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Project Summary

Engineering Assessment Report—Hazardous Waste Cofiring in Industrial Boilers

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The full report documents results of 42 hazardous waste combustion tests performed on 11 full-scale industrial boilers. The full report discusses the boiler operating conditions, organic and other gaseous emissions measured in the stack, and the achieved destruction efficiency of principal organic hazardous constituents (POHCs) present in the waste. The report is divided into two volumes. Volume I presents a summary of all test data, discusses conclusions, and highlights trends in POHC destruction and other byproduct emissions with respect to boiler operation and POHC type. Volume II is a compendium of boiler-specific test data summarized to provide the readers with sufficient details to perform their own analyses. Major volatile POHCs investigated were carbon tetrachloride, chlorobenzene, trichloroethylene, and toluene. The destruction efficiency of 14 other volatile and semivolatile hazardous organics is also reported. In general, industrial boilers tested achieved individual POHC destruction efficiencies in the range of 99.90 to 99.99996 percent under conditions investigated. Although not clearly evident, the collected data point out lower destruction efficiencies with transient or off-specification burner and feedrate conditions. Emissions of identifiable products of incomplete combustion (PICs) were generally one to two orders of magnitude greater than POHC breakthrough emissions. These emissions generally included dichloromethane, chloroform, tetrachloroethylene, trichloroethanes, and benzene and toluene when these compounds were not POHCs in the waste fuel. Lower PIC emissions accompanied greater POHC destruction efficiences. These and other trends are highlighted to point out areas requiring further research.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in two separate volumes (see Project Report ordering information at back).

Introduction

Current estimates indicate that 264 million metric tons of hazardous waste are generated annually.[1] Much of this waste has a high heating value so that disposal by cofiring in industrial boilers often provides an economic advantage over other regulated disposal practices such as landfill or incineration. In fact, hazardous waste incineration in industrial boilers is a widespread practice. The U.S. Environmental Protection Agency (EPA) through the Office of Solid Waste (OSW) and the Office of Research and Development (ORD) sponsored field tests on 11 full-scale industrial boilers to evaluate the resultant air emissions of this disposal practice and, in particular, to determine the destruction efficiency (DRE) of principal organic hazardous constituents (POHCs) in the waste under typical boiler operating conditions. The following sections summarize the results obtained during these tests and discuss tentative conclusions with regard to POHC DREs and other organic emissions as a function of boiler type, waste type, and selected operating conditions.

Test Site Descriptions

The industrial boiler population comprises a diverse family of steam generators varying in design type, size, fuel, and operating conditions, while industrial organic wastes vary widely in physical and chemical constituents. To obtain results representative of current or planned industry practice, a broad range of boiler designs and waste types was selected for testing. Within availability and accessability constraints, preference was given to sites which were regarded as less likely to attain a high level of waste destruction. See Table 1.

Overall, these test sites represent a good sample of the industrial boiler population. Watertube boilers are the most likely candidates for hazardous waste incineration. Their larger heat input capacities allow higher waste firing rates while still retaining low waste fuel ratios. Furthermore, these units are often equipped with multiple burners allowing one or more burners to fire waste fuel only. Steam-atomized oil guns for waste firing are used in combination with natural gas firing for single burner units. Modifications to single burner arrangements to allow oil and liquid waste cofiring are feasible as demonstrated by the site E boiler. Firetube boilers are less likely to constitute a major equipment category for cofiring practices because of generally smaller capacities. However, site G illustrates the versatility of these units for full-scale incineration with heat and resource recovery.

Boiler Operation and Test Conditions

The test protocol at each site consisted of a baseline test and replicate waste-fuel-fired tests. During the baseline test, emission measurements were performed with the boiler firing only the primary fossil fuel. The intent of this test was to measure the level of organic emissions attributable to the combustion of fossil fuel only. Three replicate cofired tests were then performed. Baseline heat input and fuel feed conditions were maintained constant between these tests. At some sites, the protocol was extended to measure the impact of high and low boiler loads and variable excess air levels.

Table 2 summarizes the test conditions investigated for each of the eleven sites.

Sites A through D were tested with as-is waste fuels. Following these four initial test sites, waste fuels were spiked with a mixture of carbon tetrachloride, chlorobenzene, and trichloroethylene to broaden the results on POHC destruction and facilitate intrasource comparison. At site H, 1,1,1-trichloroethane was substituted for trichloroethylene.

Criteria Gas Emissions

Table 3 summarizes criteria gas emissions measured at each site and highlights general boiler operation pertinent to combustion stability and combustible emissions. Highest CO emissions were measured at site A. The wood combustion

Table 1. Summary of Test Site Boilers

Site	Boiler Type	Steam Capacity, kg/s (10^3 lb/hr)	Furnace Volume, m^3 (ft^3)	Furnace Waterwall Surface, m^2 (ft^2)	Primary Fuel	Number of Burners (Injection Ports)	Typical Waste Fuels	Injection Mechanism	Control Device	Typical Operation
A	Watertube stoker	1.3 (10)	17.4 (613)	106 (1,144)	Wood waste	2	Creosote sludge	Mixed with wood	Multicyclone	Fluctuating loads, combustion air and waste feed
B	Packaged firetube	1.1 (8.5)	1.1 (39)	8.0 (83)	Natural gas	1	Alkyd wastewater	Air atomized oil gun	None	Low boiler load. Maximum waste fire rate of 42 ml/s (40 gph)
C	Field-erected watertube	29 (230)	322 (11,400)	170 (1,800)	Natural gas or oil	6	Phenolic waste	One or two steam atomized burners	None	Low load with reduced number of burners High excess air.
D	Field-erected converted watertube stoker	11.4 (90)	62 (2,200)	140 (1,520)	No. 6 oil	4	Methanol and toluene wastes with chlorinated organics	One of the lower level steam atomized burners	None	About 50 percent capacity with 3 or 4 burners in service
E	Packaged watertube	13.9 (110)	42 (1,480)	665 (7,160)	No. 6 oil	1	Methylmethacrylate byproduct wastes	Two steam atomized waste guns in main burner throat	None	Part load with maximum 250 ml/s (240 gph) waste firing rate for loads above 50 percent
F	Field-erected converted watertube	7.6 (60)	96 (3,390)	100 (1,100)	No 6 oil, gas, or propane	2	Paint solvents	Lower steam atomized oil burner	None	Part load with maximum 190 ml/s (180 gph) waste firing rate for loads above 50 percent
G	Modified packaged firetube	5.0 (40)	6.4 (226)	20 (220)	None	1	Highly chlorinated organics	Available air atomized oil gun	2 scrubbers in series	Part load with startup on natural gas. Total chlorine up to 80 percent of waste fuel.
H	Field-erected tangentially fired watertube	32 (250)	520 (18,400)	515 (5,540)	Pulverized coal	12 coal, 6 oil	Methyl acetate waste fuel	One or two steam atomized oil burners	ESP	At boiler capacity with maximum 440 ml/s (420 gph) waste firing rate
I	Packaged watertube	7.8 (62)	41 (1,430)	76 (820)	Natural gas	2	Aniline waste high in nitrate organics	Either upper or lower steam atomized burner	None	Staged combustion for low NO_x with maximum 130 ml/s (120 gph) waste flow
J	Packaged firetube	1.3 (10)	1.5 (51)	2.6 (91)	None	1	Artificially blended fuels	Available oil burner	None	Typical excess air of 17 percent
K	Packaged watertube	7.6 (60)	65 (2,270)	47 (508)	No 6 oil	1	Blended waste with light oil	Mixed with heavy oil	None	Typical 70/30 percent heavy and light oil mixture

Table 2. *Summary of Tests with Waste Fuel Firing*

Site	Number of Waste-Fuel-Fired Tests	Volumetric Heat Release Rate, kW/m³ (10^3 Btu/hr-ft³)	Surface Heat Release Rate, kW/m³ (10^3 Btu/hr-ft²)	Bulk Furnace[a] Temperature, °C (°F)	Bulk Furnace[a] Residence Time, sec	Waste Fuel Heating Value, MJ/kg (10^3Btu/lb)	Waste Heat Input, Percent of Total	POHCs of Interest
A	4	300 (29)	48 (16)	1,370 (2,500)	1.2	39 (17)	40	Phenol, pentachlorophenol, naphthalene, fluorene, 2-4-Dimethylphenol
B	3	745 (72)	106 (34)	1,320 (2,400)	0.8	0.03-0.18 (0.013-0.077)	<1	Toluene
C	3	78 (7.5)	150 (48)	1,320 (2,400)	2.0	39 (17)	38	Phenol
D	3	400 (39)	180 (57)	1,430 (2,600)	1.1	21 (8.8)	18	Tetrachloroethylene
	3	230 (22)	100 (33)	1,370 (2,500)	1.3	42 (18)	48	Bis(2-chloroethyl)ether, toluene
E	1	580 (55)	37 (11)	1,550 (2,800)	0.7	27 (12)	22	Methylmethacrylate, α-hydroxy methyl isobuty-rate and α-hydroxy isobutyrate methyl ether
	6	380-770 (37-74)	24-49 (7.6-15)	1,480-1,590 (2,700-2,900)	0.5-1.0	25-27 (11-12)	19-43	Above plus carbon tetrachloride, chlorobenzene and trichloroethylene
	1	420 (40)	26 (8.1)	1,480 (2,700)	1.1	37 (16)	56	Toluene, methylmethacrylate
F	3	114 (11)	104 (34)	1,370 (2,500)	2.0	33 (14)	9.0	Carbon tetrachloride, chlorobenzene, trichloroethylene, toluene
G	3	820 (79)	262 (81)	1,350 (2,450)	0.4	21 (9.0)	100	Carbon tetrachloride, epichlorohydrin, bis(2-chloroisopropyl)ether
H	3	180 (17)	183 (58)	1,370 (2,500)	2.0	17 (7.0)	2.4-4.3	Carbon tetrachloride, chlorobenzene, 1,1,1-Trichloroethane
I	2	340 (33)	180 (57)	1,430 (2,600)	1.8	25 (11)	8.2	Carbon tetrachloride, chlorobenzene, trichloroethylene, toluene, aniline, benzene, nitrobenzene
J	6	690-1,750 (65-170)	118-300 (37-95)	1,310-1,370 (2,400-2,500)	0.3-0.7	42 (18)	100	Carbon tetrachloride, chlorobenzene, trichloroethylene, toluene
K	1	270 (26)	370 (120)	1,370 (2,500)	1.8	40 (17)	65	Carbon tetrachloride, chlorobenzene, trichloroethylene, toluene, benzene

[a]*Not measured values. Estimates of bulk gas temperature in the furnace were used to calculate bulk furnace residence time. Values to be considered approximate.*

Table 3. *Criteria Gas Emissions and Test Conditions*

			Criteria Emissions, as Measured, Dry Basis[a]					
Site	Test	Fuels	O_2 (percent)	CO_2 (percent)	CO (ppm)	NO_x (ppm)	TUHC (ppm)	General Test Conditions
A	1, 2, 3, 4	Wood waste and creosote	6.2-16.7 (10.4)	15.4-4.4 (9.9)	470->1,000 (>530)	90-124 (105)	0-50[b] (4.3)	Transient boiler emissions resulting from probable boiler load changes, insufficient fuel-air mixing of fuel bed combustion
B	2, 3, 4	Natural gas and alkyd wastewater	3.8-6.0 (5.3)	8.8-12.4 (9.6)	35-96 (54)	38-60 (44)	8-170 (74)	Unsteady waste feed rate caused by insufficient mixing. Several episodes of waste fuel cut off.
C	2, 3, 4	Natural gas and phenolic waste	7.8-11.3 (10.3)	6.2-8.7 (7.3)	10-15 (13)	38-43 (40)	0	Steady-state boiler operation at very low boiler load and high excess air
D	2, 3, 4	No. 6 oil and methanol with tetrachloroethylene	4.3-6.4 (5.2)	11.6-15.0 (12.7)	70-128 (93)	200-230 (216)	11-32[c] (20)	Variable concentration of trichloroethylene in waste fuel. Several smoke episodes during test 2 and 3 primarily. Burner flameout and high CO during lightoff.
	5, 6, 7	No. 6 oil and toluene with bis(2-chloroethyl)ether	5.2-6.8 (6.1)	10.7-12.6 (12.0)	89-107 (93)	162-168 (165)	14-42[c] (27)	Steady boiler operation with well mixed waste fuel

Table 3. **Table 3.** *(continued)*

Site	Test	Fuels	Criteria Emissions, as Measured, Dry Basis[a] O_2 (percent)	CO_2 (percent)	CO (ppm)	NO_x (ppm)	TUHC (ppm)	General Test Conditions
E	2	No. 6 oil and methyl-methacrylate (MMA)	5.3-6.9 (5.5)	9.5-12.8 (11.6)	88-101 (92)	292-415 (325)	32-322[c] (142)	Steady boiler/burner operation with no smoke or high CO emissions
	3, 4, 5	No. 6 oil and MMA waste spiked with carbon tetrachloride, chlorobenzene, and trichloroethylene	5.3-8.0 (6.9)	9.0-12.8 (10.2)	80-155 (114)	270-450 (336)	38-142[c] (91)	Several periods of smoke and high CO emissions due to fluctuating waste feed and moderate burner settings. Most transient operations occurred during tests 3 and 4.
	6	No. 6 oil and MMA waste spiked with carbon tetrachloride, chlorobenzene, and trichloroethylene	5.2-7.4 (6.3)	10.0-12.8 (11.7)	80-120 (100)	325-398 (365)	27-29[c] (28)	Low load test; no smoke emission episodes.
	7	No. 6 oil and MMA waste spiked with carbon tetrachloride, chlorobenzene, and trichloroethylene	6.5-8.5 (7.4)	9.3-11.0 (10.4)	95-100 (98)	320-308 (270)	17-31[c] (24)	Three short periods of high CO emissions attributed to surge in waste feed. High load test.
	8	Natural gas and MMA waste spiked with carbon tetrachloride, chlorobenzene, and trichloroethylene	5.3-6.8 (6.2)	9.0-10.4 (9.6)	49-80 (65)	345-440 (405)	97-109[c] (104)	No significant transients. Steady burner and waste feed operation with low CO and smoke.
	9	Natural gas with toluene/MMA mix	6.4-8.5 (7.4)	7.8-10.4 (8.6)	50-123 (77)	100-180 (124)	52-61[c] (56)	Slightly higher stack opacity necessitated slight increase in excess air. No significant upsets.
F	2, 3, 4	No. 6 oil and solvents with carbon tetrachloride, chlorobenzene, and trichloroethylene	7.0-11.3 (8.3)	6.7-10.4 (8.9)	93-133 (103)	168-207 (190)	0-1.1 (0.4)	Inadequate burner settings caused several flameouts and some high CO and smoke emissions
G	1, 2, 3	Highly chlorinated organic wastes with carbon tetrachloride	8.2-9.4 (8.7)	8.4-10.2 (9.4)	85-140 (107)	43-54 (48)	0.2-0.5[d] (0.3)	Steady-state combustion conditions. No recorded operational upsets.
H	2, 3, 4	Pulverized coal and methyl acetate with carbon tetrachloride, chlorobenzene, and 1,1,1-trichloroethane	5.7-11.9 (6.3)	8.4-13.6 (12.4)	110-128 (118)	322-344 (332)	0-2 (0.6)	Steady boiler load with slightly variable waste feed. Test 4 performed at higher excess air condition.
I	2	Natural gas and aniline/nitrobenzene waste with carbon tetrachloride, chlorobenzene, and trichloroethylene	2.4-2.7 (2.6)	10.2-10.7 (10.4)	63-242 (180)	384-452 (420)	5-7 (6.4)	Staged combustion during test 2. Unstaged combustion during test 4. No significant boiler transients.
	4		2.5-2.7 (2.6)	10.6	22-112 (63)	1,090-1,160 (1,150)	5-6 (5.3)	Experienced feed pump problems.
J	1-6	Natural gas and mixture of toluene, benzene, carbon tetrachloride, chlorobenzene, and trichloroethylene	3.2-7.6 (5.4)	10.5-14.2 (12.5)	10-119 (76)	74-192 (116)	NA	Tests performed at three separate boiler loads. High and low excess air. No significant boiler or waste feed transients.
K	1	Heavy oil and light oil with carbon tetrachloride, chlorobenzene, and trichloroethylene	3.8-4.3 (4.0)	10.5-11.7 (11.0)	87-150 (108)	143-151 (146)	NA	No significant boiler or burner transients. Typical load and excess air conditions.

[a]*Numbers in parentheses are the average.*
[b]*Based on results for test 1 only.*
[c]*TUHC for sites D and E based on the sum of C_1 to C_6 hydrocarbon emissions.*
[d]*7 to 16 ppm was measured by on-site GC.*
NA—not available.

on a fuel bed typically results in insufficient fuel-air mixing which leads to transients in excess O_2, CO, and hydrocarbon emissions. Unsteady test conditions at site B resulted in significant hydrocarbon emissions. Unstable burner conditions were the result of initial tests at site D (tests 2 and 3) and site E (tests 3 and 4 primarily). These conditions, which caused intermittent high CO and smoke emissions, often resulted in burner flameouts. Improper waste and primary burner settings at site F also caused combustion instability and sudden flameouts. Several test periods were accompanied by peaks in high CO emissions which generally lasted less than 1 min. During most of the high smoke emission periods at these sites gas sampling was interrupted. Sites G through K showed no significant operational transients with the exception of test 4 at site H where excess air surged on a few occasions and during the staged combustion test at site I where CO emissions increased.

POHC Destruction

Table 4 summarizes site-specific DRE results for volatile POHCs. These results are based on about 120 separate gas measurements and a total of 35 individual tests at 9 boiler sites. Test sites A and C are not included in the table because POHCs were semivolatile. Results indicate DREs ranging from about 99.90 to 99.99996 percent for all POHCs with a total mass average for all sites of 99.998. The bulk of the data is available for four POHCs: carbon tetrachloride, trichloroethylene, chlorobenzene, and toluene. On the average, DREs for carbon tetrachloride and trichloroethylene were higher than chlorobenzene and toluene. The ranges in DREs, however, show nearly equal results independent of POHC.

On a site-specific basis, DREs of volatile organics at site F showed the lowest mass average DRE (99.98 percent). Next lowest mass average DREs were recorded for site H and B both at 99.991 percent and site E at 99.995 percent. It should be pointed out that chlorobenzene results for site J are misleading since low DREs were calculated based on high analytical detection limits. In reality, chlorobenzene DREs were probably much higher and site J mass average DRE would be increased passing the 99.9997 percent listed in Table 4.

A comparison of site-specific DREs highlights some important trends. The site F boiler was the only test site with a total mass average DRE less than 99.990 percent for volatile POHCs. In fact, low DREs were measured for all three cofired tests at this site. Burner operation at site F was characterized by nozzle coking, probable fuel jet impingement on the burner throat, intermittent periods of high CO and smoke emissions and burner flameouts. These problems were brought about by improper placement of the fuel guns in the burner ports. Similarly, lower DRE results at site E were recorded during tests characterized by fluctuating waste feedrates combined with intermittent periods of high CO and smoke emissions. Contrary to site F, low DREs for site E were most evident with the POHC methylmethacrylate resulting in DREs as low as 99.95 percent. Chlorinated POHCs at site E also showed lower DREs during these tests with unstable combustion conditions, however, destruction was always greater than 99.990 percent.

Table 4. Summary of Test Average DREs for Volatile POHCs[a]

POHC	Site B	D	E	F	G	H	I	J	K	Range	Weighted Average
Carbon tetrachloride			99.9990-99.9998 (99.9996)[b]	99.98-99.9990 (99.995)	99.995-99.9990 (99.998)	99.97-99.9994 (99.98)	99.9990-99.9993 (99.9993)	99.997-99.9998 (99.9990)	99.9998	99.97-99.9998	99.9992
Trichloroethylene			99.994-99.9995 (99.998)	99.98-99.998 (99.996)			99.99990-99.99992 (99.99991)	99.998-99.99993 (99.9996)	99.99990	99.98-99.99993	99.9994
1,1,1-Trichloroethane						99.97-99.9996 (99.994)				99.97-99.9996	99.994
Chlorobenzene			99.995-99.99990 (99.998)	99.96-99.992 (99.98)		99.990-99.997 (99.992)	99.997-99.9990 (99.998)	99.8-99.97 (99.95)	99.99992	99.8-99.99992	99.992
Benzene							99.97-99.98 (99.97)		99.996	99.97-99.996	99.990
Toluene	99.991	99.9992-99.99990 (99.9996)	99.997	99.90-99.97 (99.95)			99.998	99.9990-99.9997 (99.9990)	99.99996	99.90-99.99996	99.998
Tetrachloroethylene		99.994-99.9992 (99.998)								99.994-99.9992	99.998
Methylmethacrylate			99.95-99.997 (99.991)							99.95-99.995	99.991
Mass weighted average	99.991	99.994-99.99990 (99.998)	99.95-99.99990 (99.995)	99.90-99.9990 (99.98)	99.995-99.9990 (99.998)	99.97-99.9996 (99.991)	99.97-99.99992 (99.998)	99.8-99.99993 (99.9990)	99.996-99.99996 (99.9997)	99.8-99.99996	99.998

[a] *Each test average DRE is generally based on the weighted average of triplicate measurements.*
[b] *Numbers in parentheses represent the site-specific POHC average DRE.*

These trends suggest that lower DREs are more likely to occur during unstable combustion conditions leading to high combustible emissions. Therefore, an attempt was made to correlate DREs with combustion efficiency, defined as the percent carbon utilization ($1-CO/CO_2$) x 100. Figure 1 illustrates the mass average (total POHC fired taken as a whole) site-specific DREs as a function of the combustion efficiency. Site average DREs plotted in Figure 1 and in all other graphical presentations are based on all volatile and semivolatile POHCs detected in the waste fuels. A complete listing of Resource Conservation and Recovery Act (RCRA) Appendix VIII POHCs tracked for DRE measurement is presented in Appendix A, Volume I of the full report.

The data presented in Figure 1 indicate no definitive trend of lower DRE with higher CO. This is not entirely surprising because this attempted correlation does not account for site-specific considerations such as combustion characteristics of waste (POHC) types, boiler type and capacity, waste feedrate and feed mechanism, and temperature and residence time profiles. Furthermore the bulk of the data was obtained when CO emissions were in the narrow range of 70 to 140 ppm as measured corresponding to about 99.94 to 99.84 percent combustion efficiency as defined here. The only clear evidence of low DRE with high CO emissions is offered by the site A data where CO emissions were in excess of 500 ppm and the mean average DRE was lower than 99.990 percent. A tentative conclusion may be that DREs of 99.990

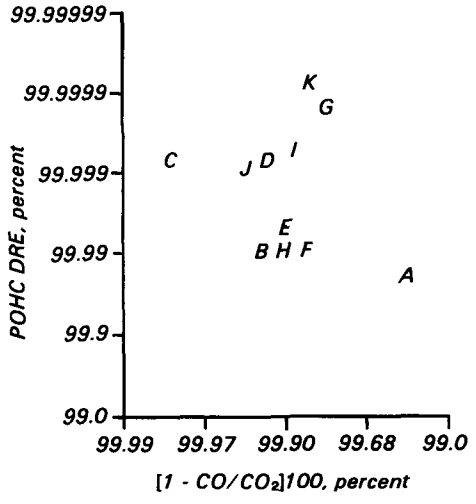

Figure 1. Site average DREs versus combustion efficiency.

percent or greater are more likely to result from combustion conditions leading to CO less than 80 to 100 ppm. However, in some cases low CO emissions may represent an overly conservative requirement for high POHC DRE. Although the validity of CO as a surrogate for DRE results remains speculative at this time, the effect of transient boiler operation and high CO emissions on DRE should be investigated in greater detail.

Figure 2 illustrates the dependence of measured DRE results on POHC concentrations in the waste fuel. The DREs are plotted versus the concentration of POHCs in the waste fuel (ppm) normalized by the ratio of the waste fuel heat input to the total heat input (W/T). The data, also based on mass average DRE for each site, suggest that higher DREs are likely with increasing POHC concentration in the waste fuel and higher waste/fuel ratios. This trend may indicate the importance of PIC formation from baseline fuels as well as the level of background contamination and error associated with low-level detection of volatile organics. PIC emission data clearly suggests that both fossil fuels such as oil and coal as well as waste fuels result in significant emissions of PICs.

Furnace waterwall heat release rate and NO_x formation can be indicators of the thermal environment in the flame and throughout the furnace. Waterwall surface heat release rate is a measure of the temperature profile through a furnace. Although radiative properties of combustion products play a predominant role, generally the higher the waterwall surface heat release rate, the higher the temperature profile through the furnace. Similarly, high flame temperature, long residence time, and turbulent mixing are conducive to high thermal NO formation. These combustion characteristics are also desirable from a POHC destruction viewpoint. Therefore, higher thermal NO may be linked with high POHC destruction. Figure 3 illustrates the trend of weighted average DREs with test loads surface heat release rates calculated for each site. The data illustrate a general trend of higher DREs with increasing waterwall surface heat release rates. This trend suggests that thermal environments throughout the boiler furnace may be more important for high POHC DREs than flue gas residence time. Furthermore, firetube boilers can be as effective in thermal POHC destruction as watertubes. This is evidenced by results obtained at sites G and J.

DRE results for sites A, B, F, and H fall below the trend indicated by the other

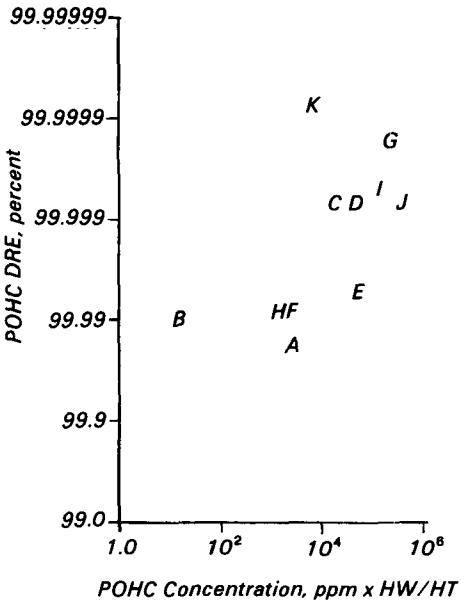

Figure 2. Site average DRE versus waste fuel POHC concentration.

test sites. As discussed earlier, boiler operation at sites A, B, and F was generally characterized by unstable combustion and burner conditions often leading to high combustible emissions. Low DRE results for site H, the only pulverized coal-fired boiler tested, may be attributed in part to low POHC concentration with respect to total heat input of the boiler and the contribution of background organic emissions from combustion of coal. Stated differently, this trend indicates that the lower limit of POHC DRE is likely to increase with furnace waterwall heat release rate. This trend is similar for DRE versus measured NO_x emissions.

Other Organic Emissions

Table 5 summarizes chlorinated organic emissions identified as products of incomplete combustion (PICs) during waste fuel firing for test sites D through H. PIC identification was based on blank corrected emission of organic compounds not detected in the waste fuels. Total chlorinated PIC emissions ranged between 0.3 and 32 mg/s. These emissions were one to two orders of magnitude greater than measured emissions of breakthrough chlorinated POHCs. Dichloromethane (methylene chloride) and chloroform generally constituted the bulk of these emissions followed by tetrachloroethylene and trichloroethanes. Methylene chloride PIC emissions are in part suspect because of possible contamination. This compound is widely used in both field test

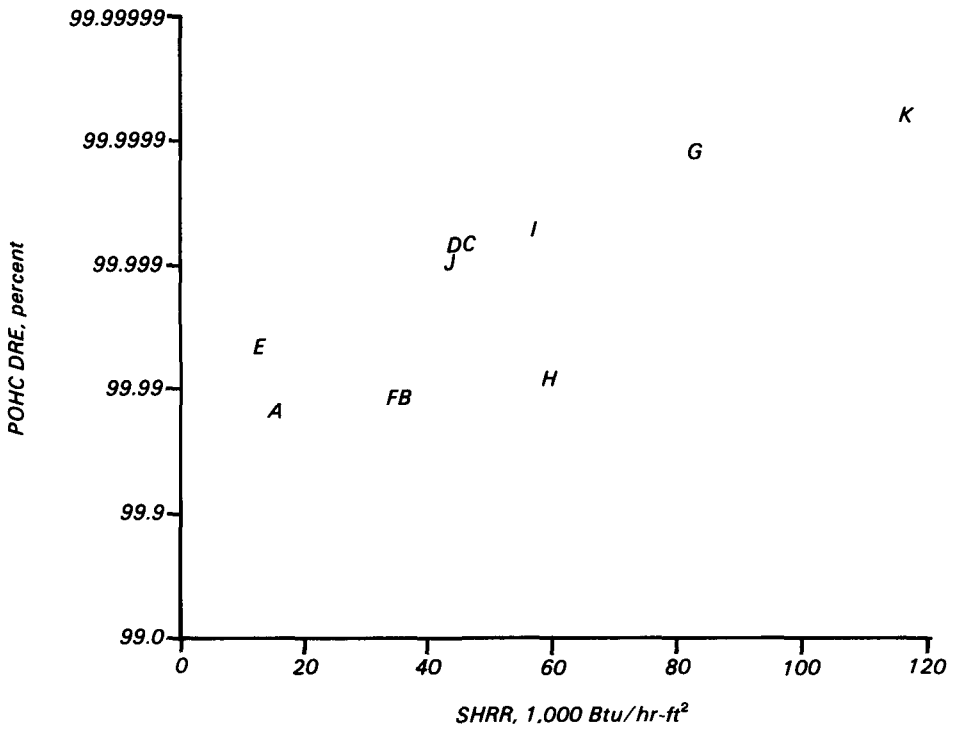

Figure 3. Effect of surface heat release rate on DRE—site average data.

activities and laboratory analyses. Nonchlorinated PICs were generally toluene and benzene.

Figure 4 illustrates a trend in PIC emissions versus POHC breakthrough for total PICs (including toluene and benzene). The data indicate a general trend of lower PIC emissions with increasing POHC destruction. This suggests that combustion conditions leading to more efficient POHC destruction are also likely to result in lower PIC formation.

Conclusions and Recommendations

Field tests conducted at 11 industrial boilers burning hazardous wastes indicate that POHC DREs generally exceeded 99.990 percent under relatively steady or normal boiler operating conditions. Although trends were not definitive, POHC DREs generally increased with higher waterwall surface heat release rates (furnace or temperature), lower CO emissions, and higher POHC firing rate. Additional research is necessary to determine the effect of unsteady or transient boiler operation on POHC DRE manifested by high CO and smoke emission.

Table 5. Volatile Chlorinated PICs Versus POHC Breakthrough

				Selected Chlorinated PICs, Percent of Total							
Site	Chlorinated Waste Fuel POHCs	Total Chlorinated POHC Breakthrough (μg/s)	Total Chlorinated PICs (μg/s)	Carbon Tetrachloride	Chloromethane	Dichloromethane	Chloroform	1,1,1-TCA and 1,1,2-TCA	Dichloroethylene and Dichloroethane	Tetrachloroethylene	PICs/POHCs
D	Tetrachloroethylene	630-880 (790)	2,600-7,700 (4,300)	3.6	0	75	6.0	6.4	2.1	--	5.4
	Bis(2-chloroethyl)ether	3.0-6.8 (4.7)	330-3,100 (1,800)	1.7	0	49	14	7.5	4.4	23	380
E	Carbon tetrachloride, chlorobenzene, and trichloroethylene	56-570 (220)	500-32,000 (7,400)	--[a]	0	NA	61	2.9	0	33	34
F	Carbon tetrachloride, chlorobenzene, and trichloroethylene	51-133 (85)	700-23,000 (8,400)	--	12	43	39	5.7	0.09	0.04	99
G	Carbon tetrachloride, epichlorohydrin, and bis (2-chloroisopropyl) ether	95-307 (170)	710-7,300 (4,900)	--	5.2	2.9	58	0	17	6.9	29
H	Carbon tetrachloride, chlorobenzene, and 1,1,1-trichloroethane	290-4,100 (1,600)	4,000-12,000 (6,900)	--	92	0	2.7	0.5	0	2.6	4.3
	Average Results	4.7-1,600 (570)	1,800-8,400 (6,700)	2.7	18	34	30	3.8	3.9	11	92

[a]*Dashes indicate POHC in the waste fuel.*
NA—not analyzed.

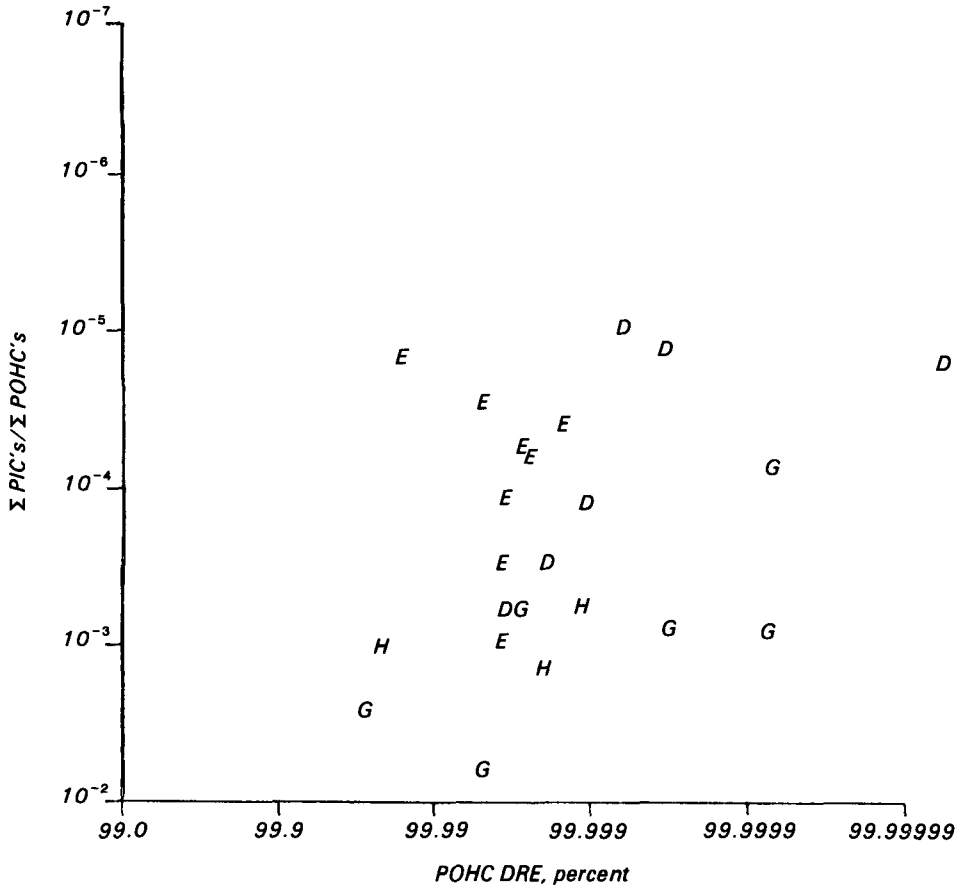

Figure 4. *PIC emissions versus test average POHC-DRE.*

The contribution of PIC emissions to POHC-DRE determination should also be investigated further.

Reference

1. Dietz, S. et al., "National Survey of Hazardous Waste Generators and Treatment, Storage and Disposal Facilities Regulated under RCRA in 1981," prepared by Westat Inc. for the Office of Solid Waste, U.S. Environmental Protection Agency under contract no. 68-01-6861, April 1984.

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The complete report, entitled "Engineering Assessment Report—Hazardous Waste Cofiring in Industrial Boilers," consists of two volumes:
"Volume I. Technical Results," (Order No. PB 85-197 838/AS; Cost: $16.00, subject to change).
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