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Project Summary

Feasibility of Commercialized Water Treatment Techniques for Concentrated Waste Spills

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The suitability and economics of using commercial water treatment techniques for onsite treatment of concentrated wastes were evaluated. The techniques included reverse osmosis, ultrafiltration, ion exchange, wet-air oxidation, high-purity oxygen-activated sludge process, ultraviolet-ozone oxidation, and coagulation/precipitation. Data from the published literature and those obtained from process suppliers provided the basis for the evaluation.

When used alone, none of the processes considered would be economically applicable to onsite mobile unit treatment of the variety of concentrated wastes encountered, although reverse osmosis, ion exchange, and wet-air oxidation meet many of the application requirements and, hence, require less pretreatment, or post-treatment. The estimated capital costs for a unit suitable for trailer mounting vary from as low as $35,000 for a 227,000-L/day (60,000-gpd) ultrafiltration unit to as high as $1.25 to $1.5 million for a 54,000-L/day (14,400-gpd), two-trailer, wet-air oxidation unit. For short-term operation, the operating cost of the mobile unit is determined largely by nonprocess-specific costs (e.g., transportation, labor, subsistence, analytical support), which vary from situation to situation.

This Project Summary was developed by EPA's Municipal Environmental 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 and Study Objectives

In recent years, considerable efforts have been directed by government and the private industry toward developing emergency response capabilities for the treatment of waters containing high concentrations of contaminants that are encountered in hazardous material spill situations and at uncontrolled waste disposal sites. The U.S. Environmental Protection Agency's (EPA) Environmental Emergency Response Unit (EERU) is currently engaged in the shakedown and field demonstration of a number of EPA-developed wastewater treatment equipment and techniques for use in emergency situations. The EERU's Mobile Flocculation-Sedimentation System and Mobile Physical-Chemical Treatment Trailers have been successfully used to facilitate cleanup operations at several uncontrolled waste disposal and hazardous materials spill sites. A number of other systems, including the Mobile Incineration System, Mobile Independent Physical-Chemical Wastewater Treatment System, Mobile System for Detoxification/Regeneration of Spent Activated Carbon, and Mobile Reverse Osmosis Treatment System, are also currently in various stages of development and testing.

In mobile unit applications involving highly concentrated organic wastes (TOC and COD levels exceeding 4,000 to 5,000 mg/L), the conventional physical-chemical treatment systems employing chemical coagulation/flocculation, filtration, and activated carbon adsorption have to be very costly. Hence, a need exists for the development of more economical alternatives for onsite treatment of concentrated wastes. The study summarized here evaluates the suitability and economics of several commercially available water and wastewater treatment processes for use in mobile units for onsite treatment of highly contaminated waters.

Processes Evaluated and Evaluation Criteria

Seven processes were evaluated for onsite treatment of concentrated wastes in mobile units.* These processes, which are briefly described in Table 1, are: reverse osmosis (RO), ultrafiltration (UF), ion exchange (IE), wet-air oxidation (WAO), high-purity oxygen-activated sludge process (HPOASP), UV-ozone oxidation (UV/O_3), and coagulation/precipitation (CP).

The process evaluation has been based on the published literature and data obtained from process and equipment suppliers. The study has generally assumed the use of a single trailer or 227,000-L/day (60,000-gpd or 42-gpm) hydraulic capacity and the use of a process alone rather than in combination with other processes in a treatment train. The process evaluation has been in terms of general process capabilities and limitations, suitability for the removal of certain pollutant types (TOC/COD, heavy metals, oily substances, etc.), and capital and operating costs for a mobile unit handling a hypothetical concentrated waste.

*To make the study more complete, gravity separation, filtration, activated carbon adsorption, and incineration (which have been used or are under development for spill control applications) were also briefly reviewed. These reviews, however, are not included in this Project Summary.

General Process Capabilities and Limitations

Table 1 presents brief descriptions of the processes reviewed and a general and qualitative assessment of their capabilities and limitations in terms of commercial experience and applicability to diverse waste types (including concentrated wastes). As noted in Table 1 (with the exception of UF and UV/O_3, for which full-scale commercial application experience is somewhat limited), the processes considered are widely used commercially in a range of applications involving water and wastewater treatment. Processes that are suitable and have been used commercially for the treatment of concentrated wastewaters are RO, UF, IE, and WAO. The remaining three processes are not suitable for treatment of concentrated wastes because of the long detention time (reactor size) required for HPOASP, the production of a large volume of bulky sludge in CP, and reduced efficiency and high ozone requirement in UV/O.

Table 2 reviews the extent of previous use in mobile units and the limitations and desirable features for such a use for each of the processes considered. RO, IE, and HPOASP have been used in mobile units of various designs for wastewater treatability studies. A 2,300-L/hr (10-gpm) WAO mobile unit, currently under design by Zimpro,* is expected to be available for use in waste treatability studies in 1981. UV/O_3 and UF systems have not been used in mobile units. CP has been used in connection with physical/chemical treatment in mobile units.

RO and IE processes appear to meet many of the requirements for applica-

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

Table 1. *Description of Processes Reviewed and Their General Capabilities and Limitations*

Process	*Major developers/suppliers*	*Description*	*Limitations*	*Commercial experience with full-scale units*	*Experience with and applicability to concentrated wastes*
RO	*Aqua Media (Sunnyvale, CA) Dow (Walnut Creek, CA) Envirogenics (El Monte, CA) Fluid Systems Div/UOP (San Diego, CA) Hydranautics (Santa Barbara, CA) Permutit (Paramus, NJ) Polymetric (San Jose, CA)*	*Use of high pressure to force solvent (for example, water) through a membrane permeable to solvent but not the solute. Several membrane types and designs available*	*Membrane fouling/degradation by suspended solids, biological growth, strong oxidizers, very low/high pH, and high concentration of specific substances (for example, phenols, calcium, silica, sulfate, aluminum). Reject requires further treatment/disposal*	*More than 300 units in operation demineralizing brackish waters. Used for treatment of industrial wastewaters (for example, plating rinses, cooling tower blowdown, petroleum stripping water) and in industrial applications (for example, food processing)*	*Industrial wastewaters containing several thousand ppm TDS, as well as sea water (3 5% TDS) successfully treated.*
UF	*Abcor (Wilmington, MA) Envirogenics (El Monte, CA) Fluid Systems Div/UOP (San Diego, CA) Osmonics (Hopkins, MN) Romicon (Woburn, MA)*	*Pressure-driven membrane separation process operating at a lower pressure than RO and suitable for separation/concentration of large molecular weight substances. Several membrane types and designs available.*	*Membrane fouling/degradation similar to RO but to a lesser extent. For wastes containing high levels of low molecular weight substances, effluent may require additional treatment. Rejects require further treatment/disposal*	*Separation and concentration of macromolecules from dilute industrial process/waste streams. Full scale units in operation in food processing, textile and metal cutting industries.*	*Feed solid concentration as high as 46,300 ppm handled. A latex waste averaging 21,000 ppm COD, 3,500 ppm oil and grease and 1,600 ppm TSS successfully treated in a 20,000 gpd unit.*
IE	*Chemical Separation Corp. (Oak Ridge, TN) Crane Co. (King of Prussia, PA) Ecodyne (Union, NJ) Illinois Water Treatment (Rockford, IL) Infilco (Richmond, VA) Permutit (Paramus, NJ)*	*Replacement of toxic/undesirable ions in waste with harmless ions "attached" to exchange resins. "Sorptive" resins remove organics via adsorption. Resins employed in columnar beds and regenerated with acid, alkali or salt solutions. Sorptive resins also eluted with organic solvents.*	*Pretreatment for suspended solids removal may be necessary for longer service. Very concentrated waste may require frequent resin regeneration. Residue requires further treatment/disposal.*	*Widely used for water softening and boiler water treatment. Used in industry for material recovery from and/or treatment of wastewaters from electroplating industry and munitions, fertilizers, dyestuff, pesticides, chlorine, and resins production.*	*Commercially used for phenol recovery from concentrated (~20%) brine and removal of color and organics from pulp mill effluents.*

Table 1. *(Continued)*

Process	Major developers/suppliers	Description	Limitations	Commercial experience with full-scale units	Experience with and applicability to concentrated wastes
WAO	Zimpro (Rothschild, WI)	Aqueous phase oxidation of reduced inorganic and organic substances with air at high temperatures (200 to 320°C) and pressures (150 to 4,000 psi). Process specially suitable for treatment of high strength or toxic/refractory organic wastes.	Requirements for skilled operators (especially for hazardous wastes) and special design and construction materials.	More than 150 units in operation worldwide; about 90% handling municipal sludges. Also used for treatment of cyanide, pulp and paper, photographic and glue manufacturing wastes.	Nearly all large applications have been for treatment of sludges and concentrated organic wastes.
HPOASP	Air Products and Chemicals (Allentown, PA) Union Carbide (Tonawanda, NY)	High purity (90-100%v) oxygen is fed to a mixed covered reactor in which microorganisms in the wastewater convert dissolved and oxidizable organics to inorganic end products and to agglomerating and settleable flocs.	Inapplicable to wastes high in toxic, volatile, or refractory substances or having low or high pH. Long detention time (large reactor size) required for concentrated wastes. Considerable time required for process start-up. Nutrient addition and pH adjustment may be necessary.	Numerous full-scale units in operation handling municipal and industrial wastewaters. Examples of industrial applications are treatment of brewery, citrus and chemical plant wastes.	The most concentrated chemical waste treated without pretreatment has a COD value of 1,000 to 3,000 ppm.
UV/O_3	Westgate Research Corp. (W. Los Angeles, CA)	Use of UV and ozone to destroy/oxidize organics (including refractory and toxic chemicals), organometallic complexes and reduced inorganics.	New process, not suitable for wastes high in organics or suspended solids, requirement for on-site O_3 generation, and release of some residual O_3 to air.	Very limited. Two plants reportedly in operation handling photographic, metal plating and cyanide wastes at any Army ammunition plant and a tool production plant.	Not suitable for concentrated wastes.
CP	Numerous	Addition of chemicals (alkali, sulfide, and aluminum/ferric salts) to precipitate dissolved substances and to coagulate suspended solids.	Ineffective for removing a spectrum of dissolved organic and inorganic substances. Optimum pH and chemical dosage vary with wastes. Large volume of bulky sludge produced with concentrated wastes.	Extensively used for treatment of municipal/industrial water supplies. Widely used in conjunction with other wastewater treatment processes.	Not suitable for concentrated wastes.

Table 2. *Mobile Unit Experience and Process Features for Mobile Unit Application*

Process	Mobile unit experience	Features for mobile unit use: Desirable features	Features for mobile unit use: Limitations
RO	Several 10,000 to 50,000 gpd trailer-mounted units operated for obtaining potable water from brackish waters.	Compact and modular units, quick startup and shutdown, conveniently serviced, not requiring skilled operators, operable with power generated on-site with diesel generator, small residue volume (10 to 25 percent of influent volume).	See general limitations in Table 1.
UF	None. Skit mounted units (5,000 to 10,000 gpd suitable for trailer mounting available).	Same as RO.	See general limitations in Table 1.
IE	Trailer-mounted units have been used in field pilot plant studies involving treatment of biologically-treated sewage and wastewaters at a munitions plant and a naval installation.	Same as for RO plus ease of automation, applicable to a range of waste types and concentrations (including those having low or high pH and oxidizing chemicals) by proper selection of resin types and system design/operation. Volume of residue seldom exceeding 10 percent of influent.	See general limitations in Table 1.

Table 2. *(Continued)*

Process	Mobile unit experience	Features for mobile unit use: Desirable features	Limitations
WAO	*None. A 0.1 gpm trailer-mounted unit used at process developer's site for waste treatability studies. A 10 gpm 2-trailer unit under design.*	*Suitable for treatment of a range of oxidizable wastes. No air pollution problem. Innocuous residue from most organic wastes.*	*General limitations in Table 1 plus size/weight limitations. 10 gpm is the largest unit which can be trailer-mounted (on 2 trailers). Supplementary heating necessary for low-Btu wastes.*
HPOASP	*Process suppliers have several mobile units used for waste treatability studies.*	*Suitable for treatment of readily biodegradable non-toxic wastes.*	*General limitations in Table 1 plus size/weight limitations and slow startup. Based on a maximum reactor size of 12,500 gal suitable for trailer mounting and a detention time of 48 hr (for a waste COD of 1,000 to 3,000 ppm), hydraulic capacity would be 4 gpm.*
UV/O_3	*None.*	*Compact and modular units, quick startup/shutdown, conveniently serviced, not requiring skilled operators, operable with on-site generated power from a diesel generator.*	*See general limitations in Table 1.*
CP	*Used by EPA in conjunction with settling and filtration and activated carbon adsorption for treatment of spills and concentrated wastes from uncontrolled chemical dump sites.*	*Wide variety of chemical feeding and metering devices available commercially.*	*See general limitations in Table 1.*

bility to the treatment of concentrated waste in a mobile unit. These processes offer compact units that can be started and shut down relatively quickly, can be serviced conveniently, would not require skilled operating field labor, can be operated with electricity produced by on-board generators, can handle a spectrum of wastes including those containing high concentrations of toxic substances and refractory organics, and can produce a relatively small volume of waste residue requiring disposal. WAO, which is particularly applicable to the destruction of refractory and toxic organics in concentrated wastes, has the limitations of small capacity and the requirement for skilled operators. UF suffers from the limitation of inapplicability to wastes containing low-molecular-weight substances, whereas highly concentrated, large-volume wastes cannot be processed by UV/O_3, HPOASP, and CP.

When used alone, none of the processes considered would meet all the requirements for use in mobile units for treatment of concentrated wastes. The applicability of these processes would be enhanced (and the treatment costs would be reduced), however, if these processes were used in combination in a treatment train. The specific process combinations that would be applicable to the types of wastes encountered in spill situations and at uncontrolled chemical dump sites remain to be evaluated.

Comparison of Processes for Reducing Specific Pollutant Categories

Table 3 summarizes and compares the capabilities of the various processes considered for the treatment of high-strength wastes. For discussion purposes, the following raw wastewater gross characteristics/constituent levels (which are typical of concentrated wastes encountered in spill situations and at uncontrolled hazardous waste disposal sites) have been assumed:

TOC:	5,000 mg/L
COD:	8,000 mg/L
Low-molecular-weight organic substances not removable by activated carbon:	Present
Oily substances:	300 mg/L
SS:	1,000 mg/L
Heavy metals:	200 mg/L
pH:	4-5

Based on the performance data in Table 3, none of the processes considered would be able to handle a waste stream with the above characteristics without some pretreatment. But, when properly designed and operated, RO, IE, and WAO should require less pretreatment and post-treatment than other processes considered. Pretreatment required with RO and IE would be primarily for the removal of suspended solids and can be accomplished by chemical coagulation and settling, or filtration, or both. WAO is not expected to effect heavy metal removal. The present engineering an

Table 3. Comparison of Process Capabilities for Reduction of Indicated Constituents/Parameters

Process	TOC/COD	Low molecular weight organics	Oily substances	SS	Heavy metals
Reverse osmosis	Generally greater than 90%.	Varies with the species and wastewater pH Removal generally decreases with increase in polarity and tendency for hydrogen bonding with membrane	Greater than 90%	Pretreatment to lower SS load necessary to prevent membrane fouling and maintain high flux.	Greater than 90% removal of ionic species, including most heavy metals.
Ultrafiltration	Greater than 90% for large molecular weight organics	Ineffective for removal of low molecular weight substances	Greater than 90%	Some pretreatment to lower SS necessary to extend membrane life and maintain high flux	Ineffective, because of low molecular size.
Ion exchange	Almost any degree of removal can be obtained with the use of sorptive resins, proper design and operating conditions (including pH adjustments)	Can remove low molecular weight organics, removal efficiency dependent on design and operating conditions	Must be removed to extend resin life.	Pretreatment to lower SS necessary to prevent bed clogging	Can remove all charged species, including heavy metals
Wet air oxidation	Greater than 90%, depending on operating conditions	Very high destruction efficiency, achievable by proper selection of operating conditions.	Very high destruction efficiency, achievable by proper selection of operating conditions.	Organic SS can be destroyed	Ineffective in removing inorganics, can destroy heavy metal-organic complexes so that heavy metals can be subsequently removed.
High purity oxygen activated sluge process	Little or no removal if organics are toxic or refractory or if waste contains a high concentration of toxic inorganics Unless waste is diluted, very long detention time would be required to achieve high removal	Removal efficiency determined by biodegradability and lack of toxicity, and not molecular weight per se	Greater than 60%, if other conditions are proper for biooxidation	Prior settling and removal of SS desirable to improve process efficiency	Heavy metals can exert toxic effects
Ultraviolet-ozone oxidation	Percent destruction limited by ozone supply capacity	Molecular weight per se not a factor in process efficiency	Should be removed to minimize interference with light transmission	Should be removed to minimize interference with light transmission.	Does not remove heavy metals; destroys metal-organic complexes so that heavy metals can be removed subsequently.
Coagulation/ precipitation	Ineffective for removal of most organics; use of high chemical doses produces large volume of sludges which are difficult to process and dispose of	Generally ineffective	Can effect removal of separable oils; 30-40% removal can be expected under proper pH and dosage	When followed by settling/ filtration and under proper pH and dose conditions can effect more than 90% removal.	Addition of hydroxide, sulfide, phosphate, etc., can effect near complete removal of many heavy metal cations

ysis did not include comparative assessment of various possible process combinations to identify promising and cost-effective treatment schemes including the use of two or more trailers housing different processes and process combinations. For example, WAO may be used to handle the smaller volumes of more concentrated residues resulting from the other processes and process combinations.

Estimated Costs

Table 4 presents the estimated capital costs for a unit suitable for installation on a flat-bed trailer. The estimated costs vary from as low as $35,000 for a 227,000-L/day UF unit to as high as $1.25 to $1.5 million for a 54,000-L/day, two-trailer WAO unit. As noted in Table 4, there are differences in labor type, materials, and fuel requirements for the operation of various processes. But in most, especially the short-duration, applications, these differences should not have a significant impact on the overall operating cost of the mobile unit. The latter is determined largely by nonprocess-specific costs such as the fixed cost for transportation, startup, and shutdown of the mobile unit; equipment insurance; labor; subsistence; and general analytical support. EPA's experience with the operation of the Mobile Physical/Chemical Treatment System indicates a nonprocess-specific fixed cost of about $10,000, a cost for one charge of carbon of $10,000 to $12,000 per deployment, and an operating cost of $2,500 to $3,000 per day.

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Table 4. *Estimated Capital Cost and Operating Fuel, Labor Category and Chemical Requirements*

Process	Capital cost*, $	Energy requirement L of fuel/1,000 L of waste	Labor category requirement†	General chemicals and materials requirement‡
Reverse osmosis	75,000§	11	Semi-skilled; 4 to 12 hrs per 24 hr operation	Acid or base for pH adjustment; scale inhibitors and biocides
Ultrafiltration	35,000	2	Semi-skilled; 4 to 12 hrs per 24 hr operation	Acid or base for pH adjustment; scale inhibitors and biocides
Ion exchange	140,000	1	Skilled; 4 to 12 hrs per 24 hr operation	1 to 3 bed volumes of acid and base (5 to 10 percent solution) required for each regeneration; organic solvents (for example, methanol or acetone) may be required for regeneration of sorptive bed
Wet air oxidation	1,250,000 to 1,500,000	230	Highly skilled; 4 to 12 hrs per 24 hr operation	—
High purity oxygen activated sludge process	200,000	1	Skilled; 1 full time operator	Acid or base for pH adjustment; nitrogen and phosphorus as supplemental nutrients; high purity oxygen
Ultraviolet-ozone oxidation	285,000	50	Semi-skilled; 2 to 6 hrs per 24 hr operation	Replacement of UV lamps
Coagulation/ precipitation	—	1	Semi-skilled; 4 to 12 hrs per 24 hr operation	Coagulant salts; acid or base for pH adjustment

*Capital costs are for a 227,000 L/day single-trailer unit, except for wet air oxidation which has a capacity of only 54,000 L/day and employs two trailers. To allow process versatility, the ion exchange system is designed with an excess capacity so that a combination of resin types can be used.

†The labor hour estimates are the minimum requirement for operation under "ordinary" conditions. For safety reasons, however, a minimum of 2 persons would be required for field operation.

‡The specific chemicals and quantities required would depend on the concentration of specific constituents in the waste; accurate estimates cannot be made for the waste considered here since detailed composition were not assumed.

§The estimated costs provided by three process suppliers were $55,000, $75,000, and $120,000 to $180,000.

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The complete report, entitled "Feasibility of Commercialized Water Treatment Techniques for Concentrated Waste Spills," (Order No. PB 82-108 440; Cost: $11.00, subject to change) will be available only from:
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