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Project Summary

Electrostatic Precipitator Efficiency on a Multiple-Hearth Incinerator Burning Sewage Sludge

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A pilot-scale electrostatic precipitator (ESP) was evaluated for its removal performance of 23 metals and for sulfur containing particles when fitted to a multiple-hearth incinerator burning sewage sludge. The small-scale ESP was installed to take a slipstream of about 3% of the total incinerator emissions. Particle size fractions were collected from the gas streams entering and leaving the ESP. Each particle size fraction was analyzed for 24 elemental species and ESP performance was evaluated for overall removal efficiency, size fraction removal efficiency, and selective removal of specific metals. Total concentrations of each element in the controlled emission stream were determined as well as the proportionate concentrations of species in the solid and volatile states. Concentrations of each metal in the emission stream were compared with the concentrations in the sludge residue.

To obtain comparisons of ESP performance with a more typical emission control device, the performance of the incinerator's full-scale wet scrubber was also evaluated.

This Project Summary was developed by EPA's Water 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

The purpose of this research project was to determine the particulate removal efficiency of an electrostatic precipitator (ESP) emission control system on a multiple-hearth furnace burning sewage sludge. Of particular interest was the fate of metals found in a city/industrial type of sludge that was incinerated and subjected to ESP air pollution control. A pilot-scale ESP was temporarily fitted to an existing multiple-hearth furnace burning sewage sludge. A slipstream of incinerator exhaust gas, amounting to about 3% of the incinerator's emissions, was taken from the top hearth of the incinerator. This afforded an opportunity to compare ESP performance with the particulate removal performance of the incinerator's wet scrubber.

The test was conducted at a treatment plant that receives sewage sludge from an industrialized urban area. The sludge feed had been digested and dewatered.

Procedure

The full-scale, six hearth, multiple-hearth incinerator was fitted with ducting to take a slipstream of uncontrolled emissions. The slipstream, amounting to about 3% of the incinerator's emissions, was fed to the ESP at temperatures averaging 525°F. The top hearth temperature of the incinerator averaged 743°F during ESP operation.

Emission tests were conducted simultaneously at inlet and outlet of the ESP and at outlet of the wet scrubber. A source assessment sampling system (SASS) train was used to collect particle size fractions of diameters of > 10 micron (μm), 3 to 10 μm, 1 to 3 μm, < 1 μm. Impingers were located downstream of the particle sizing part of the train to collect volatile metals. The impingers were immersed in an ice bath. A weak solution of nitric acid was used to facilitate capture of the metals.

Metals were analyzed by the inductively coupled argon plasma method (ICAP). The concentrations of 23 target metals plus sulfur were determined in each particle size fraction and in the impinger catches. From these results, it was possible to determine concentrations of each metal in the controlled and uncontrolled emission streams, in each particle size fraction, and in the impinger catches. Overall efficiencies of the emission control devices were determined. Removal performance of the individual metals as well as specific particle fraction were also determined.

Results and Discussion

In addition to determining the relative efficiency of the ESP and wet scrubber, the mass of various metals discharged and the distribution of metals among various particle size fractions were also made. Twenty-four elements were selected as target for investigation (Al, Sb, As, Ba, Cd, Ca, Cr, Co, Cu, Au, Fe, Pb, Mg, Mn, Ni, P, Se, Ag, Na, S, Sn, Ti, V, Zn). Concentrations in the sludge were determined on a dry, volatile-free sludge that had been heated to 550°C. Selenium and silver were not detected in the sludge, and gold was detected in only one of three samples. Of the metals detected, cobalt and gold had concentrations less than 100 $\mu g/g$.

At the other end of the range, six nontoxic elements exhibited concentrations higher than 10,000 $\mu g/g$ (calcium, iron, aluminum, phosphorus, magnesium, and sulfur). These six elements contributed 88.2% by weight of the species analyzed. The remaining metals in the intermediate concentration range (100 to 10,000 $\mu g/g$) amounted to 11.7 percent by weight of the species analyzed. The intermediate group includes all of the metals except silver and mercury that are identified as hazardous in the RCRA regulations, Section 261.0 (As, Ba, Cd, Cr, Pb, Se). Silver was not detected in the sludge, and mercury was not a target compound. Rank order of the intermediate group by concentration was as follows:

	µg/g		*µg/g*
sodium	*7850*	*chromium*	*777*
zinc	*7220*	*arsenic*	*729*
titanium	*7070*	*manganese*	*443*
copper	*5330*	*tin*	*441*
barium	*2440*	*cadmium*	*233*
lead	*992*	*vanadium*	*212*
nickel	*840*	*antimony*	*120*

Our analysis focused on this group of metals.

Emission Concentration

Table 1 presents particle concentrations at the incinerator, ESP, and scrubber outlets, along with overall removal efficiencies for the ESP and scrubber for the three runs carried out. ESP concentrations were high and efficiencies poor for Runs 1 and 2. Purge air introduced to cool the ESP electrode insulators adversely affected the results for the three runs. This air was shut off for Run 3 and efficiency improved substantially. Removal efficiencies were consistently good for the scrubber for all three runs. For the ESP, Run 3 showed the highest removals.

Particle Size Distributions

The SASS train aerodynamically separates the particulate discharges into four size fractions, thus giving the particle size distribution of the discharges (Table 2). Table 2 also shows the calculated removal efficiency for each fraction for the two pollution control devices. Only Run 3 results for the ESP are shown.

The results show marked differences in performance of the two devices. The ESP is not as efficient as the wet scrubber in collecting coarse particles (>10 μm) but is much more efficient in collecting fines (<1 μm). This result is especially significant because several troublesome metals such as cadmium and lead are capable of vaporizing in the incinerator subsequently forming fine fumes that are difficult to remove with wet scrubbers.

Elemental Concentrations in Outlet Stream

The elemental concentrations were determined in each SASS fraction for each outlet stream. Individual as well as total mass removal efficiencies can be calculated for each metal. A useful comparison to make is to determine the "enrichment" for a given element in the particles as they leave the incinerator and the air pollution control device. The enrichment from sludge to incinerator (average concentration of an element in particles divided by its volatiles-free concentration in the sludge) and from sludge to particles collected at the control device outlet (concentration at device outlet divided by volatiles-free concentration in the sludge) are presented in Table 3. Problems with analyses of the samples at the control device outlets invalidated results for some metals that are not shown. There appeared to be no problem with results collected at the incinerator outlet.

The enrichment at the incinerator outlet shows substantial enrichment of cadmium and less but still substantial enrichment of lead and tin. Enrichments from sludge feed to ESP outlets and from sludge feed to scrubber outlets are markedly different. Cadmium shows a reduction in concentration (enrichment less than 1) for the ESP and a very high enrichment for the wet scrubber. Consideration of the performance of these two devices indicate that this is a reasonable expectation. Typically, cadmium is enriched during incineration because unlike most metals, part of it is volatilized in the incinerator. It then reforms as a very fine solid on cooling. The ESP as noted above is very effective in capturing fine particles so very little cadmium escapes it. On the other hand, the wet scrubber is inefficient in capturing fine particles, so much of the cadmium escapes. It then is highly concentrated in the particles captured at the scrubber outlet. Lead and tin also show high enrichment between feed sludge and scrubber outlet, probably for the same reason as cadmium.

Conclusions

1. The experimental program demonstrated that an ESP performed at least as well as a wet scrubber for removing total particulates from the uncontrolled gaseous discharge from a sludge incinerator.

2. The ESP was especially efficient in collecting particles in the finest size range (0.1 to 1.0 μm) investigated. Because of this feature, the ESP was far more effective than the wet scrubber in removing volatile metals, (including cadmium and lead) from the stack gases.

The full report was submitted in fulfillment of Contract No. 68-03-3148 by Radian Corporation under the sponsorship of the U.S. Environmental Protection Agency.

Table 1. *Particulate Mass Emission Concentrations and Removal Efficiencies*

	Mass Concentrations (g/dscm*)			Removal Efficiency	
	Inlet	ESP	Scrubber	ESP	Scrubber
Run 1	0.75	0.11	0.013	91.5	98.4
Run 2	0.93	0.11	0.014	93.3	98.5
Run 3	0.79	0.012	0.019	98.3	97.6
Average	0.82	0.074	0.015	94.4	98.1

*Corrected to 12% O_2.

Table 2. *Particle Mass Concentrations by SASS Size Fraction (g/dscm, 12% O_2)*

	Probe and >10 micron Cyclone	>3 µm Cyclone	>1 µm Cyclone	Filter Catch	Total
Incinerator Outlet					
Run 1	0.47	0.23	0.012	0.037	0.75
Run 2	0.43	0.45	0.014	0.034	0.93
Run 3	0.40	0.30	0.022	0.065	0.79
Average	0.43	0.33	0.016	0.045	0.82
ESP Outlet					
Run 3	0.011	0.00	0.00	0.0052	0.012
R.E.(%)*	97	100	100	99	
Scrubber Outlet					
Run 1	0.0008	0.00	0.00	0.012	0.013
Run 2	0.0011	0.00	0.00	0.013	0.014
Run 3	0.0012	0.00	0.00	0.018	0.019
Average	0.0010	0.00	0.00	0.014	0.015
Ave R.E.(%)	99.8	100	100	69.0	

*R.E. — removal efficiency, calculated for each fracton from MASS flow rates in that fraction entering and leaving in the gas stream from the control device.

Table 3. *Average Enrichment Ratios:* at Incinerator, ESP, and Wet Scrubber Outlets*

Metal	Incinerator Outlet	ESP Outlet	Scrubber Outlet
Antimony	1.56	0.45	6.15
Arsenic	1.27	1.05	3.46
Cadmium	13.72	0.53	127.13
Cobalt	1.08	5.43	2.48
Copper	1.14	0.07	8.12
Gold	.56	ND	14.8
Iron	1.41	0.38	4.96
Lead	2.94	2.44	35.97
Magnesium	1.13	0.60	0.91
Phosphorous	1.17	0.03	0.57
Tin	2.57	0.89	85.63
Titanium	1.13	0.22	2.81
Vanadium	1.41	0.28	9.30
Zinc	1.21	0.07	7.98

*Enrichment ratio — the ratio of the concentration of a metal in the particles to the volatiles-free concentration of that metal in the sludge.

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***Howard Wall** and **Joseph B. Farrell** were the EPA Project Officers (see below).*
The complete report, entitled "Electrostatic Precipitator Efficiency on a Multiple Hearth Incinerator Burning Sewage Sludge," (Order No. PB 88-112 164/AS; Cost: $19.95, subject to change) will be available only from:
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