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THE UNITED STATES ENVIRONMENTAL PROTECTION AGENCY COMBUSTION RESEARCH FACILITY: A COMMITMENT TO HAZARDOUS WASTE MANAGEMENT

RICHARD A. CARNES
USEPA Combustion Research Facility, Jefferson, AR 72079 (U.S.A.)
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Summary

This article describes the United States Environmental Protection Agency Combustion Research Facility (CRF) located in Jefferson, Arkansas. The program objectives are presented along with a detailed description of the existing facility. A discussion concerning some research conducted to date is presented along with results from the official permit test burn. Future research objectives are presented.

Historical perspective

In 1975, the Environmental Protection Agency (EPA) published the results of a major research program entitled "Determination of Incinerator Operating Conditions Necessary for Safe Disposal of Pesticides" [1]. This report presented the results of a number of incineration tests covering several pesticide formulations and molecular structures. At that time, it represented the Agency's first attempt to define safe operating conditions for the thermal destruction of hazardous substances albeit pesticides. Further, under the authority granted the Agency by the Resource Conservation and Recovery Act of 1976 (RCRA), the Agency used this report along with other documents [2] to establish the incineration conditions that are required for the incineration of hazardous wastes as listed in appropriate Federal Register publications [3, 4].

During the regulatory development exercise, it became apparent that the actual performance data that were available to support the regulations were insufficient. It was determined that a major research and development effort would have to be undertaken to provide that data. This program was planned to consist of two major efforts: (a) a laboratory research program to provide basic data on the thermal stability of specific hazardous compounds and to support the second effort, and (b) an extensive series of full-scale test burns using existing equipment and facilities.

As this program moved forward, significant differences were observed between the large-scale investigations and those derived from the laboratory

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Fig. 1. USEPA Combustion Research Facility in Jefferson, Arkansas.

studies. This matter has been treated elsewhere [5]; the differences are thought to arise from simplifications that have been made in the incineration conditions maintained in the laboratory-scale experiments.

It was decided that an intermediate-scale study was needed that would more nearly approximate the thermal and chemical conditions that exist in full-scale technology, but at the same time be close enough to the laboratory studies so as to provide a bridge between the two. In July of 1978, a research contract was awarded to conduct parametric investigations of a pilot-scale hazardous waste incinerator. The program was originally scheduled to rent the technology at the manufacturer's facility and have contract personnel conduct the necessary experiments on an intermittent basis so as not to disrupt activities of the manufacturer. Unfortunately, this program never became functional and after a series of delays, changes and site relocations the USEPA Combustion Research Facility located in Jefferson, Arkansas became a reality in July, 1982 (Fig. 1).

Program objective

The USEPA Combustion Research Facility (CRF) has as its overall mission the detailed physical and chemical study of the incineration of hazardous wastes in highly instrumented and closely controlled pilot-scale incineration systems.

Specific program objectives are:

(1) To develop methods of improving the reliability and controllability of the incineration process. By systematically altering the operating parameters of each unit operation, non-compliance of individual CRF subsystems can be purposely induced to define the allowable operating range for that unit, to determine conditions under which products of incomplete combustion (PICs) and hazardous process residues (ash and scrubber liquor) are produced, and to determine the necessary on-line corrective measures required to restore compliance.

(2) To develop relationships for predicting the performance of incinerators of varying scale and design. To the extent possible, the CRF will also attempt to obtain test quantities of selected hazardous wastes which are being tested in permit trial burns by incinerator owner/operators. Parametric testing of these same wastes in the CRF pilot-scale incinerators will be used to compare performance with the full-scale tests, to examine performance scale-up criteria and evaluate the significance and applicability of pilot-scale performance data.

(3) To develop a technically defensible data base leading to additional understanding of the hazardous waste incineration process and to assist in the development of methods to predict the performance of incinerators as a function of key process operating variables. The incineration data base is intended to simplify and reduce the cost of permit and compliance testing, and would assist in forming a sound technical basis for development and promulgation of detailed design, performance, and operating standards for hazardous waste incinerators in future revised regulations. By evaluating surrogates or other indicators for incinerator non-performance, real-time process monitoring and control methods may be developed for use in increasing incineration process reliability and for potentially simplifying permit and compliance evaluations.

(4) To develop incinerator system performance data for regulated hazardous wastes to support current RCRA incinerator regulations and performance standards, and to provide an additional technical basis for those future standards which may be necessary.

Facility description

The CRF houses an incinerator room and associated control room plus locker and shop areas and laboratory space for waste characterization and trace analysis of residual organic compounds in effluent streams. Analytical capability for organics at present includes two gas chromatographs (GC) with autosamplers, a high performance liquid chromatograph (HPLC), a purge and trap device and the associated sample preparation equipment. Reliable hot-zone sampling is conducted in both the kiln exhaust and afterburner exhaust ducts in order to compliment the stack sampling. Real-time monitoring of O_2, CO, CO_2 and NO_x is provided by an automated system. EPA Method 5, Modified Method 5 (MM5) using water cooled XAD-2 resin, and the volatile organic analysis are all routinely conducted.

At the present time, the experimental system that is available at the CRF is a pilot-scale rotary kiln with afterburner and an air pollution control system consisting of a variable throat venturi, wetted elbow and packed tower scrubber. The system has been well characterized and reported on in Ref. [6]. Presently liquid and semi-liquid waste materials are fed by a positive-displacement pump through a water-cooled feed lance mounted onto the front face of the kiln. A newly designed feed face has been installed allowing for liquid and semi-liquid feeds through a variety of lance configurations and for solids or containerized solids using a ram feed device. The new feed face also accommodates a specially designed burner at this end of the kiln.

The general layout of the CRF is shown in Fig. 2. For access and safety purposes each room has been designated high hazard (HH), in which all personnel are required to wear protective gear when actual hazardous wastes are in these designated areas; intermediate hazard (IH), which infers possible chemical hazards and precaution should be observed; and low hazard (LH), in which slight hazard to personnel exists primarily from cross-contamination from other areas.

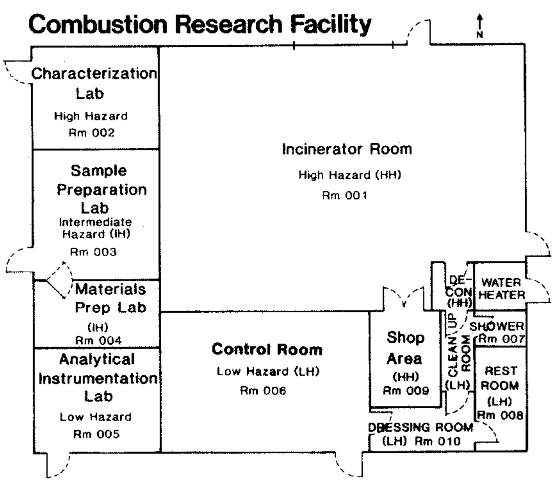

Fig. 2. CRF floor plan.

A pilot-scale liquid injection incineration system is presently being installed at the CRF, adding a second technology to this research facility. Installation is expected to be completed by spring 1985. Permit applications have been submitted to State Officials and a Part B was officially awarded August 9, 1985. A test burn is scheduled for the fall of 1985 for RCRA purposes.

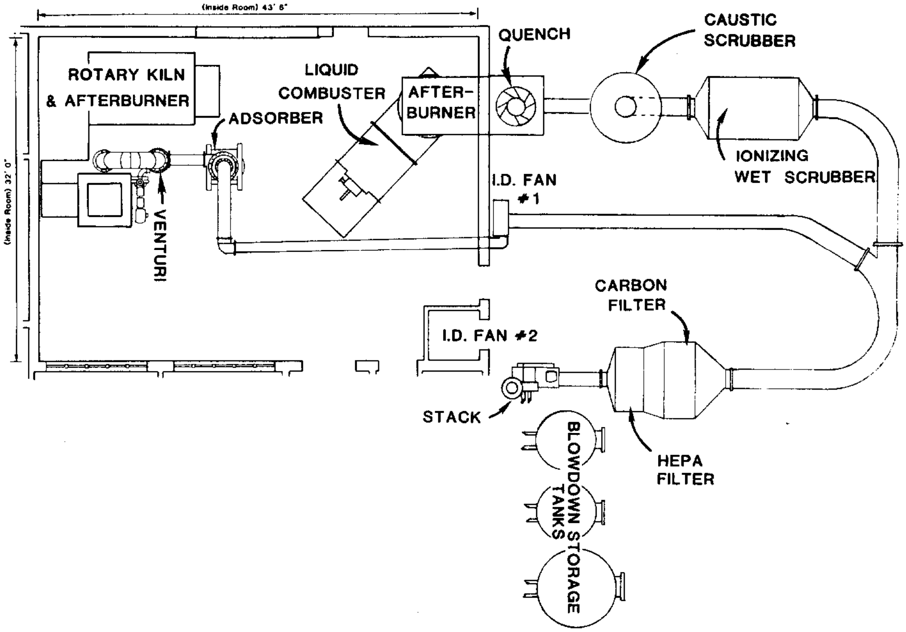

Fig. 3. Plan view of CRF incinerators.

The primary combustion chamber is sectional, designed to permit test-to-test variation of residence time. The front section contains a 3 million BTU/h burner assembly, through which steam-atomized waste is fed. Aqueous waste may be fed through nozzles around the perimeter.

The primary combustion gases are transported through an unfired afterburner, and then are quenched, first with fresh water and then with caustic solution recirculating from a quench tank. The cooled gases then pass through a packed tower scrubber for acid gas neutralization and then through an ionizing wet scrubber, before reaching a flanged "Y" where the rotary kiln system exhaust and the liquid injection system exhaust become common. A blind flange insert is used to selectively isolate either of the two independent incineration and scrubbing systems from the common downstream system.

Figure 3 presents the incinerator room floor plan and shows how all combustion gases from either technology are scrubbed with conventional equipment and then are scrubbed a second time using a carbon bed/high efficiency particulate filter arrangement. This is done so as to allow failure mode research to be conducted while not having dangerous discharge to the environment. In the configuration seen in Fig. 3 samples shall be collected prior to the carbon bed and will constitute those normally associated with discharge to the environment. A sample will also be taken at the post carbon bed location for permit compliance purposes.

During the two years of activity on the CRF program, the facility has been completed and equipped; master plans for Project QA/QC, Health and Safety, and facility operation and maintenance have been developed and implemented; and extensive modifications and upgrades have been accomplished to the rotary kiln system. The RCRA Part B permit for the CRF was recently issued by the State of Arkansas.

A series of 34 test burns was conducted between August 1983 and January 1984 in the pilot-scale rotary kiln incineration system at the CRF, using chlorinated benzenes as surrogate principal organic hazardous components (POHCs), over a range of feed compositions, POHC feed rates, rotary kiln temperatures, and afterburner temperatures.

The CRF rotary kiln system consistently produced destruction and removal efficiency (DRE) values above 99.99% for the chlorinated benzene POHCs. DRE values below 99.99% were obtained during several types of failure mode simulations (flame-out in kiln or afterburner). A large number of products of incomplete combustion (PICs) were produced and identified, a number of which are toxic or possibly carcinogenic. Deliberate reduction of excess air levels resulted in significant production of soot and PICS but did not produce higher than normal levels of CO in the combustion gases.

Hot-zone sampling just downstream of each of the two combustion chambers provided for the detailed study of PIC formation and will facilitate the future development of models of the incineration process. Helium injection techniques were used to determine combustion gas flow rates and to measure residence time distributions (which directly affect destruction efficiencies).

The results of these experiments have been evaluated and written into three separate articles. The first research article, Ref. [7], deals with the results of the incineration of hexachlorobenzene (HCB) solutions and provides data on a series of experiments, destruction and removal efficiencies (DREs) and identification, albeit tentative, of some 20 organic products of incomplete combustion found in hot-zone samples using MM5 techniques.

The second article, Ref. [8], has been submitted to a journal for review and deals with the incineration of 1,2,4-trichlorobenzene, TCB. Here, as with the HCB paper, results of experiments are presented, data concerning DREs and hot zone analyses are shown and further system evaluation is conducted. It is anticipated that this paper will be publicly available in the literature in the near future.

The third article, Ref. [9], has been published in a journal and deals with observations made at the CRF using pulses of helium gas (He) to determine residence time distributions (RTD) in the afterburner and mass flow rates of combustion gases. The utility of the He dilution techniques is illustrated by data presented in Table 1, which summarizes the results of several measurements of the $\hat{t}$ = average RTD.

From the period of August, 1983 to July, 1984, the CRF application for a RCRA Part B incineration permit for the rotary kiln system was being

TABLE 1

Typical RTD measurements

Test	T_A (°F)	Q_A (SCFM)	V/Q (sec)[a]	t (RTD)[b]
1	2000	607	1.28	1.51
2	1600	530	1.45	1.50
3	1600	565	1.77	2.70
4	1964	491	1.74	2.05
5	1820	705	1.29	1.34
6	1760	543	1.71	1.88

[a] V/Q computed on basis of cold volume of afterburner (AB) = 61.5 ft^3, which is the normal definition of residence time.
[b] Physical measurement of the mean residence time using He dilution technique developed at the CRF.

processed, reviewed, the public notified and finally issuance of the permit received. During that interim no hazardous wastes were permitted on-site, therefore operations focused on commercially available compounds that were also listed as POHCs by the EPA. Research was conducted in a very conservative mode so as to insure the operations would not violate any emission requirements but would produce meaningful data.

With the issuance of the RCRA Part B permit for the rotary kiln system the CRF was required to conduct a compliance test burn using organic compounds spelled out in advance. A detailed test burn protocol was developed and submitted to the permit authorities for review and approval. Briefly the test burn solution was the following mix: carbon tetrachloride, trichloroethylene, monochlorobenzene and toluene. Table 2 presents each constituent of the feed, feed rate and estimates for a 99.99% DRE.

The preliminary analytical results are presented in Table 3 for the target species.

During the permit test the rotary kiln was operated at 1000°F. For com-

TABLE 2

Permit feed solution/calculated emissions for 99.99% DRE

Compound	Feed rate (kg/h)	Feed rate (g/min)	mg/DSMM[a]	mg/sample[b]
CCl_4	3.309	55.2	0.24	4.8
C_2HCl_3	3.001	50.0	0.217	4.34
C_7H_8	0.901	15.0	0.062	1.24
ClC_6H_5	1.452	24.2	0.105	2.1

[a] Average flow upstream of carbon bed approximately 23 dry standard cubic meters per minute (DSMM) for DRE of 99.99%.
[b] Using a fast Volatile Organic Sampling Train (VOST) with a total sample of 20 dry standard liters.

TABLE 3

VOST results[a]

Compound	E_1 (mg/sample)	S_1 (mg/sample)	E_2 (mg/sample)	S_2 (mg/sample)	Q (mg/sample)
CCl_4	1.49	2.54	0.151	0.032	0.011
C_2HCl_3	0.014	0.166	0.020	0.067	0.003
C_7H_8	1.08	0.784	0.081	0.328	0.012
ClC_6H_5	0.033	0.016	0.01	0.10	0.001

E_1 was obtained from the entrance side of carbon bed taken during background blank.
S_1 was obtained at the stack post carbon bed during background blank.
E_2 taken same place as E_1, but with test feed solution on.
S_2 taken same place as S_1, but during feeding of test solution.
Q was a field blank.
[a]The S value is sometimes larger than the E value due in part to steam stripping occurring in the carbon bed. The bed was designed to remove large, high-boiling organics.

parison purposes it was determined that in order for the DE to be 99.99% a concentration of no more than shown in column 5 of Table 2 was needed. This is then compared to the S_2 values reported in Table 3. A quick review indicates the test to be successful regarding the 99.99% DE requirements. Further results will be forthcoming on this test burn as they are cleared by authorities.

Testing objectives for the future

The Combustion Research Facility testing objectives for the future fall into three categories:

1. Shakedown, checkout, and demonstration of components of incineration systems, and of the facility.
2. Further research progress in understanding the incineration process, and in uncovering the relationships between key operating variables and destruction efficiency, reliability and controllability. This study should lead to new methods for compliance monitoring and control.
3. Generation of incinerator performance data for targeted hazardous wastes.

A condition of the RCRA Permit is that the total hydrocarbon and POHC capture of the carbon filter is to be measured. A prerequisite is to determine whether any residual organics on the regenerated carbon sorbent would interfere with the capture determination during testing. A laboratory characterization of the impurities on the activated carbon is therefore planned.

In addition, in recognition that the keystone of the RCRA Permit in allowing research incineration tests over wide ranges of operating conditions (including those to intentionally induce simulated non-compliance upstream of the carbon filter) is the presence of a "redundant filter" in the exhaust system, verification tests of this activated carbon filter will take place prior to the formal permit compliance test burn series. It is planned to challenge the activated carbon filter and to verify its capability to sufficiently remove residual POHCs in the exhaust gas from the rotary kiln scrubber system.

The modified CRF exhaust system includes a new induced draft (I.D.) fan. When the rotary kiln incineration system is being run, two I.D. fans in series will be operating simultaneously (the old one upstream of the carbon bed and the new one downstream of this bed). Operational tests are required to verify that the two I.D. fans can operate simultaneously without coupling of transient behavior (i.e., the generation of sustained pressure oscillations resulting from positive feedback coupling between the fans).

The test series already accomplished in the rotary kiln (with chlorinated benzenes) were conducted at relatively low waste feed rates, 100 to 1000 g/h. The low turndown ratio of the existing kiln burner was the factor limiting the waste feed rate. At the lowest available burner setting, the waste feed rate (including the combustible carriers) was limited so that the total heat input rate did not exceed the nominal maximum for the kiln. With the installation of a new kiln burner and burner management system, the lower available burner settings will permit higher waste feed rates.

The performance of the rotary kiln in prior testing led to results and conclusions which should be extended into a regime of higher waste feed rates. A comprehensive test series is planned for this purpose. Included in this test series will be a simulated failure-mode sequence (intentional periodic shut-off of burners). The results of this test series using several EPA Soups (a predetermined mixture of chemicals to simulate a waste stream) will assist in the determination of the relationship between POHC emissions in upset conditions and other possible surrogate measures that allow continuous on-line monitoring.

The effect of the physical form of the waste on the completeness of incineration will be studied. Each of the controlled test materials will be studied in the liquid form, in the semi-liquid form (by addition of a gelling compound) and in the "solid" form, wherein the solution is sorbed onto a solid medium as, for example, shredded corn cobs. This will be carried out as part of the compliance monitoring test series.

With the availability of a ram feeder for feeding containerized solid wastes in discrete bundles, a test series is planned with a known waste material to study the effect on performance of this mode of feed. The quantity of combustible material in each discrete bundle fed, the quantity of hazardous (or surrogate hazardous) waste in each bundle, and the frequency of bundles fed, will be the independent variables explored.

Prior testing in the rotary kiln has been at steady-state afterburner temperatures ranging from 1600°F to 2150°F. At the waste feed rate, excess air and residence time (total flowrate in a fixed geometry) conditions explored, DRE values of above 99.99 percent were consistently measured.

Testing at afterburner temperatures below 1600°F is planned, to find the threshold conditions where DRE values (measured upstream of the carbon filter) no longer reach the compliance value of 99.99 percent. The overall system will still be in compliance because of the carbon bed filter.

NOTICE: "Although the research described in this article has been funded wholly or in part by the United States Environmental Protection Agency it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred."

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