United States
Environmental Protection
Agency

Hazardous Waste Engineering
Research Laboratory
Cincinnati OH 45268

Research and Development

EPA/600/S2-86/011 July 1986

EPA

Project Summary

Control of Air Emissions from Hazardous Waste Combustion Sources: Field Evaluations of Pilot-Scale Air Pollution Control Devices

C. W. Westbrook, C. E. Tatsch, and Lawrence Cottone

Pilot-scale air pollution control devices supplied by Hydro-Sonics Systems, ETS, Inc., and Vulcan Engineering Company were installed at the ENSCO, Inc. Incinerator in El Dorado, Arkansas in the spring of 1984. Each of these units treated an uncontrolled slipstream of the incinerator exhaust gas. Simultaneous measurements of the total particulate and HCl in the gas streams were made at the inlet to and exit from the units using an EPA Method 5 sampling train. Particle sizing at both locations using Andersen impactors was also done. The units supplied by Hydro-Sonics Systems and ETS, Inc. exhibited a high degree of HCl and particulate matter control. The Hydro-Sonic Tandem Nozzle SuperSub Model 100 gave the best overall performance for HCl and particulate control and ability to accommodate the variable composition of the exhaust gas.

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

Much hazardous waste generated has characteristics that make incineration the disposal method of choice. Incineration of these wastes must be performed according to the applicable regulations of the Resource Conservation and Recovery Act (RCRA) and State and local regulations. The RCRA regulations specify the destruction and removal efficiency (DRE) that must be achieved for principal waste components and set limits for the emission rates of particulate matter and hydrogen chloride (HCl).

Purpose

The purpose of this project was to evaluate innovative air pollution control devices and to test their performances on commercial-scale facilities. The specific goals were to examine the cleaning capabilities of each device under specified operating conditions. The pollutants to be monitored were particulates; total mass, and as a function of particle size; and hydrogen chloride (HCl).

The data developed in the project will be useful to EPA and others in the waste management community to assist in optimizing the control of air emissions from hazardous waste combustion.

Approach

Three vendors with pilot units meeting the project criteria agreed to participate. They are Hydro-Sonics®* System, Inc.; ETS, Inc.; and Vulcan Engineering. The Hydro-Sonic® pilot unit is a wet scrubber that operates by fine atomization of water

*Mention of trade marks or commercial products does not constitute endorsement or recommendation for use.

into the gas stream resulting in HCl capture and particle growth with final removal by cyclonic action. The ETS, Inc. unit uses dry lime injection for particulate capture. The unit provided by Vulcan Engineering is a high temperature (>550°C, 1000°F) metallic weave filtration system. It is not currently designed for acid gas control.

A commercial hazardous waste incinerator owned by ENSCO, Inc. in El Dorado, Arkansas was selected for the study.

A pilot unit was installed to permit a slipstream of particulate-laden gas from the emergency bypass stack to be drawn through the unit. Inlet and outlet gas streams were sampled simultaneously by EPA Method 5 for the concentration and total mass of the particulate matter and HCl. Particle size distributions were also determined at both locations.

Each APCD vendor operated his own equipment and was allowed to vary conditions to test the performance of the unit. ENSCO operated their facility in a routine manner during these tests. No special fuel blends or operating procedures were used to accommodate the units.

Test Source Description

The host plant for these tests was ENSCO, Inc.'s incineration complex in El Dorado, Arkansas. This permitted facility primarily incinerates polychlorinated biphenyl (PCB) contaminated oils and capacitors.

The plant is designed to receive and incinerate whole capacitors. The shredded parts are transported with a screw conveyor into a rotary kiln. The kiln exit gas passes through a cyclone that removes much of the large suspended particulate matter. The gases then pass into a two-chambered afterburner referred to as the thermal oxidation unit (TOU). The upstream side of the afterburner can be fired with PCB-containing oils or other high Btu liquids.

Gases leaving the TOU are drawn into a custom-designed wet scrubber. This unit consists of two circulating water loops. The first, prequench, loop removes the bulk of the particulate and HCl. Lime slurry is added for pH control. Blowdown is routed to a pond for solids settling. The clarified water is recycled. The second loop is comprised of a jet eductor, knockout vessel, and demister. Fresh makeup water is added to maintain inventory. All blowdown from this loop is used as a makeup to the first loop. No water is discharged from this system except for that evaporated and carried out with the stack gas.

The incinerator typically operates 24 hours per day, 7 days per week. In general, wastes of a specific class are accumulated onsite until sufficient quantity is available for burns of at least one day. This permits achieving and maintaining steady-state incineration conditions.

During these tests, accumulated wastes were incinerated on the schedule determined by plant management. No special wastes were burned or excluded. Close contact was maintained with plant personnel so that the APCD testing spanned only one operating condition, insofar as possible.

Description of APCD Connection to Plant

Connection was made to the emergency bypass stack. The stack, located between the TOU and the scrubber, is refractory lined. Openings around the stack cap were plugged to prevent air infiltration into the stack. A stainless steel duct was connected to a flanged opening in the stack. The duct connected to a vertical section leading to a Hastalloy cooling section. Gas cooling was by direct water spray. A temperature control device mounted at the exit of the cooling section modulated the water flow. The cooled gas was then ducted to the APCD connection via a 12-inch ID 17-foot horizontal run of insulated carbon steel pipe. The APCD gas inlet sample ports were located near the midpoint of this duct. The two ports were on the vertical and horizontal axes perpendicular to the gas flow.

Test Method Description

The test program was designed to withdraw a slipstream of incinerator exhaust gas and to test the APCD's performance in removing particulate and HCl.

Both the concentration of total particulate in the gas stream and particulate mass per unit time were determined using EPA Method 5. The impinger solutions in the back half of the train provided equivalent information for HCl. The particle size distribution at both the inlet and outlet test locations was determined using Andersen cascade impactors.

Due to the large difference in particle loadings between the inlet and outlet sites, it was not possible to obtain simultaneous impactor runs spanning the same time interval. Typically, 5 to 7 minutes operation at the inlet site produced optimum stage loadings. Operation for 60 to 90 minutes was required at the outlet location to collect an adequate sample. Impactor runs were arranged to coincide with one or more Method 5 runs.

An onsite laboratory was set up to reduce as much of the test data as possible. Facilities were available to properly clean all of the test equipment, recover samples, and to desiccate the particulate catches. A certified accurate balance was used to weigh all of the samples. A chloride ion-specific electrode and supporting electronics were available to measure chloride concentrations in the Method 5 train back-half impingers. Chloride audit solutions were onsite to audit this procedure.

The impactor data were processed at the conclusion of the test using the Particulate Data Reduction (PADRE) program.[1]

Hydro-Sonics Air Pollution Control Device

General Description

Lone Star Steel Co. originally developed this wet scrubber to control particulate emissions from various iron and steelmaking operations. It has been used on electric arc furnaces, coke oven emissions, open hearth steel furnaces, and sintering plants. The scrubbers have also been used on exhaust streams containing uranium hexafluoride and its hydrolysis products with particulate removal efficiency consistently exceeding 99 percent.

There are three versions of the scrubber: The Steam-Hydro, the Tandem Nozzle, and the SuperSub. All versions have the same basic concept. Water is atomized into the waste gas stream forming water droplets of about the same size as the particulate. The gas stream then enters a turbulent contact zone in which the particles are wetted and vapors are absorbed. Particle growth then takes place in an agglomeration zone. Because of the design, a single waste droplet may contain hundreds of micronic and submicronic dust particles. As a result of the growth of droplets containing particulate into increasingly large size, the initial size of the particulate has only a small effect on its removal. Actual removal of the agglomerated particle is accomplished in a specially designed low-pressure-drop cyclone. Water and particulate are gravity drained from the cyclone bottom, and the cleaned gases exit through the top. Demisters are not required.

The Steam-Hydro employs a supersonic ejector drive to provide the energy for pumping and cleaning the polluted gas. Steam or compressed air is commonly employed as the working fluid. The gas is drawn into the unit by the ejector nozzle which is fitted with a water injection ring at the exit of the nozzle. The expanding jet causes violent shattering of the water droplets and turbulent mixing of gas and water. The steam version is most attractive when there is a source of waste heat available to generate the high-pressure steam.

The Tandem Nozzle scrubber uses a fan drive to pump the polluted gas and to provide the energy to generate the fine water droplets. The system uses two subsonic nozzles and agglomeration sections in series. Both nozzles are equipped with water spray rings. The first section serves to condense vapors, remove the larger particulates, and initiate growth of the fine particulate. Additional water is atomized at the exit of the second nozzle and is turbulently mixed to continue the agglomeration of the particles.

The SuperSub version of the system is a combination of the above two system concepts. A small supersonic ejector (steam or air) is located upstream of the subsonic nozzle. The system's main driving force is fan power as in the Tandem Nozzle version. This arrangement provides good water atomization for fine particle control coupled with the lower energy requirements of the fan drive. Water consumption is about the same as a venturi scrubber.

Test Results

Test data for these units were collected between March 15, 1984, and March 23, 1984. Table 1 shows the removal efficiency data for total particulate and chloride organized by the APCD operating version. With the exception of the Tandem Nozzle runs, chloride removal for all combinations was greater than 98 percent. Runs using recycle water from the ENSCO scrubber show higher removal of chloride than those using freshwater. Since the recycle water contained some alkalinity, this is not surprising. In a commercial application, alkalinity would be added to the scrubbing water. Thus, chloride removals of 99 percent or better should be expected for any version of this unit.

Particulate removal efficiency ranges from about 82 to 88 percent for the Steam-Hydro and Tandem Nozzle versions. The SuperSub version achieved a particulate removal efficiency of about 95 percent. It should be noted that these removal efficiencies refer only to the gas stream brought into the APCD and not the efficiency that might be obtained on the entire gas stream from the ENSCO incinerator. Since the APCD connection to the main gas duct resulted in a bias toward the smaller particles, we would expect that substantially higher removal efficiencies would have been obtained if the APCD had been treating the unbiased gas stream.

Shown in Table 2 are the percent mass less than 1 micron at the inlet and outlet of the unit. Much of the particulate matter exists below 1 micron, whether at the inlet or outlet of the control device. It must be noted that the design philosophy of the unit is to agglomerate fine particles. Thus, it is to be expected that some submicron particles entering the device exit as particles greater than 1 micron in size. These data indicate that the SuperSub configuration is the most effective of the versions tested for control of the submicron particulate matter from this source.

ETS, Inc. Dry Scrubber

General Description

The unit has two major components: the dry reactor and a particulate collection device. The patented dry reaction has a number of unique components. The basic operating principles are as follows. Flue gas is directed cyclonically into the reactor. The rotating slinger unit (driven by a hydraulic motor) delivers the dry reactant (usually 200 mesh hydrated lime) perpendicular to the flue gas flow. This creates maximum mixing and intimate contact of the reactant and pollutants. An internal recirculator, with no moving parts, is located above the slinger. This device increases the contact time and enhances removal of the acid gases. The slinger then directs the dry reaction products down and into an expansion section where the larger particles are removed. The finer particulate matter is carried into the particulate collection device.

The particulate collector can be a conventional baghouse, an electrostatic fabric filter (ESFF) baghouse, or a Reduced Entrainment Precipitator (REP) developed by ETS. The lime dust entrained in the flue gas continues to react with acid gas components throughout the transport ductwork. In addition, the lime dust aids in building a reactive filter cake on the fabric filters. This serves two purposes. First, reaction with acid gas components continues until final particulate removal occurs. Secondly, the precoat assists in removing the fine particulate without excessive pressure drops across the filters.

This system is totally dry. The reactants are delivered as dry powder, not as a slurry required for the spray dryer type scrubbers. The reacted product is also a dry powder and can be handled as one handles dust collected in a baghouse. Since no water is used at any point in the

Table 1. *Particulate and Chloride Removal Efficiencies: Hydro-Sonic Scrubber*

Configuration[a]	*Particulate efficiency (Percent)*	*Chloride efficiency (Percent)*
SH/Lo/R	81.6	99.1
SH/Lo/F	87.4	98.7
SH/Hi/R	88.2	98.8
TN/-/R	92.1	99.8
TN/-/F	86.3	96.0
SS/-/F	95.4	98.3

[a] *Configuration codes are: SH = Steam-Hydro; TN = Tandem Nozzle; S = SuperSub; Hi = High energy input; Lo = Low energy input; - = not applicable to this version; Fresh = Freshwater used in APCD; R = Recycle water from ENSCO scrubber used in APCD.*

Table 2. *Comparison of Fine Particle (<1 Micron) Enrichment Factors (Out/In) for Various Operating Conditions*

Operating Condition	*Inlet Impactor Run No.*	*Percent of Mass <1 Micron*	*Outlet Impactor Run No.*	*Percent of Mass <1 Micron*	*Out/In*
SH/Lo/F	2	43	3	69	1.6
SH/Lo/F	3	57	4	67	1.2
TN/-/F	4	38	5	60	1.6
SS/-/F	5	64	6	36	0.6
SS/-/F	6	70	7	26	0.4

system, there is no mist carryover problem, little or no corrosion in the exhaust stack which remains dry, and minimum loss of stack gas buoyancy since this energy is not used to evaporate water.

Test Results

The ETS system was installed during the last week of March 1984. The system was operated and tested during April 1-10 and April 23-26, 1984. Two reactant materials, hydrated lime and nahcolite were evaluated for HCl removal effectiveness.

The unit tested has a rated capacity of 2000 ACFM. The dry scrubber was connected to a pulse jet baghouse which used Nomex® fabric cartridges. An induced draft fan was located at the outlet of the baghouse forcing the cleaned gas into the 12-inch I.D. vertical exhaust stack.

Given in Table 3 are the particulate and HCl removal efficiency data for the two reactants at the various stoichiometries. Six of the nine tests using lime as the reactant indicate an HCl removal efficiency of over 98 percent. Only one of the tests using nahcolite achieved over 90 percent HCl removal. The stoichiometric ratio (SR) ranges from 2 to 9 for the tests in which lime was the reactant. The data suggest that the SR for lime must be nearly 3:1 to ensure scrubbing efficiencies of 99 percent.

Due to limitation in the feed equipment, nahcolite was injected at much lower stoichiometric ratios. The HCl removal efficiency does not appear to correlate with the nahcolite/HCl stoichiometric ratio up to a ratio of 1.7. Therefore, from these tests, it is not possible to determine the nahcolite/HCl ratio required to achieve 99 percent HCl removal.

The particulate removal efficiencies are calculated strictly from the Method 5 data. No allowance has been made for the reactant materials added in the dry reactor. For most of the runs, the weight of reactant added ranged from about 40 percent to over 100 percent of the weight of particulate entering the system from the incinerator. The reactants added were 100 percent less than 200 mesh (74 microns). Obviously some of the material was much smaller and may have passed through the baghouse.

The calculated particulate removal efficiencies for the first 10 runs were all greater than 90 percent with most in the 95 to 98 percent range. It should be noted that, due to the bias toward smaller particles caused by the slipstream sample withdrawal, this is the removal efficiency for the finer particles in the ENSCO incinerator exhaust gas. Since the unit would be expected to remove the larger particles more easily, the removal efficiency for the total gas stream would be expected to be even higher.

Table 3. *Summary Results: ETS Unit*

Reactant used	*Stoichiometric ratio*	*HCl Efficiency percent*	*Particulates efficiency percent*
Lime	*2.80*	*98.7*	*91*
Lime	*4.53*	*89.0*	*97*
Lime	*4.50*	*98.0*	*96*
Lime	*6.61*	*99.2*	*95*
Lime	*8.71*	*98.9*	*95*
Lime	*8.07*	*99.6*	*98*
Lime	*5.29*	*99.8*	*90*
Lime	*1.94*	*56.3*	*98*
Lime	*2.42*	*79.1*	*98*
Nahcolite	*0.70*	*93.2*	*96*
Nahcolite	*0.53*	*82.0*	*(1)*
Nahcolite	*0.87*	*54.7*	*76*
Nahcolite	-	*(2)*	*75*
Nahcolite	*0.56*	*53.8*	*85*
Nahcolite	*1.73*	*68.1*	*83*
Nahcolite	*0.98*	*33.1*	*38*

(1) Torn baghouse cartridge.
(2) Sample lost.

It is suspected that the low efficiencies measured for the last six nahcolite runs were due to persistent difficulties in sealing the cartridges in the baghouse. In addition, a tear was discovered in one cartridge after the second nahcolite run. The particulate removal efficiencies reported for the last six nahcolite runs do not accurately reflect the particulate removal capabilities of the unit.

The particulate control capability of the ETS unit as a function of particle size was also determined. Table 4 shows the percentages of particulate matter less than 1 micron in size in the inlet and outlet samples. In our opinion, these data imply that a significant fraction of the particulate matter in the unit exhaust originated with the lime injected for HCl control.

Table 4. *Comparison of Fine Particle (<Micron) Enrichment Factors Out/In for ETS Impactor Runs*

Inlet percent (<1 micron)	*Outlet percent (<1 micron)*	*Out/In*
31.4	*5.26*	*0.17*
31.7	*3.01*	*0.09*
52.6	*10.2*	*0.19*
30.7	*0.14*	*0.004*

Vulcan Engineering Company Hi-Tac Filter

General Description

The high temperature air cleaning (Hi-Tac) device was developed by Vulcan Engineering Company for the removal of particulate matter from gas streams at higher collector inlet temperatures than previously possible. The unit is not designed nor equipped to control HCl emissions. Although the Hi-Tac unit looks much like a conventional baghouse, there are substantial differences.

The filter media is entirely metallic. This results in greater resistance to moisture, temperature, corrosion, abrasion, and pressure than is provided by conventional fabric media. Although temperatures below 500°F do not decrease the collection efficiency, the media is designed to operate in the 600°F to 1350°F range. Temperature excursions to 2000°F can be tolerated. The filter elements will even tolerate flame temperatures.

The unit was developed for use in the iron and steel industry to control particulate from the many high temperature sources. The initial tests on the unit were performed on exhaust gas from an iron cupola. The gas entering the unit was 750°F and contained 1.39 grains of particulate per dry standard cubic foot (dscf). The unit operated with an air-to-cloth ratio of 16:1 and collected 99.2 percent of the particulate.

Test Results

The unit tested is completely portable and self-contained. Connection to an electrical power source and the exhaust duct are the only setup requirements. The unit is mounted on a Talbert 47-ft double drop Tandem axle trailer.

Each of the four cleaning modules mounted on the trailer houses four removable cartridge elements. Each element consists of a metallic reinforcing framework covered with stainless steel mesh. The weave may be varied to determine the appropriate design for a particular source.

During this test program, the following three types of weaves were in the unit:

Module I - 150 x 105 plain weave
Module II - 325 x 325 twilled weave
Module III and IV - 50 x 250 dutch weave.

The total removal efficiencies for particulate matter are shown in Table 5. Removal efficiency for particulate matter was quite erratic, varying from 34 percent to 98 percent. Excluding run number 1, the average removal efficiency was 89.7 percent. Inspections of the cartridges before and after test runs indicated that cake formation on the filter fabric was not reliable. During several inspections following cartridge cleaning, it was observed that a very large portion (about 70 percent) of the fabric surface was still covered by the filter cake, with about 20 percent of the surface clean down to the fabric. The sticky particulate from the incinerator interferred with proper cake formation and filter cleaning. It is possible that fabric weave changes or precoating of the fabric might correct this difficulty. The test program was not designed to explore these options.

Particulate removal versus gas flow rate through the APCD, and particulate removal versus air-to-cloth ratio showed no clear trends. It is suspected that the peculiar cake formation properties and resultant filter cleaning problems made these standard plots of little value.

Recognizing the difficulties cited above for particulate control, an attempt was made to assess the removal efficiency at various particulate size ranges. These data indicated 90 percent or better control of particles of less than 1 micron but decreasing efficiency as the particle size increases.

Table 5. *Vulcan High Temperature Baghouse*

Run number	*Particulate removal (Percent)*
1	34.2
2	93.1
3	90.4
4	92.5
5	94.2
6	84.3
7	89.3
8	74.8
9	90.0
10	98.4

These apparently strange results may be due to the method used, determining small differences between highly variable numbers, or to agglomeration of fine, sticky particles passing through the filters.

In summary, the test results indicate that effective control of the fine particulates generated by hazardous waste combustion may be achievable by the Hi-Tac unit. Additional development work to address the problem of sticky particulate will be required.

Conclusions

1. All versions of the Hydro-Sonic units tested achieved excellent HCl control, considering that no alkalinity was added to the scrubber water for pH control. Ninety-nine percent removal of HCl was obtained without adding additional alkalinity to the ENSCO scrubber recycle water. With additional alkalinity, any of these units should be capable of well over 99 percent HCl removal.
2. The Tandem Nozzle SuperSub Model 100 achieved the best particulate removal of the three Hydro-Sonic units tested.
3. The ETS dry scrubber achieved both high removal efficiencies for HCl and particulate.
4. The ETS scrubber reagent hydrated lime consumption appears to be high (3 moles lime per mole HCl) but cannot be stated with confidence since no attempts were made to improve utilization through reagent recycle.
5. The ETS unit does not presently have capability to adjust reagent feed rate to accommodate rapidly varying HCl content in the gas to be treated.
6. The Vulcan Hi-Tac unit is not designed to, and cannot presently, remove acid gases from the exhaust gas being treated. Therefore, it is not applicable to incinerators burning significant amounts of halogenated hazardous wastes.
7. Further development work and/or emissions testing will be required before the Hi-Tac unit demonstrates the capability to reliably control sources which might produce sticky particulate as encountered in the exhaust of the ENSCO incinerator.
8. Considerable variability was encountered in the ENSCO exhaust gas for particulate concentration, particulate size distribution, HCl concentration, flue gas moisture content, and exhaust gas temperature. It is necessary that any air pollution control device installed on a hazardous waste incinerator have design features that allow compensation for this variability.
9. Of the APCDs tested in this project, the Hydro-Sonic Tandem Nozzle SuperSub gave the best overall performance in terms of HCl and particulate removal and ability to accommodate variability in the gas stream being treated.

Reference

1. Tatsch, C.W., W.M. Yeager, and G.L. Johnson, 1984. PADRE: A computerized data reduction system for cascade impactor measurements. *Journal of the Air Pollution Control Association*, Volume 34, No. 6, pp. 655-660.

C. W. Westbrook and C. E. Tatsch are with Research Triangle Institute, Research Triangle Park, NC 27709; and Lawrence Cottone is with Engineering-Science, Inc., Fairfax, Virginia 22030.
***Harry M. Freeman** is the EPA Project Officer (see below).*
The complete report, entitled "Control of Air Emissions from Hazardous Waste Combustion Sources: Field Evaluations of Pilot-Scale Air Pollution Control Devices," (Order No. PB 86-151 677/AS; Cost: $16.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Hazardous Waste Engineering Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

BULK RATE
POSTAGE & FEES P
EPA
PERMIT No G-35

Official Business
Penalty for Private Use $300

EPA/600/S2-86/011