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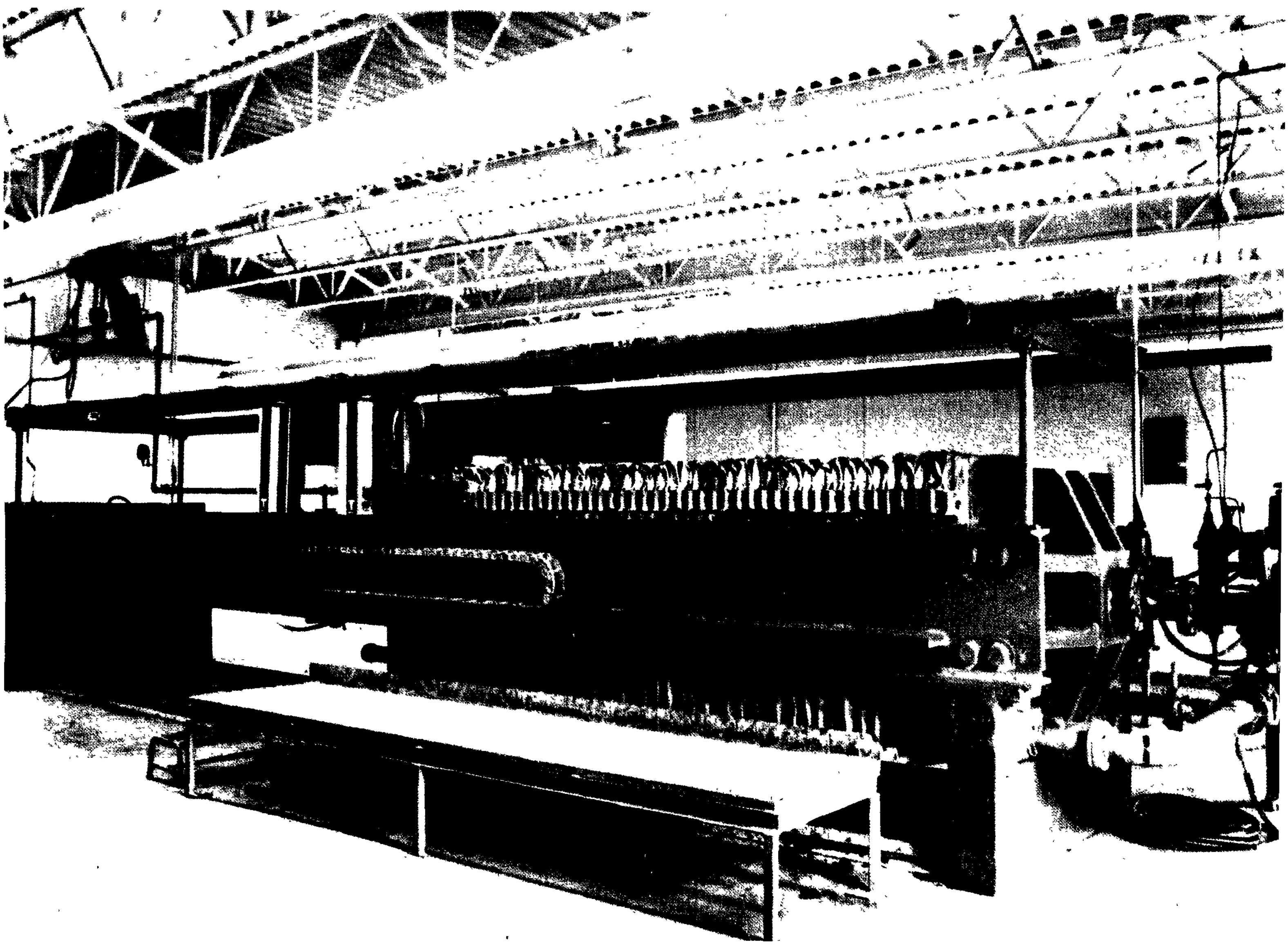
Cincinnati OH 45268

Technology Transfer

Environmental Pollution Control Alternatives:

Sludge Handling, Dewatering, and Disposal Alternatives for the Metal Finishing Industry



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This report has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

COVER PHOTOGRAPH: Recessed plate filter press with in-ground bin to receive discharged cake

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1. Overview

Under regulations implementing the Clean Water Act of 1977 (Public Law 95-217) metal finishing facilities may be required to treat spent process wastewaters to remove regulated pollutants before the wastewaters are discharged. Treatment for heavy metal pollutants generally consists of reducing the solubility of the metals, then separating the resulting precipitants from the wastewater. Consequently, the treatment yields a solid waste, or sludge, containing a high concentration of potentially harmful or toxic substances. This sludge must be disposed of in a manner that ensures that the pollutants, once removed from the wastewater, will not pose a threat to the environment.

Recognizing the increased rate of solid waste generation and the need for environmentally safe disposal, the U.S. Congress included provisions for solid waste disposal in the Resource Conservation and Recovery Act (RCRA) of 1976 (Public Law 94-580). Subtitle C of RCRA contains provisions for hazardous waste management. It directs the U.S. Environmental Protection Agency (EPA) to identify those wastes that are hazardous, and to establish national standards for generators and transporters of hazardous wastes and for operators of hazardous waste management facilities involved in the treatment, storage, and disposal of these wastes.

The EPA has classified the following metal finishing wastes as hazardous materials:[1]

- Plating baths and the sludge accumulated in these baths
- Stripping and cleaning solutions
- Sludge resulting from wastewater treatment

Metal finishing shops disposing of any of these wastes are regulated by the RCRA standards. Under RCRA, EPA holds waste generators responsible for the ultimate safe disposal of their wastes. Waste generators are also required to keep records, use proper labels and containers, and keep a manifest system to document proper disposal.

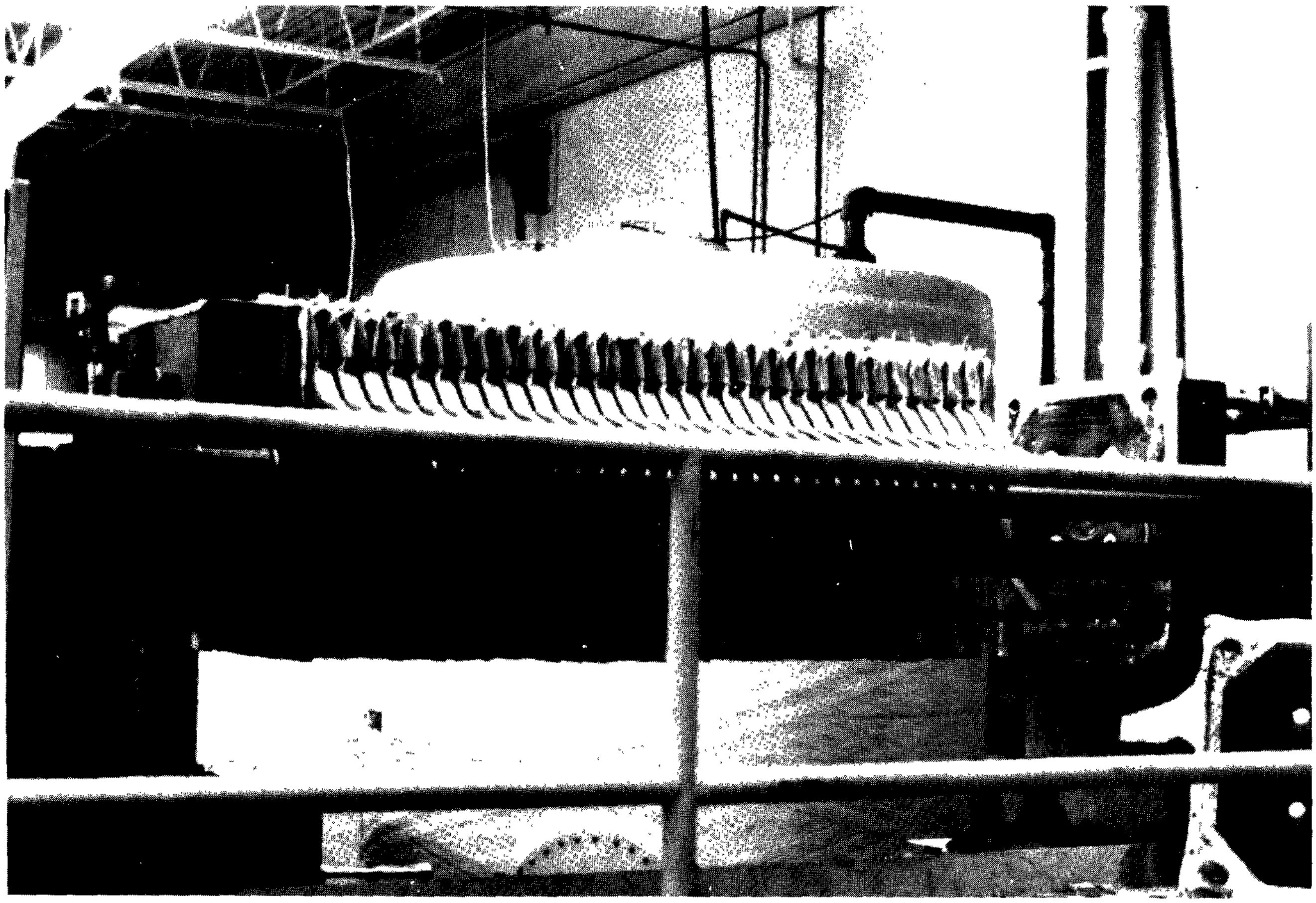
The more stringent control of hazardous waste disposal means that plating shops may have difficulty in finding licensed disposal facilities, and may incur higher prices for hauling and disposal than if their wastes were nonhazardous.

Hauling costs depend on the distance to the disposal site and the size of the load. Haulers typically use trucks designed for loads of 40,000 lb (18,000 kg), or 5,000 gal (19,000 L); they can transport liquids or solids. A partial load would be charged the same price as a full load. Prices for long hauls are in the order of \$3 to \$5 per loaded mile for the 5,000-gal (19,000-L) load, based on the distance one way.[a] A 300-mi (480-km) trip, therefore, would cost \$0.18/gal to \$0.30/gal of waste, assuming the truck had a full load. Because there are so few disposal sites, long-distance hauling is becoming the rule, not the exception.

Disposal facilities operating state-of-the-art secure chemical landfills charge according to volume, type of waste, and type of container. Disposal of drum quantities is by far the most expensive. Fees at disposal sites range from \$25 to \$50 for each drum that requires burial in the site. The equivalent cost per gallon would be \$0.60 to \$1.20, based on 42-gal (159-L) drum capacity. Adding drum and hauling costs could bring the total disposal cost to \$100 per drum.

Bulk liquids, which include dilute sludges and spent process baths, are less expensive to dispose of than drum quantities; however, the disposal cost includes the cost for solidifying the waste before it is placed in the landfill site. Costs range from \$0.25/gal to \$0.75/gal.

[a]All costs in this report are in 1981 dollars.



Elevated installation of recessed plate filter press

For dewatered sludge, which is placed untreated in the landfill site, disposal cost ranges from $0.20/gal to $0.50/gal.

The hazardous waste generator has two alternatives for reducing the cost of disposal. One approach is to seek relief from the RCRA regulatory requirements; the other is to reduce the volume of waste.

The generator can avoid the regulatory requirements of RCRA by having the waste classified as nonhazardous. The EPA has established a procedure that provides a means of petitioning the Agency to exclude from regulatory control a waste that is generally classified as hazardous.[1,2] Obtaining such an exclusion for a wastewater sludge usually entails proving that the sludge does not leach hazardous substances at harmful concentrations into the ground water. If such proof is to be established, the waste must be subjected to the Extraction Procedure, a test developed to simulate the aggressive leaching that occurs in a municipal codisposal landfill.

An exclusion from many of the RCRA requirements has been allowed for generators producing less than 2,200 lb/mo (1,000 kg/mo) of hazardous waste.[1] The waste must still be disposed of safely, but many of the associated record-keeping and reporting responsibilities are not required of generators of small quantities of waste.

There are several means of lowering the cost for waste hauling and disposal. The generator can reduce the amount of metals, chemical compounds, and wastewater that must be treated by the waste treatment process. The solids can be concentrated with dewatering equipment to reduce the volume of water contained in the sludge.[3] Minimizing wastes, implementing recycle and recovery modifications where possible, and using processes and reagents that generate less sludge can significantly reduce the amount of sludge solids requiring dewatering. The remaining solids can be dewatered for final off-site disposal for a further reduction in volume of more than 90 percent.

The high cost of sludge disposal justifies purchase of dewatering equipment for all but those plants generating very small volumes of sludge.

The properties of individual sludges vary widely, however, and some form of pilot testing is needed to determine whether a particular type of dewatering equipment is suitable.

Of the types of equipment available, filter presses are usually the least expensive to install. Filter presses have further advantages in their mechanical simplicity and in their ability to achieve higher cake solids concentrations than other dewatering equipment types. Good performance with a filter press requires a sludge with good filtration characteristics. Sludges that have highly compressible, delicate particles or that tend to blind the media are not well suited for equipment of this type.

Poor-filtering sludges can be dewatered by centrifuges, pressure belt filters, or vacuum filters that use a precoat filter aid. These devices are more mechanically sophisticated than filter presses and usually cost more. Their automation, however, often reduces the need for operating labor.

This report is provided to aid the metal finisher in assessing waste generation alternatives and developing a cost-effective means of compliance with the regulatory requirements. The section that follows constitutes an overview of the regulatory framework developed for hazardous waste disposal. Section 3 reviews the disposal methods and associated costs of commercially operated secure chemical landfills. Section 4 reviews factors influencing waste generation and describes what can be done to reduce waste volume and the cost of disposal. The main emphasis of the report is the final section, which evaluates the types of dewatering equipment available and their cost and performance.

2. Resource Conservation and Recovery Act

On May 19, 1980, EPA issued regulations under RCRA as a basis for a national hazardous waste management program. The regulations came as a result of 1976 Congressional legislation that directed EPA to:

- Identify those wastes that are hazardous
- Establish national standards for generators and transporters of hazardous wastes and for operators of hazardous waste management facilities involved in the storage or disposal of these wastes

Hazardous wastes are regulated from the time they are created to the time of their disposal. This cradle-to-grave monitoring is achieved by a manifest system.[4-6] Any waste that is transported off site for treatment, storage, or disposal must be accompanied by a manifest that:

- Identifies who generated the waste
- Provides a full description of the contents and quantity of the waste
- Designates the facility to which the waste must be shipped

Under RCRA, EPA holds the generator of a waste responsible for the ultimate safe disposal of that waste. Strict civil penalties can be imposed for any violations of the regulations. In addition, regulations governing the transportation of hazardous materials over public roads were published on May 22, 1980, by the U.S. Department of Transportation (DOT).[7]

Regulatory Framework

Table 1 gives the structure of the RCRA regulations. Part 261 of Subtitle C defines four characteristics of wastes that would present an environmental threat if disposed of improperly (Table 2). A solid waste is hazardous if it exhibits any of these four characteristics, or if it is specifically listed in Part 261 as hazardous.[1] In the latter case, EPA evaluated the hazard associated with unregulated disposal of wastes for which adequate information was available. Then, if the findings so warranted, the Agency made a general determination that a given waste is hazardous. Figure 1 shows the four common plating shop wastes that are generally classified as hazardous. All four wastes were determined to be toxic; plating baths, sludge from plating baths, and stripping and cleaning solutions may exhibit reactive properties as well.

RCRA standards for solid waste generators such as plating shops are defined in Part 262 of Subtitle C.[4] They include provisions for record keeping, reporting, implementing a manifest system, and obtaining an EPA identification number.

Table 1.

Structure of RCRA Subtitle C Regulations

Description	Part (40 CFR)
General provisions and definitions	260
Identification and listing of hazardous waste	261
Standards applicable to:	
Generators storing wastes <90 d	262, Sec. 262.34
Transporters	263 (and Pts. 171-179 of 49 CFR)
Permitted treatment, storage, and disposal facilities	264
Interim status standards applicable to treatment, storage, and disposal facilities	265
Permits for treatment, storage, and disposal facilities	122, 124
Guidelines for State hazardous waste programs	123

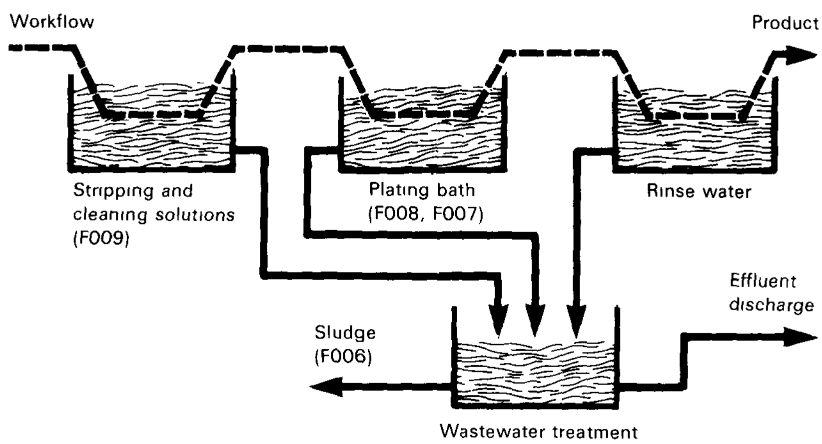
SOURCE: U.S. Environmental Protection Agency, "Hazardous Waste Management System: General," *Federal Register* 45(98).33067, May 19, 1980.

Table 2.

Four Hazardous Waste Characteristics

Characteristic	Description
Ignitability.	The waste is capable of causing fires during routine transportation to storage and disposal, or of burning so vigorously as to create a hazard.
Corrosivity.	The waste is aqueous and has a pH ≤ 2 or ≥ 12.5 or corrodes steel at a rate >0.25 in/yr.
Reactivity	The waste is extremely unstable and tends to react violently or explode, thus posing a problem at all stages of waste management.
Extraction Procedure toxicity	When the waste is subjected to a specified leaching procedure, the leachate fraction contains certain contaminants in a concentration >100 times that specified in the National Interim Drinking Water Standards.

SOURCE: U S Environmental Protection Agency, "Hazardous Waste Management System: Identification and Listing of Hazardous Wastes," *Federal Register* 45(98):33121-33122, May 19, 1980.



EPA hazardous waste no.	Hazardous waste	Hazard code
F006	Wastewater treatment sludge from electroplating operations	Toxic
F007	Spent plating solutions	Reactive, toxic
F008	Spent plating bath and sludges from bottom of bath	Reactive, toxic
F009	Spent stripping and cleaning solutions	Reactive, toxic

SOURCE: U S. Environmental Protection Agency, "Hazardous Waste Management System: Identification and Listing of Hazardous Waste," *Federal Register* 45(98):33123, May 19, 1980

Figure 1.

Hazardous Wastes from Electroplating Operations

If a hazardous waste is transported off site for treatment, storage, or disposal, the generator must prepare a manifest.[4,5] The manifest designates the treatment, storage, or disposal facility to which the waste is being transported; in the event an emergency prevents delivery to this facility, an alternate receiving facility is designated. The manifest must contain a full description of the waste being shipped in terms of contents and quantity, and it must identify the generator and transporter. Sufficient copies of the manifest are needed to provide a copy for the records of the generator, each transporter, and the receiving facility, as well as a copy to be returned to the generator after disposal of the waste.

The EPA considers that a generator storing hazardous waste on site for more than 90 days is an operator of a storage facility, and therefore must have applied for a facility permit before November 19, 1980, to continue such operations.[6] Storage for less than 90 days does not require a permit, but certain standards must be met. Regulations specify:

- Provisions for inspection of containers
- Precautions for ignitable or reactive waste containers
- Personnel training
- Contingency plans and emergency procedures for dealing with the release of hazardous wastes from their containers or tanks

The hazardous waste management regulations issued on May 19, 1980, specified that plants operating a waste treatment system regulated by the Clean Water Act still had to comply with the RCRA standards for hazardous waste treatment and storage facilities. After reviewing comments on the regulations, EPA decided to award operators of wastewater treatment and neutralization units a permit-by-rule if they comply with certain specified standards. Accordingly, plants with waste treatment facilities do not have to apply for a treatment and storage facility permit or comply with the interim status standards for those facilities. (Some State agencies administering the RCRA Program, however, have not adopted the permit-by-rule exclusion.) Details of this Wastewater Treatment Tank Exclusion were published on November 17, 1980.[8]

Exclusion from RCRA

Costs related to RCRA compliance can be lowered in one of two ways. The rate at which hazardous waste is generated can be reduced to below 2,200 lb/mo (1,000 kg/mo), or the generator can have the waste declared nonhazardous.[1]

Reducing the Waste Generation Rate. An exclusion from many of the RCRA requirements has been allowed for generators producing less than 2,200 lb/mo (1,000 kg/mo) of hazardous waste (small generators). This upper limit applies to the total mass of waste and includes water and other nonhazardous constituents. The waste must still be disposed of either in authorized hazardous waste management facilities or in facilities approved by a State agency for municipal or industrial waste disposal. The associated record keeping, reporting, and waste manifest are not required of the small generator. Lacking an EPA identification number and waste manifest, however, the generator may have more difficulty in finding a disposal facility that will accept metal finishing wastes. Moreover, within 2 to 5 yr, EPA may initiate rules to include in the RCRA requirements small generators producing more than 220 lb/mo (100 kg/mo) of hazardous waste.

Seeking Nonhazardous Status. For some plating shops, having the waste declared nonhazardous (delisted) is effective in reducing RCRA-related costs.[1,2] The EPA has established an appeals procedure that provides a generator with a means of petitioning the Agency to exclude from the regulatory controls a waste that is usually classified as hazardous. The Agency has authority to grant a temporary exclusion on the grounds of significant likelihood that the appeal will be successful.

A plating shop seeking to have its waste delisted must prove its waste nonhazardous, which means proving that the waste does not exhibit toxic or reactive characteristics. Proving the waste nonreactive generally requires testing to verify a low level of cyanide. Proving the waste nontoxic requires subjecting the waste to the Extraction Procedure and proving that the sludge could not leach hazardous substances at harmful concentrations into ground water. The Extraction Procedure is designed to simulate the aggressive leaching that occurs in municipal codisposal landfills. A sample of the waste is extracted and analyzed to determine whether it possesses any toxic contaminants identified in the National Interim Primary Drinking Water Standards (NIPDWS) and, if so, at what levels. The waste will be considered hazardous if it contains concentrations of contaminants 100 times greater than those specified in the NIPDWS (Table 3). In addition, a complete chemical assay of the waste must be included in the delisting petition.

If a waste is to be delisted, it must be tested for each characteristic that is assumed to be present. Sufficient tests (at least four) of each type must be conducted to ensure representative results. Costs to perform the testing should range between $300 and $1,000. The test results are an essential step in the appeals procedure. Every reason for a waste being judged hazardous must be refuted. Even if a waste passes the Extraction Procedure, however, EPA may rule that sufficient hazard exists to warrant denying the appeal.

Table 3.

Extraction Procedure Toxicity Limits

Contaminant	Maximum concentration (mg/L)
Arsenic	5
Barium	100
Cadmium	1
Chromium	5
Lead	5
Mercury	0.2
Selenium	1
Silver	5

SOURCE U S Environmental Protection Agency, "Hazardous Waste Management System: Identification and Listing of Hazardous Wastes," *Federal Register* 45(98), 33122, May 19, 1980

Cadmium, chromium, and lead are the only common plating compounds included in the Extraction Procedure toxicity limits (Table 3). These contaminants usually result from only a few point sources within a plating facility. Therefore, segregating these wastes from the rest of the plant's waste streams can result in the major waste stream exhibiting nontoxic characteristics during the Extraction Procedure testing.

Regulatory Requirements

Transporters of Hazardous Wastes. Under RCRA, the role of the hazardous waste transporter is simply to supply transportation to the generator. The transporter delivers the waste to the hazardous waste management facility that the generator designates on the manifest. Any person transporting hazardous waste within the United States must obtain an EPA identification number, and must comply with EPA and DOT regulations for transporters of hazardous wastes.[5,7] The EPA regulations are adopted from the regulations developed by DOT. They include vehicle specifications, requirements for reporting hazardous material incidents, and requirements for handling, loading, unloading, and segregating hazardous materials.

The requirements for transporters apply to both inter- and intrastate transportation and are enforceable by EPA or DOT.

A transporter may not accept a hazardous waste from a generator unless both parties have an EPA identification number and the waste is accompanied by a signed manifest. The transporter must sign the manifest and return a copy to the generator before leaving the generator's property. When the shipment is transferred to another transporter or to the designated hazardous waste management facility, the original transporter must obtain the signature of the next party on the manifest and keep one copy. The second transporter retains one copy of the manifest and transmits the remaining copies to the next party. The designated treatment, storage, or disposal facility is required to send one copy, with all the signatures, back to the generator. Special requirements exist for bulk shipments by rail or water.

Treatment, Storage, and Disposal Facilities. Facilities that treat, store, or dispose of hazardous wastes are also regulated under RCRA.[6] Interim operating permit status has been granted to all such facilities provided they:

- Had been in operation or under construction before November 19, 1980
- Had notified EPA of their hazardous waste activities by August 18, 1980
- Had applied for a permit by November 19, 1980

Requirements for disposal sites cover:

- General facility standards
- Emergency precautions and actions
- The manifest system
- Record keeping and reporting

Requirements for facilities on interim status cover:

- Reactive, ignitable, and incompatible wastes
- Closure and postclosure care
- Containers and tanks
- Surface impoundment, waste piles, land treatment, and landfills
- Incinerators
- Underground injection
- Thermal, chemical, physical, and biological treatment
- Financial responsibility and liability

For the foreseeable future, disposal in a landfill is the only feasible method of disposing of many hazardous wastes. The regulations are intended to provide long-term protection of ground water and human health. They specify monitoring requirements; failure to monitor the land treatment facility is a violation of the regulations. They include requirements for controlling and monitoring water run-on and run-off, as well as general requirements for ignitable, reactive, and incompatible wastes. Owners and operators must consider specific factors and methods in addressing closure and postclosure requirements. Also, record keeping and surveying are required so that the exact location and contents of each waste cell will be known.

EPA has proposed financial requirements intended to ensure that funds will be available for closure of treatment, storage, and disposal facilities, and for postclosure monitoring and maintenance at disposal facilities.[9] The proposed requirements also include liability coverage for injuries resulting from operation of a hazardous waste management facility. These proposals allow a number of ways to provide financial insurance.

3. Hazardous Waste Disposal Sites

The secure chemical landfill is the state of the art for disposal of metal finishing waste treatment sludges.[10,11] It is designed to preclude the risk of ground water contamination by toxic heavy metals that would leach through the soil and into the ground water unless prevented from doing so. The secure chemical landfill provides a means by which toxic wastes can be buried in an environmentally acceptable manner.

Landfill Design

There are basically two designs for a secure chemical landfill. The first takes advantage of natural geological barriers created by impermeable clays. The second adds a flexible elastomer liner as further protection against leaching of pollutants into the ground water. In both cases, disposal involves direct burial of wastes in cells designed to avoid contaminating the surrounding environment.

The wastes to be buried are classified and segregated, and their positions within a burial cell are recorded. Bulk liquid wastes are solidified with lime or cement dust before burial; bulk solids are buried directly. Drums of wastes are surrounded by sufficient sorbent material to absorb the entire contents of the drum, thereby eliminating the presence of any free liquids in the cell. Only compatible wastes are placed in a given disposal cell. When a cell is full, a compacted clay cover is placed over the top to prevent precipitation from filtering into the cell, thereby minimizing the formation of leachate and preventing its migration from damaged drums.

A piping system for leachate collection is buried in a permeable bottom layer at the center of each cell. All leachate is recovered and is periodically pumped out of the cell through a standpipe connected to the piping system. The recovered leachate is solidified, then buried in the landfill. A monitoring-well system is placed outside the landfill cells for early detection of any leachate that may leak out of the area. A properly operated secure chemical landfill does not usually experience leachate in its monitoring wells.

Waste Identification Procedure

Before a hazardous waste disposal site will accept a waste for disposal, it will require the generator to submit a completed waste identification profile. The procedure includes an analysis of a sample of the waste to be landfilled. The analysis includes, for example, pH, flash point, and heavy metals content. From the profile and analysis, the disposal facility can determine whether the waste is compatible with the landfill disposal methods and operating permits. (Many secure chemical landfills do not accept reactive wastes containing cyanides.) If the waste is acceptable, the generator prepares a shipping manifest that identifies the waste origin (generator), destination (disposal facility), hazard class and material identification number, EPA hazardous waste number, and weight. The manifest is carried by all transporters and is presented to the disposal facility when the waste is delivered. Appropriate copies of the manifest are returned to the transporter and the generator.

When the waste is received at the landfill site, a representative sample is taken and analyzed to ensure that the waste material received is the same as that identified by the waste profile documents. If the waste is accepted, it can then be landfilled. If rejected, it is usually returned to the generator.

Disposal Cost Factors

The total cost for disposing of sludge wastes consists of the costs for hauling, for disposal site pretreatment, and for landfilling. These costs depend on the physical nature and chemical composition of the wastes, and on the distance be-

Table 4.

Typical Secure Chemical Landfill Sites: Summary of Costs

Company and site	Description	Cost[a]	
		Disposal	Hauling[b]
Chemical Waste Management, Emelle AL	Clay base 500-700 ft thick, permeability $<10^{-8}$ cm/s Liquid waste solidified with lime or cement dust. Leachate collection system in segregated cells, sampling wells.	\$25-\$35/drum \$0.25/gal liquid \$0.025-\$0.03/lb for dewatered sludge	\$2.96/loaded mi
Rollins Environmental Services, Baton Rouge LA	Clay base, elastomer-lined cells Leachate-monitoring wells.	\$0.03/lb for dewatered sludge	NS
U.S. Pollution Control, Inc, Lone Mountain OK	Clay liner, permeability $<10^{-8}$ cm/s. Leachate-sampling wells.	\$44/drum \$0 03/lb bulk waste	\$0.42/100 lb at 20 mi \$5/100 lb at 700 mi)
SCA Services, Inc., Pinewood SC	Fuller's earth base 10 ft thick, permeability $<10^{-8}$ cm/s, elastomer liner over 5 ft compacted clay, 2 ft clay over liner. Leachate collection system, leachate-monitoring wells, segregated cells	\$26-\$31/drum \$0.065/lb bulk liquid \$0.04/lb for dewatered sludge	\$0 99/100 lb bulk liquid (<100 mi) \$320/100 lb bulk (>100 mi)
Nuclear Engineering Co, Louisville KY	Impermeable clay base Leachate-monitoring system	\$0 055-\$0.10/lb for dewatered sludge	\$2/loaded mi

[a]1981 dollars

[b]40,000-lb truckloads

Note —NS = data not supplied

SOURCE: Secure chemical landfill companies

tween generator and disposal site. Table 4 summarizes information on transportation and landfilling costs for a number of hazardous waste management facilities.[b]

The cost for burying a sludge waste depends on whether the waste is delivered as a bulk liquid, as a bulk solid, or in drums. Sludge is generally considered a liquid if it is pumpable. Drum disposal is usually the most expensive—ranging from \$25 to \$50 for a 42-gal (159-L) drum—because considerably more handling is needed. Moreover, the value of the drum container is lost.

Sludge disposal in bulk liquid quantities is the next most expensive, ranging from \$0.25/gal to \$0.75/gal. Although bulk liquid is more easily handled than drums, the liquid waste must be solidified before burial. In

[b]Chemical Waste Management and SCA Services, Inc., personal communications to Peter Crampton.

Dewatered sludge discharged from centrifuge

this step, the liquid is usually mixed with lime, cement dust, or clay, and the cost of the solidification material becomes part of the total disposal cost.

Disposal of bulk solid quantities of waste sludge is the least costly, typically ranging from \$0.025/lb to \$0.05/lb (\$0.20/gal to \$0.50/gal). A bulk solid needs no special treatment before burial if it contains no free liquid. Also, the overall cost of disposal is lower per unit of dry solids because of the smaller volume of the water associated with the waste. In general, the average disposal costs for all bulk loads of sludge are approximately $0.25/gal (see Table 4). Unfortunately, some disposal sites do not have the material-handling capabilities to dispose of nonpumpable wastes. It is important, therefore, to determine the local disposal conditions before developing a waste disposal strategy.

The cost for hauling sludge wastes depends on three significant factors:

- Load size
- Distance hauled
- Fuel costs

A typical bulk load of sludge is hauled by a truck with a 40,000-lb (18,000-kg) capacity. A load that is less than full will incur the same hauling cost as a full load. From Table 4, the average hauling cost is $3 per loaded mile in bulk loads. Therefore, if a bulk load of sludge is hauled 300 mi (480 km), the average hauling cost is about $0.18/gal. When sludges are hauled to distant disposal sites, it is common for a number of small generators to combine and thus make full use of the hauling capacity of a truck. To maintain proper responsibility for the individual waste volumes, the wastes are segregated in separate hoppers or drums.

Pretreatment Capabilities

In general, the hazardous waste management facility does not pretreat or process sludge wastes on site except to mix liquid waste with solidification materials. Physical or chemical treatment—such as dewatering, drying, or pH adjustment—is not performed on site. Some of the large chemical waste disposal companies do have or are planning to have facilities that offer a wide range of treatment capabilities. For example, RCRA does not allow landfill disposal of sludges containing reactive materials such as cyanide. The disposal facility would therefore increase its potential market by providing chemical treatment for cyanide oxidation, making these wastes compatible for landfill disposal. As an alternative to solidifying dilute sludges, sludge dewatering could also be done at the treatment facilities.

4. Reducing Sludge Generation and Cost of Disposal

Sludge handling and disposal costs normally depend heavily on sludge volume. The high cost of disposal provides a strong incentive for modifying plating procedures to reduce this volume. A program to minimize chemical losses and water consumption can reduce sludge generation significantly.[12-14] After wastewater treatment, the dilute sludge can be dewatered mechanically to reduce the volume by 90 to 95 percent.

Many factors contribute to the formation of insoluble solids during wastewater treament; major factors are:

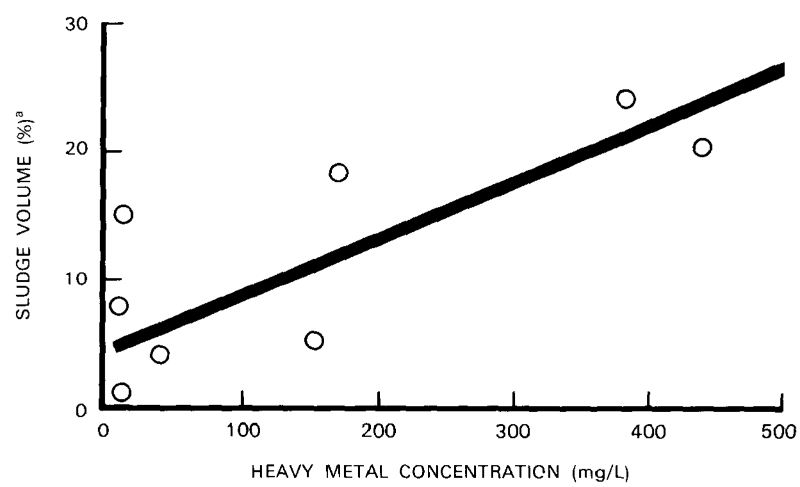
- Concentration of heavy metals and other dissolved solids that precipitate during treatment
- Volume of water to be treated
- Reagents, conditioners, and unit processes used in treatment

Incremental reductions in the amount of hazardous waste generated will lower disposal costs. Reducing the waste generation rate to below 2,200 lb/mo (1,000 kg/mo) will exempt the plant from reporting requirements defined in RCRA for hazardous waste generators. Eliminating toxic materials (cadmium, lead, chromium) from the waste stream will result in a sludge that would prove nonhazardous if analyzed according to the Extraction Procedure.

Reducing Sludge Generation

Waste Composition. The concentration of heavy metals in the wastewater will influence the amount of solids generated in the neutralization-precipitation process.[14,15] Particularly with systems using lime as the neutralizing reagent, however, metal hydroxides will usually constitute less than 25 percent of the solids. The rest will be calcium salts (carbonates, phosphates, sulfates) and other insoluble compounds that are formed by reactions with the lime.

Figure 2 shows the sludge volume resulting from lime neutralization of electroplating wastewater over a



[a]Volume of sludge per volume of wastewater treated after 1 h settling Treatment consists of lime neutralization.

SOURCE: Robinson, A K., and J. C. Sum. "Sulfide Precipitation of Heavy Metals," prepared for U S. Environmental Protection Agency under EPA Grant No. 5805413, Seattle WA, Boeing Corporation, undated

Figure 2.

Influence of Wastewater Heavy Metal Concentration on Sludge Volume range of heavy metal concentrations. Based on the relationship shown, lime neutralization of 1,000 gal (3,800 L) of wastewater containing 100 mg/L of heavy metals would yield, after 1 h of settling, 90 gal (340 L) of sludge. Although the data do not define the suspended solids concentration of the sludge, metal hydroxide sludges will typically gravity settle to between 1 and 5 percent solids by weight.

Reducing chemical losses, therefore, will reduce sludge generation rates as well as chemical replacement and wastewater treatment costs. The in-plant modifications that can reduce chemical losses are well-documented[16-18] and include such procedures as:

- Dragout recovery and recycle
- Maximum use of stripping and cleaning solutions before they are discarded
- Drip trays and splash guards to direct losses back to the bath
- A good housekeeping and maintenance program to permit rapid finding and repair of leaks in tanks, valves, and pump seals

Table 5 gives the amount of metal hydroxide solids precipitated during treatment for various metals in the raw wastewater, as well as the associated sludge volume at 3 percent and 25 percent solids by weight. Loss of 1 lb (0.45 kg) of nickel into the wastewater will result in 6.1 gal (23.1 L) of sludge at 3 percent solids by weight. The cost of disposing of this volume of sludge will usually be greater than the original cost of the nickel salt.

Water Use. The amount of sludge generated is also affected by the volume of water needing treatment.[15] In areas of hard water, precipitation of natural water contaminants, such as carbonates and phosphates, can generate a sludge volume exceeding that associated with chemicals discharged to the waste stream. Moreover, consumption of many treatment reagents and chemical conditioners used in wastewater treatment depends on the volume of water treated. These compounds frequently end up in the sludge and increase its volume.

Several steps can be taken to reduce water use.[16-18] The major water requirement is for rinsing; multiple stage counterflow rinse systems and adequate agitation in the rinse tank will significantly reduce the amount of rinse water needed. For automated plating lines, flow restrictors on the rinse water feed can be used to control fresh water additions at the minimum required for good rinsing. Rinse tank conductivity meters can do the same for intermittent plating operations. Reusing spent rinses or treated effluent for less critical water requirements will reduce water consumption.

The benefits of reducing water use go far beyond decreasing the amount of sludge generated, but the impact on sludge disposal should not be ignored in cost-benefit evaluation of potential modifications.

Pretreating the water to reduce its hardness level can reduce the contribution of naturally occurring water contaminants to sludge generation. Water softeners using ion exchange resins or reverse osmosis systems can remove calcium and magnesium from water supplies.

Treatment Processes. The reagents, conditioners, and unit processes employed in wastewater treatment should be evaluated in terms of their effect on sludge generation rates. For example, lime and caustic soda are the two alkali neutralizing agents used most frequently.[15] Lime has advantages over caustic soda in that it costs less per unit of neutralizing capacity, produces sludge that settles and dewaters more readily, and can reduce the solubility of metals to lower levels in some applications (primarily because of the complex-breaking capabilities of the calcium ions). Lime has disadvantages, however, in that it requires a higher investment in the reagent feed system, takes longer to react in the wastewater, and, depending on the chemical composition of the wastewater, can produce as much as 10 times the dry weight of sludge produced by caustic soda.

Coagulating agents commonly used to improve floc formation before clarification also can contribute to sludge generation.[12] Alum and ferric

Table 5.

Sludge Generated and Sludge Disposal Volume for Electroplating Waste Treatment System

Waste metal components	Dry solids (lb/lb metal precipitated)[a]	Sludge (gal/lb metal precipitated)	
		Generated (at 3% solids by weight)	Dewatered (to 25% solids by weight)
Aluminum	2.89	11 2	1 14
Cadmium	1.3	5	0.51
Chromium	1 98	7.7	0 79
Copper	1.53	5.9	0.6
Iron	1 61	6 2	0 63
Nickel	1 58	6 1	0.62
Zinc	1 52	5 9	0.6

[a]Using sodium hydroxide

SOURCE U S Environmental Protection Agency, *Environmental Pollution Control Alternatives: Economics of Wastewater Treatment Alternatives for the Electroplating Industry,* EPA 625/5-79-016, June 1979 chloride are widely used, and ultimately both are converted to hydroxides and add to the amount of sludge for disposal. Although polyelectrolyte conditioners are more expensive than inorganic coagulants, they do not add to the quantity of sludge and have provided effective solids-settling rates. Their actual cost may therefore be lower.

The significance of treatment process selection can be appreciated when the different systems used to reduce chromium are considered.[14,15] Three types have been demonstrated:

- Chemical reduction using a sulfur compound—sulfur dioxide (SO_2) or sodium bisulfite ($NaHSO_3$)
- Electrochemical reduction using sacrificial iron electrodes
- Reduction using a slurry of insoluble ferrous sulfide (FeS)

Using sulfur dioxide or sodium bisulfite has an advantage because, except for the chromium, no insoluble byproducts are formed in the reduction reaction:

$$3SO_2 + 2H_2CrO_4 + 3H_2O \rightarrow Cr_2(SO_4)_3 + 5H_2O$$

In electrochemical reduction units, an electric current is used to generate ferrous ions that react with the hexavalent chromium ions:

$$3Fe^{+2} + CrO_4^{-2} + 4H_2O \rightarrow 3Fe^{+3} + Cr^{+3} + 8OH^-$$

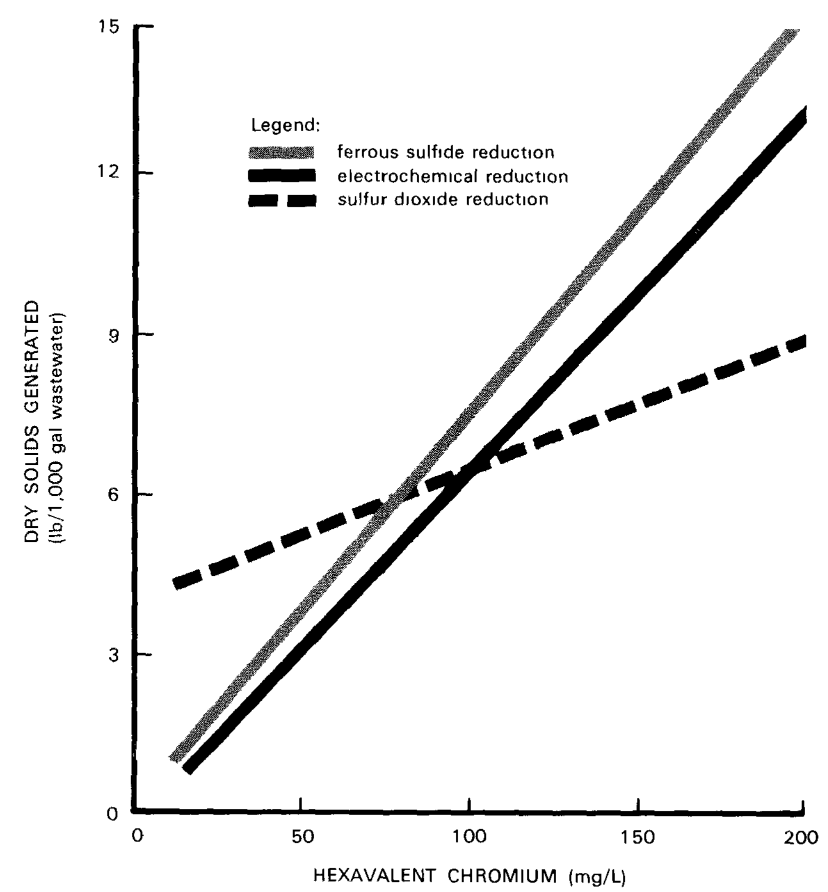
The ferric ions generated by the reduction will precipitate at a neutral pH and add to the sludge volume.

Similarly, using ferrous sulfide as the reducing reagent will generate ferric ions and sulfur, both of which will add to the sludge volume:

$$H_2CrO_4 + FeS + 4H_2O \rightarrow Cr(OH)_3 + Fe(OH)_3 + S + 2H_2O$$

It would appear that the electrochemical and ferrous sulfide reduction processes would be unfavorable, at least in terms of sludge generation rates; however, there is an additional factor to consider. Reduction using sulfur dioxide or sodium bisulfite requires a wastewater pH between 2 and 3. Consequently, a significant amount of acid may be needed to lower the pH, then a significant amount of base would be needed to raise it back to neutral to precipitate the chromium as chromic hydroxide [$Cr(OH)_3$]. Electrochemical and ferrous sulfide reduction systems can operate at neutral pH. Particularly in sulfur dioxide and bisulfite reduction systems employing sulfuric acid and lime, the amount of calcium salts precipitated can exceed the amount of precipitants resulting from the ferric ions and sulfur generated in the alternative reduction processes.

Figure 3 shows the sludge generation rates of the three reduction systems over a range of hexavalent chromium concentrations.[14,15] The electrochemical and ferrous sulfide processes actually generate less sludge solids at chromium concen-



SOURCES: U.S. Environmental Protection Agency, *Control and Treatment Technology for the Metal Finishing Industry: Sulfide Precipitation*, EPA 625/8-80-003, Apr. 1980.
U.S. Environmental Protection Agency, *Economics of Wastewater Treatment Alternatives for the Electroplating Industry*, EPA 626/5-79-016, June 1979.

Figure 3.

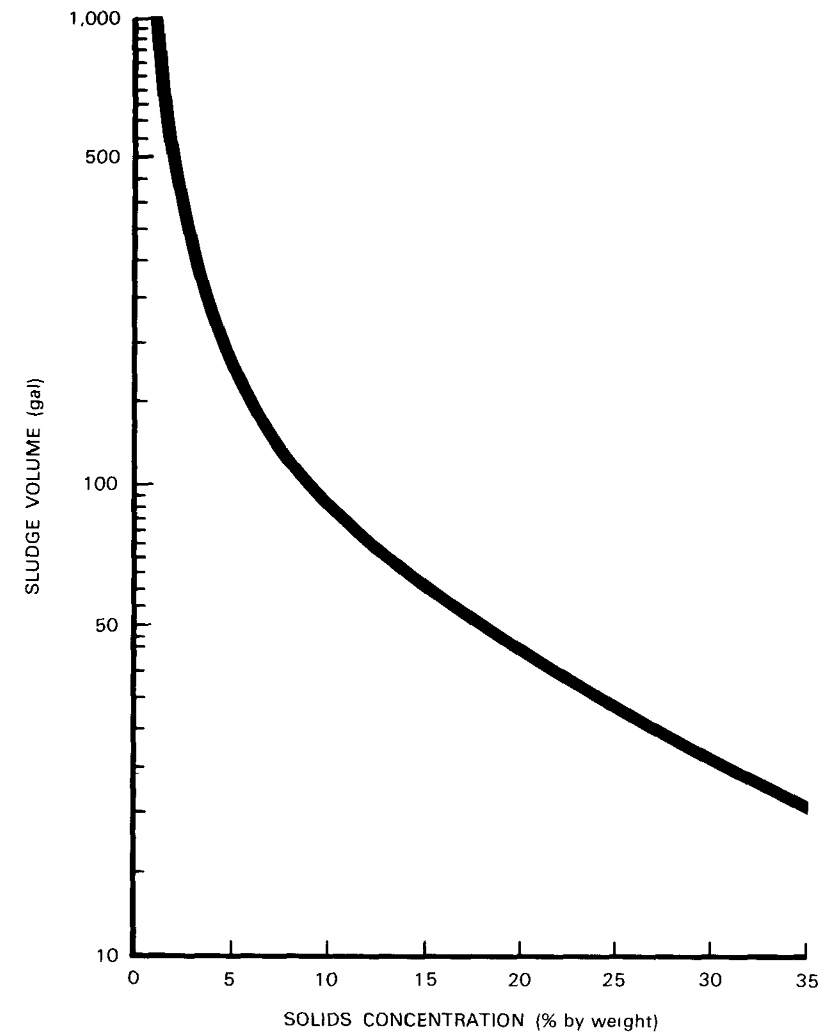
Sludge Generation Factors for Alternative Chromium Reduction Processes trations below 75 mg/L. It is important to remember that the solids generation rates are based on assumptions regarding the initial pH of the wastewater and the neutralizing reagent employed. Any firm conducting a similar analysis for its treatment system should test to determine how much sludge is generated by each of the different treatment alternatives.

To reduce sludge disposal costs, it is necessary to select the waste treatment techniques that generate the least amount of waste sludge.[12,13] Although some of the newer treatment techniques produce an effluent of high quality, they generate much more sludge than the conventional approaches they replace. The high cost of waste disposal requires that the foregoing sludge generation factors influence the selection of wastewater treatment systems.

Sludge Dewatering

Although the volume of sludge can be reduced significantly by modifications that reduce the pollutant and wastewater loadings on the treatment system, a sludge residue will result from wastewater treatment. The cost to dispose of this residue will depend primarily on volume. The volume of sludge can be reduced significantly by mechanical dewatering equipment. Figure 4 shows the reductions possible when sludge is dewatered from 1 percent solids by weight to different solids concentrations.

Normally the clarifier underflow will contain between 0.5 and 3 percent solids by weight. Allowing the clarifier underflow to settle in a thickener tank will increase the solids content to between 2 and 5 percent by weight. Using the curve in Figure 4, 1,000 gal (3,800 L) of sludge at 1 percent solids by weight would be reduced to 330 gal (1,250 L) when thickened to 3 percent solids by weight. A mechanical dewatering device will achieve anywhere from 10 to 50 percent solids by weight, depending on the type of equipment and the dewatering properties of the sludge. Assuming dewatering to 25 percent solids by weight, the sludge volume would be reduced to 40 gal (150 L)—4 percent of the original clarifier underflow volume.



Note —Initial conditions, 1,000 gal at 1% by weight

Figure 4.

Sludge Volume versus Solids Concentration

Vacuum filters, filter presses, pressure leaf filters, belt filters, and centrifuges have been applied successfully for mechanical dewatering of metal hydroxide sludges. The properties of individual sludges vary widely, however, and some pilot evaluations are necessary to determine whether a particular type of dewatering equipment is suitable. As a rule, equipment vendors will provide testing if supplied with a sample of the sludge.

Four features are common to sludge dewatering systems (Figure 5a):

- A solids collection sump
- One or more feed pumps
- Elevation of the dewatering device
- Filtrate return upstream

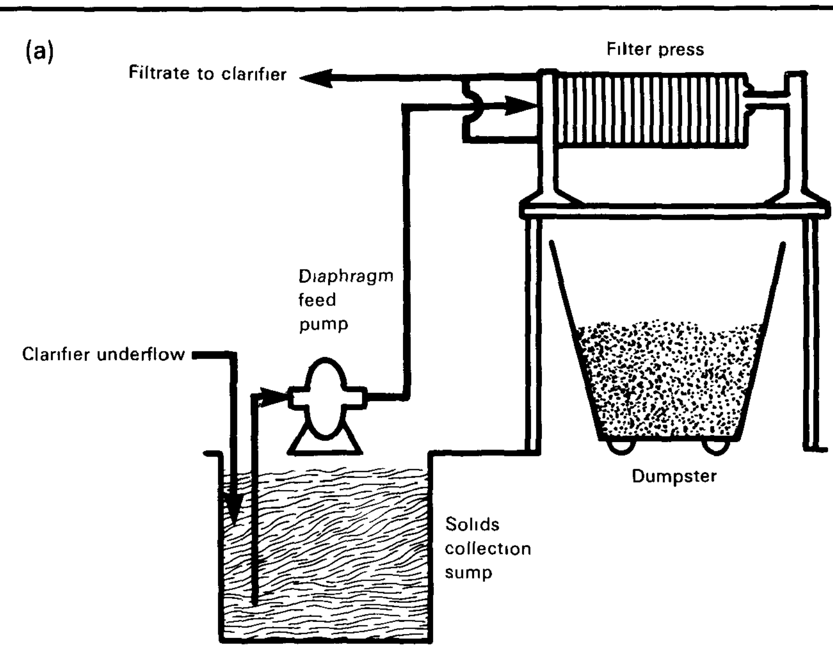
The solids collection sump receives the dilute clarifier underflow and provides a reservoir of feed solution so that the mechanical dewatering device can be fed continuously.

The feed pump delivers the sludge to the dewatering device. Pump type depends on the physical properties and viscosity of the sludge, and on the type of dewatering device. Specially designed centrifugal, diaphragm, and progressive cavity pumps are suitable for handling slurries.

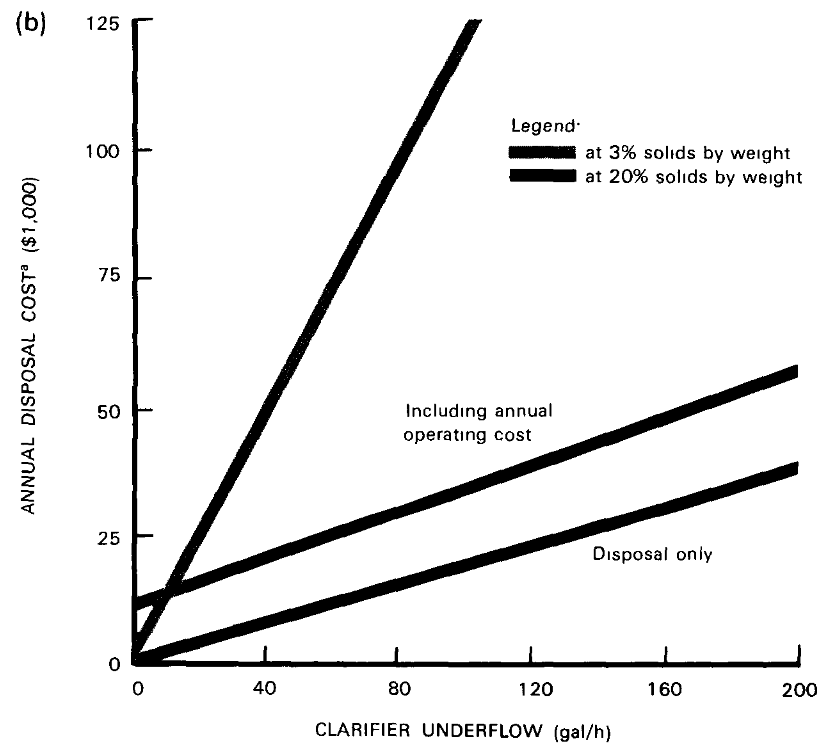
Elevating the dewatering device facilitates handling dewatered sludge. Ideally, the dewatered sludge should be discharged directly into a hopper—the transport medium to the disposal site. If this approach is impractical, a straight run of conveyors can be used to transport the sludge to a point over the hopper.

Filtrate is returned to the clarifier or other upstream process vessel. Usually the level of suspended solids is too high to allow direct discharge.

The basic premise in the design of sludge-handling systems is to prevent the flow path from becoming plugged with sludge or debris. Plugging is usually caused either by buildup of debris behind an obstruction in the flow path, or by solids settling in the pipes. To minimize the chance that such occurrences will interrupt operation, the system should use valves, instrumentation, and so forth, that do not obstruct flow through pipes, and should include provisions for flushing out clogged lines.



SOURCE: U.S. Environmental Protection Agency, *Environmental Regulations and Technology: The Electroplating Industry,* EPA 625/10-80-001, Aug. 1980.



[a]At $0.50/gal.

Figure 5.

Recessed Plate Filter Press: (a) Unit and Auxiliaries Needed for Sludge Dewatering and (b) Annual Sludge Disposal Cost

Basket centrifuge discharging centrate

Determining the capacity needed in the dewatering system requires testing. If a treatment system is already in place, capacity can be determined easily by measurement of the clarifier underflow volume and suspended solids concentration. Lacking a treatment system, a representative wastewater sample should be treated in a manner similar to the manner employed in the proposed treatment system. After treatment and settling, the volume of sludge generated per unit volume of water treated can be determined visually. A sample of the settled sludge can be analyzed for suspended solids content.

The high cost of sludge disposal will justify purchase of dewatering systems for all plants except those generating very small volumes of sludge. As a further incentive, if dewatering reduces the mass to below 2,200 lb/mo (1,000 kg/mo), the generator is excluded from many of the regulatory requirements of RCRA. Before evaluating the benefits of sludge dewatering, however, the capability of local disposal sites to handle nonpumpable sludges should be ascertained.

Consider, for example, the installation of a recessed plate filter press to dewater a dilute clarifier underflow from 3 percent to 20 percent solids by weight. Figure 5b compares the annual cost of disposal, at $0.50/gal of sludge, for the two concentrations. At 20 percent solids by weight, the figure shows the disposal cost with as well as without the annual cost to operate the filter press. Even with its cost included, the filter press reduces annual disposal costs at underflow rates exceeding 8 gal/h (30 L/h).

Thus, mechanical dewatering is usually cost effective, except for plants generating very small sludge volumes. Under RCRA requirements, sludge must be dewatered or solidified before it is used in land application. Modern disposal facilities that accept industrial solid waste are likely to have some means of dewatering or solidifying the waste. Plants generating small sludge volumes may find it more cost effective to use the dewatering capabilities at a central disposal facility.

Sludge Segregation

A mixture of hazardous and nonhazardous waste is considered a hazardous waste. Segregating wastes will reduce the volume of hazardous waste considerably and, therefore, the cost of treatment and disposal.[2,19] The sources of toxic contaminants in plating are usually limited to a few operations. Cadmium, lead, and chromium are the only common plating materials on the EPA list of toxic substances. If toxic wastes are separated from the rest of the waste stream, the treatment residue from the nontoxic waste streams should be able to pass the Extraction Procedure and be judged nonhazardous by EPA. Disposal of a waste that is judged nonhazardous should be less costly.

The segregated sludge containing toxic substances must be disposed of in a manner acceptable for hazardous wastes; however, the volume should be considerably less than the total amount of waste generated. The generator will avoid the reporting and manifest requirements if the hazardous waste amounts to less than 2,200 lb/mo (1,000 kg/mo).

Toxic substances can also be eliminated from a plant's waste by recovery and recycle of the toxic contaminants. Dragout from cadmium, lead, and chromium plating operations has been recovered by recovery systems. The combined benefits of material recovery, waste treatment cost reduction, and producing a nonhazardous sludge can provide significant returns on the investment in recovery equipment.

5. Sludge Dewatering Equipment

Mechanical dewatering devices are used to achieve a higher sludge solids concentration than can be obtained by gravity thickening. Weak attractive forces bind much of the water contained in a sludge to the solid particles; when the bonds are subjected to mechanical force, much of the water remaining in the sludge after gravity thickening can be removed. The following types of equipment can be used for mechanical dewatering of electroplating sludges:

- Pressure filters
- Vacuum filters
- Centrifuges
- Compression filters

When pressure filters are employed, the dilute sludge is pumped into the filter; the solids are retained on the filter membrane and the filtrate is discharged. Recessed plate filter presses use this method. They can dewater sludge to high solids content owing to the large pressure gradient they can apply across the sludge cake.

Vacuum filters dewater sludge by applying a vacuum on one side of a water permeable membrane that has a sludge layer or suspension on the other side. In response to the pressure gradient, the water passes through the membrane. Rotary drum and vacuum belt filters use this principle.

Centrifuges dewater sludge similarly to gravity thickening, but by rapidly rotating the sludge, they create a centrifugal force thousands of times more powerful than normal gravity. The strong centrifugal force greatly speeds up the settling process and magnifies the compaction effect. This dewatering mechanism makes centrifuges most suitable for compressive sludges that settle well.

Compression filters dewater sludge by squeezing it between water permeable membranes. They have proven effective mainly for dewatering highly compressive sludges typical of those resulting from polyelectrolyte conditioning.

Criteria for selecting one of the foregoing devices for a specific application include:

- Sludge properties (solids concentration, particle size, compressibility)
- Volume of sludge to be dewatered
- Local disposal requirements

Table 6 compares some of the characteristics of the different equipment types. Table 7 summarizes the performance of different dewatering systems for metal finishing sludges in industrial applications.

The data in Table 7 indicate that centrifugation will normally achieve

Table 6.

Dewatering Equipment for Electroplating Sludge: Typical Performance Characteristics

Equipment	Feed		Solids retention (% by weight)[a]	Cake solids concentration (% by weight)	Installed cost ($1,000)[b]
	Rate (gal/min)	Solids (% by weight)			
Filter press	2-250	1-5	95-99	20-50	20-200
Vacuum filter	1-250	3-10	50-99	15-40	30-150
Precoat vacuum filter	1-250	0 5-3	95-99	20-50	30-150
Basket centrifuge	2-60	2-5	50-95	5-25	20-175
Pressure belt filter	5-200	2-6	90-95	20-40	40-200

[a]Feed solids in sludge cake

[b]1981 dollars. Includes auxiliary equipment

Table 7.

Performance of Dewatering Equipment for Electroplating Sludge

Equipment type and unit size	Sludge feed rate (gal/h)	Solids (% by weight)		Comment
		Feed	Cake	
Recessed plate filter press:				
8.5-ft^3 sludge-holding capacity	95	3	30	NA
10-ft^3 sludge-holding capacity	300	1-2	30	Plastic-plating lime sludge
12.5-ft^3 sludge-holding capacity	NA	NA	40	Chromium hydroxide dewatering
21-ft^3 sludge-holding capacity	825	5	35-40	Operation attention 2-h shift, unit cleaned every 6-8 wk with recirculated 50% HCl
260-ft^3 sludge-holding capacity	12,000	3-6	30	Heat-treated zinc hydroxide sludge
Vacuum filter[a]	NA	3-5	70-75	Metal oxide waste treatment sludge
Rotary precoat vacuum filter:				
9.4-ft^2 filtration area	100-150	NA	15	Low maintenance
37.7-ft^2 filtration area	330	1-5	30	Cloth life 1 yr; repairs <$200/yr
Basket centrifuge:				
1-gal bowl capacity	120	3	12-20	Satisfactory performance; low maintenance
4-gal bowl capacity	120-150	5	18	High maintenance
Pressure belt filter: 9.8-ft-wide sludge-holding capacity	800	2-6	NA	Aluminum hydroxide sludge

[a]Unit size not available

Note —NA = not available

solids concentration in the range of 12 to 20 percent by weight. Both precoat vacuum filtration and pressure filtration can achieve 30 percent cake solids by weight if the sludge has good filtration properties.

The one data point given for vacuum filtration (without precoat) shows that the equipment achieved 70 to 75 percent cake solids by weight. This high cake concentration resulted because the sludge was composed of metal oxides rather than metal hydroxides. The metal oxide precipitants can be dewatered to higher solids content than can hydroxides because, unlike hydroxides, they do not have water chemically bound to the metal oxide molecule. Also, the metal oxide solids are much less compressible and they filter better. It is possible to generate metal oxide sludge, but the wastewater treatment is significantly different from that of conventional hydroxide precipitation systems.

Only one data point is given for a belt filter press; this equipment has been used to a limited degree for metal finishing waste sludge. Its higher cost usually restricts its use to applications where other equipment types cannot operate satisfactorily.

Filter Presses

The Equipment. Filter presses come in two basic types: recessed plate and plate and frame. In both cases, the press is a series of parallel plates pressed together by a hydraulic ram, with cavities between the plates. The plates are recessed on each side to form the cavities in the recessed plate press. A frame of equal dimension is placed between flat plates in the plate-and-frame press (Figure 6). The plates come in a variety of materials; originally they were fashioned from wood, later from steel or ductile iron. Plates in predominant use today are made of light weight, chemically durable polypropylene or fiber-reinforced polyester.

A filter press is a batch unit. At the start of the cycle, slurry is pumped into the cavities through a port that runs through the bank of plates. When the cavities are full, the pressure forces the filtrate through the filter media, along the drainage surface of the plates, into orifices that are located in the corners of the plates and connected to the filtrate port. The process continues until the cake solids in the cavities thicken to a degree such that, at the pressure limit of the press, only a small volume of filtrate is being produced. The pump is shut off at this point, the ram is withdrawn, and each cavity is emptied individually. The press is then closed and the cycle begins again. Usually the filter cakes are dropped into a hopper under the press or are transported to a hopper by a screw conveyor, which also breaks up the cakes.

The filter press has a number of advantages over other filtration equipment. Filter presses can operate well at variable or low feed solids conditions. They can produce a very dry cake because of the high pressure differential they can exert on the sludge. Some commercial units are designed with a pressure limit of 225 lb/in^2 gauge (1,653 kPa), and produce sludge cakes with solids content in the range of 50 to 70 percent by weight. Filter presses are mechanically reliable; the hydraulic ram and the plate-shifting mechanism (which facilitates cake discharge on the larger units)

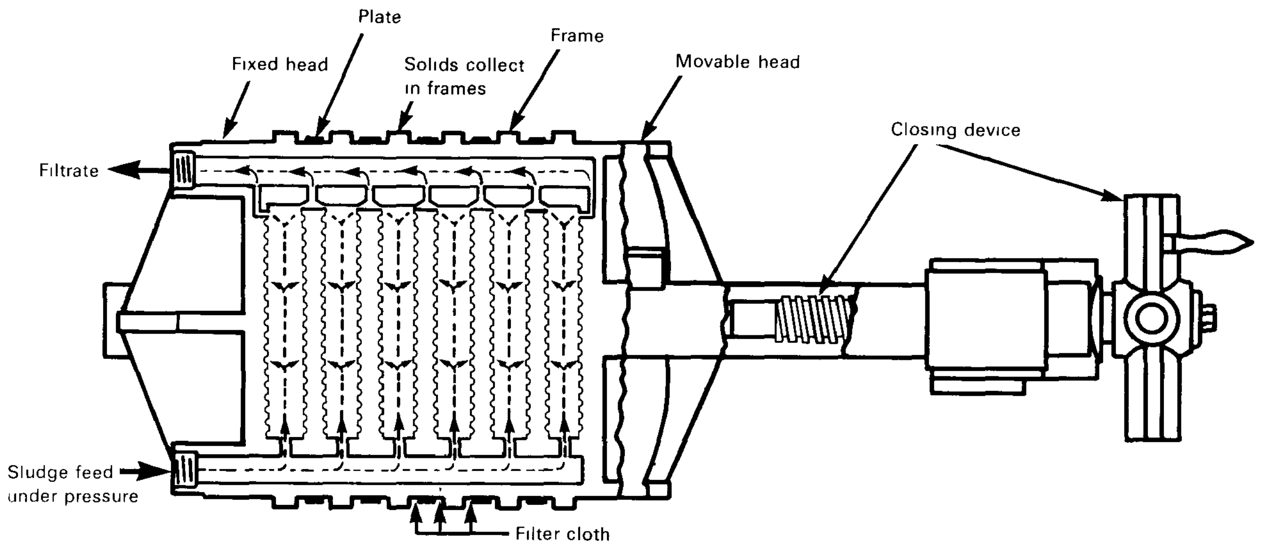


Figure 6.

Plate-and-Frame Filter Press

are the only moving parts. Power consumption is low; the only significant power use is for feed pump operation [2 to 20 hp (1.5 to 15 kW)].

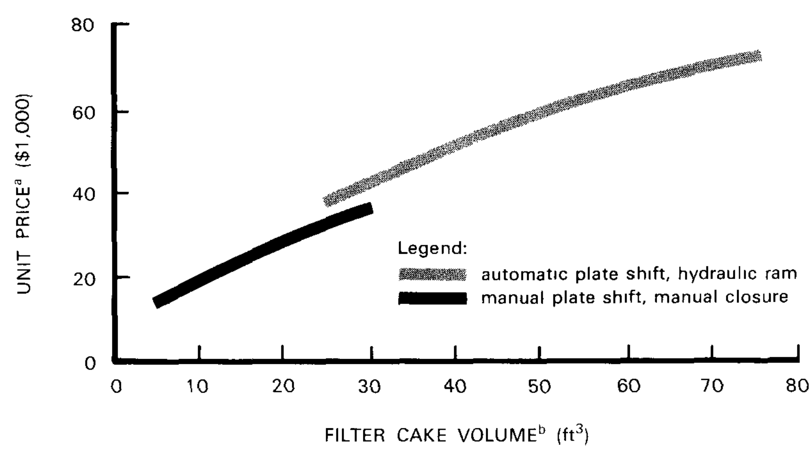
The disadvantages of the filter press include its batch operating cycle, the labor associated with removing the cakes from the press, and the downtime associated with finding and replacing worn or damaged filter cloths. At the end of each filtration cycle, about 30 min of operator labor will normally be needed to empty the press and start a new cycle. A filter press is usually sized to operate on a 4- to 8-h cycle.

Determining Applicability. The most reliable way to test whether a filter press is applicable is to obtain a small bench-scale unit from a press manufacturer. Several design specifications can be determined by bench-scale testing:

- Press filter cake volume
- Press filtration area
- Pressure limit
- Optimum cycle time

Press filter cake volume relates to the solids loading rate and the expected cake solids concentration and filtration cycle time.

Press filtration area actually relates to the optimum cake thickness between the plates in the press. Recesses between plates in filter presses range from 1 in (2.5 cm) to as much as 3 in (7.6 cm). The wider the spacing, the less expensive the filter press per unit of cake volume, but the lower the filtration capacity (gallons of filtrate per hour) per unit of cake volume.



[a]Includes carbon steel frame, polypropylene plates, and filter cloths.

[b]Based on sludge cakes 1.25 in thick

SOURCE: Equipment vendors

Figure 7.

Recessed Plate Filter Presses: Unit Prices

Feed solids concentration and filterability of the sludge affect the choice of spacing.

Pressure limit relates to the solids content of the sludge cake versus the applied pressure.

Optimum cycle time is determined by the press volume and filtration area specified. The longer the cycle time, the lower the labor requirements, because cake discharge and restarting occur less frequently. A longer cycle time will require a larger unit, which of course will cost more.

Testing with a bench-scale filter press, however, can be costly and time consuming. The applicability of a filter press, or of any filtration technique, can be determined more simply by use of a filter leaf test apparatus.[20] Several factors can be evaluated, for example, filterability, medium fouling, and cake release from the medium. Vendors of filter press equipment can scale up filter leaf test data to determine the required size of a filter press.

As an alternative to testing, filter press vendors need only a sludge sample and the volumetric rate and solids content of the press feed to determine the required size and cost of the unit.

Costs. Figure 7 shows the relationship of filter press purchase price to the volume of cake solids for a press with a 1.25-in (3.2-cm) cake recess and an operating pressure of 100 lb/in^2 gauge (790 kPa). The cost covers only the purchase price of the press; auxiliary equipment needed includes:

- High pressure feed pump or pumps
- Sludge feed storage
- Filtrate return to the clarifier
- Cake solids handling and discharge

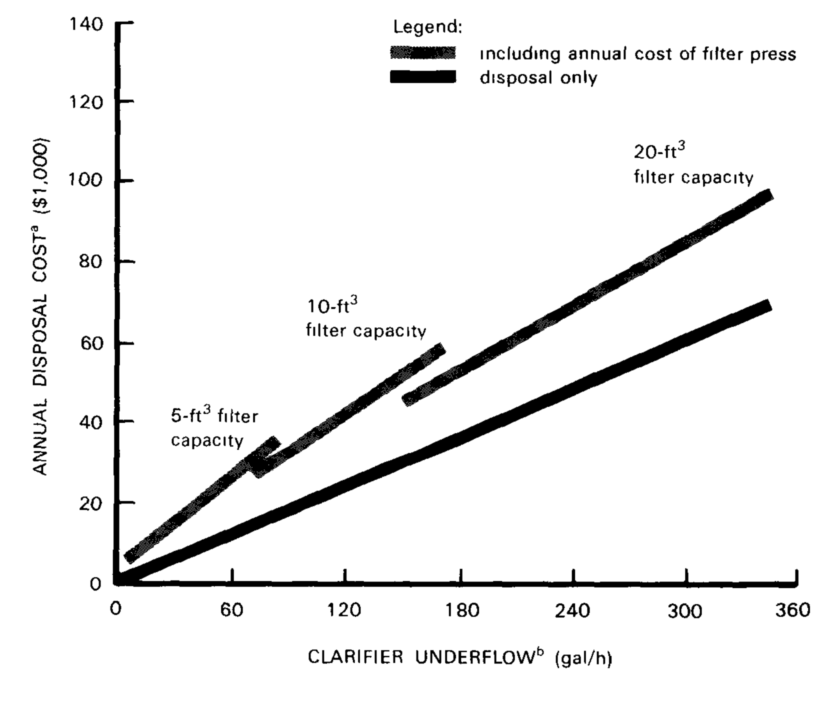
The cost of auxiliaries can be considerable, but fortunately there are alternatives that can eliminate some of the expense. Sludge feed piping, filter, and filtrate discharge piping can be designed as a closed hydraulic system. This approach enables the sludge feed pump to provide the pressure head needed to return the filtrate to the clarifier, thus eliminating the need for a filtrate receiving tank and return pump in applications where gravity flow return is not feasible.

Handling and disposal of the cake solids can be simplified by elevation of the press, enabling the filter cake to be discharged directly into the disposal hopper. This approach will eliminate the need for solids conveying systems and reduce the amount of operator attention associated with discharge of the cake solids.

Owing to the batch operation of the filter press, storage volume is needed for the sludge feed. Normally, a sump to receive the clarifier underflow will provide the necessary storage volume. If the solids retention time in a clarifier is high, the clarifier can be used as the storage chamber; otherwise a holding tank will be required to provide adequate sludge storage.

Operational costs associated with the press are for power to operate the feed pumps and labor to turn the press around at the end of each cycle. Minor operational costs are associated with maintaining the filter media in good condition. These costs include replacement of damaged or worn filter cloths and periodic cleaning to control media blinding.

In Figure 8, the cost associated with using a filter press for sludge



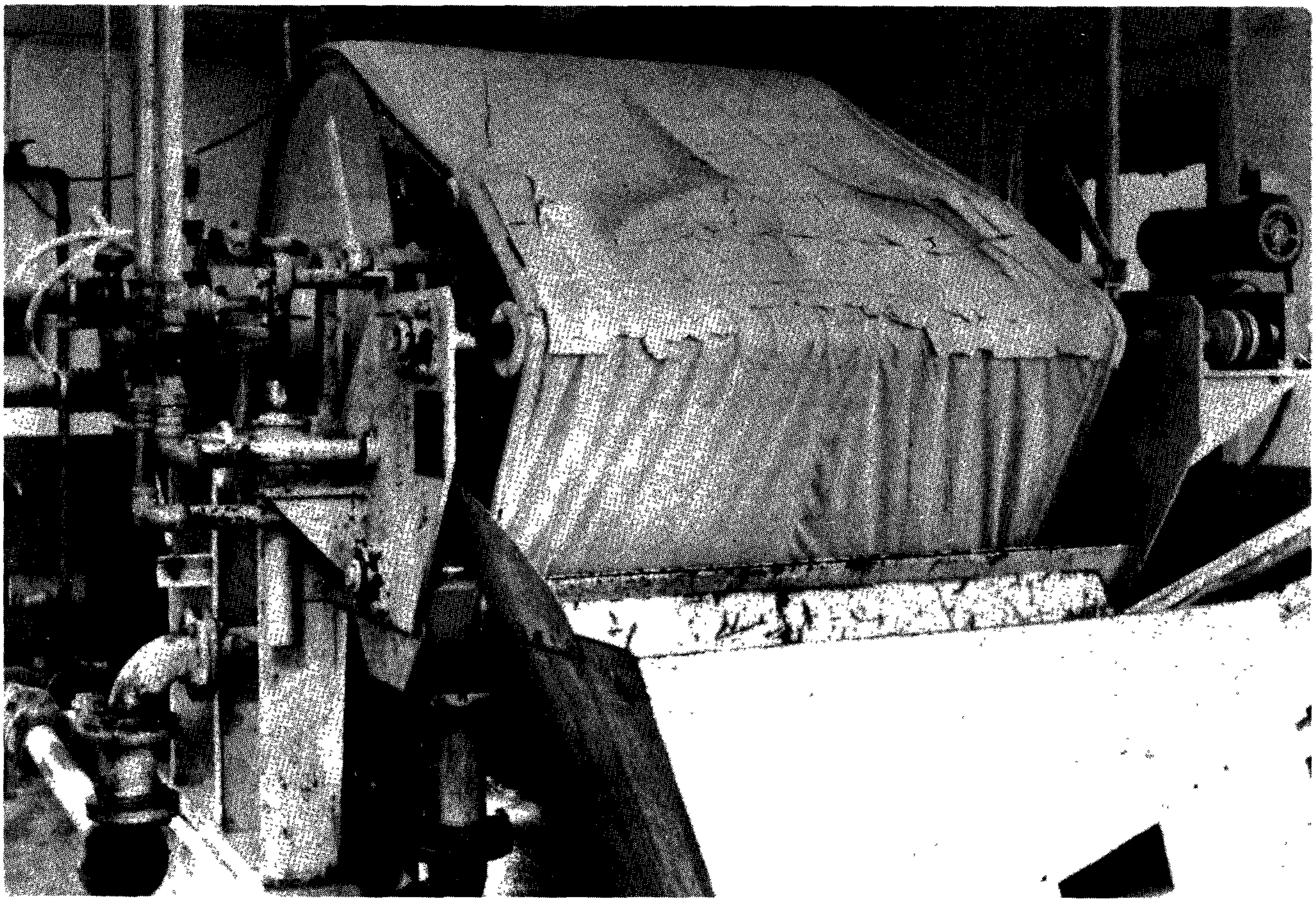
^{a}At $0.43/gal. Sludge dewatered to 25% solids by weight.

^{b}At 3% solids by weight.

Note.—4,800-h/yr operation.

Figure 8.

Filter Press Dewatering Systems: Annual Sludge Disposal Costs



Rotary vacuum filter with belt discharge for enhanced cake-medium separation

dewatering is shown as a function of the clarifier underflow rate, including costs for transporting and disposing of the sludge at a secure chemical landfill as well as costs associated with the filter press. It is assumed that the clarifier underflow is dewatered from 3 to 25 percent solids by weight. Disposal is assumed at \$0.43/gal (\$0.25 for disposal and \$0.18 for hauling), representing the average cost for a bulk load of 40,000 lb (18,000 kg) shipped 300 mi (480 km) to the landfill. Cost for the filter assumes a unit sized to operate on a 4-h cycle.

For example, with a clarifier (or thickener) underflow rate of 100 gal/h (380 L/h) at 3 percent solids by weight, the annual disposal cost would be \$39,000: \$21,000 for transporting and disposing of the dewatered sludge and \$18,000 for depreciation and operation of a press with 10 ft^3 (0.3 m^3) of filter capacity. If the same volume of sludge were disposed of without dewatering, the annual disposal cost would be \$200,000. Based on the assumptions in Figure 8, the filter press installation saves \$161,000 per year.

The economic benefits of installing dewatering equipment are also realized for plants generating small volumes of sludge. The filter press achieves a net disposal cost reduction where clarifier underflow rates exceed 5 gal/h (19 L/h).

The rate of return on the investment associated with a recessed plate filter press is a function of the volume of sludge and the cost of sludge disposal. For a plant disposing of its sludge at \$0.43/gal, the investment in a filter press with a 5-ft^3 (0.15-m^3) filter capacity yields a 30-percent after-tax return when the feed rate exceeds 12 gal/h (45 L/h). The cost of the press would be \$19,000; installation with the required auxiliaries should bring the total to \$29,000.

Vacuum Filters

The Equipment. The rotary drum (Figure 9a) is the most common type of vacuum filter. The drum is positioned horizontally and rotates partly submerged in a vat filled with a slurry.

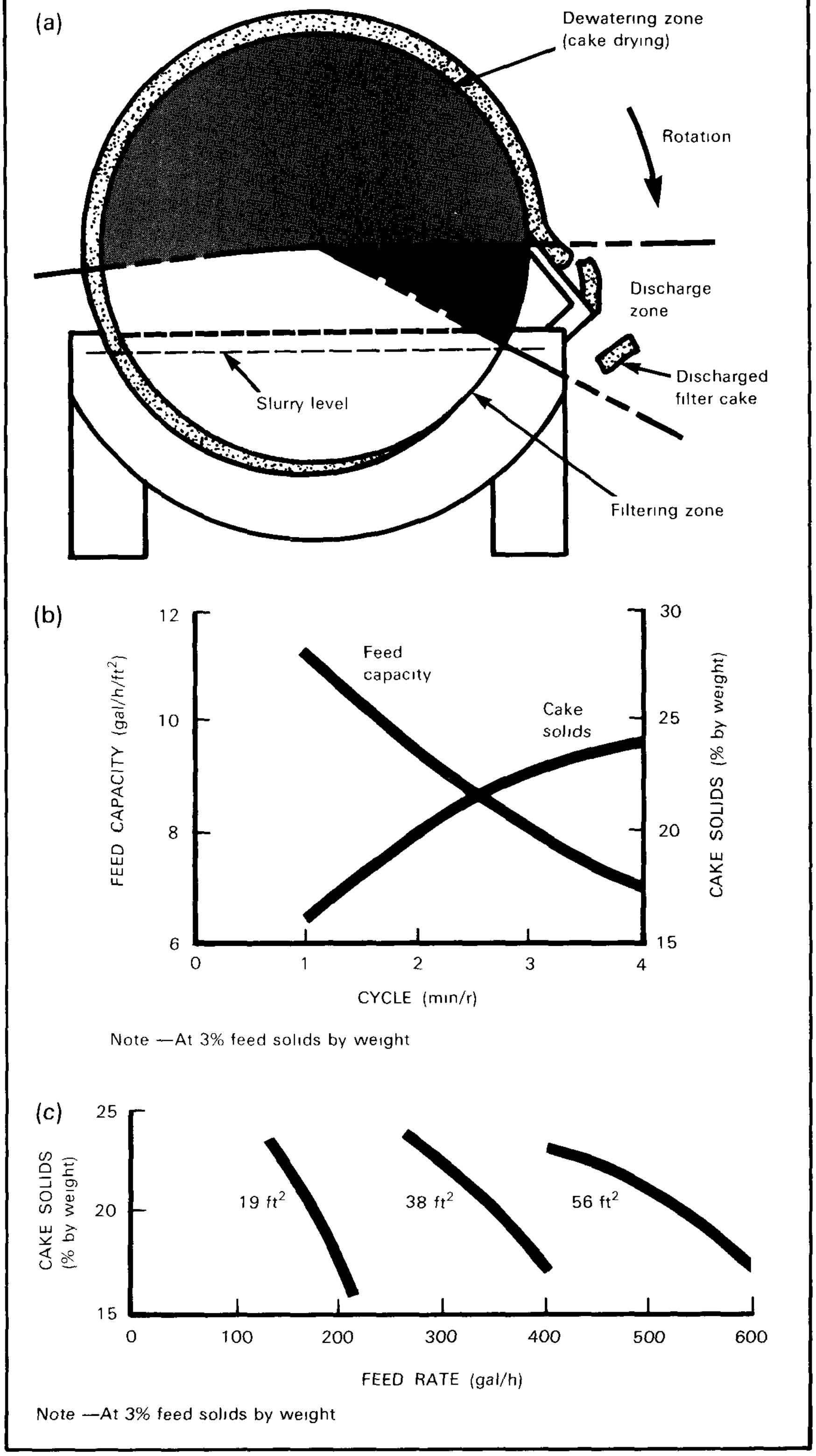


Figure 9.

Rotary Vacuum Filter: (a) Basic Principle of Continuous Rotary Filtration, (b) Filter Cake Capacity and Cake Dryness (from Filter Leaf Test), and (c) Scale-Up Performance

The surface of the drum, which is covered by a filter medium, consists of a series of horizontal panels. Vacuum is applied independently to each panel by pipes inside the drum; the pipes connect to a common vacuum source, usually provided by a vacuum pump.

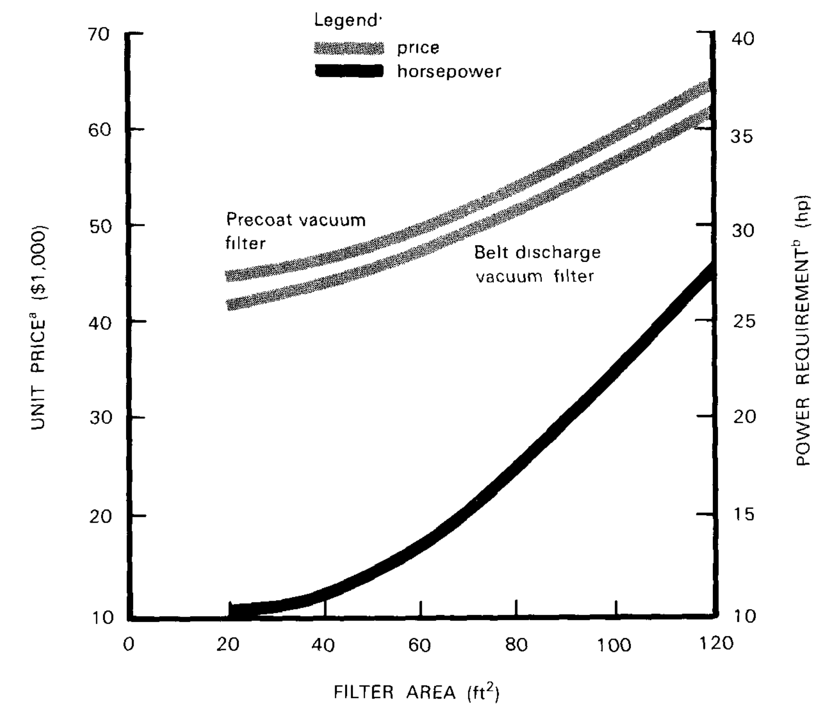
The filter has three basic operating zones: filtering, cake drying (dewatering), and cake discharge. In the first zone, vacuum is applied as a section of the drum submerges in the slurry. A cake forms on the filter medium as the solids are captured, and the filtrate is drawn to the vacuum source. The vacuum is maintained as the drum section rotates out of the slurry into the second zone. The vacuum removes additional water and draws air through the cake to promote further drying. In the last zone, the discharge of the cake is accomplished when the vacuum is replaced with a blast of air that separates the cake from the medium.

Other means have been developed to facilitate discharge of the filter cake. In one variation, a series of parallel strings, tied around the drum, separate from the drum in a tangential plane at the discharge point, lifting the filter cake from the medium. The strings pass around a roller and the cake separates from the strings and is discharged. In another variation, the medium is separated from the drum, passes over a roller where the cake is discharged, and is washed before being directed back to the filter drum by another roller. These variations were developed to make the rotary filter more versatile—able to handle slurries forming gelatinous cakes that are difficult to discharge and, consequently, that foul the filter medium.

A third variation of the rotary drum filter uses a precoat, usually diatomaceous earth, that acts as the filter medium. As the drum rotates past a scraper, a thin portion of the precoat cake is removed along with the collected solids, resulting in a clean, unfouled surface each time a section of the drum enters the slurry. Precoat filtration provides excellent filtrate quality and can remove slimy solids that are difficult to filter and that would rapidly foul a permanent filter medium.

Precoat filtration is generally used to dewater dilute sludges because it offers a high filtration rate per unit of filter area. Precoat consumption usually ranges from 5 to 20 lb (5 to 20 kg) for each 100 lb (100 kg) of sludge solids ($0.50-$2/100 lb sludge solids). The precoat does add to the quantity of solids for disposal, but often precoat filtration yields a cake with higher solids content than does standard vacuum filtration.

Determining Applicability. The filter leaf test[20] is the common procedure for evaluating the applicability of vacuum filtration and determining required unit size. The filter leaf is a small disk with drainage grids similar to production filters. Filter cloths of different materials and weaves can be attached to the disk for evaluation.



[a]Skid-mounted unit complete with vacuum pump, separator, filtrate removal pump, and internal piping

[b]Includes power for vacuum and filtrate pumps and for belt drives

SOURCE Equipment vendors

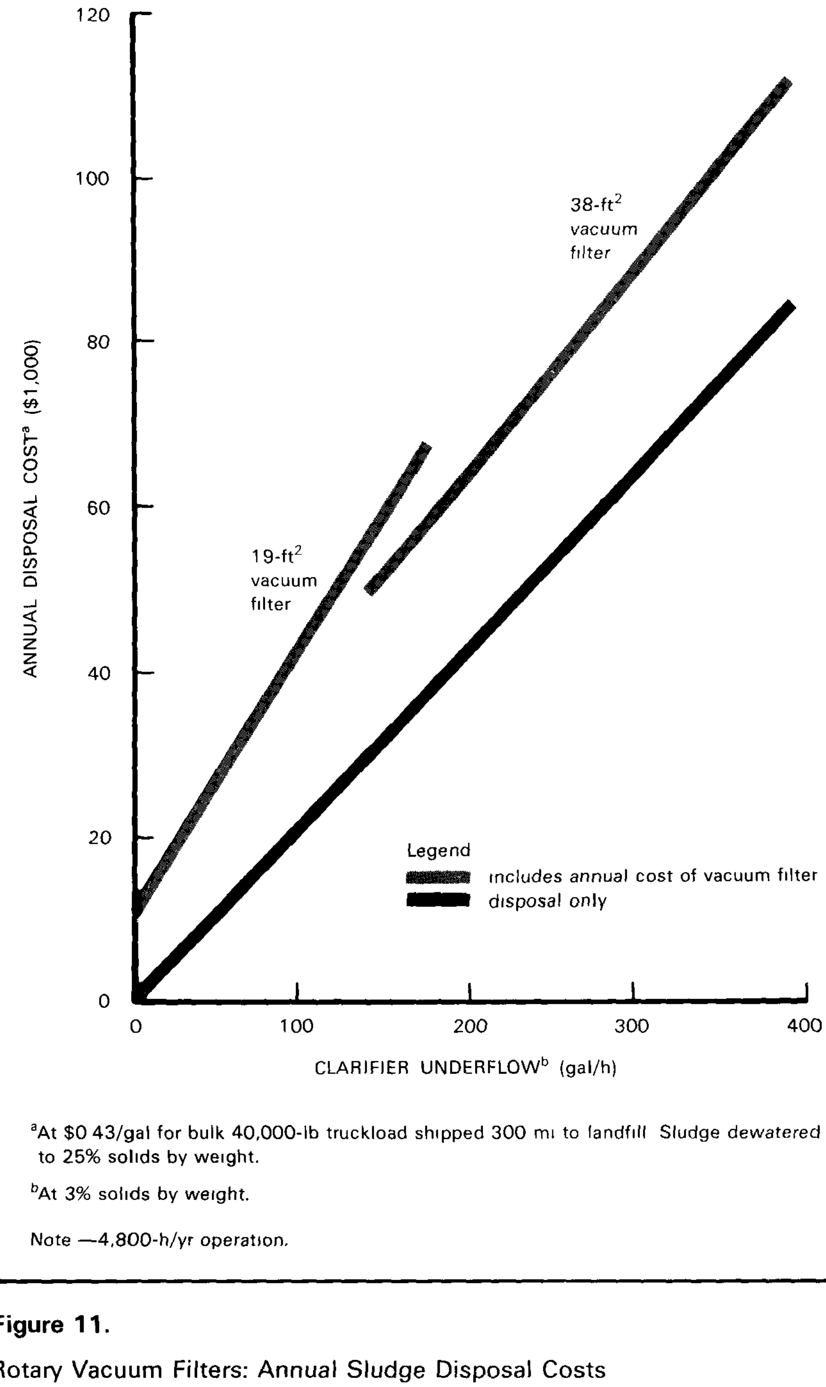
Figure 10.

Rotary Vacuum Filters: Unit Prices and Power Requirement

The leaf is submerged in the agitated slurry for a specified time, then removed. After the vacuum has been allowed to dry the cake for a set period of time, quantity of filter cake, cake solids percentage, and filtrate volume are determined. The test is repeated with different filtration and drying times to determine the most effective operating conditions. The two key factors are dry solids capacity in pounds per hour per square foot (kilograms per hour per square meter) of filter area, and cake solids concentration. Varying the test cycle time is equivalent to varying the revolution speed on the filter drum. After a number of runs, curves similar to those in Figure 9b can be developed. The figure shows that slowing the drum revolution speed increases cake solids concentration and reduces filter capacity.

The curves can be used to predict the performance of a full size filter as a function of filtration area. As the solids loading rate (or feed rate) for a particular application is set, the cake solids concentration will depend on filtration area (Figure 9c). A disposal cost analysis is needed for different filter sizes to determine the optimum filter size for a given application. The analysis will require defining the disposal cost of the sludge as a function of solids concentration and obtaining equipment and operating costs for the filters.

It is also important in pilot testing to determine how easily the cake releases from the medium at the end of each run. To determine the potential effect of cloth blinding, the filter leaf test can be repeated a number of times while the different variables are held constant. If the collected filtrate is measured after each run, any deterioration



[a]At $0.43/gal for bulk 40,000-lb truckload shipped 300 mi to landfill Sludge dewatered to 25% solids by weight.

[b]At 3% solids by weight.

Note —4,800-h/yr operation.

Figure 11.

Rotary Vacuum Filters: Annual Sludge Disposal Costs

in filtration rate caused by medium fouling can be observed. Selecting a suitable filter cloth fabric and weave can often reduce cloth blinding.

As a rule, rotary drum vacuum filters perform best with feed solids ranging from 3 to 5 percent by weight. A thickener should be installed to concentrate dilute sludge from a clarifier. Precoating the filter is an effective means of dewatering dilute sludges. Without precoat, good filtration rates and trouble-free cake release are usually realized with a sludge having solids that are not too sticky or compressible. Chemical and thermal conditioning or precoat body feeding will often improve sludge filtration characteristics. Such conditioning can become economically attractive in reducing equipment size and improving performance.

Vendors of filters, filter cloths, filter aids, and sludge conditioners will provide guidance in test procedures and supply product samples to aid the potential customer in evaluating the applicability of vacuum filtration to a given sludge disposal situation.

Costs. Figure 10 shows the unit cost and power requirement for a rotary vacuum filter as a function of filter area. The cost is for a prepiped, skid-mounted unit that includes the filter, the vacuum pump and associated vacuum lines, a vapor-liquid separator, and a filtrate removal pump. No costs are included for handling the discharged sludge cake. The major cost of operating a vacuum filter is associated with the power supplied to the vacuum and filtrate pumps and the drum agitator drives. The unit operates continuously and should only require operator attention for maintenance and repairs. As with most membrane filters, the filter medium requires periodic cleaning with an acid or alkaline solution to remove fouling agents. Regular filter cloth replacement is also necessary, but should not constitute a major expense.

Figure 11 shows the annual disposal cost for sludge dewatered using a rotary vacuum precoat filter as a function of the clarifier underflow rate. Total disposal cost includes the cost of operating the filter as well as that of hauling and landfill disposal. A typical precoat filtration rate of 12 gal/h/ft² (489 L/h/m²) was used to determine the necessary filtration area. It is assumed that the filter dewaters the underflow from 3 to 25 percent solids by weight. Using the cost components indicated, the vacuum filter realizes a cost reduction compared with sludge disposal at 3 percent solids by weight when the underflow exceeds approximately 10 gal/h (38 L/h)—even though at that feed rate the smallest commercial unit available would have considerable excess capacity.

The savings in hauling and disposal cost justify investment in the equipment. For a plant disposing of its sludge at $0.43/gal, the installation of a vacuum filter with a 19-ft^2 (1.8-m^2) filter area yields a 30 percent after-tax return on investment when the feed rate exceeds approximately 30 gal/h (113 L/h). The investment required for installation of a 19-ft^2 (1.8-m^2) filter would total $73,000.

Basket Centrifuges

The Equipment. Centrifuges dewater sludge in a manner similar to gravity thickening, but by rapidly rotating the sludge they create an apparent gravity thousands of times more powerful than normal. The centrifugal force thus created speeds up settling and magnifies the compaction effect, making centrifuges most suitable for compressive sludges that settle well. Several centrifuge types are available commercially, including basket, scroll, and disk centrifuges. Only the basket centrifuge is used to any degree to dewater plating sludge.

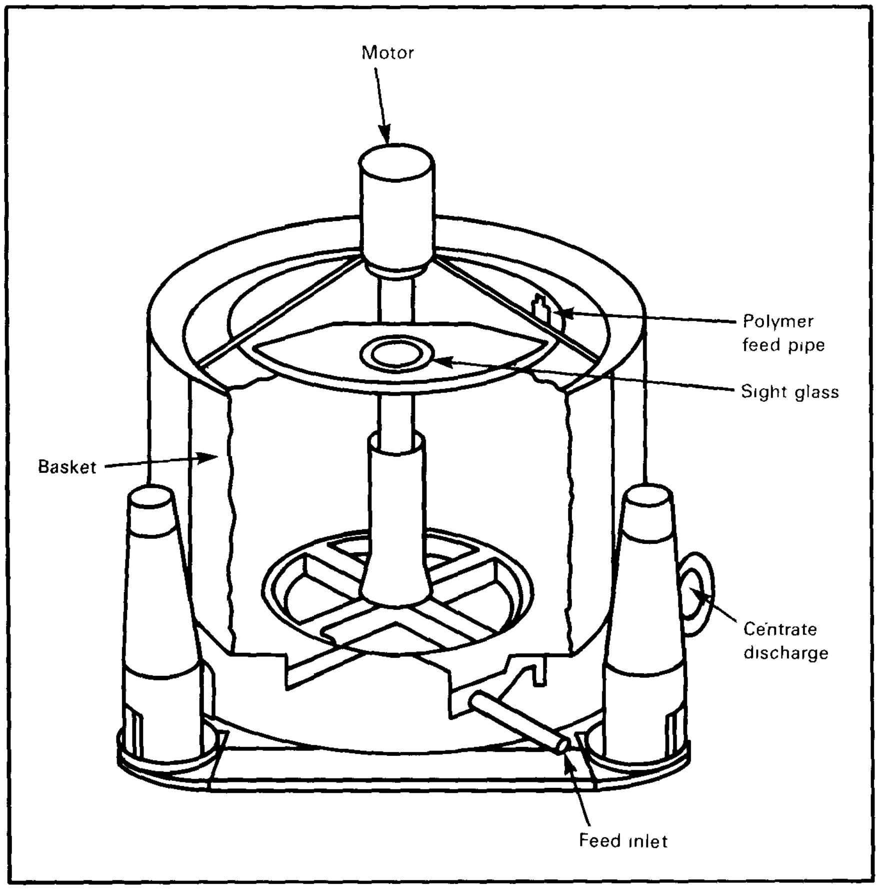


Figure 12.

Basket Centrifuge

The basket centrifuge (Figure 12) is a vertical rotating bowl that has a lip extending inward at the top. Sludge is introduced into the bottom of the unit and the solids, owing to their greater density, are thrown against the inner wall of the basket. When the basket becomes full, clarified liquid (or centrate) is decanted over the inner lip and removed from the unit.

The rotating basket comprises two zones: against the outer wall of the basket is the solids retention zone, which contains the accumulated sludge solids; the rest of the basket constitutes the clarification zone, which separates the solids from the incoming feed. As the cycle continues, the volume of accumulated solids increases and consequently reduces the capacity of the clarification zone until the residence time of the fresh feed in the clarification zone is insufficient to settle out the suspended solids. At this point, the level of solids in the centrate increases dramatically. This change, or "breakover," is detected by a monitor. The feed is cut off and a skimmer is run into the basket to remove excess water from the cake surface. The basket then decelerates from operating speed (anywhere from 1,000 to 3,000 r/min) to approximately 75 r/min. A plow enters the basket and pushes the cake out at the bottom of the centrifuge. As the plow retracts, the basket is accelerated and the feed is resumed.

The time required for the phases of the operating cycle when the unit is not receiving feed usually varies from 6 to 8 min. A unit of this type has a feed rate up to 60 gal/min (225 L/min), with solids recovery of 50 to 95 percent. It can produce a sludge cake ranging from 10 to 25 percent solids concentration.

Determining Applicability. Centrifuges are effective for dewatering sludges that contain solids of an apparent density greater than water, that is to say, solids that want to settle. Usually the feed is treated with polymer conditioning agents to improve the settling characteristics of the solids. Centrifuges, unlike some filters, are well suited for dewatering compressible sludges. They are also attractive because of their compact size and automated operation.

Cake solid concentration obtainable with a given sludge can be determined by testing the sludge on a bench-scale centrifuge. Most vendors have a number of these units and will perform field tests or do the work in their own laboratories if a feed sample is supplied.

The pilot test procedure determines the required size and performance of a solid bowl centrifuge for a particular sludge. Tests are performed to determine whether polymer conditioning is needed and, if so, the optimum dose. The unit's performance is evaluated at the optimum dose with varying feed capacities. Normally, the cake solids concentration decreases with increasing feed rate, as does solids recovery (the percentage of feed solids contained in the filter cake).

There is a disadvantage, however, in many centrifuge applications; owing to high rotation speed, if rotating elements are not well maintained, frequent breakdown can occur. This problem is particularly likely with sludges containing abrasive solids. Moreover, considerable power is required to operate the unit. New low-speed units, capable of operating with improved power efficiency, are being marketed.

Costs. Figure 13 shows the unit cost for the two available classes of basket centrifuge. These units typically use 75 percent of the available power during the feed-and-skim stage of the cycle. Figure 13a

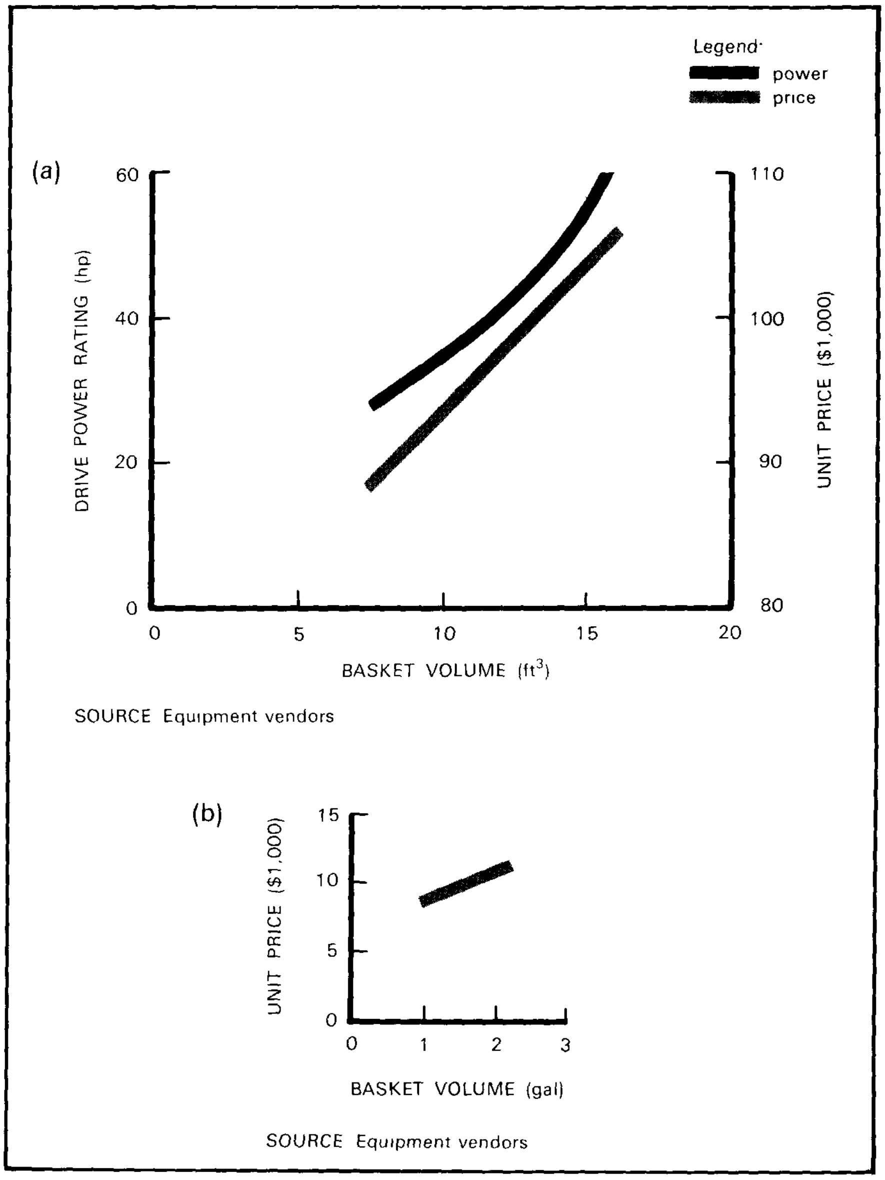


Figure 13.

Basket Centrifuges: (a) Large Unit Price and Hydraulic Drive Horsepower and (b) Small Unit Price

includes the horsepower rating of the unit drive for the large centrifuge. Large units are available with basket volumes between 8 and 16 ft^3 (0.23 and 0.45 m^3).

Small units, which are not automatically cycled, are available with basket volumes of 1 to 2 gal (3.8 to 7.5 L). Small units have minimum installation requirements, and their unit price (Figure 13b) is markedly lower than that of the large units. They are well suited for small operations disposing of drum-load quantities of sludge. The dewatered sludge can be discharged directly into the drum. The 2-gal (7.5-L) unit can handle as much as 100 gal/h (378 L/h) of sludge feed. Solids recovery, however,

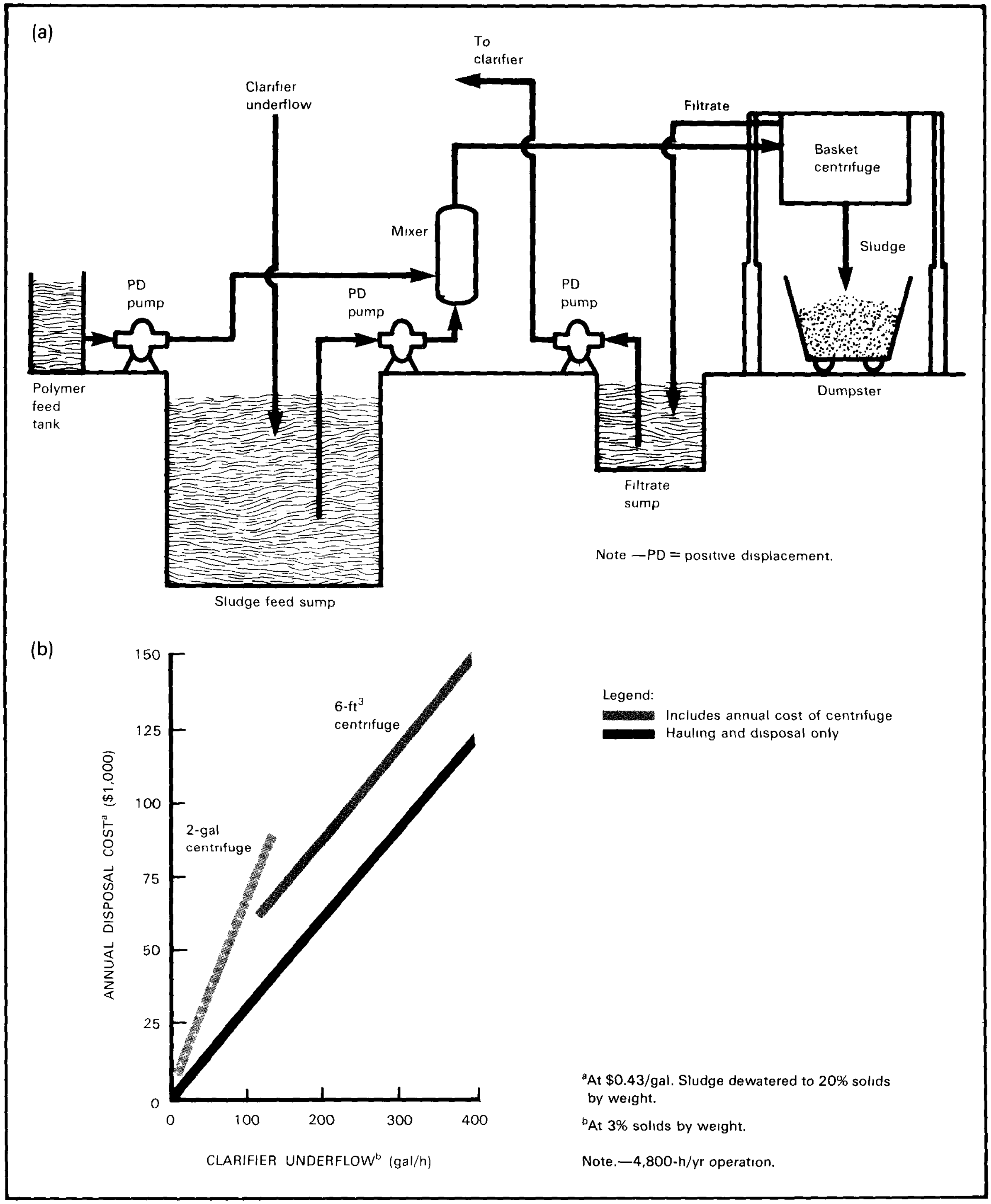


Figure 14.

Basket Centrifuge Systems: (a) Dewatering System with Auxiliary Equipment and (b) Annual Sludge Disposal Costs tends to deteriorate at the higher flow rates.

The unit costs in Figure 13 include the centrifuge and drive system and the control hardware needed to cycle the unit properly. Other associated costs are for site preparation, feed pump, centrate removal, and piping. Operating cost will be primarily for power to operate the unit and for polymer conditioning agents, which are commonly used to improve the performance of the unit and increase its processing capacity. The small manual units will also require operating labor to cycle the unit. The large units are automated and should require minimum operator attention.

The small units are reasonable in cost, but the operating labor required is excessive for dewatering systems with average feed rates over 15 gal/h (57 L/h). As an example, a 2-gal (7.5-L) basket centrifuge dewatering sludge from 3 to 20 percent solids by weight could process approximately 13 gal (50 L) of sludge feed per cycle. Where the sludge feed rate is 50 gal/h (190 L/h), the unit would have to be cycled four times per hour. Each cycle requires operator control, so labor cost would be excessive compared with that of other equipment.

Figure 14a is a flow diagram of a typical basket centrifuge sludge dewatering system. Figure 14b shows the annual cost, based on clarifier underflow rate, of disposal of sludge dewatered in a basket centrifuge. Based on the assumptions in Figure 14b, at underflow rates exceeding 18 gal/h (68 L/h) the centrifuge system nets a reduction in annual disposal cost compared with disposal of sludge without dewatering. At a disposal cost of $0.43/gal, installing a 2-gal (7.5-L) basket centrifuge will generate a reasonable after-tax return on investment (over 30 percent) for a clarifier underflow greater than 18 gal/h (68 L/h).

Pressure Belt Filters

The Equipment. The pressure belt filter (Figure 15) is finding increased application because it offers certain advantages over other commonly used dewatering devices. This filter is especially suitable for dewatering the large, highly compressible particle floc char-

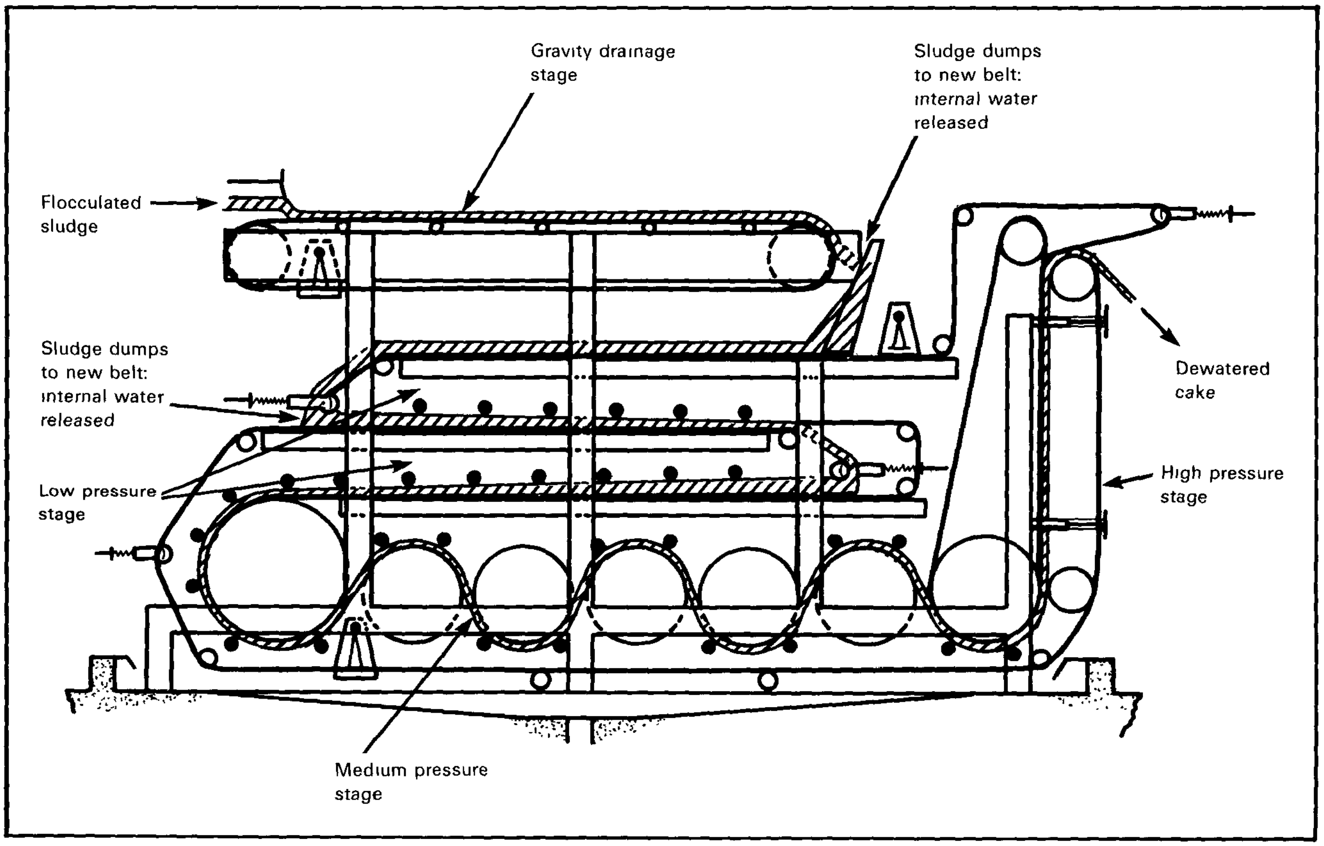


Figure 15.

Pressure Belt Filter

acteristic of polymer-treated sludges. A common problem with such sludges is that, when subjected to a pressure gradient, the solid particles collapse against the filter medium and block the transport of water through the medium. The belt press eliminates this problem by using gravity to remove most of the water. Then, as the belt travels through successive regions, a gradual increase in pressure forces additional water from the sludge.

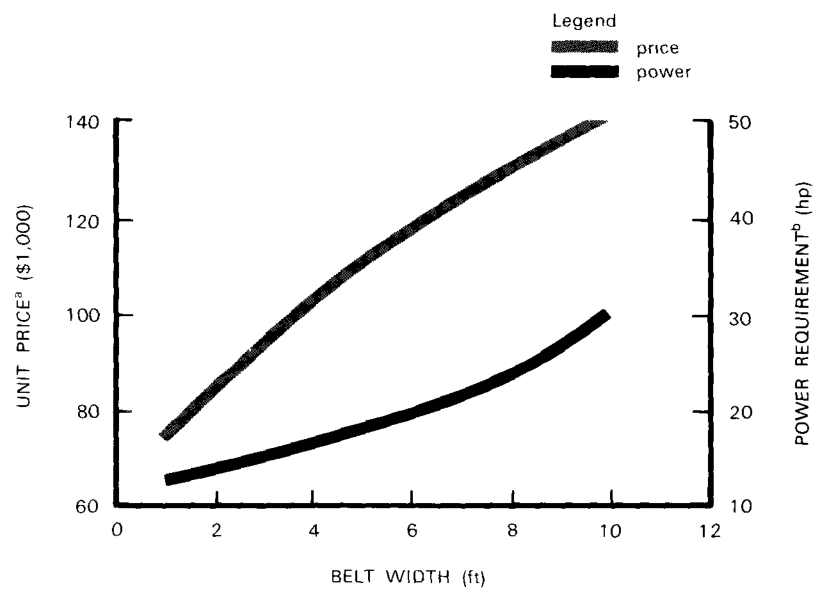
In the first stage of unit operation, the polymer-dosed sludge is spread over a slow-moving filter cloth belt and any free water drains off. To be suitable for further processing, the sludge should form a cohesive, continuous blanket in this region. The sludge blanket leaves the drainage section and enters the mild compression zone. It is compressed between water permeable membranes, more water is forced out, and the sludge layer becomes a more nearly solid mass. The more cohesive the sludge layer becomes, the more compressive force it can adsorb without extruding through the filter medium or being forced from between the belts. The compressive force gradually increases as the sludge layer travels through the unit—some models have compressive limits as high as 100 lb/in^2 (680 kPa). Sludge properties, cake thickness, time under compression, and the magnitude of the compressive force all influence the cake dryness.

The capacity of a belt press is determined by belt width and belt speed. Belt width depends on the model selected, and ranges from 1 to 10 ft (0.3 to 3 m). Belt speed sets the time the sludge will travel through the press. Unit capacity can be increased by adjustment to the belt speed to compensate for a higher feed rate, but only to a limited degree. The major criterion for good filter operation is formation of a cohesive, solid sludge blanket in the gravity drainage zone. When feed rate increases, the belt speed will normally be lowered to allow additional drainage time; however, as with other filtration equipment, cake dryness will usually fall off as feed rate increases. For greater flexibility in meeting changing feed conditions, some units have separate filter belts and speed controls for the gravity dewatering and compression zones. This design also permits the use in each zone of a filter medium designed specifically for that zone.

Determining Applicability. Pressure belt filters are suitable for polymer-treated sludge that drains well and forms a cohesive, compressible sludge cake when dewatered. The best way to determine their performance on a specific sludge is to have a press manufacturer perform pilot tests with a bench-scale unit.

The pilot testing will determine the performance of the filter in terms of cake dryness and solids capture efficiency at varying polymer dose rates, thus establishing the optimum polymer dose. Once the optimum dose is known, the performance of the unit as a function of feed rate can be determined. From these relationships, the size and performance of full-size units can be estimated.

Costs. Figure 16 shows the cost and power requirement of a high-pressure belt filter package unit as a function of belt width. The package unit comes complete with a



[a]Skid-mounted unit complete with polymer feed pump and dilution tank, flash mix chamber, sludge feed, and wash water pump

[b]Includes power for press drives, conditioning tank drive, polymer feed pump, polymer tank mixer, and belt wash pump (if needed)

SOURCE Equipment vendors

Figure 16.

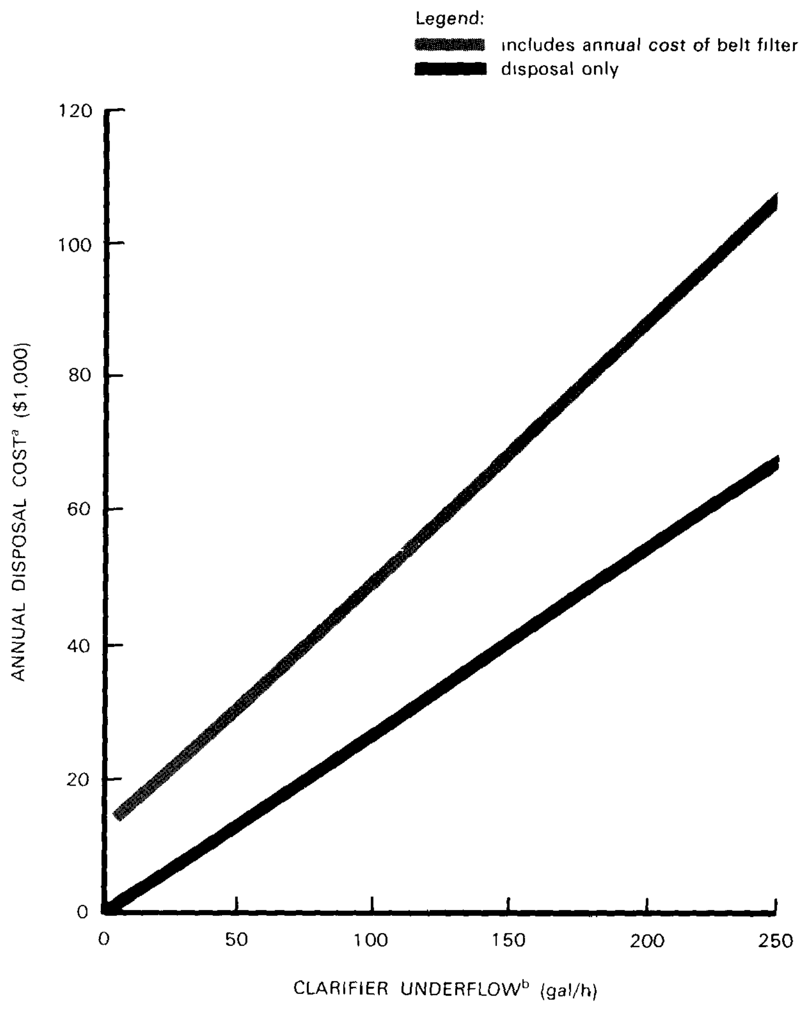
Pressure Belt Filter: Unit Price and Power Requirement polymer-mixing and feed system, and includes belt-washing auxiliaries. The necessary piping and valves are preassembled and the unit is skid mounted. The cost range shown is representative for high-pressure units; however, prices vary among the different systems marketed, mainly because of variation in belt configuration and degree of compression achieved.

Belt presses have a major advantage over centrifuges and vacuum filters in that they consume considerably less power. Depending on the size and manufacturer of the belt press system, total power consumption ranges from 5 to 30 hp (4 to 22 kW). Centrifuges and vacuum filters, sized to accomplish the same service, consume between 15 and 100 hp (11 and 75 kW).

Other associated operating costs include chemicals for polymer conditioning and wash water for continuous cleaning of the filter belt. Polymer cost can be significant in the operation of belt filters; for some sludges, optimum polymer dose per ton (megagram) of dry solids can be as high as 200 lb (100 kg). Polymer dose rates generally range from 10 to 50 lb/ton (5 to 25 kg/Mg), at a cost of \$30/ton to \$150/ton of dry solids. Rates for wash water to clean the filter belt of fouling agents vary from 10 gal/min (38 L/min) for small units to 100 gal/min (380 L/min) for larger models. The wastewater load associated with the belt wash water has been reduced significantly by use of the filtrate from the gravity dewatering zone of the press to supply part, if not all, of the wash water.

In Figure 17, the annual cost of sludge disposal associated with pressure belt filtration is shown as a function of clarifier underflow rate, assuming dewatering to 20 percent solids by weight. The pressure belt unit size used in the cost analysis was determined by assuming a maximum hourly feed rate of approximately 300 gal/ft (37 L/cm) of belt width. At this feed rate, a unit with a belt 1 ft (30 cm) wide (the smallest size available) could process about 75 lb (34 kg) of dry solids per hour. Based on the disposal cost formula used in Figure 17, the pressure belt filter yields a cost reduction compared with disposal at 3 percent solids when the underflow rate exceeds 10 gal/h (38 L/h)—despite the unit's high initial cost and its low utilization at that feed rate.

For a plant disposing of its sludge at \$0.43/gal, the pressure belt



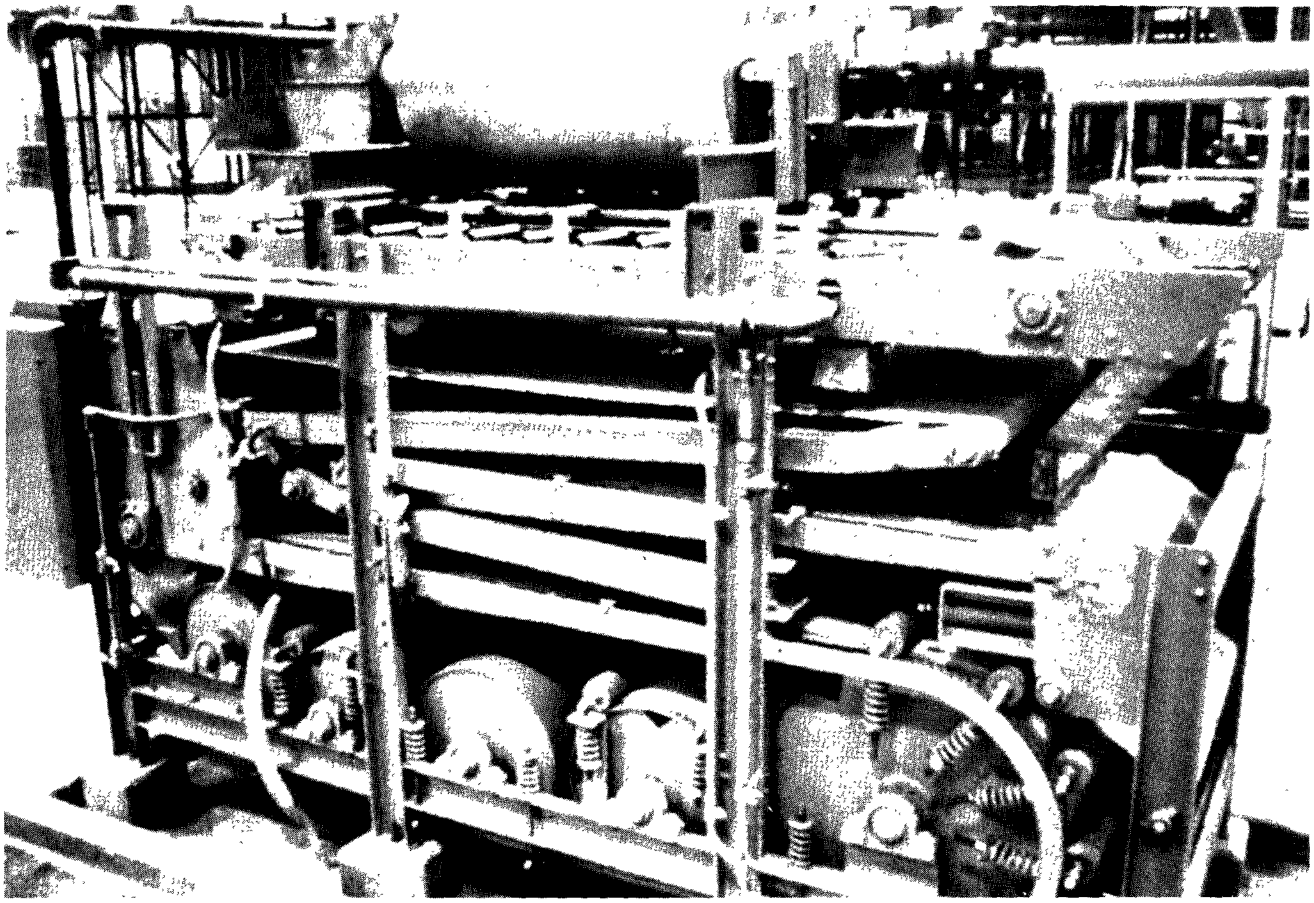
[a]At \$0 43/gal Sludge dewatered to 20% solids by weight

[b]At 3% solids by weight

Note —4,800-h/yr operation

Figure 17.

Pressure Belt System: Annual Sludge Disposal Cost



Pressure belt filter

Table 8.

Comparative Total Investment and Annual Operating Costs for Sludge Dewatering

Feed sludge volume[a] (gal/h)	Costs ($)							
	Filter press		Precoat rotary vacuum filter		Basket centrifuge		Pressure belt filter	
	Installed investment[b]	Annual[c]	Installed investment[b]	Annual[c]	Installed investment[b]	Annual[c]	Installed investment[b]	Annual[c]
50	29,900	23,000	73,000	24,000	34,000	37,000	104,400	31,000
100	39,100	37,000	73,000	39,000	34,000	70,000	104,400	50,000
150	39,100	51,000	73,000	55,000	48,000	85,000	104,400	69,400
200	51,700	63,000	78,000	68,000	174,000	89,000	104,400	88,000
250	51,700	76,000	78,000	80,000	174,000	102,000	104,400	107,000
300	51,700	89,000	78,000	93,000	174,000	115,000	125,000	126,000

[a]Assumed at 3% solids by weight.

[b]Includes all system auxiliaries.

[c]Includes equipment operating, fixed, and sludge disposal costs

Note.—1981 dollars.

filter installation with a belt 1 ft (30 cm) wide would have a reasonable rate of return (30 percent return on investment after taxes) at feed rates exceeding 50 gal/h (190 L/h).

Evaluating the Cost for Sludge Dewatering Alternatives

The foregoing sections have described the operation, cost, and performance of equipment types commonly used for sludge dewatering. Vacuum filters, filter presses, centrifuges, and belt presses have all found application for dewatering sludge from metal finishing waste treatment. It is not usually necessary, however, to evaluate each alternative before selecting a dewatering system. Some general guidelines follow.

If disposal costs are less than $15,000/yr, it is unlikely that dewatering equipment would be justified economically. Many landfill sites can solidify or dewater dilute sludge, and their capabilities should be used.

The lowest cost alternatives in terms of capital investment are filter presses and small manual basket centrifuges. Minimum size versions of both systems can be installed for under $30,000.

The small filter press system, although equal in cost to the centrifuge, will usually have more capacity. At low feed rates, the cost per unit of capacity is lowest for the filter press. The low capacity per cycle of the basket centrifuge will require significant operating labor at flow rates above 10 to 15 gal/h (38 to 57 L/h).

Poor-filtering sludges can usually be dewatered by precoat vacuum filtration. With polyelectrolyte conditioning, most sludges can be dewatered effectively with a centrifuge or belt filter.

Table 8 compares the investment and annual operating costs of the four equipment alternatives for flows ranging from 50 to 300 gal/h (190 to 1,135 L/h). At all levels, the filter press was least costly in general; however, at the higher range of flows the cost advantage was less significant. Table 9 gives the cost factors included in the analysis, using the example of a precoat vacuum filter dewatering 50 gal/h (190 L/h) of clarifier underflow. The investment had an excellent return, with payback after only 1.5 yr.

Table 9.

Economic Evaluation of Precoat Rotary Vacuum Filter Sludge Disposal Alternative

Item	Cost
Installation of modifications ($):[a]	
Equipment:	
Filter	45,000
Auxiliary equipment	11,500
Total equipment cost	56,500
Installation	4,500
Total cost including installation	61,000
Contingency, 20% of total including installation	12,200
Total installed cost	73,200
Annual costs ($/yr):[b]	
Fixed costs:	
Depreciation on equipment	7,300
Taxes and insurance	1,600
Cost of capital	NA
Total fixed costs	8,900
Operating cost:	
Equipment:[c]	
Power at $0.05/kWh (10 hp at 0.75 kWh/hp)	500
Precoat chemicals at $0.10/lb	700
Operating labor, at $10/h (0.5 h/8 h operation)	700
Maintenance	1,000
Total equipment operating cost	2,900
Sludge disposal fee, at 25% solids and $0.43/gal	12,380
Total annual operating cost	15,280
Total annual cost including fixed cost	24,180
Investment justification:	
Current disposal cost at 3% solids ($/yr)	103,000
Reduction from current cost ($/yr)	78,820
Average return on investment (%)[d]	59
Investment payback (yr)[e]	1.5

[a]Elevated installation of precoat rotary vacuum filter with 19-ft² filter area.

[b]Based on 1,050 h/yr of filter operation.

[c]4,800 h/yr and 22% operating factor.

[d]($78,820 × 0.55)/$73,200 (0.55 based on a 45% tax rate).

[e]$73,200/[($78,820 × 0.55) + 7,300].

Note.—1981 dollars. Dewatering 50 gal/h from 3% to 20% solids by weight. NA = not applicable.

Table 10.

Sludge Disposal Under Four Dewatering Alternatives: Analysis of Annual Costs

Item	Present conditions	With installed modifications			
		Filter press[a]	Precoat rotary vacuum filter[b]	Basket centrifuge[c]	Pressure belt filter[d]
Disposal solids concentration (% by weight)	3	25	25	20	20
Cost of modifications ($)	—	29,900	73,200	34,000	104,400
Annual cost of modifications ($).					
Fixed	—	3,100	8,900	4,000	12,500
Operating	—	7,600	2,900	16,400[e]	2,500
Annual sludge disposal cost ($)	103,000	12,300	12,300	16,600	16,000
Total annual cost ($)	103,000	23,000	24,100	37,000	31,000
Annual savings ($)	—	80,000	78,900	60,200	68,200
Average return on investment (%)[f]	—	147	59	97	36
Investment payback (yr)[g]	—	0 6	1.5	0 9	2 2

[a]5-ft^3 filter capacity, 4-h cycle time

[b]19-ft^2 filter area

[c]Batch solid bowl centrifuge with 2-gal basket

[d]1-ft-wide belt

[e]Does not include cost of polymer treatment, which may be required.

[f](Annual savings X 0 55)/total investment (0 55 based on a 45% tax rate).

[g]Total investment/[(annual savings X 0.55) + depreciation].

Note —1981 dollars 50 gal/h clarifier underflow.

Comparing the vacuum filter with the other equipment types (Table 10), however, shows that equipment payback ranges from 0.6 yr for a filter press to 2.2 yr for a belt filter press. The filter press proves the best choice, mainly because of the low investment and manpower requirements. The 5-ft^3 (0.14-m^3) cake volume of the press would only need dumping every 6 h. A larger press could be selected to reduce labor, but the investment would be greater. Of course, if pilot testing indicated a sludge with poor filtration properties, either the properties would have to be modified or different equipment would have to be selected.

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