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Project Summary

Destruction of Hazardous Wastes Cofired in Industrial Boilers: Pilot-Scale Parametrics Testing

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The full report presents the results of pilot-scale testing of the destruction of hazardous wastes. A combustion unit burning no. 2 distillate oil cofired with various materials found in the Resource Conservation and Recovery Act (RCRA) Appendix 8 list was tested for its destruction and removal efficiency (DRE) with respect to the Appendix 8 compounds. The pilot-scale unit was configured to simulate the thermal history of a 40 million Btu/hr watertube boiler. The operating parameters of the combustor were varied over a range of values representative of the normal operating envelope of an industrial-sized packaged watertube boiler. Compounds employed in the testing included carbon tetrachloride, chloroform, 1,2-dichloroethane, and chlorobenzene. Variables studied included firing rate (two values), flame shape or swirl (three values), excess air rate or stoichiometry (three values), waste to fuel ratio (three values), and waterwall effects. In addition to direct measurements of DRE, efforts were made to model the thermal and DRE histories of the combustor unit.

A total of 44 runs were conducted generating 99 individual DRE data points. It was found that under most operating conditions most compounds could be destroyed to greater than 99.99 percent efficiency. However, under selected conditions certain compounds exhibited less than 99.99 percent DRE. Parameters most affecting DRE were waterwalls (by heat extraction), and excess air rate. Excess air rate effects were found to be non-linear. That is, there was found to be an optimum excess air rate for DRE. The simulation effort cumulated in a mathematical model. The model runs on a personal computer, predicts temperature profiles within 50 degrees Celsius, and predicts destruction efficiency conservatively.

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 a separate report of the same title (see Project Report ordering information at back).

Introduction

Thermal destruction of wastes by direct incineration or by cofiring with conventional fuels in boilers, furnaces, or kilns is one of the most effective methods currently available for disposal of hazardous organic material. While direct incineration of hazardous wastes is regulated by Part 264 of the Resource Conservation and Recovery Act (RCRA) as adopted in January 1981, boiler cofiring is currently exempt from RCRA provisions. However, the potential for boiler cofiring regulations has been evaluated by the U.S. Environmental Protection Agency (EPA) and they are, at the time of writing, in the process of preparing regulatory positions and drafting regulations for promulgation. To support this effort, EPA's Incineration Research Branch (IRB) in conjunction with the Office of Solid Waste is conducting research and development programs on incineration effectiveness and regulatory impacts.

The global purpose of this study was to gather data to aid the EPA in selecting a strategy or set of strategies for regulating the combustion of hazardous wastes in boilers. The specific objectives were twofold: to identify which of several boiler operational parameters has a major impact, positive or negative, on boiler DRE; and, to evaluate and if practical, establish a mathematical model for predicting a maximum amount of cofired waste that a particular boiler configuration might emit. In particular, those parameters that could be easily changed by an operator or might represent major differences between boiler types were studied. A secondary objective of the study was to gain sufficient information to allow judgements of what particular parameters to monitor closely during full-scale testing. Within that objective was the intent to establish some common basis for comparing full-scale boilers. A final objective was to obtain information that would give insight on how regulations might be cast so that trial burns would not be needed.

Procedures

The facility used to achieve the purpose and objectives of the study is the Acurex pilot-scale furnace whose thermal characteristics closely approximated a 12-megawatt (40 million Btu/hr) packaged D-type watertube boiler.

The furnace has a single burner, front-wall-fired, into a horizontally oriented firebox. The premixed fuel oil/waste mixture is pumped out of drums through a pressure-atomizing nozzle and stabilized at the front wall. The fuel flow is monitored by rotameter. Combustion air is preheated and injected in the annular region around the fuel delivery tube. The IFRF/Acurex burner design allows swirl adjustments by rotating swirl blocks. Air flow is monitored by hot wire anemometer.

The postflame gases travel down the 4.55m (15 ft) by 83.5 cm (33 in.) diameter radiant section tunnel. The walls are refractory lined with optionally mounted waterwalls. Ports along the top and sides of the furnace accommodate ceramic type R thermocouple probes for gas temperature profiles. Type K probes are embedded in the refractory for wall temperature determinations. Thermocouples are also placed at the manifold inlet to and from the outlet of each cooling panel, and to and from the burner quarl. Cooling fluid flow measurements are made by rotameter.

After traversing the radiant section, the hot gases make a 90-degree turn and pass upward through the convective section. The U-tube cooling drawer assemblies extract heat from the gas stream as necessary to bring the temperature down to levels that can be handled by the bag house. Downstream of the last tube bank, a stainless steel probe extracts gas samples for continuous emissions analysis. Electro-optical analyses are used to define levels of CO, CO_2, O_2, NO_x, and total unburnt hydrocarbon (THC) (Appendix A.5). Samples for the Volatile Organics Sampling Train (VOST) are extracted with a stainless steel probe from the end of an 8-in. diameter 15-ft long duct. The gases are then exhausted to a 45-ft high stack.

The test plan divided the tests into three subsets: a baseline study burning only distillate oil, a single compound study of one hazardous waste compound cofired with distillate oil, and a multiple compound study burning more than one compound simultaneously. Parameters studied included excess air rate, fuel firing rate, amount of waterwall surface area, burner swirl setting, and waste type. The selection of waste types for the composite "soup" encompassed a large range of predicted destructibility. The baseline study was designed to define the thermal environment within the facility under the various operating conditions of choice, to define the magnitude of the effects of changes in variables on the thermal environment, and to demonstrate the ability of a simulation to predict the thermal environment resulting from a specific set of variable settings. The single compound studies had two goals: to define the magnitude of variable effects on destruction efficiency; and to define the effects of cofiring wastes on the expected thermal environment. The final, multiple compound studies were to determine the destruction efficiencies of several compounds with known thermal environments.

Results and Discussion

A summary of the results of this program is presented in Table 1. The values are penetration values or C/C_o (= (100-DRE)/100). The penentration value is the mass rate of waste flowing into the combustor (C_o) divided by the mass rate of waste leaving (C). A semiquantitative summary of the effects of the operating variables on DRE is presented in Table 2. These values are rough estimates of the difference between either temperature or DRE for two runs where only the specified parameter was varied. For example, a change in firing rate between 0.8 million Btu/hr and 1.2 million Btu/hr changed the temperature profile by about 110°C (200°F). The corresponding change in DRE was about a factor of three.

For each firing condition, radial temperature profiles were measured at five cross sections. During the first several runs, about 120 individual temperature points were measured. After establishing the reproducibility of the individual location temperatures, the number of points measured per run was reduced to 40. The reproducibility of the thermal distribution is shown in Table 3.

Having a thermally well-characterized and accessible combustor allowed a detailed simulation effort based upon the simple, conservative, destruction-prediction model forwarded by one author in 1981. The simulation is comprised of two modules—one that predicts the bulk gas thermal history and the second that estimates the corresonding amount of destruction. The model does not consider the 90 to 99 percent destruction that occurs in the flame. Yet it conservatively predicts within about two orders of magnitude the destruction efficiency of this combustor. The set of data for carbon tetrachloride is presented in Figure 1.

Conclusions and Recommendations

The primary purpose of this study was to determine which boiler operational variables play the most significant part in boiler DREs. The study determined that within the pilot-scale unit the use of waterwalls and the variation of excess air were significant, and that there appeared to be an optimal excess air rate. The study also demonstrated that operational variables could change DREs by two to three orders of magnitude. Further experimental work should be carried out to verify some of the findings. The modeling results should be applied to full-scale units to estimate the model's ability to aid permitting. Specific conclusions are that:

- Of the variables studied, the order of influence on DRE is: waterwalls $>$ compound $\geq$ excess air $>$ firing rate $\geq$ flame shape. The order of influence on temperature profiles is: waterwall $>$ excess air $>$ firing rate $>$ compound $\simeq$ flame shape.
- Except for waste composition, the influence of operational variables on DRE corresponds to the influence on bulk temperature profiles.

Table 1. *Average Fractional Breakthrough C/C_0 for Each Waste and Firing Condition*

	Condition	Chlorobenzene[a,b]	Carbon Tetrachloride	Chloroform	1,2 Dichloroethane
I[c]	(0.8, 10, 7.5, 8)	$1.4 \pm 0.1 \times 10^{-4}$ (4)	$1.6 \pm 0.2 \times 10^{-4}$ (2)	$1.6 \pm 0.2 \times 10^{-5}$ (3)	$5 \pm 2 \times 10^{-6}$ (3)
Ia[d]	(0.8, 10, 7.5, 0)	4.2×10^{-6} (1)	--[e]	--	--
II	(0.8, 25, 7.5, 8)	$1.4 \pm 0.3 \times 10^{-5}$ (4)	$5 \pm 3 \times 10^{-5}$ (5)	$2.6 \pm 2 \times 10^{-5}$ (5)	$1 \pm 0.5 \times 10^{-6}$ (2)
IIa	(0.8, 25, 7.5, 0)	$4 \pm 3 \times 10^{-7}$ (6)	--	--	--
III	(0.8, 50, 7.5, 8)	$8.9 \pm 6 \times 10^{-5}$ (5)	2.1×10^{-4} (1)	$2.0 \pm 0.8 \times 10^{-5}$ (3)	$1 \pm 0.2 \times 10^{-6}$ (3)
IIIa	(0.8, 50, 7.5, 0)	$2.5 \pm 2 \times 10^{-7}$ (3)	--	--	--
IV	(1.2, 10, 7.5, 8)	$6 \pm 8 \times 10^{-5}$ (5)	$1.2 \pm 0.3 \times 10^{-4}$ (2)	$3.2 \pm 0.5 \times 10^{-5}$ (3)	--
IVa	(1.2, 10, 7.5, 0)	$2.2 \pm 0.5 \times 10^{-7}$ (3)	--	--	--
V	(1.2, 25, 7.5, 8)	$4.5 \pm 2 \times 10^{-6}$ (5)	$2.5 \pm 1 \times 10^{-5}$ (2)	$8.8 \pm 2 \times 10^{-5}$ (3)	--
Va	(1.2, 25, 7.5, 0)	$0.5 \pm 0.3 \times 10^{-7}$ (3)	--	--	--
VI	(1.2, 50, 7.5, 8)	$5.5 \pm 2 \times 10^{-5}$ (4)	$7.9 \pm 6 \times 10^{-5}$ (3)	$1.1 \pm 0.02 \times 10^{-4}$ (2)	$8 \pm 4 \times 10^{-6}$ (2)
VIa	(1.2, 50, 7.5, 0)	$3.4 \pm 0.7 \times 10^{-7}$ (3)	--	--	--
VII	(0.8, 25, 5.0, 8)	--	$6.3 \pm 3 \times 10^{-5}$ (3)	--	--
IX	(1.2, 25, 5.0, 8)	$2.0 \pm 0.5 \times 10^{-6}$ (3)	$1.5 \pm 0.3 \times 10^{-4}$ (3)	--	--

[a]± represents 1 standard deviation from average.
[b]( ) indicates number of valid data points.
[c](Firing Rate in Million Btu/hr, percent Excess Air, Swirl, percent Waterwall).
[d]Run conditions suffixed with an "a" are without waterwalls. All other conditions are with waterwalls in place.
[e]Not tested under that condition.
[f]C_0 = mass rate of compound in; C = mass rate of compound out.

- From comparison of DRE with high heat extraction and low heat extraction in the combustor, it is concluded that in-flame destruction accounts for only about 90 to 99 percent of the DRE. The remaining destruction must be achieved from postflame thermal oxidation and decomposition.
- Residence time within the flame is insufficient to destroy both POHCs and PICs. Without sufficient postflame time and temperature, the quantity of PICs passing out of the boiler will be significant.
- Significant volatile PICs emitted during combustion of chlorinated organics include methylene chloride, ethylene trichloride, perchloroethylene, and the ethylene dichlorides. Suspected PICs—but not positively identified—include chloromethane, chloroethane, chloroethylene, and propylene chloride.
- A model capable of predicting within a few degrees the temperature profile within a furnace has been validated. The model can be used to predict within an order of magnitude the destruction efficiency of the modeled furnace.
- Conclusions on CO versus DRE versus excess air cannot be drawn from this data. Carbon monoxide levels showed minimal variation over the range of DRE observed.

Table 2. *Semiquantitative Estimation of the Effects of the Independent Variables on Temperature Profile and DRE*

Variable	Range of Temperature Changes °C (± °F)	Range of DRE Changes (Factor)[a]
Waterwalls	275 (500)	100
Excess air rate	165 (300)	10
Firing rate	110 (200)	3
Burner swirl	30 (50)	1
Compound	30 (50)	20

[a]C/C_0 is mass rate of waste out divided by mass rate of waste in.

Table 3. *Reproducibility of Temperature Measurements at Four Selected Points Within the Pilot-Scale Furnace*[a]

	Number of Points	Average Difference[b] °C (°F)	Standard Deviation °C (°F)
Within run (with waterwalls)	40	10 (18)	6 (10)
Within run (without waterwalls)	48	7 (13)	4 (7)
Between all runs	40	29 (53)	17 (30)

[a]The points are at 8 and 12 in. from the wall and at cross sections C-3 and E-2.
[b]Difference between two measurements at the same location.

This study showed that certain variables play a major role in determining DRE and gave insight on underlying physical and chemical mechanisms. Results of the program suggest the following areas of research which need to be addressed:

- The study strongly reinforced the concept that only a fraction of the destruction of a compound is achieved in the flame zone. Verification and quantification of the breakthrough phenomenon is necessary with flames closely approximating full-scale boiler flames.
- In close conjunction with the study of

breakthrough of compounds from the flame zone, there should be studies on the formation and destruction of PICs in both the flame and postflame zones.

- This program clearly demonstrated the effect of compound structure on DRE. This fact should be applied to testing of potential surrogates (such as sulfur hexafloride) for establishing boiler and incinerator capabilities.
- The observation of optimum DRE in the excess air region of 20 to 50 percent should be studied in detail, and verified on a full-scale unit.
- A key operating criterion that should be considered when using boilers for waste destruction is the placing of upper and lower limits on excess air rates.
- The current thermal destruction model should be applied to full-scale boiler data to calibrate empirical approximations and evaluate the level of conservatism.
- The weakest point in the model appears to be the availability of reliable pseudo-first-order empirical global kinetic data for the thermal destruction of a wide range of compounds. Further work in this area would be a definite asset.
- Material following aerodynamic paths outside of the bulk gas flow pattern is the chief contributor to insufficient DRE. Studies of breakthrough mechanisms and their relative significance should be undertaken.
- Thermal NO_x appears to show a strong upper bound correlation. That is, for a given NO_x level the DRE will be at least a certain amount. Qualitatively this correlation was expected, but it needs to be verified in other units.

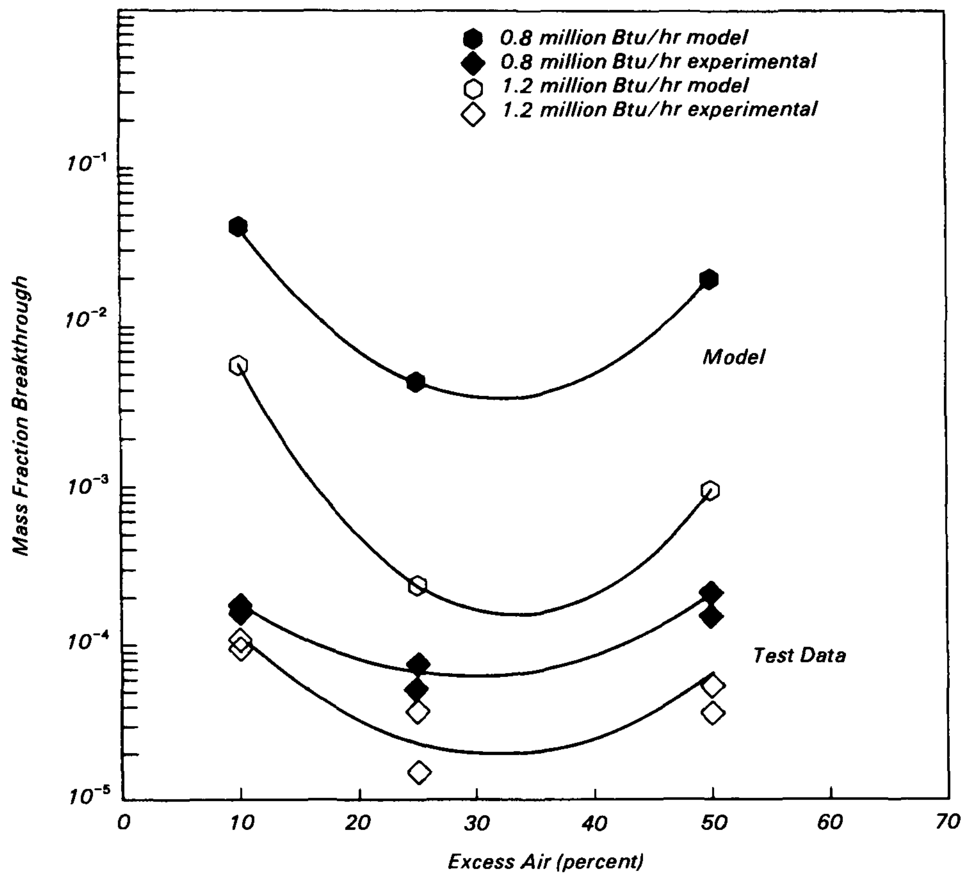

Figure 1. Comparison of weighted average model prediction and pilot-scale carbon tetrachloride destruction data at variable excess air.

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The complete report, entitled "Destruction of Hazardous Wastes Cofired in Industrial Boilers: Pilot-Scale Parametrics Testing," (Order No. PB 85-242 139/AS; Cost: $16.95, subject to change) will be available only from:
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