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Project Summary

A Selection Guide for Volatilization Technologies for Water Treatment

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The full guide presents a methodology for evaluating applicability of volatilization technologies for removing volatile organics from water. The volatilization technologies assessed in this study include: surface sprayers, surface aerators, bubble columns, cooling towers, steam strippers, unaided evaporation from an impoundment, spray columns, and packed air-stripping columns. The guide enables users to assess performance and cost under a variety of operating conditions (e.g., temperature, influent concentration, allowable liquid and gas effluent concentration, and flow rates) for representative equipment designs that could be transported on a trailer 2.4 m wide, 13.7 m long, and with a maximum height of 4.1 m. The designs are used as a basis to calculate representative contaminant removal efficiency, treatment rates, air emissions, and treatment costs of each technology. A key parameter used in assessing these technologies is the Henry's Law constant (H). A tabulation of available values of H is provided for volatiles designated as hazardous by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Methods for estimating H are also described. Qualitative guidance is provided on other factors that should be considered during site-specific assessments of the technical and economic feasibility of volatilization technologies. Offgas treatment is not described. An example problem is solved to demonstrate the methodology.

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 purpose of this full guide is to aid in determining whether volatilization is an appropriate technology for the remediation of a hazardous waste site or spill. It describes how to evaluate the performance of common volatilization technologies and provides a format for selecting the appropriate technology for a given situation. Data necessary for the evaluation are described, and, whenever possible, background data given for selected hazardous organics. In addition to being useful for equipment selection, it can be used as an educational tool for background data on volatilization technologies or as a decision-making tool for purchasing a mobile technology. The guide is, of necessity, written about "representative" types of equipment and about selected situations. Although the final selection of equipment should take into account the factors cited in the guide, it will be necessary to consider the individual characteristics of the equipment and the situation in which it will be applied.

The impetus for developing this guide stems from the involvement of the Hazardous Waste Engineering Research Laboratory's Releases Control Branch in technical assistance activities that require assessment of the feasibility and cost of various treatment options. It was recognized that EPA On-Scene Coordinators (OSC) and their technical support personnel are often faced with changing or uncertain conditions that could affect the cost and feasibility of removing volatile substances from water. As conditions change or as some of the uncertainties are resolved, the OSC's technical support personnel are called upon to revise their estimates accordingly. It was recognized that the OSC and their technical support staffs did not have a concise guide on the subject of volatilization technologies and their application to spill cleanup operations.

People with some technical training in chemistry and thermodynamics, but limited experience in conducting or coordinating cleanup activities at uncontrolled hazardous waste sites will find the guide useful. The OSC can use this guide to reduce duplication of effort, accelerate the production of cost and performance estimates for decision-makers, and promote consistency in estimation procedures. Technical personnel who support the OSC by developing cost and performance estimates for water treatment options are the principal audience for this guide. An example problem is solved using the methodology developed in this guide to select the most suitable and cost-effective volatilization technology for a city drinking water field contaminated with trichloroethylene.

How to Use This Guide

This guide assists the reader to apply a five-phase process for evaluating the applicability of a volatilization technology:

- Phase 1. Preliminary assessment of the feasibility of volatilization
- Phase 2. Site characterization
- Phase 3. Calculation of basic material properties
- Phase 4. Technology evaluation
- Phase 5. Equipment selection

Figure 1 provides general instructions for using this guide. Phase 1 should be an analysis of the applicability of volatilization technologies. Normally, volatilization is considered for removing only low concentrations of volatile materials. Water with a high percentage of organics should be treated in some other manner. Further, compounds that will volatilize at a rate close to or below the evaporation rate of water are not likely candidates for volatilization.

Site Characterization (Phase 2) requires a complete evaluation; a checklist of important site data for the evaluation is provided in Table 1.

Phase 3 involves determining the properties of the spilled material. The Henry's Law constant, solubility, lower flammability limits, and azeotrope concentrations of selected compounds are provided; however, for a variety of different organics, other sources must be used to determine the characteristics of the spilled material.

Phase 4, (Technology Evaluation) is designed to eliminate technologies from consideration at each evaluation step, thus avoiding additional work on technologies that are not suitable for the application. In the Technology Evaluation phase the following parameters are determined in the sequence shown:

1. Removal ranges
2. Flowrate and time requirements for treatment
3. Emissions generated by treatment

Technologies still under consideration after evaluation of these performance parameters should then be examined on the basis of their costs. Costs for pretreatment, disposal of treated water, emission controls, and water polishing units should be added to costs for treatment by volatilization (Section 4). This process is intended to eliminate technologies based on performance, allowing the best technology to remain based on cost.

Based on the differences inherent in accurately estimating operating costs, it is recommended that cost differences of a factor of two or more should be used as a basis for eliminating technology from further consideration.

Phase 5 enables the user of the guide to select a specific volatilization treatment unit to be used at the site. This is a complex decision for which no summary method is possible. The guide provides background information on volatilization technologies as well as equipment designs and evaluations to help the reader participate in making a well-informed selection.

Scope of the Guide

The guide specifically addresses volatile organics that are classified as hazardous substances under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). A Materials Property Table for 74 compounds is provided in the guide and includes data—water solubility, vapor pressure, and theoretical and empirical Henry's Law constant—that are commonly used in estimating the performance of volatilization technologies.

Because the guide is targeted to support removal actions that require relatively rapid mobilization and short set-up times, only those technologies that can be legally transported by truck (i.e., vehicles and trailers no more than 2.4 m wide, 13.7 m long, and 4.1 m high) are considered. For each class of technology selected, the largest transportable design is considered for performance comparisons between technology types.

The volatilization approaches that are addressed are: solar evaporation from a pond, surface spraying, high speed surface aeration, bubble column air stripping, spray column air stripping, countercurrent packed tower air stripping, cooling tower air stripping, and steam stripping. These technologies provide a wide range of options in terms of capital and operating costs, removal efficiencies, treatment rates, complexity, availability, and air emissions.

A variety of other technologies, such as cross-flow air stripping and a proprietary activated carbon/stripping hybrid technology, are not included because of their similarity to other technologies or because systems are not available for widespread use. Mobile or transportable technologies for treating the offgases from the described volatilization processes are not described.

Development of Performance Estimates

System performance is estimated in the manual for material removal efficiencies, treatment time requirements, and emission rates. Cost data are also provided.

For each type of technology, a representative design is chosen that has the largest available treatment capacity and meets the transportability requirements described above. For each design, several operating conditions are selected, performance estimates are made, and the results are tabulated or plotted. Organic removal efficiency and the time required to treat a model impoundment are calculated for each design case system and operating condition.

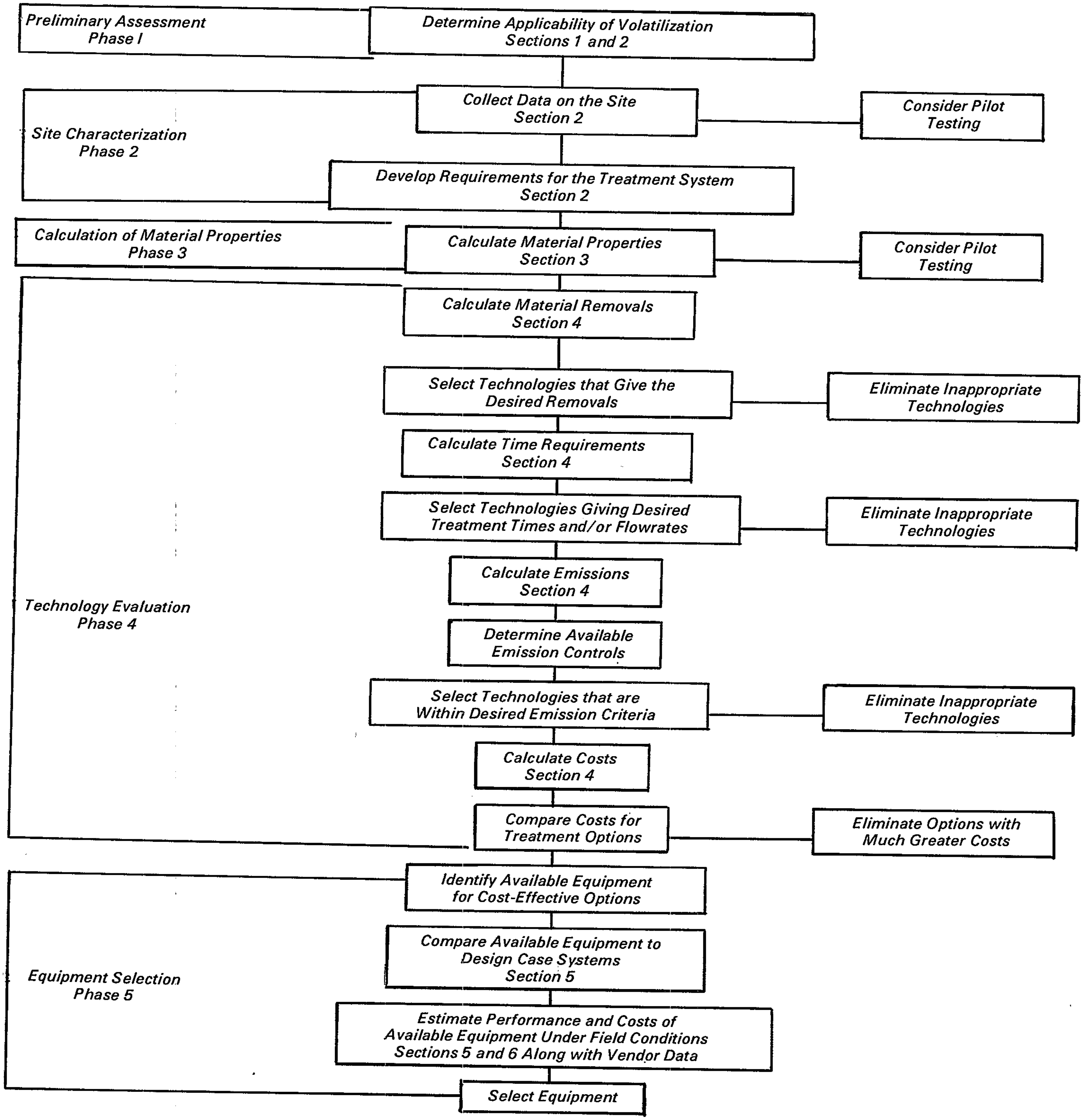

Figure 1. *Decision tree for volatilization process selection.*

Table 1. Checklist for Site Evaluation

- Influent characterization
  - —Contaminant identity
  - —Contaminant concentration (mole fraction) in water
  - —Total quantity of water to be treated
  - —Number, type, and thickness of nonaqueous layers
  - —Influent flowrate
- Effluent requirements
  - —Available discharge options
  - —Available discharge capacity
  - —Discharge concentration limits
  - —Discharge flow requirements
- Properties of spilled material (see Section 3)
  - —Henry's Law constant (mole fraction)
  - —Solubility
  - —Toxicity
  - —Sorptive properties
  - —Reactivity (hydrolysis, photolysis, biodegradation)
  - —Flammability of vapor
  - —Handling requirements (safety)
  - —Disposal requirements for concentrated material
  - —Other contaminants in water
- Climate
  - —Season during which water treatment is anticipated
  - —Average ambient air temperature
  - —Average precipitation
  - —Solar radiation
  - —Wind
  - —Relative humidity
- Site-specific considerations
  - —Water temperature
  - —Site accessiblity
  - —Water location (surface/ground water)
  - —Response time requirements
  - —Volatile emissions limits
  - —Altitude
- Integration with other treatment options
  - —Relationship with other water treatment technologies at the site
  - —Emission control devices
- Environmental considerations
  - —Residential characteristics
  - —Ambient air quality
  - —OSHA requirements
  - —Municipal requirements

Organic Removal Efficiency Estimation

The air stripping and steam stripping systems are compared based on the calculated organic removals achievable using a representative design on a single-pass basis. A total of 32 performance curves (Hc vs. percent removed) are presented for these column systems. The performance curves are generated for a range of configurations (single unit, parallel, and series; one-pass vs. recycle treatment of an impoundment), and operating conditions (i.e., gas and liquid flow rates, number of theoretical stages, and packing). The performance computations are based upon the premise that the effect of the air flow rate, Hc, and the number of theoretical stages is described mathematically for a continuous isothermal air stripper in the Kremser equation:

$$f = \frac{1 - (G/L)(H)}{1 - [(G/L)H]^{(N+1)}}$$

where:

f = fraction of material left in liquid phase;

G = molar flow rate of gas [in moles/sec, for air, G = 73.68 x flow rate (cm^3/sec)];

L = molar flow rate of liquid [in moles/sec, for water, L = 1.74 x flow rate (l/sec)];

H = Henry's Law constant of strippable component (mole fraction/mole number);

N = number of stages in column.

Although steam stripping is a comparatively expensive and complex technology, the use of appropriate vent controls can reduce air emissions below those produced by treatment technologies that discharge the contaminants directly into the air, such as air stripping. However, caution must be exercised, since a concentrated product from steam stripping can also pose health and flammability hazards.

The column diameter of the model system is limited by the physical size and weight of the auxiliary system equipment required to operate the column. The largest standard column diameter (and consequently heat duty) that can be placed on a flatbed trailer is 0.46 m. Random packing is preferred over trays because of ease of cleaning and over rigid packing because of availability. The height of the packing in the model steam stripper is 7.6 m, which is a realistic size for a flatbed trailer. Performance is estimated for four different boil-up ratios (3%, 5%, 10%, and 30%). The treatment rate varies from 6 to 1.5 l/sec. The organic removal efficiency for evaporation, surface aeration, and surface spraying is considered only as a function of operating time.

Treatment Time Requirements

A model impoundment with a volume of 2834 m^3 (30.5 m x 30.5 m x 3 m) is used as the basis for comparing the treatment time required to remove organic contaminants from water for the described systems. It is assumed that there is no net flow into or out of the impoundment during the treatment period (i.e., batch system). The model is representative of a typical body of contaminated water and is large enough to accommodate available commercial-sized mechanical agitation equipment.

The criterion for comparison is the half-life of the organic contaminant in the model impoundment. The half-life (t_h) is the operating time required to reduce the organic concentration to 50% of its original level. Values for t_h for the surface sprayer, surface agitator, and solar evaporation are calculated from the following equation, which is derived in the text:

$$t_h = 0.693/(K_L s)$$

where K_L is the overall mass transfer rate coefficient (m/hr), and s is the specific surface area of the liquid phase (m^2/m^3). Values of t_h vs. Hc are plotted for both surface spraying and surface aeration for two sizes of commercial units. No attempt is made to quantify effects of other incidental variables such as climatic conditions of wind and temperature, differences in a particular equipment design, and quality of the contaminated water. Instead, reasonable average values for the key variables are estimated based on probable field conditions.

The operating time required to obtain a desired removal efficiency can be determined by multiplying t_h by the number of half-lives (n) required to determine the desired percent reduction (R) in the contaminant concentration.

The continuous systems of air and steam stripping could be used to augment volatilization from an impoundment. In this case, the discharge from the treatment system could either be placed back into the impoundment or sent to off-site disposal. When the discharge is returned to the impoundment, the half-life in the pond is governed by the equation:

$$t_h = 0.693 \frac{V}{L(l-f)}$$

where:

- t_h = half-life or organic in the impoundment;
- V = volume of the impoundment;
- L = liquid flowrate of the treatment unit;
- f = fraction of organic remaining after treatment, based on the Kremser equation.

The results of this equation have been plotted in Figures 12-19 of the guide for the design case systems and operating modes in treating the model impoundment.

These performance estimates neglect volatilization that would naturally occur from the impoundment. The actual half-life, including this or any other competing removal mechanism, may be obtained using the following equation:

$$\frac{1}{t_h} = \frac{1}{t_{h1}} + \frac{1}{t_{h2}} + \ldots$$

where:

- t_h = half-life of the organic on the impoundment; and
- t_{hx} = half-life of the organic considering mechanism x.

Examination of the half-life figures allows the conclusion that surface aerators are normally the best option to agument volatilization from an impoundment. However, operational constraints of surface aeration, the desire to control organic emissions, or the unavailability of a surface aerator may require the use of another unit for this service.

For handy reference, a list of advantages and disadvantages appears in each technology subsection. The guide also compares the design case continuous treatment based on the assumption that off-site discharge is available. In this case, the treatment time is purely a function of liquid flow rate.

Emission Rates and Costs

The guide also considers additional factors affecting the performance and cost evaluation process of specific technologies. These include material-specific factors such as multicomponent mixtures, safety considerations of toxic and combustible emissions, absorption and adsorption, decomposition in water, and site-specific factors like season and water quality.

Conclusion

By following the evaluation process in the guide, the user will be able to identify promising types of volatilization technologies and will find the information useful for more in-depth evaluations of cost and performance of specific technologies. However, the manual is not designed to be the sole reference for making the final selection of a treatment system. There are situation-specific considerations that are beyond its scope. Examples of such considerations include addressing the problems caused by poor water quality due to salts, solids, biological material, etc.; evaluating the significance of differences between equipment of the same type or performing pilot tests. Appropriate sources are cited.

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The complete report, entitled "A Selection Guide for Volatilization Technologies for Water Treatment," (Order No. PB 88-165 683/AS; Cost: $19.95, subject to change) will be available only from:
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