

Dioxin and Trace Metal Emissions From Combustion of Carbonized RDF Slurry Fuels

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INTRODUCTION

In 1994, the U.S. generated approximately 209 million tons of Municipal Solid Waste (MSW), with 61% landfilled, 24% recycled, and 15% processed through Municipal Waste Combustion (MWC).¹ In order to divert a larger portion of this generated MSW from landfills, MWC will have to play a growing role in MSW disposal. However, recently promulgated New Source Performance Standards (NSPS) for MWC will add an additional financial burden, through mandated emission reductions and air pollution control technologies, to an already financially pressured MWC marketplace.²

In the past, Refuse Derived Fuel (RDF), a solid fuel produced from MSW, has been fired in industrial and coal boilers as an alternative means of MWC. While lower sulfur dioxide (SO₂) emissions provided the impetus, firing RDF in industrial and coal boilers frequently suffered from several disadvantages including increased solids handling, increased excess air requirements, increased air emissions, increased slag formation in the boiler, and higher fly ash resistivity.³

Bituminous and higher rank coals can generally be slurried in water to form pumpable fuels of satisfactory solids loading, and hence heating value.⁴ These slurry fuels, sometimes termed Coal-Water-Mixtures (CWM) or Coal-Water-Fuels (CWF), are commercially fired in pulverized coal and oil boilers.⁵ However, low rank coals and solid fuels like MSW and RDF do not slurry as well. Supported by the U.S. Environmental Protection Agency (EPA), U.S. Department of Energy (DOE), and U.S. National Science Foundation (NSF), EnerTech has developed a process called SlurryCarb[™], which greatly improves the solids loading, heating value, chlorine content, and uniformity of MSW and RDF slurry fuels. It is anticipated that the enhanced carbonized slurry fuels can be effectively fired in pulverized coal or oil boilers without the previously cited disadvantages. This paper summarizes the latest emissions and combustion tests with the carbonized RDF slurry fuel. EnerTech completed this program in conjunction with the American Plastics Council (APC - Washington, DC) and the Energy and Environmental Research Corporation (EER - Irvine, CA).

With EnerTech's SlurryCarb[™] process (see Figure 1), a pumpable slurry of RDF is continuously pressurized with a pump to between 1200 and 2500 psi. The RDF slurry is pressurized above the saturated steam curve to maintain a liquid state when the slurry is heated to approximately 480 to 660°F. Slurry pressure and temperature then are maintained for less than 30 minutes in plug-flow reactors. At this temperature and pressure, oxygen functional groups in the molecular structure of the RDF are split off as carbon dioxide gas. This evolved carbon dioxide gas comprises a significant weight percentage of the feed RDF, but only a minimal percentage of the heating value. While the mass of total solids is reduced approximately 20-70%, the carbonized product still contains approximately 95-98% of the energy content of the feed RDF. The carbonized RDF particles are dramatically reduced in size and can be concentrated to a higher solids loading, and hence specific heating value, comparable to CWM and CWF. In addition, chlorinated organics in the RDF are decomposed to hydrochloric acid, neutralized with alkalis, and removed as chloride salts (along with a majority of other slag forming compounds), producing an essentially chlorine free carbonized RDF slurry fuel.

RESEARCH PERFORMED

The primary objective of this program was to determine the emissions of dioxins/furans, trace metals, and other flue gas pollutants from combustion of the carbonized RDF slurry fuel in a pilot scale pulverized coal boiler simulator. The combustion tests were completed in EER's 800,000 Btu/hr pilot scale Boiler Simulation Facility (BSF). Flue gases were sampled after an electrostatic precipitator, according to EPA

protocols, for dioxin/furans and trace metal emissions. Continuous Emission Monitors (CEMs) were utilized to determine carbon monoxide (CO), nitrogen oxides (NO_x), SO₂, and hydrochloric acid (HCl) emissions.

Carbonized RDF Slurry Fuel Preparation

RDF pellets from Thief River Falls, Minnesota have been used as the source material throughout EnerTech's process development program. This source of RDF was chosen due to its proximity to EnerTech's research facilities, and heating value and ultimate analysis similarity to RDF produced with wet based resource recovery operations (see table 1). The Thief River Falls Material Recovery Facility (MRF) receives mainly MSW, some commercial office waste, and limited agricultural solid waste. The incoming waste is shredded and hand picked to remove glass bottles, aluminum cans, and PET and HDPE plastic bottles. The remaining waste is trommeled, air classified, subjected to magnetic separation, and finally pelletized. The RDF for EnerTech's development program was purchased as pellets and then shredded by EnerTech in a Nelmor granulator to a minus 1/16-inch particle size. It is roughly estimated that the RDF consisted of approximately 60-70 wt.% paper, 15-20 wt.% plastics, and the balance "other" (dry basis).

The carbonized RDF slurry fuel for the combustion tests was produced using the University of North Dakota's Energy & Environmental Research Center's continuous 7.5 ton/day (wet basis) hot-water-drying pilot plant. A detailed description of this facility can be found in previous papers by EnerTech.^{6, 7, 8} In January 1996, a series of experiments was completed with this pilot plant in which the plastic content of the RDF was varied by adding the appropriate amount of virgin plastic materials. The objective of this program was to assess the effect of plastics on carbonized slurry fuel properties. Using a factorial design-of-experiment methodology, RDF total wt.% plastic, RDF plastic composition, reactor temperature, and RDF chlorine content were varied across eight distinct test conditions, and samples of each product stream were analyzed for relevant properties. The carbonized RDF from these eight tests was blended together and used as the carbonized RDF slurry fuel for the combustion tests described in this paper.

Fuel Delivery and Combustion Facility Description

Combustion tests with the carbonized RDF slurry fuel were completed in EER's pilot scale 800,000 Btu/hr BSF. The BSF (please see Figure 2) is a pulverized coal boiler simulator and was designed to provide an accurate simulation of the flue gas temperatures and residence times in a full scale utility boiler. The BSF consists of a burner, vertically down-fired radiant furnace, horizontal simulated convective pass, and electrostatic precipitator. A Moyno progressive cavity pump was used to pump the carbonized RDF slurry fuel to a variable swirl diffusion burner with an axial fuel injector. Compressed air was used to atomize the slurry fuel. In the burner, primary air was injected axially, while the secondary air stream was injected radially through the swirl vanes to give controlled fuel/air mixing. The cylindrical furnace section is constructed of eight modular refractory-lined sections with an ID of 22 inches and an overall furnace height of 22 feet.

The convective section of the BSF also is refractory lined, and consists of three horizontal passes, with each pass having a length of 18 feet and square dimensions of 8 inches by 8 inches. The convective section contains air cooled tube bundles to simulate the reheater, superheater, and economizer sections of a full scale boiler. A tubular electrostatic precipitator is located at the end of the convective pass for particulate control. Numerous coals, oils, and other fossil fuels previously have been tested in the BSF by EER, leading to the development of an extensive database of test procedures and results.

CEMs and Flue Gas Sampling Systems

Flue gas emissions from combustion of the carbonized RDF slurry fuel were determined through extractive manual sampling and a Continuous Emission Monitor (CEM) system. CEM components included a water cooled sample probe, sample conditioning system (to remove water and particulate), and gas analyzers. CEM sampling was performed in the convective pass upstream of the electrostatic precipitator (ESP), at a gas temperature of 600°F. Species analyzed, detection principles, and limits of precision are as follows:

- Oxygen (O₂): paramagnetism, 0.1 vol.% precision
- NO_x: chemiluminescence, 1 ppm precision
- CO: nondispersive infrared spectroscopy, 1 ppm precision
- Carbon Dioxide (CO₂): nondispersive infrared spectroscopy, 0.1 vol.% precision
- SO₂: nondispersive ultraviolet spectroscopy, 1 ppm precision
- HCl: gas filter infrared spectroscopy, 1 ppm precision (Servomex Model 2510 HCl analyzer)

Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) were determined from combustion of the carbonized RDF slurry fuel through extractive sampling downstream of the ESP by EPA Method 23. The facility was operated such that the ESP inlet temperature was 320°F and the outlet temperature was 280°F where sampling was performed (temperature drop across the ESP was due to radiant and convective heat losses). With EPA Method 23, a flue gas sample is extracted isokinetically from the stack through a heated probe and filter, and directed into an impinger train. The sample trains were recovered immediately after sampling and the samples were sent to an analytical laboratory the next day for extraction and analysis. Analytical work was performed by Alta Analytical Laboratory, Inc. using high-resolution gas chromatography and mass spectrometry (DB5 column only since 2378-TCDD concentration was below 10 pg per sample and DB225 column was not needed). Quality assurance procedures included leak-checks, strict precleaning of apparatus, and charging and recovery of impinger modules under controlled conditions.

Coincident with PCDD/PCDF sampling, emissions of trace metals from combustion of the carbonized RDF slurry fuel were determined using EPA Method 29. Again, a flue gas sample was extracted isokinetically from the stack through a heated probe and filter, and directed into an impinger train. Metal analyses were performed by Research Triangle Institute. Mercury analysis was performed by cold vapor atomic absorption spectroscopy. All other metals were analyzed by inductively coupled plasma mass spectrometry. Rigorous quality assurance procedures again were applied, including leak-checks and strict precleaning of apparatus. Determination of mercury emissions included analysis of the KMnO₄ impinger. This procedure has been updated to prevent cross-contamination by using an empty impinger between the HNO₃ and KMnO₄ impingers. A lab blank also was run which did not reveal any interference or contamination.

RESEARCH RESULTS

Fuel Properties

Table 1 summarizes the fuel and rheological characteristics of the carbonized RDF slurry fuel used for the combustion test. As discussed, the carbonized RDF slurry fuel employed in this study was derived from a densified RDF spiked with additional plastics. When compared to CWFs or CMWs, the heating value and solids loading of the carbonized RDF slurry fuel were comparable. In addition, SlurryCarb[™] has significantly reduced the chloride, mercury, and cadmium content of the carbonized RDF slurry fuel from the Thief River Falls RDF. In order to complete the combustion tests with the worst case scenario

slurry fuel, the carbonized RDF was not washed to reduce chloride content, and the slurry fuel still contained significant chloride (approximately 700 ppm, dry basis). Washing of a small sample of the carbonized RDF reduced the chloride content to below 100 ppm (dry basis).

Slurry viscosity was determined by shearing a slurry sample in the annular space between a rotating cylinder and a stationary cup. The torque necessary to rotate the cylinder at a given speed was measured by a torsion spring. In general, slurry fuels are nonnewtonian fluids. With nonnewtonian fluids, the viscosity is dependent upon the shear rate and as a result, the rotating speed of the cylinder.

Emissions

The baseline firing rate of the carbonized RDF slurry fuel during the combustion test in EER's BSF was approximately 750,000 Btu/hr (approximately 130 lbs/hr, wet or slurry basis). Approximately 20% excess air was provided based upon the ultimate analysis of the slurry fuel. The total combustion air flow rate was 150 scfm. Primary air flow rate was 15 scfm or approximately 10% of the total combustion air. Atomization air also was approximately 15 scfm, with the balance of combustion air as secondary air (approximately 120 scfm). Tertiary air was not used. Combustion air was preheated to 200°F. Flue gas flow rate from the ESP was approximately 145 dry scfm.

EPA Method 23 was used to determine PCDD/PCDF emissions from combustion of the carbonized RDF slurry fuel. Two sampling periods were completed, and the analytical results were speciated into total PCDD/PCDF, five congeners (tetra- through octa-), and nine 2,3,7,8 substituted individual isomers. Table 2 summarizes the results of the two PCDD/PCDF sampling periods and calculated averages. Sampling times and analytical methods were established to provide a level of precision more than an order of magnitude greater than current regulatory NSPS for MWC. Each sampling period lasted approximately 2 hours. As can be seen from Table 2, total PCDD/PCDF concentration averaged 0.38 ng/dscm (7% O₂, dry basis) for the two sampling periods, which is 97% lower than the NSPS for MWC of 13 ng/dscm.

Figure 3 and Figure 4 depict the PCDD and PCDF congeners distribution. Reasonably good agreement was obtained between the total PCDD/PCDF concentration for the sampling periods, although the levels of individual isomers varied between each sampling period. Most species were present in measurable quantities, including all congener groups. The less chlorinated species were more abundant for both the PCDD and PCDF. A few isomers were below detection limits. Most notably, 2378 TCDD concentration was below the detection limit of 0.0013 ng/dscm (7% O₂, dry basis) for both runs.

Table 3 and Figure 5 summarize the 13 trace metal emissions characterized from the two sampling periods and calculated averages. Agreement between the two sampling periods was fairly good. For both sampling periods, arsenic and thallium were below the detection limits of 0.0005 and 0.0008 mg/dscm (7% O₂, dry basis), respectively, while beryllium was below the detection limit for the first run only. As can be seen from Table 3 and Figure 5, mercury emissions averaged 0.0066 mg/dscm (7% O₂, dry basis) for the two sampling periods, which is approximately 92% lower than the NSPS for MWC of 0.08 mg/dscm. Cadmium emissions averaged 0.0017 mg/dscm (7% O₂, dry basis), which is 83% lower than the NSPS for MWC of 0.01 mg/dscm. Lead emissions averaged 0.0346 mg/dscm (7% O₂, dry basis) for the two sampling periods, which is over 65% lower than the NSPS for MWC of 0.1 mg/dscm.

Table 4 includes the average emissions of NO_x, CO, SO₂, and HCl across both sampling periods (approximately 4 hours) and compares them to the recently promulgated NSPS for MWC. CO emissions averaged 59 ppmv (7% O₂, dry basis) with a standard deviation of 22 ppmv. These CO emissions were

comparable to the NSPS for MWC of 50-150 ppmv (7% O₂, dry basis), but were significantly higher than previous reported combustion experiments by EnerTech with the carbonized RDF slurry fuel.⁸ The higher CO emissions likely were due to lower flame temperatures caused by the higher water content of the slurry fuel, and poorer atomization. Please note that CO emissions from the carbonized RDF slurry fuel were achieved with excess air levels of approximately 20%.

NO_x emissions averaged 132 ppmv (7% O₂, dry basis) with a standard deviation of 16 ppmv. These NO_x emissions were approximately 12% lower than the NSPS for MWC, without any catalytic or non-catalytic reduction. The NSPS for MWC of 150 ppmv (7% O₂, dry basis) is based upon selective non-catalytic reduction NO_x control.

HCl emissions from combustion of the carbonized RDF slurry fuel averaged 6 ppmv (7% O₂, dry basis) with a standard deviation of 2 ppmv. Compared to the NSPS for MWC, HCl emissions were 75% lower, without any acid gas scrubbing. Please note that the NSPS for MWC is based upon acid scrubbing for HCl emission control. Based upon the carbonized RDF chloride content, the theoretical HCl emission concentration was 40 ppmv (7% O₂, dry basis) assuming complete conversion of chloride to HCl. This indicates that approximately 85% of the fuel chloride was not converted to HCl or was removed from the flue gas through capture by alkaline ash components.

SO₂ emissions averaged 71 ppmv (7% O₂, dry basis) with a standard deviation of 8 ppmv, or approximately 0.13 lbs SO₂/10⁶ Btu. The theoretical emission concentration was 80 ppmv (7% O₂, dry basis), based on the carbonized RDF slurry fuel sulfur content and assuming complete conversion of fuel sulfur to SO₂. This indicates that approximately 12% of the fuel sulfur was captured by ash mineral matter or not converted to SO₂. SO₂ emissions were higher than the NSPS for MWC of 30 ppmv, and likely would require approximately 60% reduction through sorbent injection to comply with this standard. However, when compared to coal, the carbonized RDF slurry fuel would be considered a premium ultra-low sulfur fuel, even under Phase II of the Clean Air Act Amendments of 1990 (CAAA). The CAAA Phase II SO₂ emission limit for coal boilers will be approximately 1.2 lbs/10⁶ Btu. Under the CAAA, up to 30% of the coal boiler's input could be the carbonized RDF, and SO₂ emissions would be regulated under the 1.2 lbs/10⁶ Btu standard.

Emissions of CO, NO_x, and PCDD/PCDF are not only dependent on fuel composition but also burner design and furnace operating conditions, and comparison to full scale boiler performance requires application of scaling parameters on a boiler specific basis. The CO and NO_x emissions from combustion of the carbonized RDF slurry fuel were near the low end range of CO and NO_x emissions measured for several dozen coals at EER's BSF and should be similar to commercial scale performance of pulverized coal boilers. In general, SO₂ and HCl from EER's BSF are indicative of commercial scale performance and scaling factors are not needed. Insufficient data exists for PCDD/PCDF emissions from coal combustion in EER's BSF to make any inferences about necessary scaling factors and commercial scale performance.

The filter on the EPA Method 23 train was used to measure fly ash loading of the combustion flue gases. During the two sampling periods, the average particulate matter (PM) loading of the exit flue gases from the ESP was 31.2 mg/dscm (7% O₂, dry basis). Compared to the NSPS for MWC, the PM emissions would have to be reduced approximately 50% to comply with the standard of 15 mg/dscm. However, this is easily accomplished through a higher collection efficiency with the ESP. Based upon ash content of the carbonized RDF slurry fuel, approximately 99.6% of the PM was removed by dropout in the BSF and by the ESP.

A high volume sampler with a full page filter was used to obtain an ash sample upstream of the ESP for carbon burnout analysis. Through laboratory analysis, carbon content of the fly ash was determined to be 0.46 wt.% (dry basis). This corresponds to 99.92% carbon burnout, which is extremely good. This carbon conversion also is similar to or slightly better than carbon burnout levels typically obtained with pulverized coal firing.

CONCLUSIONS

The carbonized RDF slurry fuel combusted exceptionally well, under conditions which were typical of a modern pulverized coal or oil boiler. Overall, the emissions from combustion of the carbonized RDF slurry fuel ranged significantly lower to comparable to the recently promulgated NSPS for MWC, especially total PCDD/PCDF emissions. Total PCDD/PCDF emissions were approximately 0.38 ng/dscm (7% O₂, dry basis) or 236×10^{-6} lbs/10¹² Btu, which were 97% lower than the promulgated NSPS.

As a comparison, dioxin and furan emissions recently have been characterized from a number of coal boilers. The emissions from nine of these coal boilers have been summarized in a recent report to the DOE.⁹ In general, the reported concentrations for individual isomers and total PCDDs/PCDFs were at the detection limit values or invalidated by a blank detection at similar concentrations. As an example, the total PCDD/PCDF emissions were determined using EPA Method 23 across three days of stack sampling from Cooperative Power Association's 1,100 MW Coal Creek Station Unit No.1 in Underwood, North Dakota, firing 100% lignite coal from the Falkirk mine. Fourteen out of seventeen of the individual isomers were below detection limits for all three sampling periods. An emission factor then was estimated as a summation of half the detection limit plus the concentrations all isomers detected. Based upon this calculation procedure, the total PCDD/PCDF emissions from the Coal Creek Station were estimated to be approximately 38×10^{-6} lbs/10¹² Btu.¹⁰ These coal-fired dioxin/furan emissions were the same order of magnitude for dioxin/furan emissions from combustion of the carbonized RDF slurry fuel. However, the variety of coal types and boiler configurations is immense and emission data of total PCDD/PCDF limited, so that any conclusions or comparisons should be interpreted cautiously.

The emissions of several trace metals from the nine coal boilers also were summarized in the previously cited report to the DOE.⁹ Unlike PCDD/PCDF emissions from coal boilers, the majority of individual trace metal emissions were higher than the detection limits and could be quantified. Table 5 compares the range of trace metal emissions from the nine coal boilers to the carbonized RDF slurry trace metal emissions. For the majority of the characterized metals, the carbonized RDF slurry fuel emissions were near the low to middle range of the coal boiler emissions, except for antimony and lead which were near or over the high range. It is noteworthy that the coal boiler trace metal emissions generally vary by one to four orders of magnitude, and again any conclusions or comparisons should be interpreted cautiously.

The results presented in this paper and previously cited papers by EnerTech formed the basis for the design and construction of a 20 ton/day (as received MSW basis) demonstration facility of wet resource recovery and SlurryCarbTM. The demonstration facility was designed and constructed in Japan by a consortium of Japanese companies and began operation in February 1997. Future technical papers will discuss this facility.

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TABLES

	Reno, Nv. Wet RR RDF^{a,b}	Thief River Falls, Mn. RDF	Carbonized RDF Slurry Fuel
Ultimate, wt.%, dry			
Carbon	52.3	45.7	68.4
Hydrogen	7.9	5.6	7.7
Nitrogen	0.9	0.9	0.4
Sulfur	0.3	0.2	0.1
Oxygen (difference)	32.0	39.2	11.4
Ash	6.6	8.4	12.0
Chlorine, µg/g, dry	4,100	3,000	700
Mercury, µg/g, dry	N.D.	0.30	0.09
Cadmium, µg/g, dry	N.D.	1.28	0.50
Lead, µg/g, dry	N.D.	29.8	82.0
Rheology (Sheared)			
Viscosity, cP @ 100 Hz↓	500	500	340
Solids Load., wt.%	11.2	9.1	43.9
Higher Heating Value			
dry, Btu/lb	9,560	7,995	13,350
Slurry, Btu/lb	1,070	730	5,865

a) Wet RR = Wet based resource recovery process

b) Reno, Nevada MSW was processed with Biomass Systems, Inc. (San Leandro, Ca.) wet RR pilot plant

Table 1 - Fuel Properties of Raw RDF and Carbonized RDF Slurry Fuel.

	Sampling Period 1 (ng/dscm) ^a	Sampling Period 2 (ng/dscm) ^a	Average (ng/dscm) _a
Total TCDD	0.0838	0.0167	0.0502
2378 TCDD	<0.0013	<0.0013	<0.0013
Total PeCDD	0.0603	0.0116	0.0360
12378 PeCDD	<0.0017	<0.0017	<0.0017
Total HxCDD	0.0540	0.0273	0.0407
123478 HxCDD	0.0024	<0.0014	0.0018
123678 HxCDD	0.0041	0.0029	0.0035
123789 HxCDD	0.0031	0.0022	0.0027
Total HpCDD	0.0238	0.0233	0.0236
1234678 HpCDD	0.0119	0.0127	0.0123
OCDD	0.0343	0.0360	0.0352
Total PCDD	0.2562	0.1149	0.1857
Total TCDF	0.1050	0.0558	0.0804
2378 TCDF	0.0044	0.0024	0.0034
Total PeCDF	0.0365	0.0385	0.0375
12378 PeCDF	0.0034	0.0044	0.0039
23478 PeCDF	0.0033	0.0039	0.0036
Total HxCDF	0.0217	0.0314	0.0266
123478 HxCDF	0.0050	0.0066	0.0058
123678 HxCDF	0.0028	0.0047	0.0037
123789 HxCDF	<0.0019	0.0031	0.0025
234678 HxCDF	0.0026	0.0034	0.0030
Total HpCDF	0.0182	0.0355	0.0269
1234678 HpCDF	0.0084	0.0223	0.0153
1234789 HpCDF	0.0029	0.0061	0.0045
OCDF	0.0112	0.0344	0.0228
Total PCDF	0.1926	0.1956	0.1942
Total PCDD/PCDF	0.4488	0.3105	0.3799
TEQ^{b,c}	0.0057	0.0063	0.0061

a) All emissions corrected to 7% O₂, dry basis

b) TEQ = Toxicity Equivalency of 2,3,7,8-TCDD (EPA Toxic Equivalent Factors - 1989)

c) Totals include half the detection limits for those compounds that were below detection limits

Table 2 - Summary of PCDD/PCDF Emissions From Combustion of the Carbonized RDF Slurry Fuel.

	Sampling Period 1 (mg/dscm) ^a	Sampling Period 2 (mg/dscm) ^a	Average (mg/dscm) _a
Antimony (Sb)	0.0176	0.0304	0.0240
Arsenic (As)	<0.0005	<0.0005	0.0002
Barium (Ba)	0.0076	0.0120	0.0098
Beryllium (Be)	<0.0001	0.0001	0.0001
Cadmium (Cd)	0.0013	0.0021	0.0017
Total Chromium (Cr)	0.0041	0.0086	0.0064
Copper (Cu)	0.0162	0.0322	0.0242
Lead (Pb)	0.0250	0.0443	0.0346
Manganese (Mn)	0.0233	0.0241	0.0237
Mercury (Hg)	0.0060	0.0071	0.0066
Nickel (Ni)	0.0029	0.0045	0.0037
Selenium (Se)	0.0001	0.0001	0.0001
Thallium (Tl)	<0.0008	<0.0008	0.0004

a) All emissions corrected to 7% O₂, dry basis

Table 3 - Summary of Trace Metal Emissions From Combustion of the Carbonized RDF Slurry Fuel.

	EnerTech		Municipal Waste Combustion	
	Carb. RDF Emissions ^a	Control Technolog y	1995 NSPS ^{a,b}	Required Control Technology
Carbon Dioxide (CO ₂), vol. %	11.1	-----	-----	
Carbon Monoxide (CO), ppmv	59	None	50-150	Good Combustion Practice
Nitrogen Oxides (NO _x), ppmv	132	None	150	SCR or SNCR
Sulfur Dioxide (SO ₂), ppmv	71	None	30	Acid Scrubber
Hydrochloric Acid (HCl), ppmv	6	None	25	Acid Scrubber
Total PCDD/PCDF, ng/dscm	0.38	None	13	Activated Carbon Injection
TEQ ^c , ng/dscm	0.0061	None	0.20 ^d	Activated Carbon Injection
Mercury (Hg), mg/dscm	0.0066	None	0.08	Activated Carbon Injection
Cadmium (Cd), mg/dscm	0.0017	ESP	0.01	Baghouse or ESP
Lead (Pb), mg/dscm	0.0346	ESP	0.1	Baghouse or ESP
Particulate Matter (PM), mg/dscm	31.2	ESP	15	Baghouse or ESP

a) All emissions corrected to 7% O₂, dry basis

b) NSPS = New Source Performance Standards, published December 19, 1995 in the *Federal Register*

c) TEQ = Toxicity Equivalency of 2,3,7,8-TCDD (EPA Toxic Equivalent Factors - 1989)

d) Dioxins are not regulated by TEQ under the NSPS, and TEQ is presented for reference only

Table 4 - Summary of Emissions From Combustion of the Carbonized RDF Slurry Fuel and Comparison to NSPS For MWC.

	Carbonized RDF Slurry Fuel		Range From Coal Boilers ⁹	
	Average (mg/dscm) ^a	Average (lb/10 ¹² Btu)	Low (lb/10 ¹² Btu)	High (lb/10 ¹² Btu)
Antimony (Sb)	0.0240	20.22	0.04	2.4
Arsenic (As)	0.0002	0.22	0.14	3.5
Barium (Ba)	0.0098	8.25	N.A.	N.A.
Beryllium (Be)	0.0001	0.07	0.04	1.7
Cadmium (Cd)	0.0017	1.43	0.03	3.2
Total Chromium (Cr)	0.0064	5.37	0.13	51
Copper (Cu)	0.0242	20.39	N.A.	N.A.
Lead (Pb)	0.0346	29.17	0.53	29
Manganese (Mn)	0.0237	19.95	2.60	30
Mercury (Hg)	0.0066	5.53	0.44	22
Nickel (Ni)	0.0037	3.13	0.55	40.1
Selenium (Se)	0.0001	0.08	0.02	193
Thallium (Tl)	0.0004	0.34	N.A.	N.A.

a) All emissions corrected to 7% O₂, dry basis

Table 5 - Comparison of Carbonized RDF Slurry Fuel and Coal Boiler Trace Metal Emissions.

FIGURES

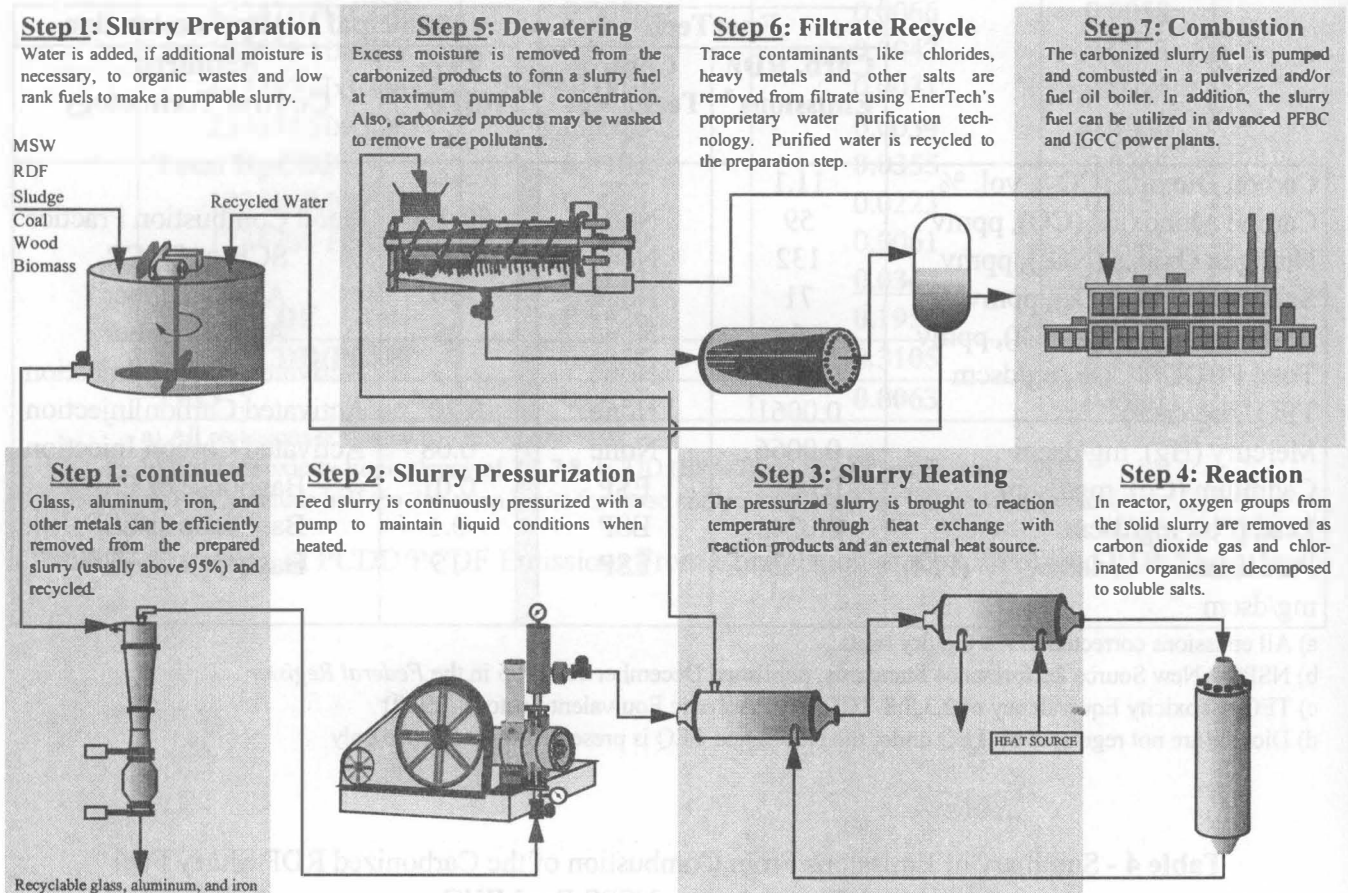


Figure 1 - Simplified Flow Diagram of EnerTech's SlurryCarb™ Process.

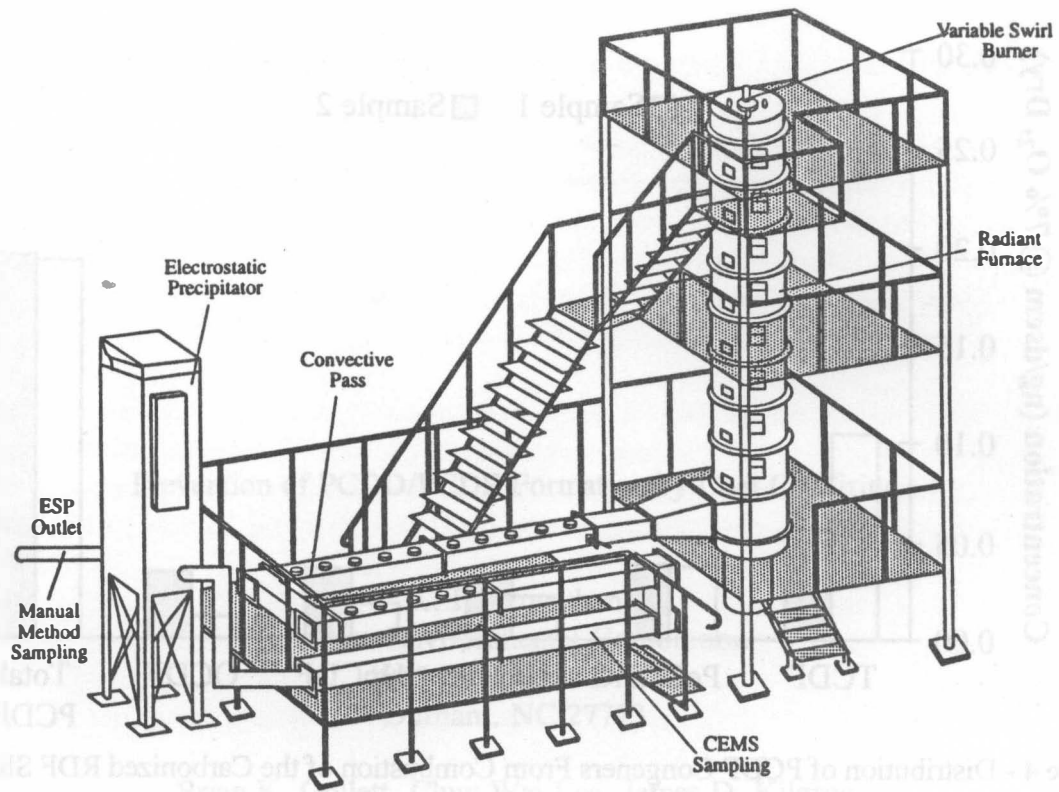


Figure 2 - Simplified Schematic of EER's 800,000 Btu/hr Boiler Simulation Facility (BSF).

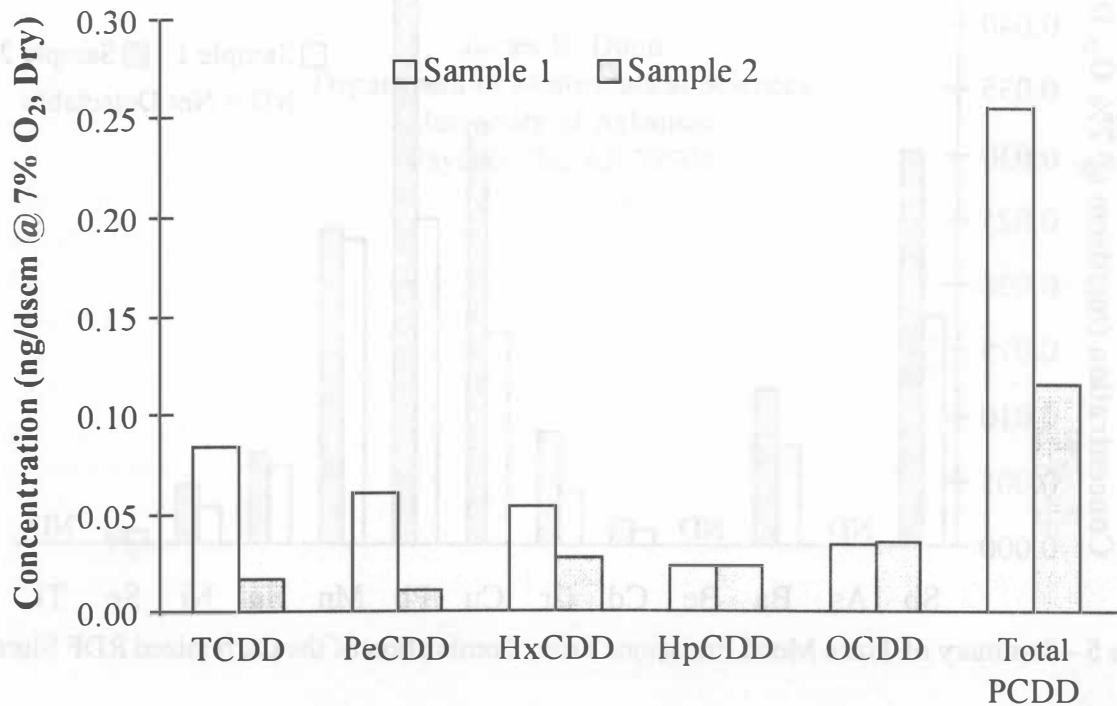


Figure 3 - Distribution of PCDD Congeners From Combustion of the Carbonized RDF Slurry Fuel.

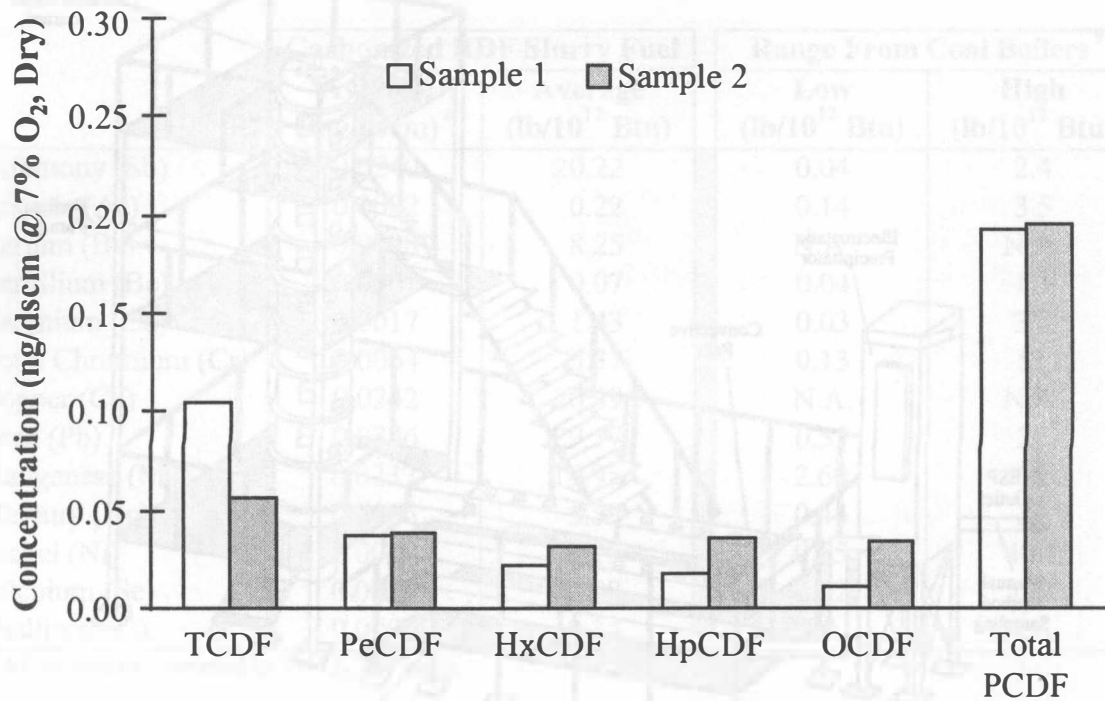


Figure 4 - Distribution of PCDF Congeners From Combustion of the Carbonized RDF Slurry Fuel.

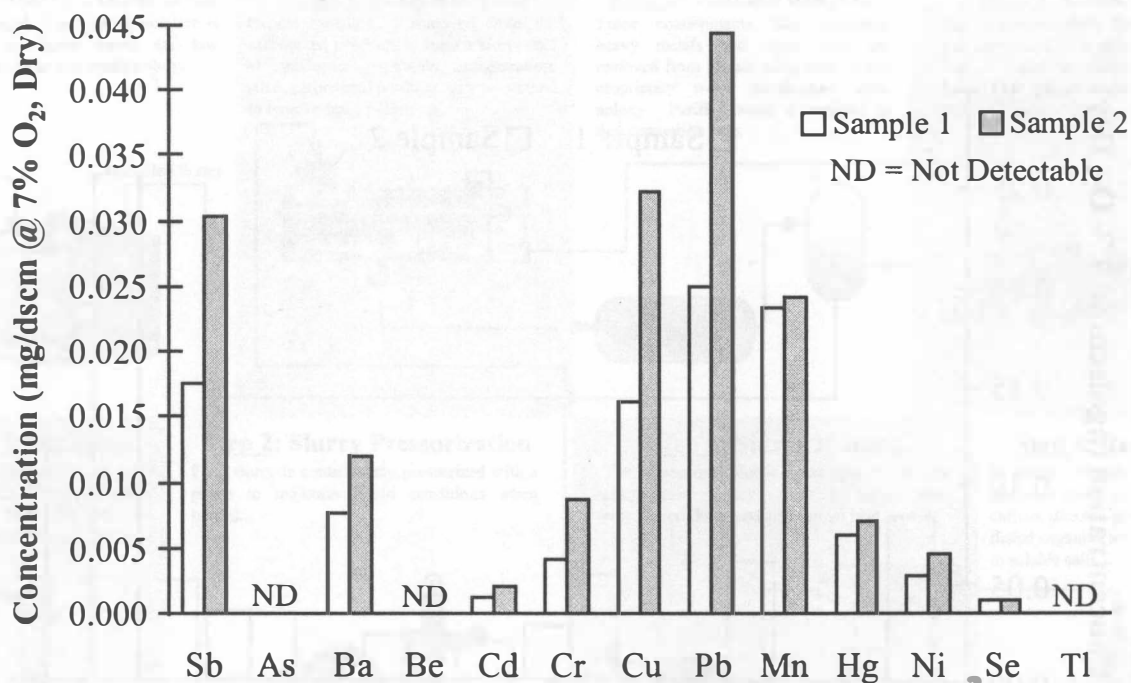


Figure 5 - Summary of Trace Metal Emissions From Combustion of the Carbonized RDF Slurry Fuel.