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Project Summary

Field Evaluation of Hazardous Waste Pretreatment as an Air Pollution Control Technique

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Three types of commonly used commercial treatment processes were investigated for the removal of volatile organic compounds (VOCs) from hazardous waste: thin-film evaporation, steam stripping, and distillation. These unit operations were evaluated for their potential to control emissions from hazardous waste treatment, storage and disposal facilities (TSDFs) by reducing waste VOC content.

One-day visits were conducted at three sites which operate thin-film evaporators to gather data on the types of waste that can be treated, the treatment costs, and the major emission points. Steam stripping and distillation of six different wastes were evaluated during 3-4 day site visits to two recycling firms. Data collected on these two processes permitted calculation of unit cost-effectiveness and determination of compound-specific stripping rate constants for each batch. Air emission factors were also estimated for these two processes.

The full report also contains generic descriptions of thin-film evaporators and distillation processes. Typical unit designs, operating modes, and estimates of unit costs are included.

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

The EPA Office of Air Quality Planning and Standards (OAQPS) is developing regulations to control emissions from hazardous waste treatment, storage, and disposal facilities (TSDFs). The purpose of the OAQPS air emissions regulations is to protect human health and the environment from emissions of volatile organic compounds (VOCs) and particulates.

The Hazardous Waste Engineering Research Laboratory (HWERL) is supporting the OAQPS regulatory development programs by characterizing TSDF air emissions and determining the effectiveness of emissions control alternatives. This Summary describes the field assessment of one control alternative: waste treatment processes that could be used to remove VOCs from wastes, thus reducing the potential for later VOC emissions.

This Summary presents the results from field studies of three treatment techniques: thin-film evaporation, steam stripping, and distillation. The processes investigated were located at waste recycling facilities.

The full report also contains sections providing general descriptions of thin-film evaporators and distillation units. These sections are intended to supplement the data gathered in the field assessment by indicating other process design options and associated costs. The reader is referred to a recent EPA report[1] for similar descriptions of steam stripping processes.

Objectives

The overall objective of this study was to determine the cost-effectiveness of VOC removal from hazardous waste based on field assessments of waste treatment processes. The degree to which VOCs could be removed from waste streams was measured and the cost of removal was estimated, in order to determine the cost of treating waste either (1) to a specified percent VOC removal or (2) to a specified level of VOC content. Cost-effectiveness was calculated in terms of both $/liter waste treated and $/megagram ($/Mg) VOC removal. Since all processes studied are used in other industries, costs which are peculiar to hazardous waste treatment were identified, along with limitations on the types of waste which a given process could treat. Finally, the mass of residuals (e.g., air emissions) produced by the process per unit waste treated and per unit VOC removed was determined.

Approach

In a previous investigation[2], 11 commercially available processes were considered for their potential in treating hazardous wastes to remove VOCs. Four processes were identified as being applicable to a wide variety of wastes with VOC concentrations of 0.1 weight percent or above. They are evaporation, steam stripping, distillation, and air stripping.

The present study considered three potentially applicable techniques from this group: agitated thin-film evaporation, batch direct-injection steam stripping, and batch fractional distillation. Other techniques, particularly air stripping, are being assessed in another investigation.

One-day site visits were conducted at five hazardous waste treatment and disposal sites to collect engineering design and operating information on the three processes. Table 1 identifies the plants which were visited and the treatment processes which were studied. The types of wastes which each technique was used to treat were determined and residual streams were identified. At the first four sites, samples were obtained of (1) wastes which were being treated and (2) air emissions from the processes.

Return visits were made to two sites to conduct 3-day sampling of the influent and effluent waste streams and of the process residuals. At one site, Plant D, measurements were made during the processing of four different batches of waste through a direct-injection steam stripper (500 gallon capacity). At the other site, Plant B, measurements were made during the processing of two different batches of waste through fractional distillation columns of different sizes.

Waste samples were analyzed for general composition (water, organic and solids content; pH; and viscosity) and for their VOC content (both total and individual organic compounds). A headspace analysis for VOC was also performed on waste samples. The treatment products and residual effluent streams were analyzed for their VOC content. In addition, the total and compound-specific concentrations of gas samples of air emissions were analyzed and emission flow rates were measured.

For each process, information was obtained from plant operators on (1) special maintenance requirements, (2) capital and operating costs, and (3) limitations in the types of wastes which could be treated. In some cases, the field data were supplemented by data obtained from process vendors.

Process Effectiveness

Table 2 describes the waste streams that were sampled at each process and indicates the final VOC content of the treated stream, as well as the percent VOC removal efficiency.

Thin-film evaporators are used in many solvent recovery operations where the waste contains solids. For streams which are predominantly composed of high boilers and solids, at least 80 percent of the volatiles can typically be recovered. The concentrations of volatiles in equilibrium with the bottoms will therefore be reduced.

However, if the waste being treated is predominantly composed of low boiling point liquids, gas phase equilibrium concentrations may not be significantly reduced. As a result, emissions rates from the treated wastes may not be significantly lower than from the untreated wastes, although total emissions will be lower due to lower volumes of waste being disposed.

Both direct-injection steam stripping and fractional distillation will remove volatile organic compounds from oils and waste water to low levels (<1%). Steam strippers can operate at lower temperatures than thin-film evaporators and are therefore more appropriate for some reactive materials. The volatile organic compounds can be recovered from the process by decanting, if the organic phase separates from the condensed steam.

Plant D stripped waste material by direct injection of live steam into a waste batch. The process of stripping continued until the VOC recovery that the facility desired was achieved. Four batches of liquid wastes were evaluated: (1) an aqueous xylene mixture, (2) a chlorinated organic-oil mixture, (3) a chlorinated organic-water mixture, and (4) a mixed solvent-water mixture.

Table 1. *Treatment Processes Studied*

Plant Identifier	*Treatment Processes*
A	*Thin-Film Evaporator*
B	*Thin-Film Evaporator, Fractional Distillation*
C	*Thin-Film Evaporator*
D	*Direct-Injection Steam Stripper*
E	*Fractional Distillation*

Table 2. *Waste Streams Studied and Observed Process Effectiveness*

Process	*Plant*	*Stream Composition*	*Final VOC Content of Treated Stream (mg/L)*	*Percent VOC Removed*
Thin-Film Evaporator	*A*	*5% Chlorinated organics* *95% Oil*	*1,700*	*97*
	B	*Alcohol, xylene and VOCs*	*ND*	*ND*
	C	*83% VOCs* *17% High boiling organics and resins*	*760,000*	*8*
Direct-Injection Steam Stripping	*D*	*26% Aromatics* *74% Water*	*498*	*99.8*
		74% Mixed VOCs *26% Oil*	*1,400*	*99.8*
		18% Chlorinated organics *82% Water*	*12,000*	*93*
		3% Mixed VOCs *97% Water*	*385*	*99*
Fractional Distillation	*B*	*23% Acetone & VOCs* *77% Water*	*<700*	*99.6*
		5% MEK & VOCs *95% Water*	*<600*	*98.8*

ND = Not Determined.

VOC removal efficiencies ranging from 93% to 99.8% were observed and it is expected that higher efficiencies could have been obtained if the economics of waste recycling had not dictated that stripping be terminated when it was.

For all four waste streams, the concentrations of the volatile organic compounds at equilibrium in the cooled waste (25°C) were found to decrease as their concentrations decreased during treatment. The waste material generally showed at least an order of magnitude decrease in the vapor concentrations at equilibrium with the waste due to treatment.

The distillation system at Plant B differed from the direct injection at Plant D in that the capacity of Plant B is larger, the steam heats the waste directly through coils, and the stream of vapors is processed in a distillation column. Two different waste streams were selected for the field evaluation. Both were composed of VOCs in water, consisting primarily of methyl ethyl ketone (MEK) and acetone, respectively. Total-VOC removal efficiencies of over 98% were obtained.

Process Costs

The full report provides example unit treatment costs ($/L waste and $/Mg VOC removed) for all three treatment systems. These are based on cost information obtained from vendors and/or facility operators. Costs were found to be strongly dependent on a number of factors, including system size and waste stream composition. For example, the cost of VOC removal from the four steam-stripped batches varied from $318/Mg ($0.14/lb) VOC recovered to $9,472/Mg ($4.30/lb).

Sufficient data on waste treatment and disposal costs and waste steam stripping rate constants were obtained to perform additional cost-effectiveness analyses on the four batches which were steam stripped. These analyses produced curves of unit VOC removal costs as a function of the percent VOC removed. Percent removal ranged from 68 percent to 99.9 percent. The analyses accounted for the following cost estimates which are specific to the waste stream and/or treatment facility: waste condensate treatment, batch cycle time, steam cost, waste collection revenues, solvent sale credits, and treated waste disposal costs (to landfill or municipal waste water treatment). The results show that, for a given waste stream, the net cost or credit for VOC removal (assuming that the VOC has a resale value) can vary by as much as $12,000/Mg VOC removed. The principal factor influencing the net cost was the cost of disposal of the treated waste.

Process Residuals

The significance of air emissions from the treatment processes are of interest, as well as the liquid and solid residuals which they produce. The treatment would be of little use if substantial quantities of VOC-contaminated by-products were produced. For the processes considered here, the principal residuals are either organic materials (which could be incinerated) or aqueous streams with the VOCs removed. A small amount of the VOCs were lost to the atmosphere.

Air emissions were evaluated from the three thin-film evaporators and two steam strippers. At Plants A and B, the major air emission source identified at the thin-film evaporators was the vent from the vacuum pump. The thin-film evaporator at Plant C was operating at atmospheric pressure and the concentrations of VOC in this process were not significant.

The most significant vent emissions from the direct injection steam stripping unit and distillation units were the condenser vents. Emissions of 10 - 100 μg VOC/g waste treated were observed. Emissions of less than 10 mg/sec were estimated to occur from closed roof storage tanks associated with the steam stripping process, but these emissions could not be measured at the distillation units.

Conclusions

General Conclusions

1. Waste treatment is not practiced at many TSDF sites for the purpose of VOC control.
2. Based upon information obtained from these field tests, Table 3 presents potential uses of three treatment techniques for VOC removal. All three techniques are applicable to aqueous, as well as organic and mixed aqueous/organic streams. However, their applicability is limited by other waste characteristics shown in the table.
3. The cost of waste treatment is sensitive to the concentration of VOC in the influent waste. For a fixed percent of VOC removal, costs rise as the initial VOC concentration decreases. For many wastes, the value of the recovered VOCs is less than the treatment costs.
4. Treatment of aqueous waste streams for VOC removal can significantly decrease their disposal cost by making them amenable to discharge to municipal sewers.

Thin-Film Evaporator Conclusions

1. Thin-film evaporators permit the recovery of VOCs from waste materials containing sludges and tars. Thin-film evaporators may not adequately process wastes that are reactive (polymerize) or that contain large pieces of solids. VOC removal efficiencies of 23 to 99.9% were observed.*
2. The overhead product from the thin-film evaporator can be treated by distillation, carbon adsorption, and other separation or reaction processes applicable to liquids.
3. The major air emissions source from the thin-film evaporator is the vacuum pump vent. Under abnormal operations (such as inadequate cooling in the condenser), the emissions could be significant. For properly operated evaporators, the air emissions from thin-film evaporators are much less than the VOCs recovered.
4. The degree of emissions reduction that can be achieved with a thin-film evaporator is very dependent upon the relative volatilities of waste constituents. In many cases emissions reductions are just proportional to reduction in waste volume; emission rates per unit volume decrease little.
5. Costs of waste treatment using thin-film evaporation ranged from $0.033 to $0.37/L of VOC recovered.

Steam Stripping Conclusions

1. Steam stripping is effective for reducing the concentration of VOCs to levels of 0.1 percent or lower. Removal efficiencies of 99 to 99.8% were observed.
2. The amount of steam required to remove the VOCs in waste materials is greater than predicted from equilibrium partitioning based on vapor pressures and solubility in dilute aqueous solutions.
3. The rate of volatile removal is logarithmic in nature, with substantially longer times required to remove the VOCs present in wastes at lower concentrations than at higher concentrations.
4. The air emissions from the steam stripping process tested are much lower than the amount of VOCs recovered from the waste.
5. Costs of treatment ranged from $0.17 to $0.53/L VOC recovered for streams

* All processes tested were at recycling firms and the extent of waste stream treatment was determined by economic considerations, not technical constraints. Therefore, VOC removal efficiencies reported here are lower limits for the combinations of processes and waste streams tested.

that are typically recycled at the facility visited, but were as high as $4.34/L for streams of low (<10%) VOC concentration.

Distillation Conclusions

1. The individual VOC components can be removed from the waste material by batch distillation. Removal efficiencies of 99% and greater were observed, with resultant VOC concentrations below 0.1%.
2. The removal rates of the components are a function of the waste matrix and the ratio of the rate of steam flow to the batch size, and are generally proportional to the VOC concentration in the waste. In the distillation process with reflux to the column, the more volatile materials are removed first from the waste.
3. In the two processes tested, air emissions from the process vents represented only a relatively small fraction (less than 0.2 percent) of the VOC present.
4. Costs of treatment were typically in the range of $0.20 to 0.70/L of VOC recovered, but were estimated to be as high as $1.18/L for streams of low (<10%) VOC concentration.

References

1. Shukla, H.M., and R.E. Hicks. 1984. Process Design Manual for Stripping of Organics. U.S. Environmental Protection Agency, EPA-600/2-84-139.
2. Spivey, J.J., et al. 1984. Preliminary Assessment of Hazardous Waste Pretreatment as an Air Pollution Control Technique (Draft). U.S. Environmental Protection Agency, Contract No. 68-03-3149. October 1984.

Table 3. *Limitation of Technologies Due to Selected Waste Characteristics*

	Thin-film evaporation	Batch steam stripping	Distillation
Over 50% Water Content	A	A	A
Polymerizable waste	P	P	P
Presence of dissolved solids	A	A	P
Waste containing sludges and tars	A	P	N
Highly viscous waste	N	N	N

A Applicable technique.
P Potentially applicable.
N Not applicable.

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The complete report, entitled "Field Evaluation of Hazardous Waste Pretreatment as an Air Pollution Control Technique," (Order No. PB 86-183 076/AS; Cost: $22.95, subject to change) will be available only from:
National Technical Information Service
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