of individual process conditions in controlling emissions.

CONCLUSIONS

A cursory analysis of the performance test results support the following tentative conclusions:

- Combustor emissions of CO and PCDD/PCDF as measured at the SDA inlet were sensitive to the amount and distribution of overfire air. Combustion air distributions which result in poor mixing and low excess air margins are believed to be the primary causes of increased CO emissions.

- PCDD/PCDF stack emissions of less than 0.40 ng/Sm^3 were achieved at the Mid-Conn Facility when good operating conditions were maintained on both the combustion and FGC processes.

- FF outlet concentrations of PCDD/PCDF are dependent on SDA/FF operating conditions. The lowest emissions were associated with medium to low gas temperatures at the SDA outlet, while the SDA lime slurry flow rate was set to provide medium to low SO_2 concentrations at the FF outlet.

ACKNOWLEDGMENTS

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REFERENCES

1. Boley, G.L. and M.L. Smith. Startup and Operations of the Mid-Connecticut Resource Recovery Project. Paper presented at the International Conference on Municipal Waste Combustion, Hollywood, Florida, U.S.A., April 1989.

2. Kilgroe, J.D. and A. Finkelstein. Combustion Characterization of RDF Incinerator Technology. Paper presented at the International Conference on Municipal Solid Waste Combustion, Hollywood, Florida, U.S.A., April 1989.

3. Brna, T.G. and R.K. Klicius, Characterization of a Lime Spray Dryer Absorber/Baghouse on a Refuse-Derived Fuel Combustor. Paper presented at the International Conference on Municipal Waste Combustion, Hollywood, Florida, U.S.A., April 1989.

4. Nelson, L.P., P. Schindler, and J.D. Kilgroe, Development of Good Practices to Minimize Air Emissions from Municipal Waste Combustors. Paper presented at the International Conference on Municipal Solid Waste Combustion, Hollywood, Florida, U.S.A., April 1989.

5. Hagenmaier, H., H. Brunner, R. Haag, and M. Kraft, Environmental Science and Technology. 21(11):1085, 1987.

6. Stieglitz, L. and H. Vogg, Formation and Decomposition of Polychlorinated Dibenzo-dioxins and -furans in Municipal Waste, Report KfK4379, Laboratorium fur Isotopentechnik, Institut fur Heisse Chemie, Kernforschungszentrum Karlsruhe, Februar 1988.