



## Project Summary

# The Environmental Characterization of RDF Combustion Technology—Mid-Connecticut Facility, Hartford, Connecticut

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The environmental characterization of refuse-derived fuel (RDF) semi-suspension burning technology was undertaken jointly by Environment Canada and the U.S. Environmental Protection Agency (EPA) as part of ongoing programs of both agencies that assess municipal solid waste combustion technologies. The facility tested is located in Hartford, Connecticut, and represents a state-of-the-art technology, including a spray dryer/fabric filter flue-gas cleaning (FGC) system for each unit.

Results were obtained for a variety of steam production rates, combustion conditions, flue gas temperatures, and acid gas removal efficiencies. All incoming wastes and residue streams were weighed, sampled, and analyzed. Key combustor and FGC system operating variables were monitored on a real time basis. A wide range of analyses for acid gases, trace organics, and heavy metals was carried out on gas emissions and all ash residue discharges.

Very low concentrations of trace organics, heavy metals, and acid gases in stack emissions were observed. High removal efficiencies were attained by the FGC system for trace organics and metals in the flue gas. Trace organic contaminants in the residues were not soluble in water, while only very small amounts of most trace metals present in the residues were soluble in water. A significant reduction in metal mobility was achieved for fabric filter residue that was solidified using cement and waste pozzolanic materials. Multi-

variate correlations were found between trace organics at the furnace exit and indicators of combustion conditions, such as operating variables and easily monitored combustion gases. These parameters could potentially be used to control incinerator operating conditions to ensure minimal trace organics in the flue gas entering the FGC system.

*This Project Summary was developed by EPA's National Risk Management Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).*

### Introduction

A joint Environment Canada (EC)/U.S. Environmental Protection Agency (EPA) program to evaluate the combustion and air pollution control systems for a modern RDF combustor was performed on Unit 11 at the Mid-Connecticut (Mid-Conn) facility in Hartford. The test program was conducted with the cooperation and assistance of the owner, Connecticut Resources Recovery Authority (CRRRA), and the operator, ABB Resource Recovery Systems [formerly Combustion Engineering, Inc. (CE)]. It involved characterization and performance test phases. This Summary outlines the 13 valid performance tests and describes the results of combustion system, flue gas cleaning (FGC) system and ash characterization/stabilization evaluations.

## Test Facility Description

The Mid-Conn facility contains a processing plant and a RDF power plant. 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, a tubular combustion air preheater, FGC equipment, and ash handling equipment (see Figure 1) 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 (see Figure 2) 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 10 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 OFA ports on the front wall and two rows on the rear wall.

The 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 ( $\text{SO}_2$ ) concentration at the FF outlet. The FF inlet temperature is controlled by the lime slurry flow rate. The  $\text{SO}_2$  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 Method and Test Conditions

All tests were run at slightly derated load conditions because of problems with wet RDF and performance of the induced draft fan. Combustion and FGC process test conditions for the performance tests were based on the results of 28 characterization tests conducted in January 1989. 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 ( $\text{O}_2$ ), carbon monoxide (CO), carbon dioxide ( $\text{CO}_2$ ), total hydrocarbons (THC), hydrogen chloride (HCl),  $\text{SO}_2$ , and nitrogen oxides ( $\text{NO}_x$ ) at the SDA inlet and FF outlet. CEMs were also used to measure the concentration of CO, HCl, and  $\text{SO}_2$  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. Test program sampling locations are shown in Figure 1.

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 polychlorinated dibenzo-*p*-dioxin and polychlorinated dibenzofuran (PCDD/PCDF), CO,  $\text{SO}_2$ , and HCl data presented in this summary have been corrected to 12%  $\text{CO}_2$ . All PCDD/PCDF data are given in nanograms per standard cubic meter [ $25^\circ\text{C}$ , 101.3 kPa ( $77^\circ\text{F}$ , 1 atm)] as noted by ng/ $\text{Sm}^3$ .

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-OFA ratio, and OFA 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

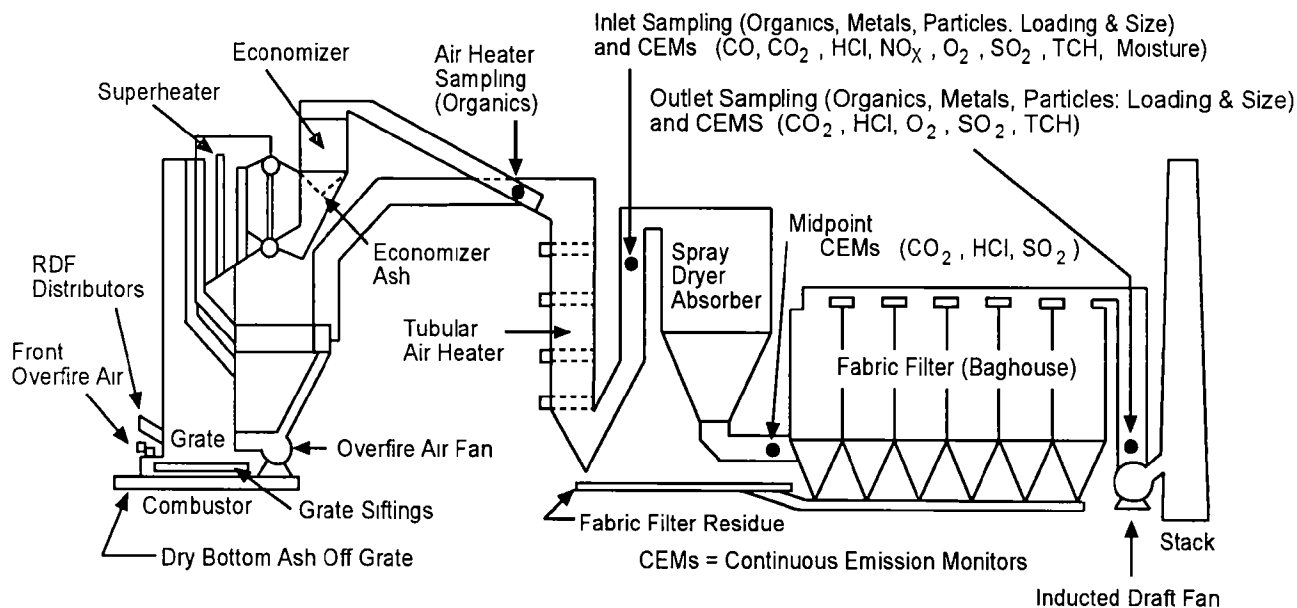


Figure 1. RDF Spreader stoker with spray dryer absorber and fabric filter.

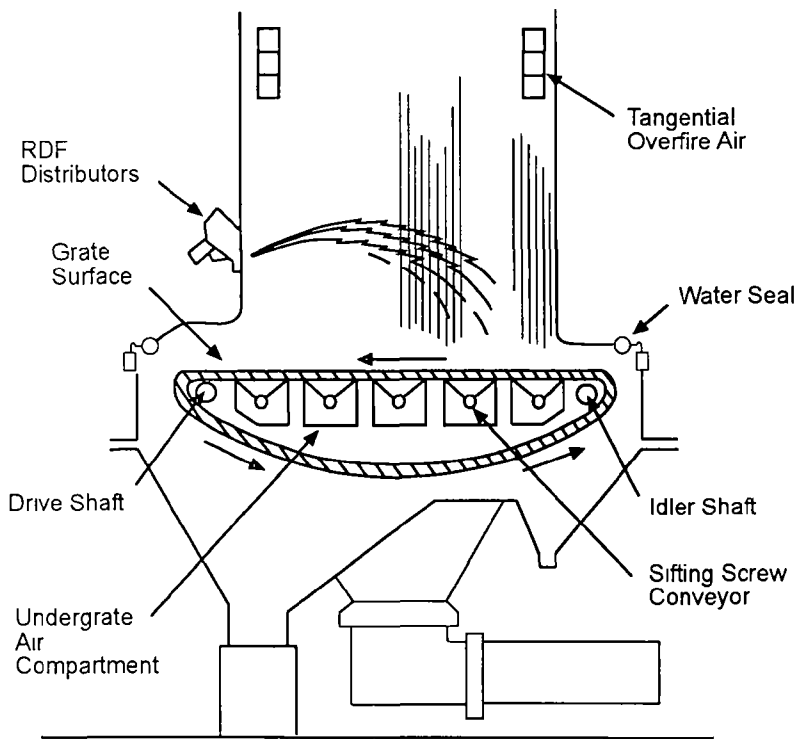


Figure 2. RDF spreader stoker boiler (Combustion Engineering).

(L), intermediate (I), normal (N), and high (H) boiler steam flow rates. Underfire-to-OFA ratios, which influence the relative amount of RDF burned in suspension and the entrainment of particulate matter (PM) in the flue gases (PM carryover), were controlled by changing the number of levels of OFA. Distributional mixing effects were evaluated by changes in the underfire-to-OFA 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 reconstructed averages based on measured values at the SDA inlet and FF outlet. The PCDD/PCDF values are from the SDA inlet.

FGC tests were run at nine different test conditions corresponding to high [166 to 171°C (330 to 339°F)], medium [141 to 142°C (285 to 287°F)], and low [122 to 124°C (252 to 255°F)] temperature at the SDA outlet and high (>100 ppm), medium (21 to 100 ppm), and low (<21 ppm) SO<sub>2</sub> concentration at the FF outlet. The SDA outlet temperature was used as a surrogate for approach to saturation temperature since the latter parameter was not directly measurable. The SO<sub>2</sub> concentra-

tion served as an on-line indicator of sorbent-to-acid gas ratio (or lime stoichiometry) during the test program and was used as a qualitative measure of stoichiometry for evaluation of test data. The plant's lime slurry density measurement was inoperative during the test program and the lime stoichiometry could only be estimated. Stoichiometry is used in this summary to denote the ratio of lime sorbent to acid gases (HCl and SO<sub>2</sub>) corresponding to high, medium, and low lime flow rates. FGC tests conditions and average acid gas control results are summarized in Table 2.

The four ash streams—bottom ash (BA), grate siftings (GS), economizer (EC) ash, and FF residues (collected combustor flyash and SDA reaction products)—that were sampled during the 13 performance tests were also subjected to ash characterization and treatment tests. Note that, while the ash products generated by the facility are normally combined and disposed of in a monofill, no sampling or analysis was done on this combined product. Ash characterization and treatment work included trace organic and trace metal analyses on ash samples from all 13 performance tests; chemical analyses of leachates generated from EC's Sequential Chemical Extraction Procedure; and chemical analyses and engineering tests on solidified mixtures of FF ash, waste pozzolanic material, and Portland Type II cement.

Table 1. Combustion Conditions and Results at SDA Inlet

Test No. (PT)	Load 1000 kg/h	Comb. Cond. <sup>a</sup>	Overfire Air			CO, ppm	NO <sub>x</sub> ppm	PCDD/PCDF ng/Sm <sup>3e</sup>
			TOFA <sup>b</sup>	ROFA <sup>c</sup>	OFA <sup>d</sup>			
13	71 (L)	G	2	nil	47	158	157	599
14	74 (L)	G	2	nil	49	70	177	428
10	87 (I)	G	2	nil	52	77	186	667
02	88 (I)	G	2	nil	52	108	184	946
05	84 (I)	P	1	65	38	903	149	1861
09	95 (N)	G	2	65	51	92	188	449
08	96 (N)	G	2	65	48	89	193	1162
11	96 (N)	G	2	65	52	68	175	536
07	101 (N)	P	3	nil	51	387	172	1003
04	98 (N)	P	3	nil	54	214	172	774
03	99 (N)	P	1	65	44	432	160	1008
12	117 (H)	G	2	65	53	116	180	282
06	118 (H)	P	2	nil	57	397	157	1202

<sup>a</sup> Good (G) or poor (P) combustion conditions

<sup>b</sup> Number of levels of TOFA

<sup>c</sup> Pressure in ROFA plenum, mm Hg

<sup>d</sup> OFA as a percentage of total combustion air

<sup>e</sup> Standard conditions: 25°C, 101.3 kPa

**Table 2. Flue Gas Cleaning (FGC) System Performance: Acid Gases**

Test Run <sup>a</sup>	FGC Cond. Temp./SO <sub>2</sub> <sup>b</sup>	Concentrations, ppm				Removal, %	
		Inlet		Outlet		HCl	SO <sub>2</sub>
		HCl	SO <sub>2</sub>	HCl	SO <sub>2</sub>		
2,5	L/H	470	173	20	121	95.7	35.3
3,11	H/L	416	187	20	17	95.2	90.9
4	H/M	471	186	31	44	93.4	76.3
6	M/L	404	192	10	32	97.5	95.3
7	L/L	399	183	8	17	98.0	90.7
8	M/H	538	184	41	126	92.4	31.5
9	H/H	432	178	98	189	77.8	-6.2 <sup>c</sup>
10	L/M	429	194	19	74	95.6	61.9
12,13,14	M/M	444	187	18	59	95.9	68.5

<sup>a</sup> Values are averaged for multiple runs.

<sup>b</sup> High temperatures (H) ranged from 166 to 171°C (330 to 339°F), medium temperatures (M) from 141 to 142°C (285 to 287°F), and low (L) temperatures from 122 to 124°C (252 to 255 °F) for the spray dryer outlet gas. Fabric filter SO<sub>2</sub> outlet concentrations were above 100 ppm for high (H) concentration, between 21 and 100 ppm for medium (M) concentration, and 20 ppm or less for low (L) concentration. All concentrations are referenced to 12% CO<sub>2</sub> in dry gas [25°C (77°F), 101.3 kPa (1 atm)]

<sup>c</sup> Desorption of SO<sub>2</sub> in the filter cake is suspected for low lime stoichiometry and relatively high HCl concentration.

## Combustion Test Results

Test results were evaluated to assess the effects of combustion conditions on furnace emission of organics, NO<sub>x</sub>, and metals using the concentration of these pollutants at the SDA inlet

Although organic compounds (such as PCDD/PCDF) may be in the waste feed, it is unlikely that they will pass through the combustor undestroyed. They may also be formed in high temperature regions of the furnace from the thermal decomposition products which are incompletely oxidized due to insufficient combustion air, mixing, temperature, or residence time. They may also originate from catalytic reactions on the surface of flyash downstream of the combustion chamber.

Multiple regression analyses show that PCDD, PCDF, chlorophenol (CP), chlorobenzene (CB), and polynuclear aromatic hydrocarbon (PAH) concentrations at the SDA inlet can be best correlated with two or more of the following easily monitored furnace/flue gas properties: CO concentration, THC concentration, NO<sub>x</sub> concentration, moisture (H<sub>2</sub>O) concentration, and temperature in the furnace or at the economizer outlet

For example, the best correlation for PCDD concentrations at the SDA inlet (R<sup>2</sup>=0.9)\* is based on the CO, NO<sub>x</sub>, and H<sub>2</sub>O concentrations at this location.

\* R<sup>2</sup> is the correlation coefficient; R<sup>2</sup>=1.0 indicates a perfect (exact) correlation.

Multiple regression analyses provide correlations that indicate that the combustor operating variables (steam load, combustion air flows, RDF moisture content, etc.) can be used to control PCDD, PCDF, CP, CB, and PAH concentrations at the SDA inlet. These operating variables control combustion in the furnace by impacting the fundamental combustion parameters: time, temperature, air/fuel ratio, and mixing

Multiple regression analyses based on easily monitored flue gas properties provide for better correlations of organics (R<sup>2</sup>=0.8 to 0.98) than combustor operating variables (R<sup>2</sup>=0.6 to 0.8). Optimum control systems for limiting the furnace emission of organics will probably require both flue gas property measurements and combustion operating variables as inputs.

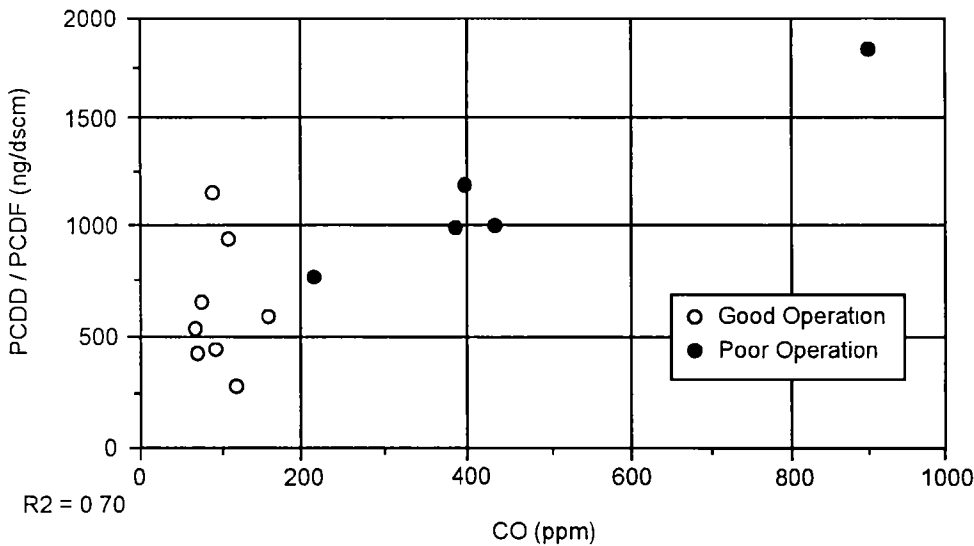
Single parameter regression analyses using average test values show that either CO or THC tracks the furnace destruction of organics. While only moderately strong correlations were obtained between CO (or THC) and PCDD/PCDF at the SDA inlet [R<sup>2</sup>=0.70 (or 0.68)], they provided the strongest correlation for any single monitoring or control variable (see Figures 3 and 4). Single parameter correlations between average CO (or THC) concentrations and CP, CB, or PAH concentrations at the SDA inlet provided better correlations [R<sup>2</sup>=0.88 (0.92), 0.83 (0.87), and 0.83 (0.85), respectively] than those for PCDD or PCDF. There were no signifi-

cant correlations between average CO (or THC) and PCB at the SDA inlet. Thus, either CO or THC concentration at the SDA inlet is a good relative indicator of furnace emission of most trace organics of concern.

Previous field tests have shown a strong positive correlation between the amount of PM entrained in flue gas (PM carryover) and emissions of PCFF/PCDF. The Mid-Conn data show a fair correlation (R<sup>2</sup>=0.61) between PCDD/PCDF and PM concentrations at the SDA inlet for good combustion conditions (CO<200ppm), yet, no significant correlation between these variables was seen for all combustion conditions. Possibly for good combustion, the emission rate of PM (as PM is postulated to provide reaction sites where PCDD/PCDF are formed) is the principal variable affecting the furnace PCDD/PCDF emission rate. For poor combustion, the effects of other parameters obscure the relationship between PM and PCDD/PCDF.

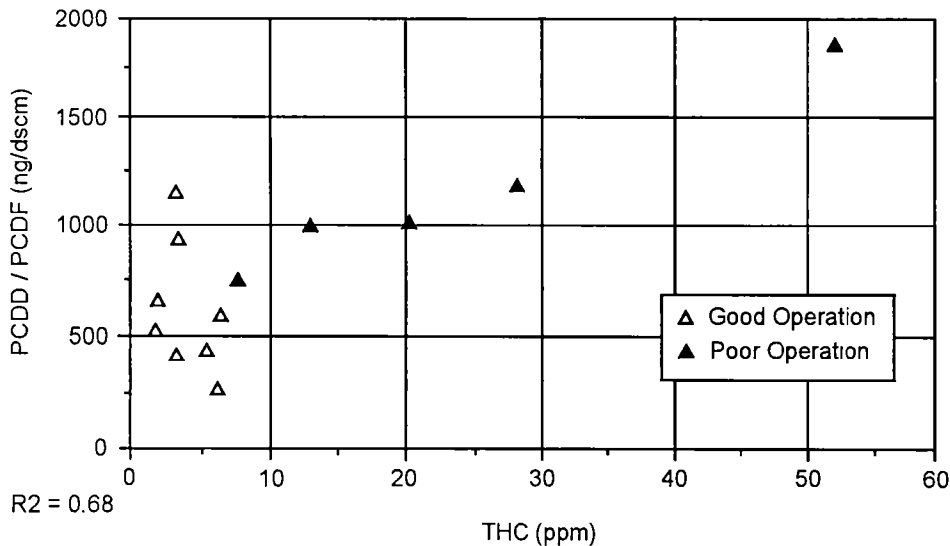
PCDD/PCDF and other chloro-organic compounds can be formed downstream of the furnace by *de novo* synthesis reactions on the surface of flyash. The amount formed is believed to be proportional to the amount of flyash and the time individual particles with reaction sites exist in the temperature range of about 450 to 150°C (750 to 300°F). Mid-Conn has an air heater just upstream of each SDA with flue gas in the upper end of this range. Thus, an increase in PCDD/PCDF concentrations across the air heater due to *de novo* synthesis was expected. The flue gas temperature at the economizer outlet (which approximates that at the air heater inlet) typically ranges from 343 to 388°C (650 to 730°F), while the temperature at the outlet of the air heater ranges from 177 to 210°C (350 to 410°F). To evaluate the hypothesis that PCDD/PCDF form on particulate deposits within the air heater, PCDD/PCDF measurements were made during four test runs just upstream of the air heater inlet simultaneously with those at the SDA inlet (air heater outlet). Contrary to expectations, a comparison of measurements at the inlet and outlet of the air heater indicated a reduction of PCFF/PCDF concentrations during three of four runs. No explanation for these unexpected results is presently available.

Average NO<sub>x</sub> emissions ranged from 149 to 193 ppm. Generally, NO<sub>x</sub> emissions increase with increased combustion temperatures and improved mixing. Accordingly, low CO emissions corresponded with high NO<sub>x</sub> emissions. Conversely, the lowest NO<sub>x</sub> emissions were associated with



Values corrected to 12% CO<sub>2</sub>

Figure 3. Uncontrolled PCDD/PCDF vs CO emissions.



Values corrected to 12% CO<sub>2</sub>

Figure 4. Uncontrolled PCDD/PCDF vs. THC at SDA inlet.

high concentrations of CO, THC, and organics at the SDA inlet. An evaluation of 30-second emission averages from the CEM data indicates that, to obtain NO<sub>x</sub> emission less than 180 ppm (the new U.S. New Source Performance Standards requirement for large municipal waste combustors), the Mid-Conn units would have to operate at a CO emission concentration of 71 ppm or higher.

There were no apparent correlations between combustion conditions and the concentration of metals in flyash at the SDA inlet.

### Flue Gas Cleaning Test Results

The HCl and SO<sub>2</sub> concentrations were monitored continuously, and their averaged values along with removals for each test run are shown in Table 2. Note that the test conditions for Runs 2 and 5; 3 and 11; and 12, 13, and 14 have been grouped, since the FGC system setpoints (SDA gas outlet temperature and FF outlet SO<sub>2</sub> concentration) were the same.

These data show that the HCl and SO<sub>2</sub> values at the SDA inlet averaged 445 and 185 ppm, respectively, over the tests, with the individual test values being ±10% of these averages, except that for Run 8 when the HCl concentration was about 20% higher.

As expected the HCl and SO<sub>2</sub> removals increased with decreasing SDA outlet gas temperature (approach to saturation temperature) and increasing lime stoichiometry. The HCl removal averaged 95% or more, and the SO<sub>2</sub> removal was greater than 90% when the lime stoichiometry was high (low FF outlet SO<sub>2</sub> concentration) and showed only a slight decrease with temperature as the average SDA outlet temperature increased from the 122 to 166°C (252 to 330°F). The HCl removal was above 92% for all temperature and stoichiometry combinations tested, except for high temperature (171°C or 339°F) and high stoichiometry when it was about 78%. The SO<sub>2</sub> removal was more sensitive to the change in stoichiometry than to temperature: 91 to 95% for high stoichiometry and 62 to 76% for medium stoichiometry over the tested SDA outlet temperature range [122 to 171°C (252 to 339°F)]. At low stoichiometry, the SO<sub>2</sub> removal fell from 35 to 32% as the SDA outlet gas temperature increased from 122°C (252°F) to 142°C (287°F); however, the SO<sub>2</sub> removal was -6% at 171°C (339°F) (i.e., the SO<sub>2</sub> concentration at the FF outlet was greater than the SDA inlet), suggesting that SO<sub>2</sub> was being desorbed in the filter cake. This suspected desorption was similar to that observed in the Mid-Conn characterization test series, is

consistent with pilot study findings, and is likely due to displacement of SO<sub>2</sub> by the more reactive HCl in the filter cake. These results suggest that normal operation of the SDA/FF system [140°C (285°F), moderate stoichiometry] would be expected to yield 95% or more HCl removal and about 70% SO<sub>2</sub> removal.

Table 3 provides inlet concentrations and removal efficiencies for selected organics. With the exception of run 9 (highest SDA outlet temperature and low stoichiometry), the PCDD removal was at least 99.8% for SDA inlet concentrations ranging from 95 to 397 ng/Sm<sup>3</sup>. This low PCDD removal efficiency was probably the result of low inlet concentration and high SDA outlet temperature. The PCDF removal was 99.9% or greater for all runs, although the SDA inlet PCDF concentration changed almost three-fold from 341 to 1007 ng/Sm<sup>3</sup>. CP control was usually slightly better than CB control, with CP control generally being 97% or more and CB control being 95% or more. The CP inlet concentration ranged from 11,329 to 62,938 ng/Sm<sup>3</sup>, being more than double that for CB. The PAH removal generally increased with inlet concentration, ranging from 58.6 to 97.7% as the concentration rose from 6,289 to 88,626 ng/Sm<sup>3</sup>. The lowest PAH removals in the FGC system correspond to the lowest inlet concentrations and occurred during good combustion (low CO). However, the PAH (as well as other organic) emissions varied

with FGC system variables. Generally, organics removal was high (over 95%), except PAH removal which was usually moderately high (over 92%), for all test runs and conditions so that changes in the FGC process variables had little effect over the range evaluated; e.g., the removal of combined PCDD and PCDF was 99.7% or higher for all test runs.

As shown in Table 4, the PM concentration in the flue gas at the SDA inlet ranged from 3,274 to 4,949 mg/Sm<sup>3</sup>, while the outlet concentration ranged from 2.68 to 7.62 mg/Sm<sup>3</sup>. The corresponding PM removal was 99.8% or more. Because of the low outlet concentration for all runs, the effects of FGC process changes on PM removal efficiencies could not be distinguished. Table 4 also presents selected metals control data, with control of arsenic (As) and cadmium (Cd) to concentrations below detection limits for all test runs.

The removal of lead (Pb) followed very closely the removal of PM, usually being above 99%, despite a five-fold ratio of the maximum to minimum inlet concentration for the tests. Surprisingly, Hg control was over 96% for all the tests. The chromium (Cr) removal was high and paralleled that of mercury (Hg).

While high carbon content in flyash, which is characteristic of RDF combustors, may be a factor in the observed high control of Hg emissions, conclusive test data were not obtained on carbon content

during the test program. However, the loss-on-ignition data in Table 5 range from 4.26 to 10.45% and suggest high carbon content, since these values are believed representative of the carbon plus water of hydration content of the fabric filter ash. Since the carbon concentration in flyash from highly efficient mass burn combustors is from 1 to 2%, the values in Table 5 suggest carbon values greater than this range even for water of hydration contents as high as 50%. Also, the higher PM loading in RDF combustor flue gases may lead to increased mercury control because of the relatively higher particulate surface areas for absorption of volatile metals.

### Ash/Residue Results

The average loss on ignition (LOI) in bottom ash/grate siftings (0.7 to 1.5%) was lower than that measured in bottom ash from waterwall mass burn systems (1.5 to 5.0%) and much lower than in bottom ash from two-stage combustion systems (12 to 30%).

Concentrations of PCDD/PCDF in the bottom ash and grate siftings were at or below the detection limit. PCBs were below detection limits in all ash/residue streams.

Generally, the organics concentrations in the combustor ash (BA, GS, and EC ash) were considerably less than in the FF residue. For example, over 99% of the total PCDD/PCDF associated with the residues was measured in the FF residue.

**Table 3. Flue Gas Cleaning (FGC) System Performance: Organics**

Test Run <sup>b</sup>	FGC Cond. Temp/SO <sub>2</sub> <sup>c</sup>	Inlet Concentrations, ng/Sm <sup>3a</sup>					Removal, %				
		PCDD	PCDF	CB	CP	PAH	PCDD	PCDF	CB	CP	PAH
2,5	L/H	397	1,007	10,860	62,938	60,176	99.9	99.9	96.2	97.4	92.0
3,11	H/L	161	611	6,159	20,798	46,976	99.8	100 <sup>d</sup>	95.2	99.1	92.2
4	H/M	151	623	5,964	16,964	22,519	99.8	99.9	98.4	99.0	91.3
6	M/L	317	885	9,403	41,588	88,626	99.9	100 <sup>d</sup>	94.3	96.9	97.7
7	L/L	207	796	7,074	25,168	51,774	99.9	100 <sup>d</sup>	98.5	99.1	97.3
8	M/H	211	951	7,071	20,226	10,259	99.9	100 <sup>d</sup>	98.4	99.1	76.7
9	H/H	71	378	4,848	11,329	32,421	99.2	99.9	97.7	96.6	92.5
10	L/M	243	424	6,170	16,198	6,289	99.9	100 <sup>d</sup>	99.3 <sup>d</sup>	99.5	58.6
12,13,14	M/M	95	341	4,647	14,419	7,747	99.9	100 <sup>d</sup>	100 <sup>d</sup>	99.4	63.2

<sup>a</sup> Organics are polychlorinated dibenzo-*p*-dioxins (PCDD) and dibenzofurans (PCDF), chlorobenzenes (CB), chlorophenols (CP), and polynuclear aromatic hydrocarbons (PAH).

<sup>b</sup> Values are averaged for multiple runs.

<sup>c</sup> High temperatures (H) ranged from 166 to 171°C (330 to 339°F), medium temperatures (M) from 141 to 142°C (285 to 287°F), and low temperatures (L) from 122 to 124°C (252 to 255°F) for the SD outlet gas. Fabric filter SO<sub>2</sub> outlet concentrations were above 100 ppm for high (H) concentrations, between 21 and 100 ppm for moderate (M) concentration, and 20 ppm or less for low (L) concentration. All concentrations are referenced to 12% CO<sub>2</sub> in dry gas [25°C (77°F), 101.3 kPa (1 atm)].

<sup>d</sup> Value is based on rounding off to three significant figures.

**Table 4. Flue Gas Cleaning (FGC) System Performance: Particulate Matter and Selected Metals**

Test Run <sup>a</sup>	FGC Cond. Temp./SO <sub>2</sub> <sup>b</sup>	Particulate Matter (PM) mg/Sm <sup>3</sup>		Inlet Concentration, µg/Sm <sup>3</sup>					Removal, %					
		Inlet	Outlet	As	Cd	Cr	Pb	Hg	PM	As <sup>c</sup>	Cd <sup>c</sup>	Cr	Pb	Hg
2,5	L/H	4,949	4.83	250	548	859	13,472	680	99.9	100	100	98.2	99.7	99.0
3,11	H/L	4,313	5.60	214	594	579	11,479	622	99.9	100	100	98.6	99.6	96.9
4	H/M	3,274	7.62	168	536	538	10,050	614	99.8	100	100	98.1	99.6	97.8
6	M/L	3,308	2.68	194	437	353	7,229	583	99.9	100	100	97.9	99.5	98.0
7	L/L	4,230	4.39	176	515	520	5,877	584	99.9	100	100	98.4	99.5	98.7
8	M/H	4,745	3.88	224	832	862	4,649	646	99.9	100	100	96.4	99.1	99.3
9	H/H	3,894	5.79	196	668	1,491	2,592	644	99.9	100	100	99.3	98.5	97.8
10	L/M	4,531	4.09	210	599	871	4,770	718	99.9	100	100	98.9	99.1	98.8
12,13,14	M/M	3,433	5.46	219	569	949	8,563	668	99.8	100	100	98.2	99.5	98.6

<sup>a</sup> Values are averaged for multiple runs.

<sup>b</sup> High temperatures (H) ranged from 166 to 171°C (330 to 339°F), medium temperatures (M) from 141 to 142°C (285 to 287°F), and low temperatures (L) from 122 to 124°C (252 to 255°F) for the SD outlet gas. Fabric filter SO<sub>2</sub> outlet concentrations were above 100 ppm for high (H) concentration, between 21 and 100 ppm for medium (M) concentration, and 20 ppm or less for low (L) concentration. All concentrations are referenced to 12% CO<sub>2</sub> in dry gas [25°C (77°F), 101.3 kPa (1 atm)].

<sup>c</sup> All outlet concentrations were nondetectable and assigned zero values for calculating removal.

With the exceptions of CP and PAH in bottom ash, the relative amounts of organics in the combustor ash were lower than the stack gases. The major portions of all organics leaving the combustor were in FF residue

Average concentrations of organics and selected metals in the FF residue are summarized in Table 5 for each FGC test condition. PCDD/PCDF concentrations in the FF residue ranged from 70 to 509 ng/g. The concentrations of trace organics in the FF residue were typically higher for poor combustion conditions than good combustion conditions. Figure 5 shows normalized concentrations of organics (mg/tonne of RDF feed) in the FF residue for expanded combustion criteria defined as good combustion (CO < 100 ppm), intermediate combustion (CO from 100 to 250 ppm), and poor combustion (CO > 250 ppm)

Organic contaminants in the ashes, including PCDD, PCDF, CB, and PAH, were not soluble in water

Typically, concentrations of less volatile metals [e.g., chromium (Cr), nickel (Ni), copper (Cu)] were higher in the combined bottom ash/grate siftings, whereas concentrations of relatively volatile metals [e.g., Cd, Hg, zinc (Zn)] were higher in the FF residue. Lead concentrations were relatively high in both grate siftings and FF residue, and relatively low in the bottom and economizer ashes.

FF residue was more soluble in water (approximately 34% solubilized) than either the combined bottom ash/grate siftings or economizer ashes (approximately 7% solubilized). A substantial portion of the solubilized material from the FF residue consisted of sulfate and chloride anions (14% sulfate and 27% chloride).

Only very small amounts (typically less than 10%) of most trace metals present in the ashes/residue were soluble in water

In general, under simulated acidic conditions, larger fractions of Cd, Cr, Pb, manganese (Mg), and Zn were potentially available for leaching from the FF residue than from the bottom and grate siftings ashes. However, note that, under most controlled disposal conditions, an acidic leaching environment is unlikely given the high acid neutralization capacity of the FF residue.

Samples of FF residue were solidified using cement and three types of waste pozzolanic materials. Engineering test results indicate that these solidified materials were physically strong, durable, and relatively impermeable. In addition, results from different leach tests indicate that a significant reduction in metal mobility was achieved through both physical encapsulation and chemical fixation.

**Table 5. Fabric Filter Ash Content: Organics and Selected Metals**

Test Run <sup>a</sup>	FGC Cond. Temp./SO <sub>2</sub> <sup>b</sup>	Ash Rate kg/h	Concentration, ng/g					Concentration, µg/g					LOI <sup>c</sup> %
			PCDD	PCDF	CB	CP	PAH	As	Cd	Cr	Pb	Hg	
2,5 <sup>d</sup>	L/H	429	96	71	1,085	2,870	9,437	15	70	264	1,987	25	6.52
3,11 <sup>e</sup>	H/L	2,140	49	100	704	2,225	1,087	18	97	240	2,405	30	4.50
4	H/M	1,385	84	172	1,059	3,320	1,806	20	96	179	3,413	48	8.15
6	M/L	1,238	227	282	1,684	6,095	7,431	19	96	154	3,666	36	10.45
7	L/L	550	154	271	941	4,997	1,992	17	90	147	3,051	37	9.97
8	M/H	434	62	96	729	1,636	2,905	22	62	210	2,439	25	5.00
9	H/H	1,317	112	222	1,266	4,336	4,780	21	119	287	4,545	37	9.30
10	L/M	1,166	27	47	684	1,924	1,402	19	87	274	2,352	27	4.26
12,13,14 <sup>f</sup>	M/M	707	102	111	1,218	1,832	4,093	19	118	207	2,812	39	8.89

<sup>a</sup> Values are averaged for multiple runs.

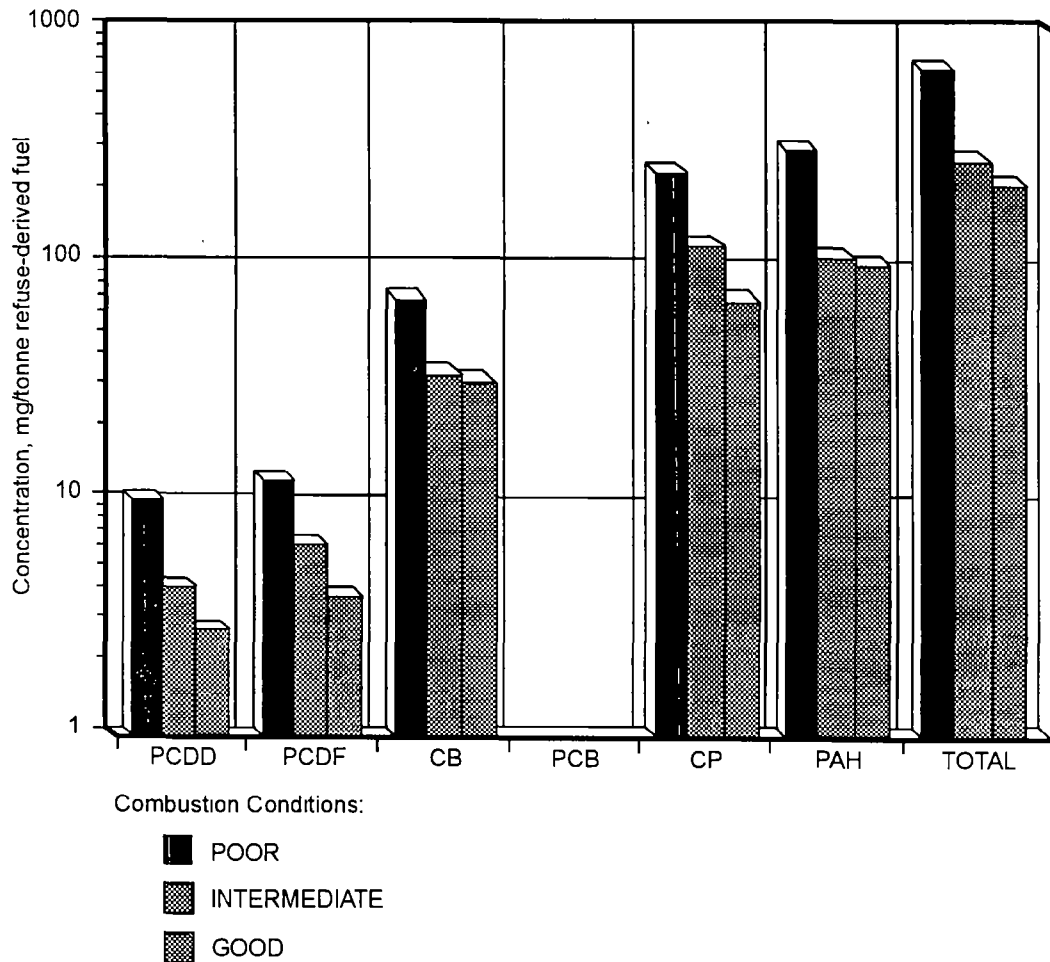
<sup>b</sup> High temperatures (H) ranged from 166 to 171°C (330 to 339°F), medium temperatures (M) from 141 to 142°C (285 to 287°F), and low temperatures (L) from 122 to 124°C (252 to 255°F) for the SD outlet gas in the FGC system.

<sup>c</sup> LOI is loss on ignition.

<sup>d</sup> Data shown are based solely on Run 5.

<sup>e</sup> Data shown are based solely on Run 11

<sup>f</sup> Data shown are based solely on Runs 12 and 14.



**Figure 5. Organics concentrations in fabric filter ash.**



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**James D. Kilgroe** is the EPA Project Officer (see below).

The complete report, entitled "The Environmental Characterization of RDF Combustion Technology—Mid-Connecticut Facility, Hartford, Connecticut," (Order No. PB96-153432; Cost: \$35.00, subject to change) will be available only from

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