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Guides to Pollution Prevention

The Metal Finishing Industry

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GUIDES TO POLLUTION PREVENTION
The Metal Finishing Industry

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NOTICE

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This document is intended as advisory guidance only to the metal finishing industry in developing approaches for pollution prevention. Compliance with environmental and occupational safety and health laws is the responsibility of each individual business and is not the focus of this document.

Worksheets are provided for conducting waste minimization assessments of metal finishing facilities. Users are encouraged to duplicate portions of this publication as needed to implement a waste minimization program.

FOREWORD

This guide provides an overview of the major metal finishing processes and operations that generate waste and presents options for minimizing waste generation through source reduction and recycling. A wide variety of processes are used in the metal finishing industry, including physical, chemical, and electrochemical processes. Metal finishing processes generate various waste streams, including contaminated plating baths, spent process baths, cleaners, rinse water, miscellaneous solid waste, solvents, and air emissions.

Reducing the generation of this waste at the source or recycling the wastes on or off site will benefit the metal finishing industry by reducing raw material use, reducing disposal costs, and lowering the liabilities associated with waste disposal.

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SECTION 1 INTRODUCTION

The purpose of this guide is to help the metal finishing industry identify, assess, and implement waste minimization options. It is envisioned that the guide will be used by metal finishing companies, particularly plant operators and environmental engineers, as well as regulatory agency representatives, industry suppliers, and consultants. To provide the industry with the information and guidance necessary to implement an effective waste minimization program, this manual contains

- A profile of the metal finishing industry and the processes used in it (Section 2)
- Well-established and practical waste minimization options for the industry (Section 3)
- Waste minimization assessment guidelines and worksheets (Section 4)
- Appendices containing case studies of waste generation/waste minimization practices in the industry and sources of information and help.

The worksheets and the list of waste minimization options were developed from assessments of San Francisco Bay Area firms in California commissioned by the California Department of Health Services (DHS 1988). Operations, manufacturing processes, and waste generation and management practices were surveyed, and existing and potential waste minimization options were characterized.

Overview of Waste Minimization

Waste minimization is a policy specifically mandated by the U.S. Congress in the 1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act (RCRA). As the federal agency responsible for writing regulations under RCRA, the U.S. Environmental Protection Agency (EPA) has an interest in ensuring that new methods and approaches are developed for minimizing hazardous waste, and that such information is made available to the industries concerned. This guide is one of the approaches EPA is using to provide industry-specific

information about waste minimization. The options and procedures outlined can also be used in efforts to minimize other wastes generated in a business.

In the working definition used by EPA, waste minimization consists of source reduction and recycling. Of the two approaches, source reduction is usually considered to be the preferable method from an environmental perspective. A few states consider waste treatment to be a third approach to waste minimization, but EPA does not, and therefore waste treatment is not addressed in this guide.

Waste Minimization Opportunity Assessment

A Waste Minimization Opportunity Assessment (WMOA), sometimes called a waste minimization audit, is a systematic procedure for identifying ways to reduce or eliminate waste. Briefly, the assessment consists of a careful review of a plant's operations and waste streams and the selection of specific areas to assess. After a particular waste stream or area is established as the WMOA focus, a number of options with the potential to minimize waste are developed and screened. The technical and economic feasibility of the selected options are then evaluated. Finally, the most promising options are selected for implementation.

In 1992, EPA published the *Facility Pollution Prevention Guide* (USEPA 1992) as a successor to the *Waste Minimization Opportunity Assessment Manual*. While the *Waste Minimization Opportunity Assessment Manual* concentrated primarily on the waste types covered in the Resource Conservation and Recovery Act (RCRA), the *Facility Pollution Prevention Guide* deals with "multimedia" pollution prevention. It is intended to help small- to medium-sized production facilities develop broad-based, multimedia pollution prevention programs. Methods of evaluating, adjusting, and maintaining the program are described. Later chapters deal with cost analysis for pollution prevention projects and with the roles of product design and energy conservation in pollution prevention. Appendices consist of materials that will support the pollution

prevention effort: assessment worksheets, sources of additional information, examples of evaluative methods, and a glossary.

Detailed information on conducting a WMOA is provided in a waste minimization manual developed by EPA. Entitled the *Waste Minimization Opportunity Assessment Manual* (USEPA 1988), the document provides instructions for conducting waste minimization assessments and developing options for reducing hazardous wastes. It describes the management strategies needed to incorporate waste minimization into company policies and structure and methods for establishing an ongoing company-wide waste minimization program, conducting assessments, and implementing options.

The four phases of a WMOA are planning and organization, assessment, feasibility analysis, and implementation. The steps involved in conducting a waste minimization assessment are outlined in Figure 1 and presented in more detail in this section of the guide. The subsequent sections of this guide provide waste minimization approaches beneficial to the metal finishing industry and information for their evaluation and implementation.

PLANNING AND ORGANIZATION PHASE

Essential elements of planning and organization for a waste minimization program are getting management commitment for the program, setting waste minimization goals, and organizing an assessment program task force.

ASSESSMENT PHASE

The assessment phase involves a number of steps:

- Collect process and facility data
- Prioritize and select assessment targets
- Select assessment team
- Review data and inspect site
- Generate options
- Screen and select options for feasibility study.

Collect Process and Facility Data

The waste streams at a facility should be identified and characterized. Information about waste streams may be available on hazardous waste manifests, National Pollutant Discharge Elimination System (NPDES) reports, toxic release inventory reports, routine sampling programs, and other sources.

Developing a basic understanding of the processes that generate waste at a facility is essential to the WMOA process. Flow diagrams should be prepared to identify the quantity, types, and rates of waste generating processes. Also, preparing material balances for the different processes can be useful in tracking various process components and identifying losses or emissions that may have been unaccounted for previously.

Prioritize and Select Assessment Targets

Ideally, all waste streams in a facility should be evaluated for potential waste minimization opportunities. With limited resources, however, a plant manager may need to concentrate waste minimization efforts in a specific area. Such considerations as quantity of waste, hazardous properties of the waste, regulations, safety of employees, economics, and other characteristics need to be evaluated in selecting target streams or operations.

Select Assessment Team

The team should include people with direct responsibility for and knowledge of the particular waste stream or area of the facility being assessed. Equipment operators and people involved in routine waste management should not be ignored.

Review Data and Inspect Site

The assessment team evaluates process data in advance of the inspection. The inspection should follow the target process from the point where raw materials enter to the point where products and wastes leave. The team should identify the suspected sources of waste. This may include the production process; maintenance operations; and storage areas for raw materials, finished products, and work in progress. The inspection may result in the formation of preliminary conclusions about waste minimization

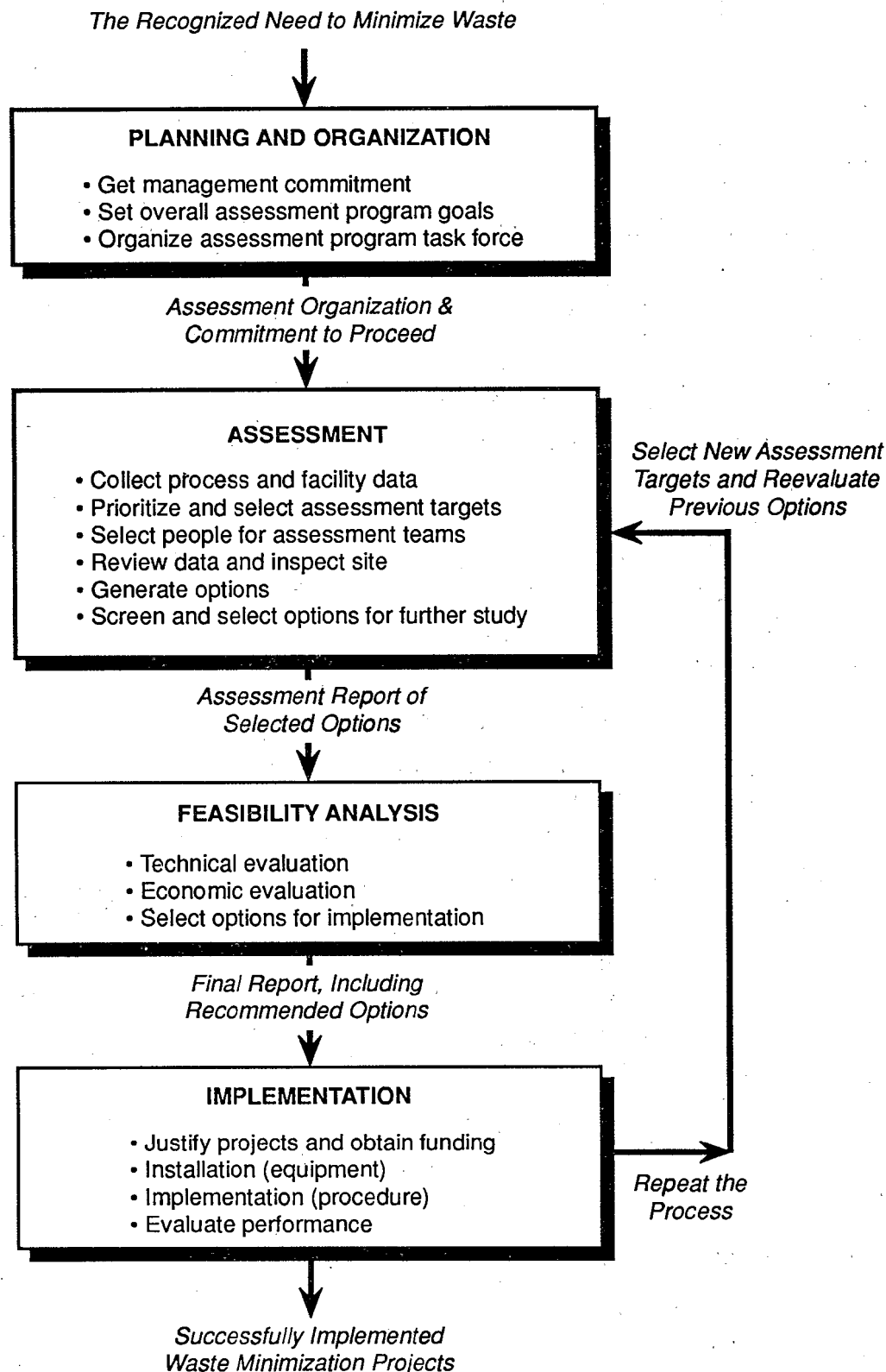


Figure 1. The Waste Minimization Assessment Procedure

opportunities. Full confirmation of these conclusions may require additional data collection, analysis, and/or site visits.

Generate Options

The objective of this step is to generate a comprehensive set of waste minimization options for further consideration. Since technical and economic concerns will be considered in the later feasibility step, no options are ruled out at this time. Information from the site inspection, as well as trade associations, government agencies, technical and trade reports, equipment vendors, consultants, and plant engineers and operators may serve as sources of ideas for waste minimization options.

Both source reduction and recycling options should be considered. Source reduction may be accomplished through good operating practices, technology changes, input material changes, and product changes. Recycling includes use and reuse of water, solvents, and other recyclable materials, where appropriate.

Screen and Select Options for Further Study

This screening process is intended to select the most promising options for a full technical and economic feasibility study. Through either an informal review or a quantitative decision-making process, options that appear marginal, impractical, or inferior are eliminated from consideration.

FEASIBILITY ANALYSIS PHASE

An option must be shown to be technically and economically feasible in order to merit serious consideration for adoption at a facility. A technical evaluation determines whether a proposed option will work in a specific application. Both process and equipment changes need to be assessed for their overall effects on waste quantity and product quality.

An economic evaluation is carried out using standard measures of profitability, such as payback period,

return on investment, and net present value. As in any project, the cost elements of a waste minimization project can be broken down into capital costs and operating costs. Savings and changes in revenue and waste disposal costs also need to be considered, as do present and future cost avoidances. In cases of increasingly stringent government requirements, actions that increase the cost of production may be necessary.

IMPLEMENTATION PHASE

An option that passes both technical and economic feasibility reviews should be implemented. The project can be turned over to the appropriate group for execution while the WMOA team, with management support, continues the process of tracking wastes and identifying other opportunities for waste minimization. Periodic reassessments may be conducted to see if the anticipated waste reductions were achieved. Data can be tracked and reported for each implemented idea in terms such as pounds of waste per production unit. Either initial investigations of waste minimization opportunities or the reassessments can be conducted using the worksheets in this manual.

References

- DHS. 1988. *Waste Audit Study: Metal Finishing Industry*. Prepared by PRC Environmental Management, Inc. for Alternative Technology Section, Toxic Substances Control Division, California Department of Health Services.
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SECTION 2

METAL FINISHING INDUSTRY PROFILE

Industry Description

The metal finishing industry uses a wide variety of materials and processes to clean, etch, and plate metallic and nonmetallic surfaces to provide desired surface properties. The materials include solvents and surfactants for cleaning, acids and bases for etching, and solutions of metal salts and other compounds to plate a finish onto a substrate. Physical, chemical, and electrochemical processes are all used to finish metal workpieces. The processes may simply polish the surface to provide a bright appearance or apply another metal to change the surface properties or appearance.

Process Description

Physical processes used in the metal finishing industry—such as buffing, abrasive blasting, grinding, tumbling, and polishing—do not generate as much waste as chemical and electrochemical processes. Physical processes involve the use of a solid material (or abrasive) to change the surface characteristics of a

workpiece, and the waste generated contains the abrasive and the material removed from the surface. The use of sand for paint stripping operations is an example of a physical finishing process.

The industry also uses chemical processes (degreasing, cleaning, pickling, etching, coating, and electroless plating) and electrochemical processes (plating, electrocleaning, electropolishing, and anodizing). These operations are typically performed in baths (tanks) and are then followed by a rinsing cycle. Figure 2 illustrates a typical chemical or electrochemical process step in which the workpiece enters the process bath containing process chemicals that are carried to the rinse water (drag-out). When the workpiece is transferred from the bath to the rinse, process solution will fall to the floor unless it is captured and returned to the process bath. In such cases, waste can be minimized by containing the process solution and returning it to the bath, which reduces the rinse flow and extends the life of the bath.

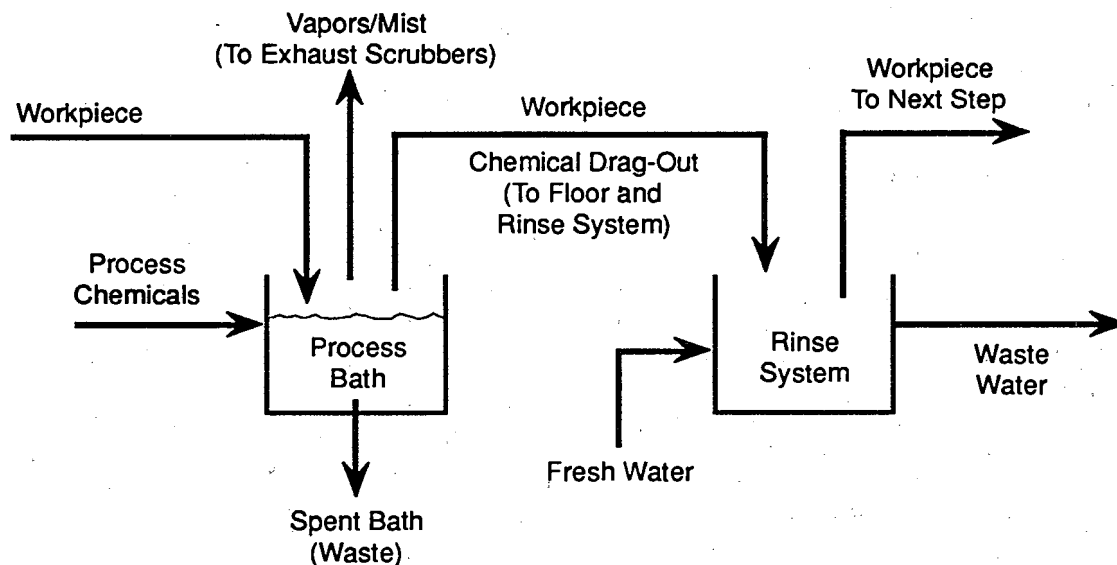


Figure 2. Typical Metal Finishing Process Step

Waste Description

Wastewater, solid waste, and air emissions are generated by the metal finishing process. Wastewater includes:

- Industrial wastewater—rinse water, cooling water, steam condensate, boiler blowdown, wash water, and exhaust scrubber solution
- Spent plating baths—contaminated or spent electroplating or electroless plating baths
- Spent process baths—etchants and cleaners that are contaminated or spent
- Strip and pickle baths—nitric, sulfuric, hydrochloric, and hydrofluoric acids used to strip metals from workpiece racks or parts
- Exhaust/scrubber solutions—solutions collected in exhaust and air emission control devices.

Solid waste includes:

- Industrial wastewater treatment sludge—sludge containing metals such as cadmium, copper, chromium, nickel, tin, and zinc
- Miscellaneous solid wastes—absorbants, filters, empty containers, aisle grates, and abrasive blasting residues
- Solvents—contaminated solvents used for degreasing.

Air emissions include vapors from degreasing and solvent cleaning and mists from chromium plating operations.

The primary source of waste in the metal finishing industry occurs in the rinsing operation. Generally, rinse water waste contains low concentrations of process chemicals carried with the workpiece into the rinse (drag-out). Typical rinse water treatment produces a metal hydroxide sludge that can be a hazardous waste. Characterizing the drag-out carried into the rinse water from the process bath requires the chemical concentration and volume to be determined. The chemical concentration of the drag-out is the

same as the chemical concentration of the process bath; drag-out volume can be determined by measuring the chemical concentration of a static rinse tank before and after a loaded workpiece rack is rinsed. The equation for calculating drag-out is as follows:

$$V_d = \frac{(C_r)(V_r)}{C_p}$$

where V_d = volume of drag-out loss
 V_r = volume of water in the rinse tank
 C_p = concentration of chemicals in the process bath
 C_r = concentration of chemicals in the rinse water.

After use, spent baths may be containerized for treatment and disposal or recycled. To determine the potential for modifying the bath's operating parameters or recycling or reusing the bath, its chemical and physical characteristics must first be quantified. The characteristics establish the potential for the baths reuse or value to a recycler.

Additional potential waste hazards in the metal finishing industry include vapors and mists emitted from process baths, spills, and samples. Vapors and mists are usually controlled by exhaust systems that must be equipped with mist collection and scrubbing systems to meet air emission regulations. Spills, if they are common, can contribute significantly to the volume of waste. Documenting their occurrence will provide valuable historical information for identifying maintenance or operational changes necessary to reduce their frequency. Samples of plating solutions provided by vendors that are not intended for use also contribute to the waste generated by the metal finishing industry. These samples often accumulate without concern for violating any waste storage time requirements. However, these samples must eventually be returned or disposed of. Outdated chemicals are additional examples of waste not typically attributed directly to the production process. Additional processing waste includes the filter elements from filtration units, empty process solution containers, abrasive blasting residues, and waste from housekeeping activities. Table 1 is a summary of the waste generated by the metal finishing industry.

Table 1. Summary Table of Metal Finishing Industry Waste

Waste	Potential Hazards	Waste Stream	Process
Alkali (hydroxide)	Corrosivity	Wastewater	Cleaning, etching
Acid (nitric, sulfuric, hydrochloric, hydrofluoric)	Corrosivity	Wastewater	Cleaning, pickling, etching, bright dipping
Surfactants	Aquatic toxicity	Wastewater	Cleaning
Oil and Grease	Aquatic toxicity	Wastewater, spent solvent	Cleaning
Cadmium, Zinc, Nickel, Copper, Other Metals	Toxicity	Plating bath, drag-out, rinse water, spent filters, sludge	Plating
Perchloroethylene, Trichloroethylene, Other Solvents	Inhalation, dermal	Spent solvent (liquid or sludge), air emissions	Cleaning
Cyanide	Toxicity	Plating bath, drag-out, rinse water, other wastewater	Plating, tumbling, stripping, heat treating, desmutting
Chromates	Toxicity	Plating bath, drag-out, rinse water, sludge, other wastewater, mist	Plating, chromating, etching
Water	—	Rinse water, drag-out, process bath, air emission (evaporation), cooling water, boiler blowdown	Various

SECTION 3

WASTE MINIMIZATION OPTIONS FOR METAL FINISHING FACILITIES

Introduction

The three key elements in any waste reduction program are management initiative, commitment, and involvement. These prerequisites include activities such as:

- Employee awareness and participation
- Improved operating procedures
- Employee training
- Improved scheduling of processes.

Employee training, awareness, and participation are critically important and potentially problematic aspects of metal finishing waste minimization programs. Employees are often resistant to broadening their roles beyond the traditional concepts of quantity and quality of products produced. Total commitment and support of both management and employees are needed for any waste minimization program to succeed. This includes the evaluation, development, implementation, and maintenance of a system to minimize waste.

Companies should continually educate themselves to keep abreast of improved, waste-reducing, pollution-preventing technology. Information sources to help inform companies about such technology include trade associations and journals, chemical and equipment suppliers, equipment expositions, conferences, and industry newsletters. By implementing better technology, companies can often take advantage of the dual benefits of reduced waste generation and a more cost efficient operation.

The specific approaches recommended for waste minimization for metal finishing facilities include source reduction and recycling/resource recovery. Source reduction technologies are designed to reduce the volume of waste initially generated. In recycling and resource recovery, waste is used as a raw material for the same or another process or valuable materials

are recovered from a waste stream before the waste is disposed of. This section provides detailed information on the two approaches for waste minimization in the metal finishing industry.

Source Reduction

Source reduction approaches decrease the amount of generated waste, and they are usually the least expensive method of minimizing waste. Many source reduction options require only simple housekeeping changes or minor in-plant process modifications. Source reduction opportunities for process baths and rinse systems are described below. In addition, improved housekeeping methods for achieving source reduction are discussed.

PROCESS BATHS

Source reduction for the metal finishing industry at the process bath level can be achieved by material substitution, extending bath life, and drag-out reduction.

Material Substitution

Pollution control regulations have provided the incentive for using less toxic process chemicals, and chemical manufacturers are gradually introducing such substitutes. Eliminating process materials, such as hexavalent chromium and cyanide-bearing cleaners and deoxidizers, eliminates the need to detoxify these wastes. It is particularly desirable to eliminate processes employing hexavalent chromium and cyanide, since special equipment is needed to detoxify both.

Because there can be disadvantages in substituting one process chemical for another, the following questions should be asked:

- Are substitutes available and practical?
- Will substitution solve one problem but create another?

- Will tighter chemical controls be required of the bath?
- Will product quality or production rate be affected?
- Will the change involve any cost increases or decreases?

Most opportunities to reduce waste by substituting materials require modifying the chemistry of process baths or replacing the chemicals used for a particular process. Since process bath chemistries vary widely from plant to plant, these options can only be described in general terms.

Purified Water. Deionized, distilled, or reverse osmosis water can be used instead of tap water for process bath makeup and rinsing. Natural contaminants, such as calcium, iron, magnesium, manganese, chlorine, carbonates, and phosphates (found in tap water) reduce rinse water efficiency, interfere with drag-out recovery, and increase the frequency of process bath dumping (USEPA 1982b). These contaminants also contribute to sludge volume when they are removed from wastewater during treatment.

Hexavalent Chromium Alternatives. Trivalent chromium plating solutions can be used for decorative chromium plating to replace hexavalent chromium. In so doing, drag-out is decreased because trivalent chromium plating baths operate with a lower viscosity and lower concentration than do hexavalent baths. The use of trivalent chromium also eliminates an extra treatment step necessary to reduce the chromium from the hexavalent to trivalent state before precipitation. In addition, using trivalent chromium eliminates the problems associated with hexavalent chromium bath misting as well as hexavalent chromium fugitive emissions in air scrubbers. However, trivalent chromium is not presently available for hard chromium plating (AESF 1991). Other chromium alternatives include sulfuric acid and hydrogen peroxide (for chromic acid pickles, deoxidizers, and bright dips) and benzotriazole (0.1 to 1.0 percent solution in methanol) or water-based proprietaries (for chromium based anti-tarnish). The latter two alternatives are extremely reactive and require ventilation.

Nonchelated Process Chemicals. Chelators are used in chemical process baths to control the concentration of free metal ions in the solution. They are usually found in baths used for metal etching, cleaning, and electroless plating. When chelating compounds enter the waste stream, they inhibit the precipitation of metals so that additional treatment chemicals must be used, and these treatment chemicals may end up in the sludge and contribute to the volume of hazardous waste. For example, when ferrous sulfate, a popular precipitant, is used to precipitate metals from chelated complexes, the precipitant adds significantly to sludge volume. For some applications, the ferrous sulfate is added in large amounts, at an 8-to-1 ratio to the contaminant metals (Couture 1984). If spent process baths containing chelators cannot be treated on site, they must be containerized for off-site treatment or disposal, which increases waste disposal costs.

Several chelators are used in metal finishing industry processes. In general, mild chelators such as phosphates and silicates are used for cleaning and etching processes, whereas electroless plating baths are typically chelated with stronger chelating compounds (citric acid, maleic acid, and oxalic acid). Ethylenediaminetetraacetic acid (EDTA) is also used but with less frequency than the others (Kraus 1988). It should be noted, however, that while chelators help extend bath life, chelated process chemicals in wastewater must be removed to required discharge levels. Often, the pH of waste streams must be adjusted to break down the metal complexes that chelators form. EDTA, for example, requires lowering the pH below 3.0 to break the complex and allow subsequent metal precipitation at high pH (Foggia 1987).

Nonchelated process chemistries can be used for some processes (e.g., alkaline cleaning and etching) in which it may not be necessary to keep the metals removed from workpiece surfaces in solution. In these cases, the metals can be allowed to precipitate, and the process bath can be filtered to remove the solids. Note, however, that for electroless plating, it is less feasible to use nonchelated chemistries because the chelators play a significant role in the chemical processes that allow the plating bath to function (Kraus 1988).

Nonchelated process cleaning baths usually require continuous filtration to remove the solids that form. These systems generally have a 1- to 5-micron filter with a pump that can filter the tank's contents once or twice each hour (Foggia 1987). The cost of a filter system ranges from approximately \$400 to \$1,000 for each tank, and in addition to purchase and setup costs, costs will be incurred for filter element replacement, disposal, and maintenance.

Savings, however, will be realized in reduced waste treatment and sludge handling costs and reduced disposal costs for spent baths. Another important advantage of nonchelated process chemicals is that the metal-removal procedure during wastewater treatment is usually improved. Therefore, the treated effluent is more likely to meet discharge requirements.

Noncyanide Process Chemicals. An alkaline chlorination process requiring sodium hypochlorite or chlorine is typically used to treat waste streams containing free cyanide. If complex cyanides are to be treated, ferrous sulfate precipitation is commonly used. These chemicals contribute to sludge volume. Therefore, using noncyanide process chemistries may reduce hazardous waste sludge by eliminating a treatment step. However, many noncyanide processes are difficult to treat and produce more sludge than cyanide baths. The following paragraphs provide examples and include advantages and disadvantages of each. The user should weigh the advantages and disadvantages for specific applications.

The waste water treatment savings will depend on the cyanide treatment method and the volume of waste. Cyanide is typically oxidized with sodium or calcium hypochlorite. These chemicals cost approximately \$1.50 per gallon of solution for sodium hypochlorite and approximately \$1.85 per pound for calcium hypochlorite powder. Assuming that a facility treats 500 gallons of dilute cyanide waste (100 mg/l) each day, treatment costs could be approximately \$15 to \$20 per day or \$300 to \$400 per month (not including subsequent metal precipitation and sludge disposal).

The use of noncyanide plating baths could eliminate or reduce this cost. For a 2 gal/min rinse water flow, using noncyanide baths means a savings of about \$12,000 in equipment costs and \$3.00/lb in cyanide

treatment chemical costs. (In this case, treatment chemicals cost about four times as much as raw sodium cyanide cleaner.)

Alternatives to cyanide cleaners include trisodium-phosphate or ammonia; both provide good degreasing when used hot in an ultrasonic bath. However, they are highly basic and may complex with soluble metals if used as an intermediate rinse between plating baths where metal ions may be dragged into the cleaner.

Alternatives to cyanide plating bath chemistries are also available. Acid tin chloride, for example, works faster and better than tin cyanide. In contrast to a heavy copper cyanide plating bath, copper sulfate baths are highly conductive and have a simple chemistry. Sulfate baths are economical to prepare, operate, and treat. Previous sulfate bath problems have been overcome with new formulations and additives (*Metal Finishing*, 1989). The copper cyanide strike may still be needed for steel, zinc, or tin-lead base metals. One disadvantage of alternatives to cyanide plating bath chemistries is that noncyanide chemistries often cost more than conventional cyanide baths.

Alkaline Cleaners. A variety of chlorinated and nonchlorinated solvents are used to degrease workpieces before they are processed. These solvents can be either recycled on site or transported off site for recycling or disposal. On-site recycling generates a solvent sludge that is disposed of off site. However, using hot alkaline cleaning baths instead of solvents permits the baths to be treated on site and discharged to certain publicly owned treatment works (AESF 1991), and less sludge is generated than by solvent degreasing. The effectiveness of alkaline cleaners can be enhanced by applying an electrocurrent, a periodic reverse current, or ultrasonics. The benefits of avoiding solvent vapors and sludges often outweigh any additional operating costs.

A 150-gallon tank to hold the alkaline cleaning solution will cost approximately \$400; tank installation, a heating system, ventilation, and an oil separation system would increase the cost to an estimated \$6,000. The cost of chemicals depends on the type of cleaners used and the frequency of replacement. Typically, alkaline cleaners cost less than degreasing solvents. A standard degreasing solvent costs between \$6 and \$13 per gallon, or \$300 to \$700 to fill a

50-gallon degreasing tank, whereas, a 150-gallon alkaline cleaning bath (using sodium hydroxide) costs \$150 to \$200. However, the life of an alkaline cleaning bath typically is shorter than that of a solvent degreasing solution: a 50-gallon tank of solvent degreaser can last up to 6 months, whereas a 150-gallon replacement of alkaline cleaner usually lasts 3 months under similar operating conditions or longer than 3 months with bath maintenance and filtration.

Disposing of a 55-gallon drum of spent solvent can cost from \$300 to \$1,200, depending on the type of solvent and number of drums. Therefore, if a facility can treat 300 gallons of spent alkaline solution on site using pH adjustment and metal removal (150-gallon bath replaced every 3 months) and dispose of the resultant sludge for less than the cost of solvent disposal, it would be economically feasible to replace a degreasing solvent with an alkaline cleaner.

Alternative Cleaners. Biodegradable cleaners may be acceptable for discharge to public sewers. However, the oxygen demand created by the cleaners during treatment and disposal of the bath may slightly increase sewer fees. Nonphosphate cleaners may help reduce waste by eliminating the generation of phosphate sludges during wastewater treatment. These and other alternative cleaners should be tested to determine their effectiveness.

Bath Life Extension

When baths become spent, they are either taken off line and treated on site or are placed in containers for off-site disposal. Waste volume and bath replacement costs can be decreased through filtration, replenishment, electrolytic dummyming (i.e., using a low current to plate out contaminants), precipitation, monitoring, housekeeping, drag-in reduction, purer anodes and bags, and ventilation/exhaust systems. These methods of extending bath life are described below.

Filtration. Filtration systems remove accumulated solids that reduce the effectiveness of the process bath operations. Continuous filtration of the bath removes these contaminants, thereby extending the life of the bath. Many acidic electroplating baths (e.g., acid copper sulfate, acid zinc, nickel sulfonate, nickel chloride) are already filtered for reasons of quality. For other

electroplating baths, filtration may not extend bath life significantly. Note that replacing the filter media generates a solid waste that adds to the operating costs; these costs need to be considered before installing a filter. However, some filters use a cleanable and reusable filter media, which may help alleviate expense and waste from disposal of the filter element.

Replenishment. The effectiveness of a cleaning bath decreases with use. Instead of disposing of the entire bath, part can be retained and replenished with fresh chemicals and water. Over time, the concentration of contaminants in the bath increases, and eventually it becomes more expensive to add chemicals than to replace the entire bath with a new solution. At this point the bath should be disposed of.

Replenishing reduces drag-out in the early life of the bath, but ultimately increases the concentrations of chemicals in spent solutions when the bath must be replaced. Although this approach does not ultimately reduce drag-out, it is still justifiable on the basis of quality control and waste reduction.

There are various automated bath monitoring and replenishing systems now available to help extend bath life. Operators can use data generated by bath monitoring systems to manually adjust and maintain process bath characteristics, such as pH, chemical concentration, and metal content, within specifications, to improve product quality and to extend bath life. Both replenishing and adjusting can also be done using automated systems.

Electrolytic Dummyming. Metal contaminants (such as copper) introduced into plating baths with workpieces degrade the effectiveness of the plating process. In zinc and nickel baths, copper can be removed by a process called "dummyming." The process is based on the electrolytic principle that copper can be plated at a low electrical current. When the copper content becomes too high, an electrolytic panel is placed in the process bath. A "trickle current" is run through the system, usually at a density of 1 to 2 amperes per square foot. At this current, the copper in the bath solution plates out on the panel, but the plating bath additives (such as brighteners) are unaffected. While some of the plating metals (zinc, nickel) are inadvertently removed, the savings realized by extending bath life justifies the slight metal loss.

Precipitation. Metals such as lead and cadmium enter the bath as impurities in anodes and can be removed from certain plating baths by precipitation. For a zinc cyanide bath, zinc sulfide can be added to precipitate lead and cadmium, and the precipitant can then be removed by filtration. As with all chemical reactions, care must be taken to ensure that precipitating reagents are compatible with bath constituents. In addition, iron and chromium contamination is common in acidic nickel baths. In most solution formulations, these metals can be removed with peroxide combined with pH elevation and batch filtration.

Monitoring. The key to determining the need for added chemicals or removal of contaminants, and hence extending the life of process bath, is the continuous analysis of bath parameters, e.g., pH and metal content. In addition, a thorough understanding of the effect of contaminants on the production process is a critical part of reducing waste as well as the number of rejected parts that must be stripped and replated. Monitoring must be treated as an ongoing process, not an event.

Housekeeping. Preventing foreign material from entering or remaining in a bath prolongs its life. When a part falls off the rack into a bath, it should be removed to reduce contamination of the bath. The racks should also be kept clean and free of contaminating material. Other waste minimization measures include protecting anode bars from corrosion, using corrosion-resistant tanks and equipment, and filtering incoming air to reduce airborne contaminants.

Drag-In Reduction. Liquids clinging to workpieces from preceding baths can shorten useful life and reduce effectiveness of subsequent baths. Rinsing helps prevent cross-contamination between baths by rinsing the drag-out from one process bath before the item is processed in another.

Purer Anodes and Bags. Impurities contained in anodes will contaminate a process bath. Pure anodes do not contribute to bath contamination, but may cost more than other, less-pure anodes. Cloth bags around anodes prevent insoluble impurities from entering a bath. However, the bags need to be maintained and must be compatible with the process solution.

Ventilation/Exhaust Systems. Scrubbers, demisters, and condensate traps remove entrained droplets and vapors from the air passing through ventilation and exhaust systems. If segregated, some wastes from scrubbers can be returned to process baths after filtering. Updraft ventilation allows mist to be collected in the ductwork and flow back to the process tank. For example, hard chromium plating baths would benefit from an updraft ventilation system.

Process baths that generate mist (e.g., hexavalent chromium plating baths, air-agitated nickel/copper baths, etc.) should be in tanks with more freeboard to reduce the amount of mist reaching the ventilation system. That is, the added space at the top of the tank allows the mist to return to the bath before it is entrained with the air entering the exhaust system. Foam blankets or floating polypropylene balls can also be used in hard or decorative chromium baths to keep mists from reaching the exhaust system.

Drag-out Reduction

Several factors contribute to drag-out, including workpiece size and shape, viscosity and chemical concentration, surface tension, and temperature of the process solution (USEPA 1982a). By reducing the volume of drag-out that enters the rinse water system, valuable process chemicals can be prevented from reaching the rinse water, thereby reducing sludge generation. The techniques available to reduce process chemical drag-out include:

- Minimizing bath chemical concentrations by maintaining chemistry at the lower end of operating range
- Maximizing bath operating temperature to lower the solution viscosity
- Using wetting agents in the process bath to reduce the surface tension of the solution
- Maintaining racking orientations to achieve the best draining
- Withdrawing workpieces at slower rates and allowing sufficient solution draining before rinsing

- Using air knives above process tanks
- Using a spray or fog rinse above process tanks
- Avoiding plating bath contamination
- Using drain boards between process and rinse tanks to route drippage back to process tanks
- Using drag-out tanks to recover chemicals for reuse in process baths.

A few of these drag-out reduction techniques require little if any capital investment; however, they do require training. For example, removing workpiece racks at a slower rate or allowing the rack to drain over the process tank for a longer time requires a conscientious operator. These procedures should not significantly affect production and should result in reducing process chemical purchases, water and sewer use fees, treatment chemical purchases, and sludge handling costs.

Other drag-out reduction techniques require some capital expenditure. Drip bars can be installed above hand-operated process tanks to allow drag-out from workpiece racks to drain back into the process tank. If PVC piping is used and installation is performed by plant personnel, this option should cost no more than a few hundred dollars for five to eight tanks.

Process Bath Operating Concentration. Drag-out can be reduced by keeping the chemical concentration of the process bath at the lowest acceptable operating level. Generally, the greater the concentration of chemicals in a solution, the greater the viscosity (USEPA 1982a). As a result, the film that adheres to the workpiece as it is removed from the process bath is thicker and will not drain back into the process bath as quickly. This phenomenon increases the volume as well as the chemical concentration of the drag-out solution.

Chemical product manufacturers may recommend an operating concentration that is higher than necessary. Metal finishers should therefore determine the lowest process bath concentration that will provide adequate product quality. This can be accomplished by mixing a new process bath at a slightly lower

concentration than is normally used. As the process bath is replenished, the chemical concentration can continue to be reduced until product quality begins to be affected. At this point, the process bath that provides adequate product quality at the lowest possible chemical concentration is identified. Alternatively, the new bath can be mixed at a low concentration and the concentration can be gradually increased until the bath adequately cleans, etches, or plates the test workpieces. Fresh process baths can often be operated at lower concentrations than used baths. Makeup chemicals can be added to the used bath to gradually increase the concentration to maintain effective operation.

Process Bath Operating Temperature. Higher temperature baths reduce the viscosity of the process solution, which enables the chemical solution to drain from the workpiece faster, thereby reducing drag-out loss. However, very high temperatures should be avoided because brighteners break down in most plating solutions, and, in cyanide solutions, carbonate buildup increases. High temperatures may also cause the process solution to dry onto the workpiece as it is removed, increasing drag-out. Operating process baths at higher temperatures will also increase the evaporation rate from the process tank. To retain some of the advantages of higher temperature baths, water or process solution from a rinse tank can be added to replenish the process bath and to maintain the proper chemical equilibrium. Deionized water should be used to minimize natural contaminant buildup (such as calcium, iron, magnesium, carbonates and phosphates) in the process bath.

Wetting Agents. Adding wetting agents to a process bath reduces the surface tension of a solution and, as a result, can reduce drag-out loss by as much as 50 percent (USEPA 1982a). However, wetting agents can create foaming problems in process baths and may not be compatible with waste treatment systems. For these reasons, impacts at both the process bath and the treatment system should be evaluated before using wetting agents.

Workpiece Positioning. Drag-out loss can be reduced by properly positioning the workpiece on the rack. Workpieces should be oriented so that chemical solutions can drain freely and not get trapped in

grooves or cavities. Following are suggestions for orienting and positioning workpieces.

- Parts should be tilted so that drainage is consolidated. The part should be twisted or turned so that fluid will flow together and off the part by the quickest route.
- Avoid, where possible, positioning parts directly over one another.
- Tip parts to avoid table-like surfaces and pockets where solution will be trapped.
- Position parts so that only a small surface area comes in contact with the solution surface as it is removed from the process bath (USEPA 1982a).

Withdrawal and Drain Time. The faster an item is removed from the process bath, the thicker the film on the workpiece surface and the greater the drag-out volume. The effect is so significant that it is believed that most of the time allowed for draining a rack should instead be used for withdrawal only (USEPA 1982a). At plants that operate automatic hoist lines, personnel should adjust the hoist to remove the workpiece racks at the slowest possible rate. However, when workpieces are removed from a process bath manually, it is difficult to control the speed at which they are withdrawn. Nevertheless, supervisors and managers should emphasize to process line operators that workpieces should be withdrawn slowly.

The time allowed for draining can be inadequate if the operator is rushed to remove the workpiece rack from the process bath and place it in the rinse tank. However, a bar or rail above the process tank may help ensure adequate drain time prior to rinsing. If drip bars are used, employees can work on more than one process line or handle more than one rack during operation. The practice, termed "rotation plating," allows an operator to remove a rack from a plating bath and let it drain above the process tank while other racks are handled. Although increased drain time can have some negative effects due to drying, some baths (such as cleaners) are not affected. The operator can return after draining is completed to begin the rinsing stage.

Air Knives. Air knives can be used above process tanks to improve draining. As the workpiece rack is raised from the process tank, air is blown onto the surface of the workpieces to improve drag-out solution draining into the process bath. High humidity air can counteract workpiece drying.

Spray or Fog Rinses. Spray or fog rinse systems can be used above heated baths to recover drag-out solutions. If the spray rinse flow rate can be adjusted to equal the evaporation loss rate, the spray rinse solution can be used to replenish the process bath. Purified water should be used for the spray systems when possible to reduce the possibility of contamination entering the bath with the spray rinse water.

Plating Baths. Contaminated plating baths (for example, a cyanide plating bath contaminated with carbonate) increase drag-out by as much as 50 percent because of the increase in solution viscosity. Excess impurities also make application of recovery techniques difficult, if not impractical. Therefore, efforts should be made to reduce the level of impurities in the bath (e.g., by carbonate removal in cyanide baths).

Drain Boards. Drain boards capture process chemicals that drip from the workpiece rack as it is moved from the process bath to the rinse system. The board is mounted at an angle that allows the chemical solution to drain back into the process bath. Drain boards should cover the space between the process bath tank and the rinse tank. This prevents chemical solutions from dripping onto the floor. Removable drain boards are desirable because they permit access to plumbing and pumps between tanks.

Drag-out Tanks (dead or static rinse tanks). Process chemicals that adhere to the workpiece can be captured in drag-out tanks and returned to the process bath. Drag-out tanks are essentially rinse tanks that operate without a continuous flow of feed water. The workpiece is placed in the drag-out tank before the standard rinsing operation. Chemical concentrations in the drag-out tanks increase as workpieces are passed through. Since there is no feed water flow to agitate the rinse water, air agitation is often used to enhance rinsing. Eventually, the chemical concentration of the drag-out tank solution will increase to the point where it can be used to replenish the process

bath. Drag-out tanks are primarily used with process baths that operate at an elevated temperature. Adding the drag-out tank solution back to the process bath compensates for evaporative losses that occur due to high temperature.

Deionized water should be used for drag-out tanks so that natural contaminants in tap water do not build up in the process baths when drag-out solutions are used to replenish them. Contamination as a result of using the tank to rinse a workpiece from another process line must also be avoided. Further, adding drag-out solution to some process bath chemistries (for example, electroless copper baths) can adversely affect the bath (Stone 1987). Often, a pretreatment step is required to remove contaminants prior to adding the recovered drag-out solution back to the process bath.

Generally, a drag-out tank can reduce both rinse water use and chemical loss by 50 percent or more (USEPA 1982a). Assuming that a chemical bath loses approximately 2 gallons of drag-out each day, the total volume of drag-out loss each month would be 40 gallons, based on 20 work days per month. If the rinse system following the process bath operates at a flow rate of 5 gallons per minute, for a total of 4 hours each day, water usage would be 24,000 gallons per month based on 20 work days per month. The savings in operation expenses are for (1) raw materials/chemicals, (2) water and sewer fees, and (3) treatment chemicals and sludge disposal. Reducing drag-out and rinse water use by 50 percent would reduce chemical losses by 20 gallons per month and water usage by 12,000 gallons if rinse water reduction is proportional to drag-out reduction. If water and sewer fees are each \$0.50 per 100 cubic feet, 16 dollars per month could be saved. Sludge reduction and raw material/chemical reduction would increase savings significantly. The solution collected in the drag-out tank must be returned to the process bath when the concentration of the solution reaches the correct level. If it is returned at too low a concentration, it can dilute the operating bath. If the concentration of chemicals in the drag-out tank gets too high (approaching bath concentration), however, the drag-out rinse becomes ineffective.

Savings for chemicals depends on the type of process chemical and the amount of drag-out returned to the process tank. The cost for process bath chemicals could range from less than \$1 to over \$20. At the

low end, the savings for process chemicals would be \$20 per month, whereas, at the high end, the savings would be \$400 per month or higher.

A savings in the cost for treatment chemicals would also be realized by reducing rinse water effluent. If a company spends approximately \$1,500 each month on chemicals to treat 200,000 gallons of water, reducing wastewater by 12,000 gallons could reduce the use of treatment chemicals by \$90 each month. This assumes the company generates approximately 10,000 gallons of wastewater per day and uses standard pH adjustment, metal precipitation, and flocculation treatment reagents. Reducing the amount of sludge requiring disposal will add to the savings.

The cost of a drag-out tank depends on the size of the tank. Since these tanks are not used as flow-through tanks, they can be set up without any plumbing. Typically drag-out solutions are added back to the process bath manually, but automation, because it maintains the best concentration in the drag-out tank, is more efficient. Technologies available to recycle process chemicals from drag-out tanks and rinse water effluent are discussed under Recycling and Resource Recovery.

RINSE SYSTEMS

Most hazardous waste from a metal finishing plant comes from wastewater generated by the rinsing operations that follow cleaning, plating, and stripping operations. The savings associated with reducing rinse water use are primarily from reduced water, sewer, and sludge disposal fees. By increasing rinse efficiency, a process line can reduce wastewater flow by as much as 90 percent (Watson 1973, Gavaskar et al. 1992). Improved rinse efficiency should also reduce treatment chemical use and sludge generation. These are dependent on rinse water hardness and the sludge precipitation chemicals used in the wastewater treatment system.

If a company spends approximately \$400 each month for water and sewer fees, a modest reduction in rinse water usage of 10 percent can, theoretically, save the company \$40 each month. If a 2-year payback on investment is acceptable, the company could justify spending approximately \$1,000 to reduce its rinse water usage. This could be spent on rinse tank agitators and flow restrictors. If greater reductions are

achievable (perhaps 50 percent), a company could justify more advanced technologies such as meters, controlling rinse water flow or counter-current rinse systems. Reducing the volume of wastewater requiring treatment can also reduce sludge disposal costs and treatment chemical use, which will contribute to the payback on investment.

Drag-out is the most significant source of process chemical loss. Treating rinse water containing these process chemicals generates hazardous waste because of the resulting sludge. The volume of sludge generated is proportional to the level of contamination in the spent rinse water.

Figure 3 illustrates the relationship between metal concentration in rinse water and sludge volume. The graph shows the percentage of sludge generated per volume of water treated at various levels of heavy metal concentration. As shown in the graph, 1,000 gallons of wastewater with a heavy metal con-

centration of 100 mg/l will produce approximately 90 gallons of sludge. If the same volume of wastewater had a metal concentration of 500 mg/L (five times the first example), approximately 280 gallons of sludge would be generated, not even three times the first example. This information indicates that treating a more concentrated waste stream results in less sludge volume.

Reducing the volume of rinse water containing process chemicals will reduce the resultant sludge even if the total weight of the process chemicals remains constant. Two techniques available for reducing rinse water volume are improved rinse efficiency and rinse water flow control.

Improved Rinse Efficiency

The following three strategies can be used to enhance rinsing between various process bath operations: (1) turbulence between the workpiece and the

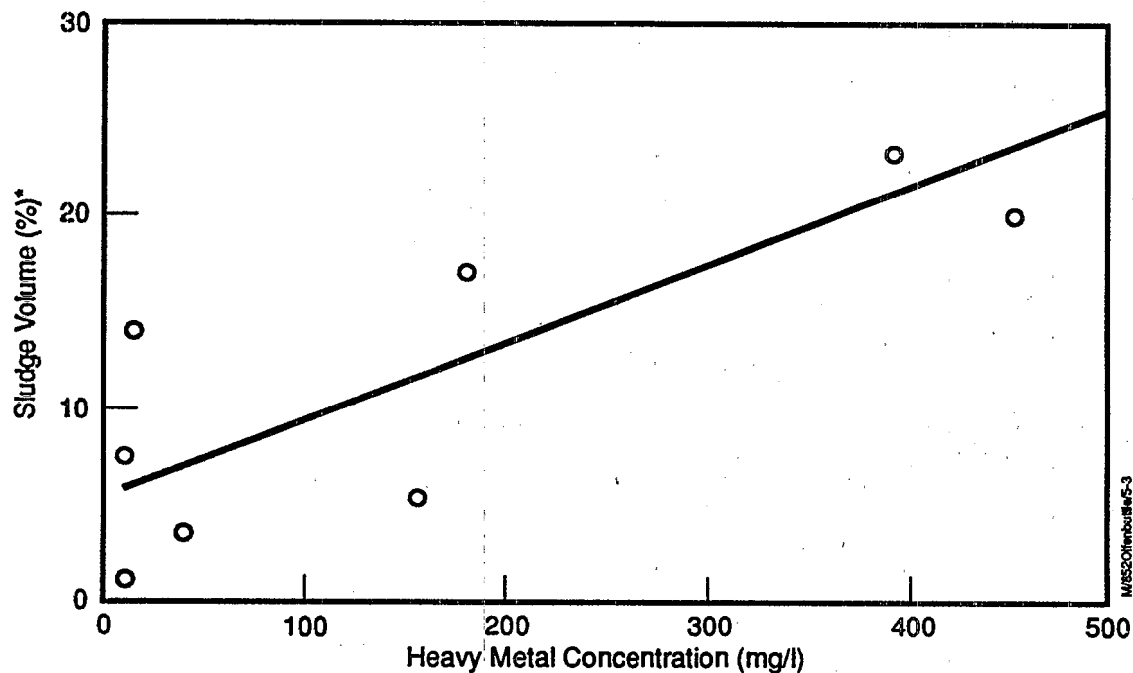


Figure 3. Sludge Volume Generation

*Volume of sludge per volume of wastewater treated after 1 hour of settling. Treatment consists of lime neutralization.

Source: USEPA, *Environmental Pollution Control Alternatives: Sludge Handling, Dewatering, and Disposal Alternatives for the Metal Finishing Industry*, October 1982.

rinse water, (2) increased contact time between the workpiece and the rinse water, and (3) increased volume of water during contact time to reduce the concentration of chemicals rinsed from the workpiece surface (USEPA 1982a). The third strategy, however, requires finishers to use significantly more rinse water than is actually necessary. Spray rinsing, agitation, increased contact time, rinse elimination, and counter-flow multiple tank rinsing, on the other hand, can be used to improve the efficiency of a rinsing system and reduce the volume of rinse water.

Spray Rinses and Rinse Water Agitation. Turbulence, which involves spray rinsing and rinse water agitation, improves rinse efficiency. Although spray rinsing uses between one-eighth and one-fourth the volume of water that a dip rinse uses (USEPA 1982a), it is not always applicable in metal finishing because the spray rinse may not reach many parts of the workpiece. However, spray rinsing can be combined with immersion rinsing. This technique uses a spray rinse as the first rinse step after the workpieces are removed from the process tank. A spray rinse removes much of the drag-out and returns it to the process bath before the workpiece is submerged into the dip rinse tank, permitting lower water flows in the rinse tank.

Spray or fog rinses can be installed above heated process tanks if the volume of rinse water from the spray system is less than or equal to the volume of water lost to heat evaporation. This practice allows the drag-out and the rinse solution to drain directly back into the process bath; in this way, the rinse solution replenishes the process bath. Deionized or reverse osmosis water should be used in this type of spray rinse system.

Workpieces can be agitated in the rinse water by moving the workpiece rack or creating turbulence in the water. Since most metal finishing plants operate hand rack lines, operators could easily move workpieces manually by agitating the hand rack. Rinsing is more effective if the pieces are raised and lowered into and out of the rinse tank rather than agitating the pieces while they are submerged.

The rinse water can also be agitated with forced air or water by pumping either air or water into the immersion rinse tank. Air bubbles create the best tur-

bulence for removing the chemical process solution from the workpiece surface (USEPA 1982a), but misting, as the air bubbles break the surface, may cause air pollution. Filtered air can be pumped into the bottom of the tank through a pipe distributor (air sparger) to agitate the rinse water. An in-tank pump can also recirculate the rinse water in the tank (a process known as forced water agitation). An agitator (mixer) can be used in a rinse tank, but this requires extra room in the tank to prevent parts from touching the agitator blades.

Air spargers, water pumps, or agitators can be installed in existing rinse tanks at a modest cost. The cost of installing air spargers with a blower to provide the air would be \$200 to \$325 for a 50-gallon tank. Air blowers eliminate the air cleaners and filters needed in compressed air systems to remove oils. An in-tank pump for forced water agitation can be purchased for \$200 to \$1,000, depending on the flow rate desired.

Increased Contact Time. If multiple tanks are set up in series as a counter-current rinse system, water usage can be reduced and contact time between the workpiece and the rinse solution can be increased. Rotation plating also increases contact time by allowing operators to leave workpiece racks in the rinse tanks while they handle other racks.

Rinse Elimination. The rinse between a soak cleaner and an electrocleaner may be eliminated if the two baths are compatible.

Counter-Current Rinse Systems. Multiple rinse tanks can be used to significantly reduce the volume of rinse water used. A multistage counter-current rinse system uses up to 90 percent less rinse water than a conventional single-stage rinse system (Couture 1984). In a multistage counter-current rinse system, workpiece flow moves in a direction opposite to the rinse water flow. Water exiting the first tank (the last tank in which the workpiece is immersed) becomes the feed water to the second tank. This water then feeds the third tank, and so on for the number of tanks in the line. Figure 4 illustrates the use of a three-stage counter-current rinse system.

The effectiveness of this multistage system in reducing rinse water use is illustrated in the following

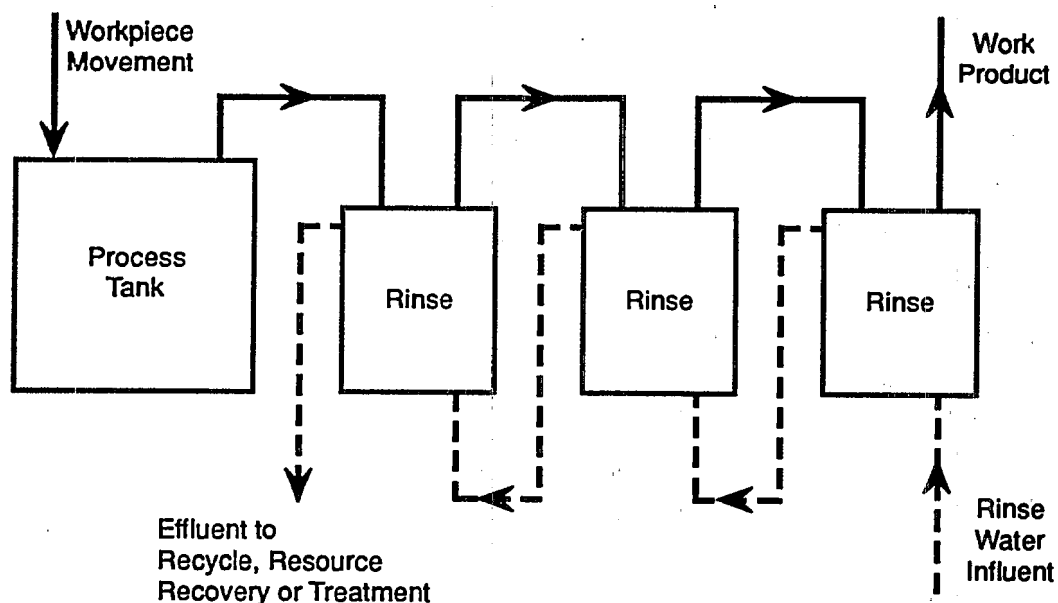


Figure 4. Three-Stage Counter-Current Rinse System

example. A plant operates a process line where the drag-out rate is approximately 1.0 gallon per hour. This process bath is followed by a single-stage rinse tank requiring a dilution rate of 1,000 to 1 to maintain acceptable rinsing. Therefore, the flow rate through the rinse tank is 1,000 gal/hr. If a two-stage counter-current rinse system were used, a rinse water flow rate of only 30 to 35 gal/hr would be needed. If a three-stage counter-current rinse system were used, only 8 to 12 gal/hr would be required (Watson 1973).

A multistage counter-current rinse system allows greater contact time between the workpiece and the rinse water, greater diffusion of process chemicals into the rinse solution, and more rinse water to come into contact with the workpiece. The disadvantage of multistage counter-current rinsing is that additional tanks and work space are needed. Since many metal finishers lack room to install additional rinse tanks, multistage rinse systems are not always feasible. One option available to a metal finishing plant that lacks floor space is to reduce the size of the rinse tanks or to segregate existing tanks into multiple compartments. This option is limited, however, by the size of the workpieces.

Installing a counter-current three-rinse system into an existing single-stage rinse system requires two additional rinse tanks and the associated piping. The cost would depend on the size of tanks. Assuming the tanks have a capacity of 450 gallons, installation could run approximately \$1,200.

Flow Controls

Rinse water use is excessive if water pipes are oversized or the water is left running when the rinse tanks are not being used. Rinse water control devices can increase the efficiency of a rinse water system.

The cost of reducing rinse water use varies depending on the method. The cost may be limited to that associated with purchasing and installing flow restrictors or timers. Savings from reduced rinse water flow rates include direct reduction of water use, sewer fees, treatment chemical use, and sludge generation.

The following equation will assist in determining the most efficient rinse water flow rate for a single-stage rinse system:

$$Q = D (C_p/C_n)$$

where

- Q = rinse tank flow rate
- D = drag-out rate
- C_p = chemical concentration in process solution
- C_n = allowable chemical concentration in rinse solution (USEPA 1982a).

The value of C_n is based on experience or on quality control standards.

The effect on rinse water flow rate for multiple stage rinse tanks can be evaluated using another equation:

$$Q = [(C_p/C_n)^{1/n} + 1/n] D$$

where

- n = number of rinse tanks in series (USEPA 1982a).

Flow Restrictors. Flow restrictors limit the volume of rinse water flowing through a rinse system by maintaining a constant flow of fresh water once the optimal flow rate has been determined. Since most small- and medium-sized metal finishers operate batch process lines in which rinse systems are manually turned on and off at the start and finish of operations, pressure-activated flow control devices, such as foot pedal activated valves or timers, can be helpful to ensure that water is not left on after the rinse operation is completed.

Installing a flow restrictor upstream of all the rinse water influent lines reduces water use. Setting the flow restrictor at a rate less than the flow rate required to operate all rinse tanks simultaneously requires operators to turn off the water in the unused rinse systems so the rinse systems in use will have adequate flow. For example, if a metal finisher operates between 20 and 24 separate rinse systems, each requiring an average flow rate of 2 gallons per minute (gpm), a flow restrictor, installed upstream of all the rinse water influent lines, could limit total water flow to 15 gpm. Therefore, operators must turn off unused rinse systems to ensure that the rinse systems requiring immediate use will operate properly. It is important to note that operator training and complete cooperation are required for this type of system to work. Otherwise parts will not be rinsed effectively and product quality will decrease.

Conductivity-Actuated Flow Controller. A conductivity-actuated flow controller controls fresh water flow through a rinse system by means of a conductivity sensor that measures the level of ions in the rinse water. When the ion level reaches a preset minimum, the sensor activates a valve that shuts off the flow of fresh water into the rinse system. When the concentration builds to the preset maximum level, the sensor again activates a valve that opens to resume the flow of fresh water.

Automated controls, such as a conductivity-actuated flow controller to control rinse water flow, can effectively reduce rinse water waste generation. A conductivity meter equipped with the necessary solenoid control valve could cost approximately \$700 per rinse system.

IMPROVED HOUSEKEEPING

Although the contribution of improved housekeeping to overall waste minimization is difficult to quantify, often simple housekeeping improvements can provide low to no cost opportunities for reducing waste. A plant can reduce waste by developing inspection and maintenance schedules, controlling the purchasing and handling of raw materials, removing dropped parts quickly from baths, keeping filters and other process equipment in good working condition, and authorizing a limited number of employees to accept and test samples from chemical suppliers.

Inspection and Maintenance

Production, storage, and waste treatment facilities should be inspected regularly to identify leaks, improperly functioning equipment, and other items that may lead to waste. Frequent inspections can identify problems before they become significant. Items that should be inspected include piping systems, filters, storage tanks, defective racks, air sparging systems, automated flow controls, and even operators' production procedures (such as drain time and rinse methods).

Dropped parts and tools should be removed from process baths quickly to reduce contamination of the bath. This can be aided by having rakes handy to recover dropped items. Maintenance schedules should

be coordinated with inspection schedules to ensure that equipment is operating at optimal efficiency.

Chemical Purchasing and Handling

Controlling the purchasing and handling of materials can reduce waste generation. Inventorying raw materials and ensuring that containers are completely empty before new containers are opened reduces stockpiling of raw materials. This practice will reduce the potential for spills and the likelihood of mixing poor process baths.

In addition, strict procedures should be developed for mixing chemicals. Mixing procedures should be designed to minimize spills; to provide correctly mixed baths, and to ensure that the baths are operated at the lowest possible concentration to reduce drag-out loss. Designating a limited number of personnel to handle and mix chemicals will improve the consistency of the solution formulations and will decrease waste.

Sample Testing

Many suppliers provide metal finishers with a variety of process chemicals for testing. However, if the material is not used, it becomes waste, and unused chemicals should not be allowed to stockpile at the site. If possible, metal finishers should stipulate that test samples will be accepted only if the supplier agrees to take back leftover samples. The unused portion of analytical samples taken from process baths should be returned to the process bath.

Recycling and Resource Recovery

Recycling and resource recovery technologies either directly use waste from one process as raw material for another process or recover valuable materials from a waste stream before they are disposed. Some spent chemical process baths and much rinse water can be reused for other plant processes. Also, process chemicals can be recovered from rinse water and sold or returned to process baths.

Segregating waste streams is essential for most recycling and resource recovery technologies. To reuse a waste material for another process, recover valuable chemicals from a waste stream, or recycle

rinse water, the waste stream must be separated from other wastes that would prohibit recycling or reuse opportunities. Therefore, recycling and resource recovery technologies typically will require process piping modifications and additional holding tanks to provide appropriate material segregation.

REUSING WASTE MATERIAL

The chemical properties of a waste stream must be understood to assess the potential for reusing the waste as a raw material. Although the chemical properties of a process bath or rinse water solution may make it unacceptable for its original use, the waste materials may still be valuable for other applications. Metal finishers should therefore evaluate waste streams for the properties that make them useful rather than the properties that render them waste.

Rinse Water

One waste material reuse option common among metal finishers is multiple-use rinse waters, in which the rinse water from one process is used for the rinse water of another. The primary cost associated with rinse water reuse is in replumbing the rinse system. Depending on the design of the rinse water reuse system, storage tanks and pumps may also be needed.

After rinse solutions become too contaminated for their original purpose, they may be useful for other rinse processes. For example, effluent from a rinse system following an acid cleaning bath can sometimes be reused as influent to a rinse system following an alkaline cleaning bath. If both rinse systems require the same flow rate, 50 percent less rinse water would be used to operate them. In addition, reusing water in this way can improve rinse efficiency by accelerating the chemical diffusion process and reducing the viscosity of the alkaline drag-out film (USEPA 1982a). Care must be exercised to make sure that tank materials and pipes as well as bath chemistries are compatible with the rinse solutions.

Acid cleaning rinse water effluent can be used as rinse water for workpieces that have gone through a mild acid etch process. Effluent from a critical or final rinse operation, which is usually less contaminated than other rinse waters, can be used as influent for rinse operations that do not require high rinse

efficiencies. Another option is using the same rinse tank to rinse parts after both acid and alkaline baths. Metal finishers should evaluate the various rinse water requirements for their process lines and configure rinse systems to take advantage of rinse water reuse opportunities that do not affect product quality.

Figure 5 illustrates rinse water reuse for an alkaline cleaning, mild acid etch, and acid cleaning line. If each of the three rinse tanks is operated at the same flow rate, total water use is 67 percent less when reused compared with no reuse.

Implementing a system to reuse rinse water effluent from one rinse system as feed water in another rinse system costs approximately \$1,000. This includes \$500 for contractor labor for 1 day and \$500 for materials (including piping and a three-quarter horsepower pump, which would be adequate for a typical rinse system). If the rinse systems are in the same process line and operate at the same flow rate, no storage tank capacity would be necessary.

The savings associated with reusing rinse water are related to water and sewer fees, treatment chemicals, and sludge handling. If each rinse system used

24,000 gallons of water each month, reusing rinse water from one rinse system could reduce water use by 24,000 gallons each month, saving \$32 per month assuming water and sewer fees are each \$0.50 per 100 cubic feet. Savings for treatment chemicals would be approximately \$120 per month if the company spends \$1,000 each month to treat 200,000 gallons of wastewater.

Spent Process Baths

Typically, spent acid or alkaline solutions are dumped when contaminants exceed an acceptable level. However, these solutions may remain sufficiently acidic or alkaline to act as pH adjusters. For example, alkaline solutions can be used to adjust the pH in a precipitation tank. Acid solutions can be used for pH adjustment in chromium reduction treatment. Since spent cleaners often contain high concentrations of metals, they should not be used for final pH adjustments, however. It is important to make sure the process solutions are compatible before they are used in this manner. Chemical suppliers may have reclamation services, some of which permit certain spent plating baths to be returned.

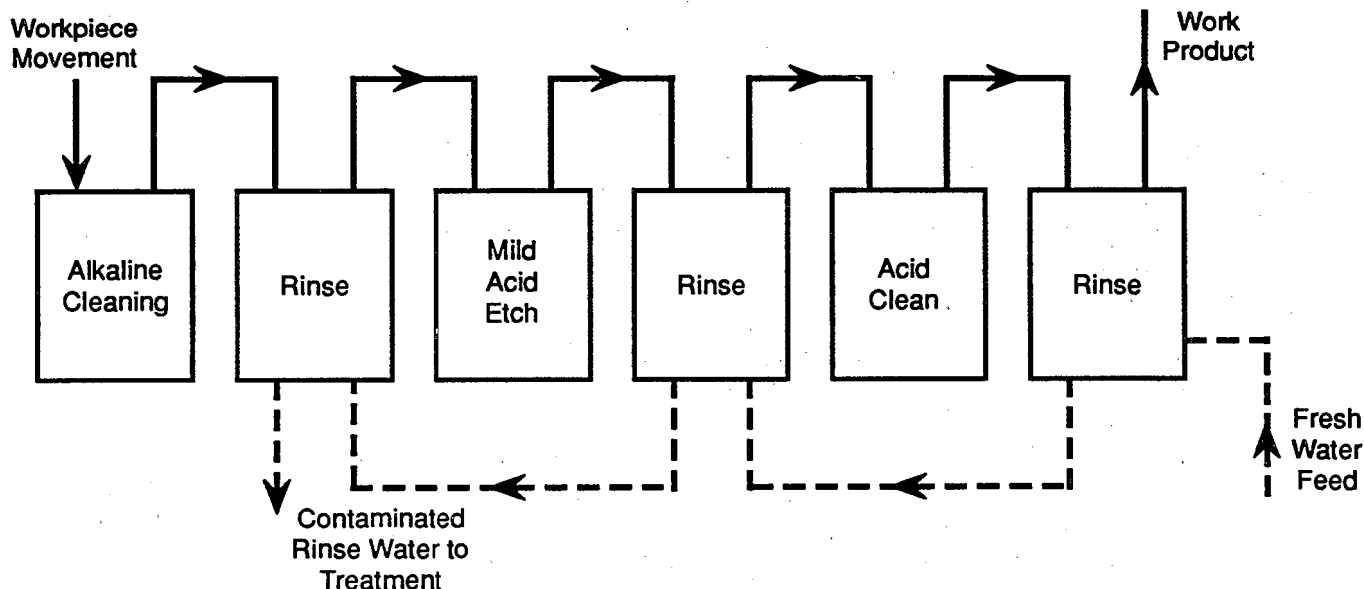


Figure 5. Multiple Reuse of Rinse Water

RECYCLING RINSE WATER AND PROCESS BATHS

Rinse water can be recycled in a closed loop or open loop system. In a closed loop system, the treated effluent is returned to the rinse system. This system can significantly reduce water use and the volume of water discharged to the wastewater treatment plant. A small amount of waste is still discharged from a closed loop system. An open loop system allows the treated effluent to be reused in the rinse system, but the final rinse is fed by fresh water to ensure high quality rinsing. Therefore, some treated effluent will continue to be discharged to the sanitary sewer. Figure 6 shows the configurations for both a closed loop and open loop rinse water recycling system.

To improve the economic feasibility of these systems, rinse water efficiency techniques should first be implemented. Multistage counter-current rinse systems, flow controls, and drag-out reduction techniques should be pursued to reduce the volume of water requiring treatment for recovery, thus reducing the equipment capital costs.

In the past, material recovery from metal finishing was not considered economical. However, effluent pretreatment regulations and treatment and disposal costs are now a significant economic factor. As a result, metal finishers may find it economical to reuse rinse water and to recover metals and metal salts from spent process baths and rinse water.

Recovered metal can be reused in three ways: (1) recovered metals (and process solutions) can be returned to baths as makeup, (2) metals can be sold or returned to suppliers, or (3) elemental metal can be sold to a reclaimer or reused on site as plating metal anode materials. Some successful technologies to recover metals and metal salts include:

- Evaporation
- Reverse osmosis
- Ion exchange
- Electrolytic recovery (electrowinning)
- Electrodialysis.

These technologies are used separately or in combination to recover chemicals from rinse water effluent.

The savings actually achieved through metal recovery will be site-specific. Factors that determine whether metal recovery is economically justifiable include the volume of waste that contains metals, the concentration of the metals, the potential to reuse some of the metal salts, and the treatment and disposal costs. Many systems may not be economically feasible for small metal finishers because the savings may not be great enough to achieve an acceptable payback on their investment.

Evaporation

Evaporation has been successfully used to recover a variety of plating bath chemicals. This simple technology is based on the physical separation of water from dissolved solids such as heavy metals. Water is evaporated from the collected rinse water to allow the chemical concentrate to be returned to the process bath. The drag-out recovered is often returned to the process tank in higher concentrations than in the original process solution. Water vapor is condensed and can be reused in the rinse system. The process is performed at low temperatures under a vacuum to prevent degradation of plating additives. Atmospheric pressure evaporators are used most commonly because of their lower capital cost. Evaporation is more economical when used with multistage counter-current rinse systems because the quantity of rinse water to be processed is small. The process is energy-intensive and becomes expensive for large volumes of water; heat pumps and multistage counter-current rinse systems have lower operation costs. Evaporation is most economical when the amount of water to be evaporated is small or when natural atmospheric evaporation can be used.

A variation on standard evaporation technology is the cold vaporization process, which works by a similar evaporation separation principle except that an increased vacuum evaporates water at temperatures of 50°F to 70°F. This type of evaporation system is less energy intensive than electrically heated systems because it gets the needed heat from the air around the unit. Some equipment uses the heat generated from the vacuum system to provide the heat needed for evaporation.

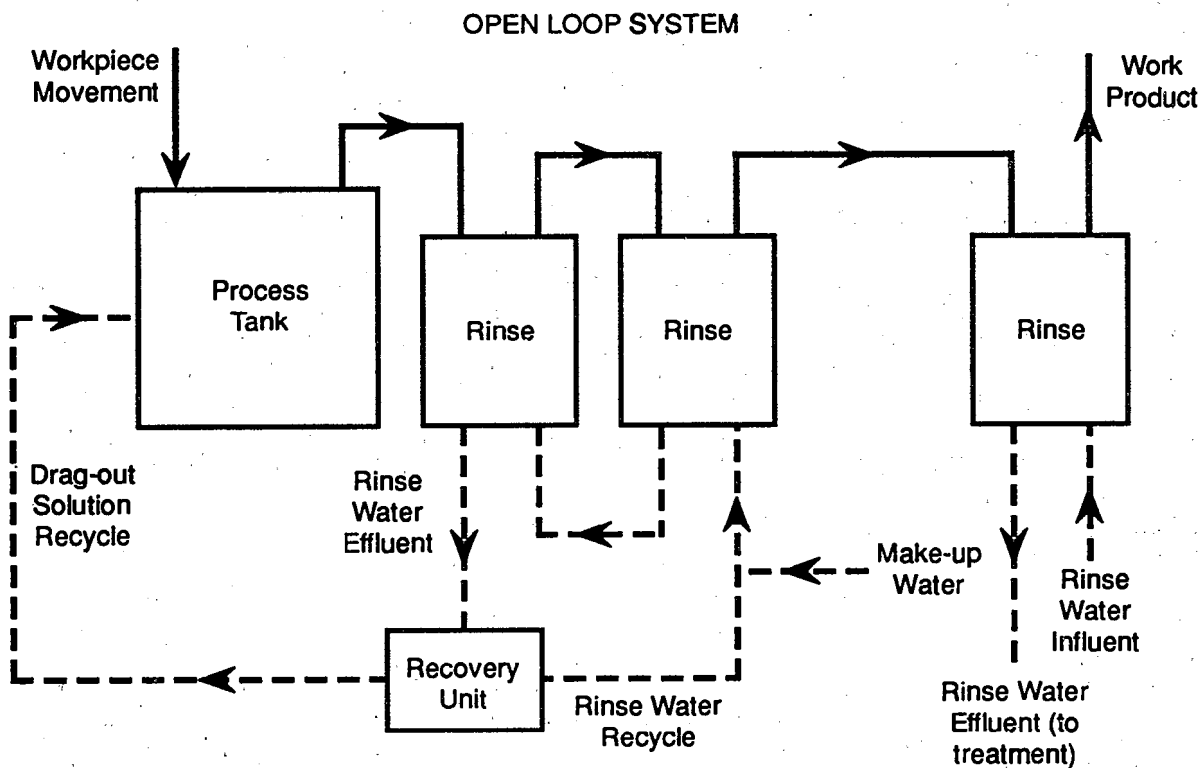
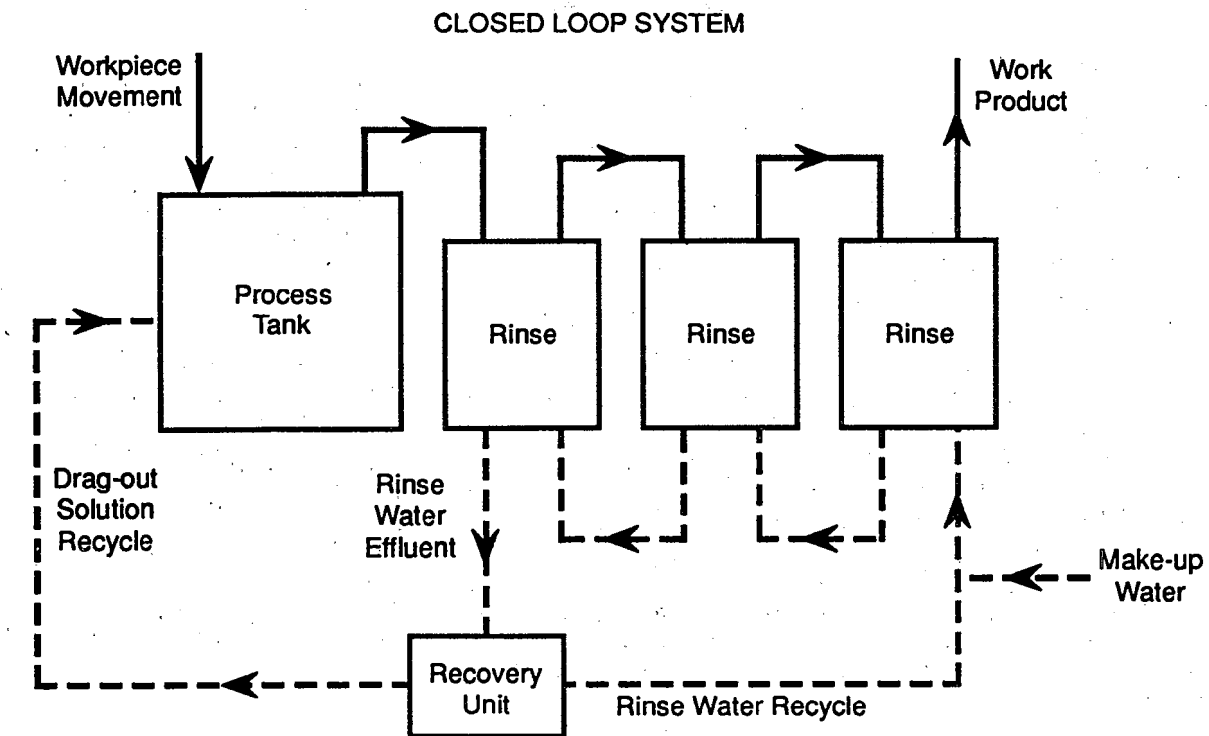


Figure 6. Chemical Rinse Water Recycling System

Reverse Osmosis

Reverse osmosis (RO) is a pressure-driven process in which a semipermeable membrane permits the passage of purified water under pressure greater than the normal osmotic pressure, but does not allow larger molecular weight components to pass through. These concentrated components can be recovered and returned to the process bath, and the treated rinse water is then returned to the rinse system for reuse. The most common application of RO technologies in metal finishing operations is in the recovery of drag-out from acid nickel process bath rinses. Although the technology is designed to recover a concentrated drag-out solution, some materials (such as boric acid) cannot be fully recovered. Also, RO is a delicate process that is limited by the ability of the membranes to withstand pH extremes and long-term pressure. RO membranes are not generally suitable for solutions having high oxidation potential (such as chromic acid). Also, the membranes will not completely reject many nonionized organic compounds. Therefore, activated carbon treatment is typically required before the rinse water solution can be returned to the rinse system. Activated carbon can be costly, but for certain cases it may be the only practical approach.

Ion Exchange

Ion exchange (IX) can be used to recover drag-out from a dilute rinse solution. The chemical solution is passed through a series of resin beds that selectively remove cations and anions. As the rinse water is passed through a resin bed, the resin exchanges ions with the inorganic compounds in the rinse water. The metals are recovered by cleaning the resin with an acid or alkaline solution. The metals then can be electrowon from the resin regeneration solution while the IX treated water can be returned to the rinse system for reuse. IX units can be used effectively on dilute waste streams and are less delicate than RO systems, but the water must be filtered to remove oil, grease, and dirt to protect the resin. Certain other metals may eventually foul the resin, requiring a special procedure to remove the foulant.

Ion exchange is commonly used to treat rinse water from chromic acid process baths. Figure 7 shows how an IX unit can be used to recover chromic acid and reuse rinse water. The rinse water waste stream is filtered prior to passing through a cation

column and two anion columns. The primary cation resin column removes heavy metals from the solution, while the anion resin column removes the chromate ions. The chromates are removed from the anion resin, with sodium hydroxide, forming sodium chromate which is then regenerated as chromic acid by passing through a secondary cation bed. The secondary bed replaces the sodium ions with hydrogen ions. The cation beds themselves are regenerated with hydrochloric acid and the spent regenerant solution is usually treated in the wastewater treatment system. It is important to note that chloride contaminates the chromium plating bath, and that treatment with silver nitrate to precipitate the chloride is expensive.

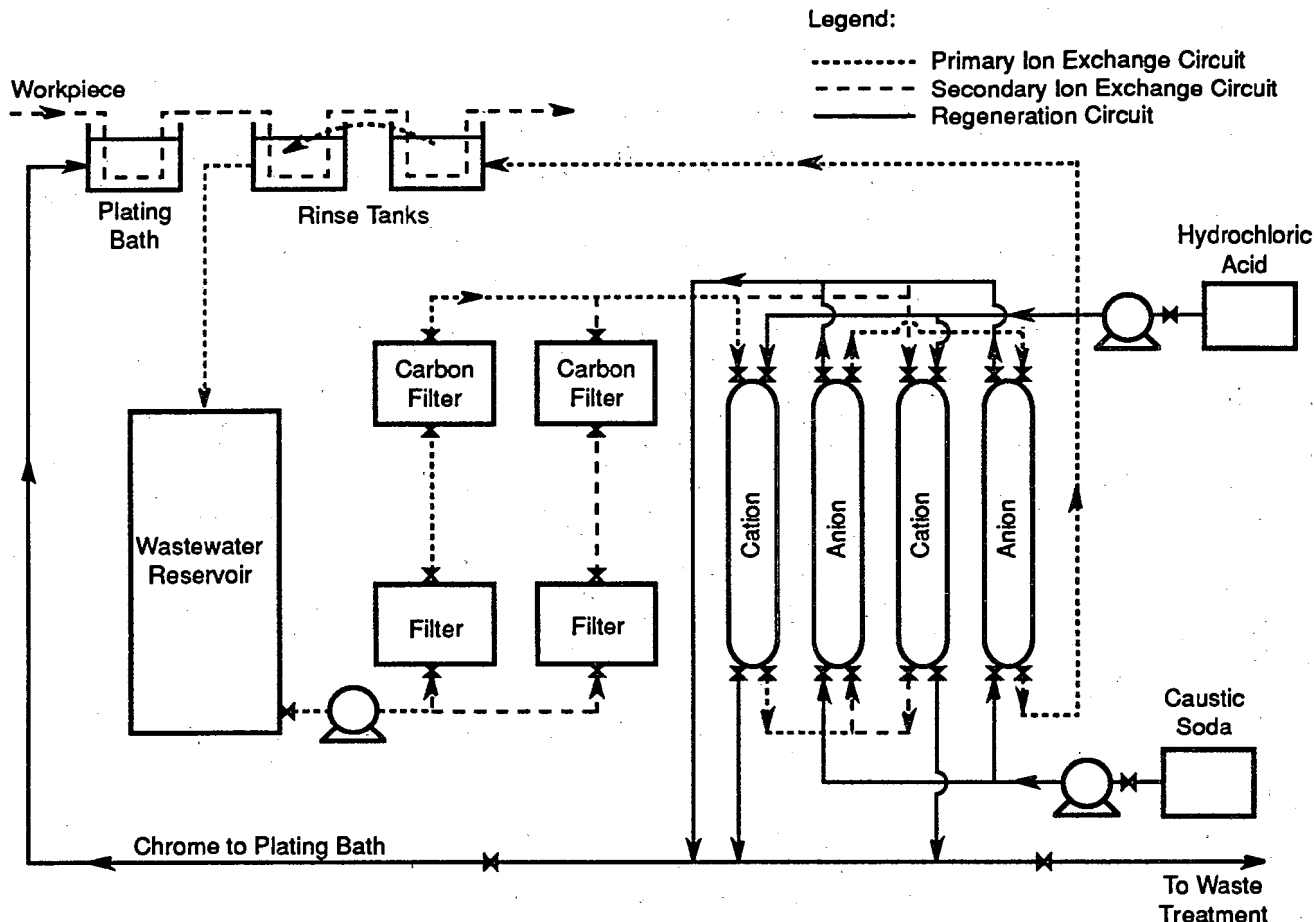
IX equipment requires careful operation and maintenance. In addition, recovery of chemicals from the resin columns generates significant volumes of regenerant and wash solutions, which may add to the wastewater treatment load.

Electrolytic Recovery/Electrowinning

Electrowinning is a process used to recover the metallic content of rinse water. It operates using a cathode and an anode, which are placed in the rinse solution. As current passes between them, metallic ions deposit on the cathode, generating a solid metallic slab that can be reclaimed or used as an anode in an electroplating tank. The electrowinning process is capable of recovering 90 to 95 percent of the available metals and has been successfully used to recover gold, silver, tin, copper, zinc, solder alloy, and cadmium (Campbell and Glenn 1982).

Several basic design features well known to the electroplating industry are employed in electrolytic recovery: (1) expanded cathode surface area, (2) close spacing between cathode and anode, and (3) recirculation of the rinse solution (USEPA 1985). Electroplaters can design their own units by closely spacing parallel rows of anodes and cathodes in a plating tank and circulating rinse solutions through the tank. This process can also be used to recover metals from spent process baths prior to bath treatment in the wastewater treatment system.

High surface area electrowinning/electrorefining is another method of electrolytic recovery. The metal-containing solution is pumped through a carbon fiber cathode or conductive foam polymer, which is used as



Source: USEPA. 1985. *Environmental Pollution Control Alternatives: Reducing Water Pollution Control Costs to the Electroplating Industry*.

Figure 7. Ion Exchange System for Chromic Acid Recovery

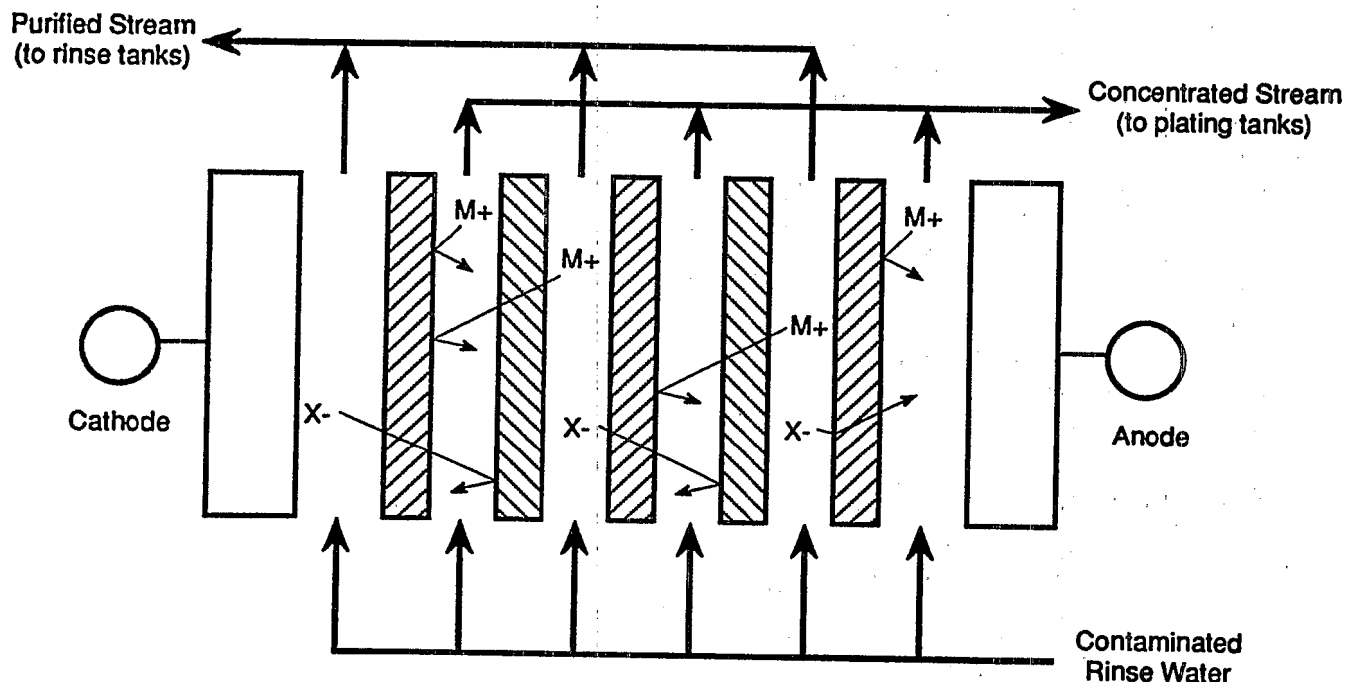
the plating surface (Mitchel 1984). To recover the metals, the carbon fiber cathode assembly is removed and placed in the electrorefiner, this reverses the current and allows the metal to plate onto a stainless steel starter sheet. These systems recover a wide variety of metals and regenerate many types of solutions. High surface area metal recovery is used mainly with dilute solutions such as rinse water effluent.

Electrodialysis

Electrodialysis is used to concentrate and separate ionic components contained in rinse water solutions, as shown in Figure 8. A water solution is passed through a series of alternately placed cation- and anion-permeable membranes. These membranes are

placed parallel to the flow of water, and an anode and cathode are placed on opposite sides of the membrane stack. The anode and cathode create an electropotential across the stack of membranes, causing the ions in the rinse solution to migrate across the membranes. The selectivity of the alternating membranes causes both anions and cations to migrate into alternating channels, and ion-depleted water remains in the other channels. The concentrated solution can be returned to the plating baths, while the treated water is recycled through the rinse system.

EPA has sponsored demonstration projects to test the application of electrodialysis to nickel recovery from rinse water. One unit was tested for 9 months without significant operating problems. This unit suc-



Legend:

M+ = Cations

X- = Anions

▨ Cation—selective membrane

▩ Anion—selective membrane

Figure 8. Electrodialysis Flow Schematic

cessfully recovered nickel salts for reuse in plating baths, allowing the treated rinse water to be recirculated into the rinse system (USEPA 1985).

RECYCLING SOLVENTS

Many companies have converted their solvent-based precleaning or degreasing processes to alkaline cleaning solutions that can be batch treated on site in a facility's existing treatment system. Nevertheless, solvent degreasing is still used for some cleaning operations in the metal finishing industry.

Solvents can be recycled off site as part of a package solvent service. Companies will rent degreasing equipment, supply all solvents, and accept the waste solvents for off-site recycling. These services may be cost effective for low volume users

of solvents. High volume users of solvent cleaners can recycle solvent waste on site using distillation technologies. The solvent is separated from the contaminants by heating the solution above the solvent's boiling point. The solvent vapors are then condensed in a condensation chamber. The contaminants remaining in the heating vessel are handled as a hazardous sludge. The economic benefits of off-site versus on-site recycling have to be judged based on virgin solvent purchase cost, off-site service fees, amount of waste solvent generation, disposal cost of waste solvent, disposal cost of distillation still bottom sludge, and cost of on-site equipment. A general rule of thumb is that on-site recovery be considered if one drum (55 gal) or more of waste solvent are generated per month.

A recent study by Gavaskar et al. (1992) looked at a company that generates 900 gallons of waste methylethylketone (MEK) solvent per year. This waste solvent could be disposed of directly at a cost of \$400 per 55-gallon drum. A 55-gallon capacity on-site batch distillation still was used to recover the MEK for use in a painting operation. Every 55-gallon batch gave 35 gallons of recycled solvent and 15 to 20 gallons of still bottom sludge, on average. This sludge was hauled away for incineration for \$500 (minimum) per 55-gallon drum. Purchasing new MEK solvent would have cost the company \$10 per gallon. Under these conditions, the batch recovery unit, which costs approximately \$30,000, has a pay-back of around 3 years. Smaller stills of 5-gallon capacity are also available in the \$5,000 to \$8,000 range. Intermediate 15-gallon stills cost between \$8,000 and \$12,000.

Summary

Table 2 provides a summary of the two main approaches to waste minimization in the metal finishing industry.

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Table 2. Waste Minimization Options

Source Reduction	Recycling and Resource Recovery
<ul style="list-style-type: none"> • Using nonchelated process chemistries • Reducing the volume of rinse water by: <ul style="list-style-type: none"> — Using spray rinse systems — Creating agitation in the rinse tank — Employing multiple use rinses for compatible processes — Using multiple stage counter-current rinse systems — Using conductivity controls and flow timers • Extending the life of the process baths through: <ul style="list-style-type: none"> — Good housekeeping — Initiating electrolytic recovery or chemical treatment and filtration — Reducing drag-in — Using distilled, deionized, or reverse osmosis water — Properly maintaining racks — Using purer anodes and bags • Reducing drag-out loss by: <ul style="list-style-type: none"> — Operating process baths at the lowest acceptable chemical concentrations — Operating process baths at higher temperatures — Withdrawing workpiece racks at a slower rate — Draining workpiece racks for longer periods — Capturing drag-out on a drainage board that drains back into the process tank — Adding wetting agents to process baths — Improving workpiece positioning — Recovering process chemicals in a drag-out tank and replenishing the process bath with the recovered solution — Spraying directly over the process tank 	<ul style="list-style-type: none"> • Reusing rinse water effluent • Implementing material reuse techniques • Regenerating spent process bath solutions • Recycling process bath chemicals and rinse water solutions through use of chemical recovery technologies, including: <ul style="list-style-type: none"> — Evaporation — Reverse osmosis — Ion exchange — Electrolysis — Electrowinning — Electrodialysis • Recycling spent solvents by distillation • Separating various waste streams for recycling, selective treatment, and batch treatment • Implementing alternative treatment systems such as ion exchange, reverse osmosis, evaporation, and electrolysis

SECTION 4

GUIDELINES FOR USING THE WASTE MINIMIZATION ASSESSMENT WORKSHEETS

The worksheets provided in this section are intended to assist metal finishing facilities in systematically evaluating waste generating processes and in identifying waste minimization opportunities. These worksheets should be used to perform the assessment phase of the waste minimization opportunity assessment procedure. The entire procedure consists of four phases, the second of which is the assessment phase. The full procedure is described in the EPA *Waste Minimization Opportunity Assessment Manual* and also in the EPA *Facility Pollution Prevention Guide*. A comprehensive waste minimization assessment includes planning and organization, gathering

background data and information, a feasibility study on specific waste minimization options, and an implementation phase. For a full description of waste minimization assessment procedures, refer to the EPA manual.

Table 3 lists the worksheets that are provided in this section. Users may wish to duplicate the worksheets and perform complete assessments for each process operation. After completing the worksheets, the assessment team should evaluate the applicable waste minimization options and develop an implementation phase.

Table 3. List of Waste Minimization Assessment Worksheets

Number	Title	Description
1.	Waste Sources	Form for listing material handling and process operations waste
2.	Waste Minimization: Material Handling	Questionnaire on handling techniques and inspections
3.	Option Generation: Material Handling	Options for minimizing material handling waste
4.	Waste Minimization: Material Substitution	Questionnaire on process operations
5.	Option Generation: Material Substitution	Options for substituting process materials
6.	Waste Minimization: Operational Practices	Questionnaire on operating practices
7.	Option Generation: Operational Practices	Options for modifying operating practices
8.	Waste Minimization: Drag-Out	Questionnaire on drag-out processes
9.	Option Generation: Drag-Out	Options for minimizing drag-out
10.	Waste Minimization: Management Practices	Questionnaire on management practices
11.	Option Generation: Management Practices	Options for implementing management practices
12.	Waste Minimization: Reuse and Recovery	Questionnaire on reuse and recovery
13.	Option Generation: Reuse and Recovery	Options for reusing and recovering process materials

Firm _____	Waste Minimization Assessment	Prepared by _____
Site _____		Checked by _____
Date _____	Proj. No. _____	Sheet ____ of ____ Page ____ of ____

WORKSHEET

2A

**WASTE MINIMIZATION:
Material Handling**

A. GENERAL HANDLING TECHNIQUES

Are off-specification material wastes generated because the material has exceeded its shelf life? ☐ Yes ☐ No

How often is an inventory performed to identify an accumulation of materials? _____

Does the company use a first-in first-out material use policy to prevent materials from deteriorating in storage? ☐ Yes ☐ No

Does the company minimize inventory to prevent material degradation due to prolonged storage? ☐ Yes ☐ No

Does the plant accept samples from chemical suppliers? ☐ Yes ☐ No

Do unused samples become waste? ☐ Yes ☐ No

Are samples tested on a bench-scale basis to minimize waste generation? ☐ Yes ☐ No

Has a person been designated for approving the acceptance of samples? ☐ Yes ☐ No

Are suppliers required to take back unused samples they provide? ☐ Yes ☐ No

Are process bath solutions mixed by designated and trained personnel? ☐ Yes ☐ No

Are inventory controls used to assure that chemicals in a container are completely used prior to opening a new container? ☐ Yes ☐ No

Are empty containers returned to the supplier? ☐ Yes ☐ No

Are empty containers empty according to 40 CFR 261.7 so they can be handled as a nonhazardous solid waste? ☐ Yes ☐ No

Are container rinse solutions used for process bath mixing? ☐ Yes ☐ No

Does the plant generate waste due to spills during material handling or storage? ☐ Yes ☐ No

If yes, describe the frequency of these spills. _____

Are personnel trained to ensure proper handling and storage of materials? ☐ Yes ☐ No

Is spill containment provided to minimize the amount of cleanup materials used to contain and clean up spills? ☐ Yes ☐ No

Describe spill containment used in material storage areas. _____

Firm _____	Waste Minimization Assessment	Prepared by _____
Site _____		Checked by _____
Date _____	Proj. No. _____	Sheet ____ of ____ Page ____ of ____

WORKSHEET

2B

**WASTE MINIMIZATION:
Material Handling**

B. DRUMS, CONTAINERS, AND PACKAGES

Are drums, packages, and containers inspected for damage before being accepted? ☐ Yes ☐ No

Are employees trained in ways to safely handle the types of drums & packages received? ☐ Yes ☐ No

Are stored items protected from damage, contamination, or exposure to rain, snow, sun & heat? ☐ Yes ☐ No

Does the layout of the facility result in heavy traffic through the raw material storage area?
(Heavy traffic increases the potential for contaminating raw materials with dirt or dust and for causing spilled materials to become dispersed throughout the facility.) ☐ Yes ☐ No

Can traffic through the storage area be reduced to prevent accidents? ☐ Yes ☐ No

Are employees properly trained in handling of spilled raw materials? ☐ Yes ☐ No

Describe handling procedures for damaged items: _____

What measures are employed to prevent the spillage of liquids being dispensed? _____

When a spill of liquid occurs in the facility, what cleanup methods are employed (e.g., wet or dry)? Also discuss the way in which the resulting wastes are handled: _____

Would different cleaning methods allow for direct reuse or recycling of the waste? (explain): _____

Do you try to order smaller containers of infrequently used materials to avoid disposing of large quantities of unused obsolete materials? ☐ Yes ☐ No

Have you tried to order larger containers of frequently used materials to reduce the number of small containers that must be cleaned and disposed of? ☐ Yes ☐ No

Are all empty bags, packages, and containers that contained hazardous materials segregated from those that contain non-hazardous wastes? ☐ Yes ☐ No

Describe the method currently used to dispose of this waste: _____

Firm _____	Waste Minimization Assessment	Prepared by _____
Site _____		Checked by _____
Date _____	Proj. No. _____	Sheet ____ of ____ Page ____ of ____

WORKSHEET

2C

**WASTE MINIMIZATION:
Material Handling**

C. INSPECTIONS

Does the company have a formal inspection program? ☐ Yes ☐ No

How often are inspections of the chemical storage area, process areas, and waste treatment areas conducted? _____

Are malfunctions in equipment or leaks in storage vessels and piping corrected immediately? ☐ Yes ☐ No

Are identified malfunctions followed up to ensure that they are corrected? ☐ Yes ☐ No

Are inspections logged and are logs maintained in permanent records? ☐ Yes ☐ No

Firm _____	Waste Minimization Assessment	Prepared by _____
Site _____		Checked by _____
Date _____	Proj. No. _____	Sheet ____ of ____ Page ____ of ____

WORKSHEET

3

**OPTION GENERATION:
Material Handling**

Meeting Format (e.g., brainstorming, nominal group technique) _____

Meeting Coordinator _____

Meeting Participants _____

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
A. General Handling Techniques		
Quality Control Check		
Test Age-Dated Material (if expired) for Effectiveness		
Return Obsolete Material to Supplier		
Minimize Inventory		
Computerize Inventory		
Formal Training		
B. Drums, Containers, and Packages		
Raw Material Inspection		
Proper Storage/Handling		
Reduced Traffic		
Spilled Material Reuse		
Cleanup Methods to Promote Recycling		
Appropriate Purchase Sizes		
Waste Segregation		
C. Inspections		
Formal Inspections		
Maintenance Inspections		
Inspection Logs/Follow-Up		

Firm _____	Waste Minimization Assessment	Prepared by _____
Site _____		Checked by _____
Date _____	Proj. No. _____	Sheet ____ of ____ Page ____ of ____

WORKSHEET

4

**WASTE MINIMIZATION:
Material Substitution**

Do any of the process solutions used contain hazardous materials (i.e., cyanide, chromium VI, chlorinated solvents, etc.)? ☐ Yes ☐ No

If yes, has material substitution been tried? ☐ Yes ☐ No

Discuss the results: _____

Is deionized or reverse osmosis water available? ☐ Yes ☐ No

Is it used for bath makeup water? ☐ Yes ☐ No

Is it used for rinse water? ☐ Yes ☐ No

If used, where, and explanation: _____

Do any of the process solutions contain chelating compounds? ☐ Yes ☐ No

If yes, has material substitution been tried? ☐ Yes ☐ No

Discuss the results: _____

Does the company generate spent process bath wastes that are not treated on site because of concerns about upsetting the treatment process? ☐ Yes ☐ No

Has the company attempted to replace all process bath chemicals, which are handled as hazardous waste when spent, with chemicals that can either be recycled or treated on site? ☐ Yes ☐ No

Firm _____	Waste Minimization Assessment	Prepared by _____
Site _____		Checked by _____
Date _____	Proj. No. _____	Sheet ____ of ____ Page ____ of ____

WORKSHEET

6

**WASTE MINIMIZATION:
Operational Practices**

- | | |
|--|--|
| Are process baths mixed by designated and trained personnel? | <input type="checkbox"/> Yes <input type="checkbox"/> No |
| Are process baths filtered to extend usefulness? | <input type="checkbox"/> Yes <input type="checkbox"/> No |
| Are process baths treated to extend usefulness (i.e., precipitation, dummying)? | <input type="checkbox"/> Yes <input type="checkbox"/> No |
| Are anodes bagged to reduce contamination? | <input type="checkbox"/> Yes <input type="checkbox"/> No |
| Are pure anodes used? | <input type="checkbox"/> Yes <input type="checkbox"/> No |
| Are process bath chemistries monitored and maintained? | <input type="checkbox"/> Yes <input type="checkbox"/> No |
| Are operators trained/aware of proper operating procedures? | <input type="checkbox"/> Yes <input type="checkbox"/> No |
| Are rinse systems only in operation when needed? | <input type="checkbox"/> Yes <input type="checkbox"/> No |
| Are rinse water flows kept at minimum flow rates? | <input type="checkbox"/> Yes <input type="checkbox"/> No |
| Are rinsing enhancements used (i.e., agitation, spray rinse, counter-current rinse, dead rinse, flow controllers)? | <input type="checkbox"/> Yes <input type="checkbox"/> No |

Sheet of Page of

Firm _____	Waste Minimization Assessment	Prepared by _____
Site _____		Checked by _____
Date _____	Proj. No. _____	Sheet ____ of ____ Page ____ of ____

WORKSHEET

8

**WASTE MINIMIZATION:
Drag-Out**

- Has an optimal removal rate and drain time for workpiece racks been determined for each process bath? ☐ Yes ☐ No
- Are personnel trained to consistently follow proper workpiece rack removal rates and drain times? ☐ Yes ☐ No
- Are personnel retrained periodically to assure that these procedures are followed? ☐ Yes ☐ No
- Can any of the chemical process baths be operated at a higher temperature without adversely affecting production quality? ☐ Yes ☐ No
- Are process baths operated at the lower end of the manufacturers' suggested range of operating concentrations? ☐ Yes ☐ No
- Are fresh process bath solutions operated at a lower concentration than replenished process bath solutions? ☐ Yes ☐ No
- Are spray rinses used above heated baths to rinse drag-out solutions back into the process tank? ☐ Yes ☐ No
- Is there space between process bath tanks and their associated rinse tanks that allows process chemicals to drip onto the floor? ☐ Yes ☐ No
- Do process baths that operate at elevated temperatures use drag-out tanks as the initial rinse following the bath? ☐ Yes ☐ No
- If yes, is the drag-out tank solution added back to the process tank? ☐ Yes ☐ No
- Has the company studied the possibility of using the drag-out solution for process bath replenishing? ☐ Yes ☐ No

Firm _____	Waste Minimization Assessment	Prepared by _____
Site _____		Checked by _____
Date _____	Proj. No. _____	Sheet ____ of ____ Page ____ of ____

WORKSHEET

10

**WASTE MINIMIZATION:
Management Practices**

Are plant and/or process material balances routinely performed? ☐ Yes ☐ No

Are they performed for each material of concern (e.g., solvent) separately? ☐ Yes ☐ No

Are records kept of individual wastes with their sources of origin and eventual disposal?
(This can aid in pinpointing large waste streams and focus reuse efforts.) ☐ Yes ☐ No

Are the operators provided with detailed operating manuals or instruction sets? ☐ Yes ☐ No

Are all operator job functions well defined? ☐ Yes ☐ No

Are regularly scheduled training programs offered to operators? ☐ Yes ☐ No

Are there employee incentive programs related to waste minimization? ☐ Yes ☐ No

Does the facility have an established waste minimization program in place? ☐ Yes ☐ No

If yes, is a specific person assigned to oversee the success of the program? ☐ Yes ☐ No

Discuss goals of the program and results: _____

Has a waste minimization assessment been performed at the facility in the past? ☐ Yes ☐ No

If yes, discuss: _____

Firm _____	Waste Minimization Assessment	Prepared by _____
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Date _____	Proj. No. _____	Sheet _____ of _____ Page _____ of _____

WORKSHEET

12

**WASTE MINIMIZATION:
Reuse and Recovery**

A. SEGREGATION

Segregation of wastes reduces the amount of unknown material in waste and improves prospects for reuse & recovery.

- Are spent processing baths segregated from wastewater streams? ☐ Yes ☐ No
- Are different solvent wastes from equipment cleanup segregated? ☐ Yes ☐ No
- Are aqueous wastes from equipment cleanup segregated from solvent wastes? ☐ Yes ☐ No
- Are waste streams not needing treatment sent to treatment? ☐ Yes ☐ No
- Are cyanide waste streams segregated? ☐ Yes ☐ No
- Are chromium waste streams segregated? ☐ Yes ☐ No

B. CONSOLIDATION/REUSE/RECOVERY

- Do you return waste solutions to the manufacturer for recycling? ☐ Yes ☐ No
- Do you recycle the materials on site? ☐ Yes ☐ No
- Are rinse water streams recycled? ☐ Yes ☐ No
- Are the metals in spent process baths reclaimed? ☐ Yes ☐ No
- Are spent process baths used for other beneficial purposes? ☐ Yes ☐ No
- Have you contacted any other platers in your area to see if they want your solutions for recycling? ☐ Yes ☐ No
- Have you contacted waste exchange services or commercial brokerage firms regarding wastes? ☐ Yes ☐ No
- Are many different solvents used for cleaning? ☐ Yes ☐ No
- If too many small-volume solvent waste streams are generated to justify on-site distillation, can the solvent used for parts and equipment cleaning be standardized? ☐ Yes ☐ No
- Is spent cleaning solvent reused as thinner or initial wash? ☐ Yes ☐ No
- Has on-site distillation of the spent solvent ever been attempted? (On-site recovery of solvents by distillation is economically feasible for as little as 50 gallons of solvent waste per month.) ☐ Yes ☐ No
- If yes, is distillation still being performed? ☐ Yes ☐ No

If no, explain: _____

Discuss other wastes that you are currently recycling and by which means: _____

Sheet of Page of

Appendix A

METAL FINISHING FACILITY ASSESSMENTS: CASE STUDIES OF PLANTS

In 1988, with funding from USEPA, the California Department of Health Services commissioned a waste minimization study, *Waste Assessment Study: Metal Finishing Industry*, that included assessments of three metal finishing facilities. The objectives of the study were to:

- obtain information on waste management practices in the metal finishing industry
- identify waste reduction options
- present information on the cost associated with implementing these options.

For a waste reduction assessment to be successful, it must be comprehensive. Although addressing various waste generation problems one at a time or in a piecemeal manner may provide some degree of waste reduction, this method overlooks the main focus of a successful assessment. The main focus is to view the metal finishing plant as a single system and to identify the relationships between material usage, production processes, and waste generation. This comprehensive approach can lead to greater reductions in waste and increases in the economic efficiency of the plant.

A comprehensive study of a company's waste problem requires more than a characterization of the

various waste streams. The solution for reducing a particular waste stream often involves modifying material input or production procedures. Therefore, an assessment must examine raw material usage, production processes and schedules, and waste handling methods together as one system.

Results of waste reduction assessments provide valuable information about the potential for incorporating waste reduction technologies into metal finishing operations. This Appendix presents summaries of the results of the assessments performed by California DHS at three metal finishers. The summaries presented are largely unedited and should not be taken as recommendations of the USEPA; they are provided as examples only. In addition, the California focus included more than waste reduction alternatives; it also addressed treatment alternatives that would lead to sludge and waste water volume reduction. These recommendations are also included in the assessment summaries.

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PLANT A WASTE MINIMIZATION ASSESSMENT

Plant A operates as a job shop metal finishing plant. The plant operates manual and automated process lines 8 hours a day, 5 days a week, with a production staff of 10. Manufacturing operations include plating, anodizing, stripping, etching, cleaning, tooling, and other finishing processes.

Process Description

Production processes that generate hazardous waste include plating, anodizing, etching, stripping, and rinsing. Wastes result from process bath and cleaning bath dumps, degreasing operations, rinsing operations, industrial wastewater treatment, and occasional spill cleanup.

PROCESS BATHS

Plant A offers a full line of metal finishing services and, therefore, operates a wide variety of process baths. Fresh baths are mixed within the chemical manufacturer's suggested concentration range using tap water. Baths are heated when specified. Process bath operating concentrations are checked when fresh baths are mixed using in-house testing methods such as the Hull cell or Kocour sets. Bath quality is evaluated through visual inspection of the workpieces. When it becomes too contaminated, the bath is taken off line and a fresh bath is made up. Continuous filtration is necessary for process baths that tend to accumulate solids.

The process area for the manual line is bermed to separate the area into three segregated sections for nickel, chromium, and other chemicals. Therefore, drag-out that falls onto the floor from the process baths flows into one of three sumps used to segregate these wastes. Wastes are then pumped to the appropriate holding tank for wastewater treatment. Plant A does not use drag-out tanks, drip bars, or drainage boards to control drag-out loss.

In the past, Plant A containerized spent baths for off-site disposal. However, the plant recently purchased a vacuum evaporation treatment unit to treat all spent baths with the exception of nitric acid, which is containerized for off-site disposal.

RINSE SYSTEMS

Plant A operates 18 rinse systems. Most of these are single-stage systems associated with the automated line. Four double-stage counter-current rinse systems are associated with the manually operated process lines. Plant A also operates two heated static rinses that are used as a final rinse for the workpieces before drying. Another static rinse tank segregates the cyanide waste stream.

Each tank of the four double-stage counter-current rinse systems is used for numerous rinsing operations, and contaminants from a variety of process baths enter each rinse system. Because the rinse tanks are in the center of the manual process line area, workpiece racks are carried across the aisles from the process baths to the rinse tanks. This allows drag-out to drip to the floor underneath the aisle grates.

The hoist used for the automated line is equipped with a spray rinse for rinsing workpieces above the process tanks. Air spargers are used in the four double-stage counter-current tanks to create turbulence and improve rinse efficiency.

WASTEWATER TREATMENT

Plant A's industrial wastewater treatment facility treats all wastewater before it is discharged to the publicly owned treatment works (POTW). The treatment facility removes metal contaminants to meet the discharge requirements set by the POTW. Effluent is tested daily for zinc, copper, nickel, chromium, and cadmium. Historically, the plant has exceeded its discharge requirements two to three times per year.

The primary source of wastewater treated at the plant is for rinsing. These wastes are segregated based on their chemical composition and pumped into one of three holding tanks. One tank receives chromium waste; another receives electroless nickel waste; and the third receives general waste from all other processes. Some spent process baths and runoff from the process area floor are also discharged into one of the three holding tanks for treatment.

Waste Reduction Recommendations

The California audit team identified several opportunities for waste reduction at Plant A. These included process baths, rinse systems, material recycling, and wastewater treatment. The following is a summary of the recommendations of the audit team.

PROCESS BATHS

The waste reduction opportunities for process baths at Plant A include material substitution, bath operation and maintenance improvements, drag-out reduction, and drag-out recovery.

Process Bath Material Substitution

The audit team recommended that Plant A replace its cyanide process bath chemistries with chemistries that do not contain cyanide. (Editor note: Replacements for cyanide bath chemistries should be investigated for their ability to fit the needs of the company.) Plant A could eliminate the need for treating rinse waters with sodium hypochlorite if it used chemistries that do not contain cyanide. This could reduce waste treatment costs.

Process Bath Operation and Maintenance

According to the audit team, Plant A may be able to extend the life of some of its baths through improved maintenance. Several techniques are available, including the use of deionized water for bath makeup, treatment of plating baths, and increased monitoring of process baths.

The audit team recommended that Plant A mix fresh baths and replenish process baths with deionized water instead of tap water. The condensate water from the vacuum-evaporation treatment unit could be used for this purpose. However, Plant A should test the water to ensure that it is deionized quality water. This may require the purchase of a holding tank that costs between \$400 and \$600.

The life of process baths can be extended by regenerating them with fresh chemicals. Instead of dumping the entire bath once its effectiveness declines, the bath can be partially dumped and fresh chemicals and

water added. As the life of the bath increases, the concentration of chemicals in the bath-replenishing solution is increased. When the cost of adding chemicals becomes greater than that of dumping the entire bath and mixing a new solution, the bath should be dumped.

The plant can also extend the life of its plating baths by periodically treating them to remove metal contaminants. "Dummying" can be used to remove copper from zinc and nickel plating baths, using a "trickle current" with a density of 1 to 2 amperes per square foot to plate the copper contaminants out of the bath. The process can be performed over a weekend when the plant is not operating. Other metal contaminants, such as lead and cadmium, can be removed through chemical treatment using zinc sulfide. The lead or cadmium will precipitate out and can be removed by filtration.

Extending process bath life requires strict bath analysis schedules. Frequently used baths should be analyzed weekly or biweekly to monitor bath concentration and contamination. These analyses can be accomplished in-house by using basic chemical titration tests or with outside laboratory analysis services.

Drag-out Loss Reduction

Numerous opportunities exist for reducing drag-out loss at Plant A. Plant A should develop operation procedures for the manually operated tanks to designate optimal removal rates and drainage time—the slower the withdrawal of workpiece racks, the thinner the film on the workpiece surface. Also, drip bars for workpiece racks above process baths would allow increased drainage before rinsing begins. The automated hoist line should be set at an optimal workpiece rack removal rate, and timers should be used to ensure that workpiece racks are drained long enough.

Drag-out loss can also be reduced by operating the baths at lower chemical concentrations. Plant A should rearrange its process tanks and rinse systems so that plant personnel do not have to carry workpieces across aisles, allowing chemicals to drip to the floor. A 150-gallon rinse tank costs approximately \$400, but the company itself could build these tanks for significantly less.

Drag-out Recovery

Plant A should replenish heated process tanks with drag-out solutions recovered in static drag-out tanks. Deionized water should be used for the static drag-out tank to minimize the addition of contaminants into the process bath. The plant should identify heated baths that can be replenished with a drag-out solution and determine how to rearrange process tanks to provide room for new drag-out tanks (which cost approximately \$400 for a 150-gallon tank.) Savings from using a drag-out tank include decreases in process and treatment chemical costs, water purchase costs, and sludge handling costs.

RINSE SYSTEMS

Rinse water reduction can improve the plant's rinsing efficiency and reduce the volume of wastewater requiring treatment. Rinse system options include waste stream segregation, multistage rinse systems, rinse water flow reduction using flow restrictors, timers, or pH/conductivity meters combined with automatic flow adjusters, and closed loop ion exchange rinse water recycling.

Rinse Water Efficiency

Plant A may be able to reduce water usage by adding rinse tanks to its manual process line. Plant A may be able to control the flow of water through its rinse systems by using automated flow controls. The rinse system could be equipped with pH/conductivity meters (which cost approximately \$700) that will automatically turn the rinse water flow on and off as needed. This can eliminate the problem of having the water running even when the rinse process is not in use.

Air spargers could be installed on all the large rinse tanks for approximately \$50 per tank. However, this assumes the company has an existing source of compressed air.

The savings associated with improved rinse efficiency are difficult to quantify. A 50 percent reduction in water usage at Plant A would save the company approximately \$150 each month in water and sewer fees (assuming water and sewer fees are \$1.15 for each 748 gallons of water purchased as indicated on past water bills for the company). In addition,

reducing water use will also reduce treatment chemical and waste handling costs.

Rinse Water Reuse

Plant A should also consider reusing the rinse water following an acid cleaning bath as rinse water following an alkaline bath. (Editor note: Provided the streams are otherwise compatible.)

For the large static rinse tanks, the schedules for dumping acidic and alkaline rinse solutions could be coordinated so that an acid rinse solution is dumped into the alkaline process bath rinse system. This practice could cut wastewater usage by 50 percent for these tanks.

Flow-through rinse systems following acidic process lines can be plumbed in series with rinse systems following acidic process baths to feed the effluent from the acidic rinse system into the alkaline rinse system. The rinse systems chosen for plumbing in series would need to operate at a similar flow rate and at the same time.

If the rinse systems in the automated process lines are used as static rinses, Plant A would only have to pump the spent rinse water from one tank to another where it can be reused, using existing portable pumps. For flow-through systems, however, additional plumbing and holding tanks would be required. Such a system, including a water pump, could cost approximately \$500.

Material Recycling

To recover treatment chemicals from rinse water, Plant A should completely segregate the rinse water effluent from other rinse water or process chemicals. An ion exchange system could be used to recover chromic acid to replenish the plating bath. The cation column could then be regenerated with hydrochloric acid. The treated rinse water could be recycled back to the rinse system. Plant A could reduce chemical purchase costs, water usage costs, and waste treatment and disposal costs by recovering chromium solutions and recycling water.

An ion exchange unit designed to treat up to 3,000 gallons designed to treat up to 3,000 gallons of water each day would cost approximately \$80,000.

Holding tanks, piping, and pumps for regenerating the resin and recovering chromate solutions would cost several thousand dollars more.

Plant A should consider chemical recovery technologies for other process lines. Treatment technologies such as ion exchange can also be used to recover rinse water. Plant A should also consider using the treated effluent from the vacuum-evaporation unit, which is considered deionized quality water, for reuse in the rinse systems or for process bath mixing and replenishing.

WASTEWATER TREATMENT

Sludge volume reduction can be achieved by using alternative treatment processes or by modifying the existing wastewater treatment system.

Wastewater Segregation

Plant A generates several rinse water wastes that should not require metal removal. Therefore, these rinse solutions should be segregated from the other rinse water wastes so that they do not go through the metal precipitation treatment process. These wastes could be blended into the treated effluent prior to final pH adjustment and discharge to the POTW. However, the rinse water should be analyzed for metals and checked for organics that are listed in the water pollution control regulations if the chemical suppliers will not confirm that regulated compounds do not exist in their process baths.

Segregation of these rinse solutions will require additional rinse systems, however. Currently, the rinse systems following dye processes are also used for other processes that typically require full treatment. Segregation of these waste streams could reduce treatment chemical purchase costs and sludge handling costs.

Plant A should also segregate all chromium wastes including the rinse water. The chromium processes used in the manual process lines appear to use the same rinse tanks as other processes such as the nickel acetate, anodize, and dye baths. This increases the volume of rinse water treated for chromium reduction. Therefore, reducing the volume of wastewater requiring treatment will reduce sludge volume by reducing treatment chemicals.

Metal Recovery

Plant A should consider electrolytic metal recovery from spent process baths and concentrated rinse solutions prior to treatment. By removing metals from these waste streams, the plant can minimize the generation of metal hydroxide during wastewater treatment and, therefore, reduce sludge volume. Metals could also be recovered from spent baths prior to evaporation treatment.

The type of electrolytic recovery equipment necessary to recover metals depends on the concentration of these metals in the waste stream. Dilute rinse solutions require a high surface area electrolytic metal recovery unit. Concentrated waste streams, however, can be batch treated in an existing plating tank. The cost of implementing batch treatment and electrolytic metal recovery processes would include construction of metal plate cathodes and inert anodes.

Plant A could batch treat spent process baths for metal recovery prior to chemical treatment. This would reduce the contaminant metal load on the treatment system and reduce the volume of sludge generated. Savings would include reduced treatment chemical purchase and sludge disposal costs. In addition, the plant could generate revenues by reselling the recovered metals.

Sludge Dewatering

Plant A can reduce sludge volume by further dewatering its sludge. Currently, the company uses a filter press to increase sludge solids to 35 percent. A sludge dryer could increase solids content up to 90 to 95 percent, representing a 60 to 65 percent reduction in sludge volume. Since the company generates approximately 50 55-gallon drums of sludge annually, (according to 1987 data) the use of a dryer could reduce that amount to approximately 17 drums. Several types of sludge drying units are available. A unit designed to handle approximately 20 gallons of sludge per day that uses an electrical heating unit costs approximately \$10,000. These types of units are energy intensive and can cost approximately \$6.00 per day to operate. Therefore, annual operating costs would be \$1,500. Other units are available that use steam as the heat source. A dryer of this type, designed to handle approximately 15 gallons of sludge per day, costs \$9,000. However, a steam source

would also be required. A steam generator would cost approximately \$4,000. These units are less energy intensive than units using electrical heating. Electrical costs to operate a steam dryer are approximately \$0.50 per day, not including the cost of generating the steam.

Savings associated with using a sludge dryer include reduced sludge disposal costs. If Plant A pays \$16,000 per year to dispose of industrial waste treatment sludge, and reduces the volume by 60 percent, it could save \$9,600 annually. Annual operating costs would be \$1,500 if a unit that operated on electricity was used. Because such a unit costs \$10,000, payback would be 15 months. Actual payback will take longer if labor and maintenance costs are included.

Alternative Treatment Processes

Plant A currently treats chromium waste with sodium metabisulfite to reduce chromium. This requires the pH of the waste stream to be between 2.0 and 2.5. The company should consider reductions with ferrous sulfate, which does not require pH adjustments down to 2.0. Although the resultant ferric ions will precipitate out and contribute to sludge volume,

often the contribution is not as great as the pH adjustment chemicals used for bisulfite reduction. Testing the ferrous sulfate treatment process will, however, require investments in time and treatment chemicals. The savings associated with alternative chromium waste treatment will include reduced treatment chemical purchases.

Plant A should evaluate its existing chromium treatment process to determine if alternative treatment chemicals could be used to reduce sludge volume. The plant should also consider electrolytic cyanide treatment to supplement its current sodium hypochlorite destruction. The advantage of this treatment over alkaline/chlorination treatment is that no sludge is generated, but this process is energy intensive and is only possible for very small batch treatment (i.e., bath dumps).

Electrolytic treatment of concentrated cyanide solutions can be performed in existing electroplating tanks. The cost of implementing electrolytic cyanide treatment would include construction of metal plate cathodes and inert anodes. Savings would include reduced treatment chemical purchases because the sodium hypochlorite treatment step is eliminated.

PLANT B WASTE MINIMIZATION ASSESSMENT

Plant B operates a job shop metal finishing plant. The company's process lines are all manually operated. The plant operates 24 hours a day, 5 days a week, with a staff of 19 platers, four assemblers, five QA/QC personnel, six compliance personnel, and one lab operator. Manufacturing operations include plating, anodizing, stripping, etching, cleaning, and other finishing processes. In the following discussion, the recommendations of the California audit team are summarized.

Process Description

Production processes that generate hazardous waste include plating, anodizing, etching, stripping, and rinsing activities. Waste includes spent baths and cleaning baths, contaminated rinse water, industrial wastewater treatment sludge, empty containers, and filter material.

PROCESS BATHS

Plant B offers a full line of metal finishing services and, therefore, operates a wide variety of process baths. Since all process baths are manually operated, workpiece racks and process baths are relatively small. Fresh baths are based on the chemical manufacturers' suggested operating parameters and on the plant's operating experience, using deionized water. Process baths are heated when specified by the manufacturer.

Bath concentrations are tested weekly in an in-house laboratory. Process baths are replenished with deionized water to prevent the buildup of natural contaminants, which are removed through continuous filtration.

If a chemical process bath no longer provides the necessary plating quality, it is replaced. Cleaning baths are usually dumped every 1 to 6 months. Plating baths will last for several years. Chromate conversion baths, however, are often replaced on a job-by-job basis.

Spent process baths are batch treated at Plant B. The spent baths are analyzed in house to identify the

necessary treatment procedures. Specific guidelines are used to treat each spent bath following analysis. At times the treatment process (such as pH adjustment) begins during the analysis stage, which enables the plant to operate more efficiently. The treatment process is recorded, treated effluent is added to the wastewater treatment system influent, and the sludge is pumped into the sludge dewatering unit.

None of the spent baths generated at Plant B are containerized for off-site disposal. Highly chelated cleaners, which were containerized for off-site disposal, have been replaced with nonchelated products. In addition, the cyanide-containing process baths, with the exception of the copper strike bath, are being replaced with noncyanide baths.

RINSE SYSTEMS

Plant B operates 22 rinse systems, most of which are multistage, counter-current rinse systems. There are 17 three-stage rinse systems and one two-stage rinse system. The flow rate varies with the work load and usually ranges from 1 to 3 gallons per minute (gpm).

Four static rinse tanks are used at Plant B. Two are heated and used for processes requiring a fast drying time. The static rinse water is normally replaced weekly or biweekly and batch treated.

Spray rinse equipment is used on the zinc and cadmium chromate rinse tanks to remove residual contaminants from the seams on sheet metal parts. This rinse system is positioned above the counter-current tank and is used after initially rinsing metal parts by immersion.

Flow restrictors have been installed on the rinse water influent lines in each rinse tank. Also, the main water line for all rinse system lines is equipped with a flow restrictor to limit total flow to 15 gpm. Because the plant has 18 flow-through rinse systems, each operating at 1 to 3 gpm, operators must turn off unused rinse systems so that those in use will operate properly.

The plant also uses rinse systems for multiple purposes that enhance rinse efficiency. A closed loop ion exchange system is used with four of the multistage counter-current rinse systems to recover rinse water. Plant B plans to convert the copper strike rinse system to a closed loop ion exchange recovery system.

These water conservation techniques have significantly reduced water usage at the plant. Rinse water use has been reduced from approximately 20,000 gallons per day (gpd) to less than 10,000 gpd.

WASTEWATER TREATMENT

Plant B's industrial waste treatment facility treats all wastewater before it is discharged to the local publicly owned treatment works (POTW). The treatment system includes chromium reduction, cyanide destruction, metals precipitation, and pH adjustment.

Wastewater influent from the rinse systems and batch treatment process is collected in two holding tanks used to segregate waste streams. One tank holds acidic and chromium-bearing wastes and the other caustic and cyanide-bearing wastes. These two tanks are used for waste equalization. Wastewater from each of the holding tanks is then pumped to one of two 1,100-gallon treatment tanks. One tank is for chromium reduction using sulfur dioxide gas; the other is for cyanide destruction using calcium hypochlorite at a pH above 10. Following treatment for chromium reduction and cyanide destruction, the wastes flow to a tank where pH adjustment and metal precipitation occurs. Following separation and thickening, the sludge is dewatered in a filter press to increase the solids concentration. The sludge is stored in metal bins prior to off-site disposal. The treated effluent is discharged to the POTW.

Waste Reduction Recommendations

Plant B has effectively implemented several technologies to reduce the amount of hazardous waste that it generates. Water conservation techniques, such as using multistage rinse systems and installing flow restrictors, have allowed the plant to significantly reduce water usage. In addition, several process lines have closed loop rinse systems. The company instructs personnel on the proper procedures for handling workpiece racks to reduce drag-out and provides

drip bars for extending workpiece drain time. Plant B has developed a batch treatment program to eliminate the need for containerizing spent baths for off-site disposal. Nevertheless, several additional opportunities for waste reduction may be available to Plant B that could further reduce hazardous waste generation.

DRAG-OUT LOSS REDUCTION

The chemical load on wastewater due to drag-out loss can be reduced by operating baths at lower concentrations. The plant should test the effectiveness of the process baths at lower concentrations to find the lowest possible operating concentration that gives acceptable results.

Drag-out loss can also be reduced by improving operator awareness of proper workpiece rack handling procedures. Plant personnel should be required to use the drip bars above the process baths so that drag-out loss can be minimized. In addition, slow workpiece rack removal techniques should be stressed. Plant B should also consider extending the drain boards to cover the space between tanks and installing drain boards on the remaining tanks.

Spray rinse systems should be used above the process bath as workpiece racks are removed. As the racks are removed, they are sprayed by nozzles positioned to maximize drag-out recovery. These systems are generally used with heated process baths since the addition of water from the rinse system would otherwise increase the process bath volume. Spray rinses can also be used as a separate rinse step before dip rinsing. If installed by plant personnel, a spray system could cost \$100 to \$200. If additional tanks are used for collecting spray solutions, the cost could increase to \$500.

DRAG-OUT RECOVERY

Plant B should replenish heated process tanks with drag-out solutions recovered in static drag-out tanks. Most heated baths will require replenishing because of evaporative water loss and chemical drag-out. A drag-out tank, used as an initial rinse before the standard flow-through rinse operation, can be used to recover lost process chemicals. Deionized water should be used for the static rinse tank to minimize the addition of contaminants into the process bath. The use of a drag-out tank will also allow the flow-

through rinse system to operate at a lower flow rate. The company should identify heated baths that can be replenished with a drag-out solution and determine how to rearrange process tanks to provide room for new drag-out tanks.

A 150-gallon drag-out tank costs approximately \$400. However, Plant B could construct its own for much less. Since Plant B already has a water pre-treatment system, the cost for deionized water would only include the cost of treatment per gallon. Other costs include personnel time for the process line rearrangements necessary to make room for an additional tank.

PROCESS CHEMICAL AND RINSE WATER RECOVERY

Plant B may be able to reduce waste generation by recovering process chemicals from several rinse water waste streams and recycling rinse water. The plant now operates closed loop rinse systems for four different chrome plating lines, but the process chemicals captured in the ion exchange columns are not recovered for reuse. Plant B should identify appropriate ion exchange resins and regenerants that can allow the plant to recover chromate solutions for replenishing process baths. Plant B can reduce chemical purchase costs, as well as waste treatment and disposal costs, by recovering chromium solutions instead of handling the chromium regenerant solutions as a waste.

Costs include the purchase of resins, regenerant solutions, and holding tanks for regenerant solutions and for recovered chromate solutions. This would not include the cost for testing various regenerants and for experimenting with reuse of the chromate solution.

Plant B should use process chemical and rinse water recovery technologies on other process lines. Approximately 2.8 percent of Plant B's sludge was nickel. Technologies that can recover nickel salts include reverse osmosis, ion exchange, and electro-dialysis. Plant B should identify the sources of nickel entering the waste stream and determine the feasibility of recovering nickel process chemicals for reuse. By implementing a recovery technology, Plant B may also be able to recycle the rinse water used for the nickel process lines.

Costs for implementing nickel salt recovery depend on the treatment capacity requirements of the recovery unit and the concentration of nickel salts in the waste stream. Plant B should identify and characterize the waste streams that carry nickel into the wastewater. This information could then be used to choose and size a recovery system and to estimate operating costs. Applicable technologies for nickel salt recovery include reverse osmosis, ion exchange, and electro-dialysis. These technologies can cost approximately \$15,000 to \$40,000, depending on the operating requirements.

If nickel salts recovery is not feasible, Plant B should consider electrolytic recovery of nickel. Assuming that the sludge generated at the plant is consistently 2.8 percent nickel by weight, approximately 5,000 pounds of nickel is disposed of annually (based on 93.5 tons of sludge generated each year). Depending on the concentration of nickel waste streams, Plant B could recover metals for resale by either installing a flow-through, high surface area electrolytic metal recovery unit or converting a plating bath tank to a batch treatment metal recovery tank.

Sludge analysis data indicate that tin was also present in relatively high concentrations. The sludge was approximately 1.5 percent tin. Although process chemical recovery technologies such as ion exchange and reverse osmosis are not typically applied to tin recovery, electrolytic recovery is still applicable. Therefore, Plant B should consider metal recovery technologies for tin.

The type of electrolytic recovery equipment necessary to recover nickel and tin depends on the concentration of these metals in the waste stream. Dilute rinse solutions require a high surface area electrolytic metal recovery unit. Concentrated waste streams, however, can be batch treated in an existing plating tank when the plant can take a plating tank out of service. The cost of batch treatment and electrolytic metal recovery processes would, therefore, only include construction of metal plate cathodes. Purchase cost of a high surface area electrolytic metal recovery unit would depend on flow rates and concentrations of the metal-bearing waste.

WASTE STREAM SEGREGATION

The plant may be able to reduce its sludge volume by further segregating its waste streams. At the present time, all acid and chromium-bearing wastes are commingled. Similarly, all alkaline and cyanide wastes are mixed. Chromium reduction and cyanide destruction are, therefore, performed on a more dilute and larger volume of wastewater than if chromium wastes and cyanide wastes were treated separately from all other waste streams. This commingling of wastes before chromium and cyanide treatment may increase the volume of treatment sludge.

Plant B can segregate its waste streams by purchasing additional holding tanks. The cost of purchasing and installing these tanks depends on their size and additional plumbing requirements. Plant B will need to identify the flow rates for the various categories of segregated wastes to determine holding capacities for the tanks.

Savings associated with segregating these wastes for selective treatment include reduced treatment chemical purchases and sludge handling costs.

Plant B may be able to estimate these savings by experimenting with batch treatment of commingled wastes and segregated wastes to determine differences in chemical usage and sludge volume.

SLUDGE DEWATERING

Plant B can reduce sludge volume by further dewatering its sludge. Wastewater treatment sludge is currently dewatered by a mechanical filter press. This increases the solids content to approximately 35 percent. The solids content of the sludge could be increased to approximately 90 to 95 percent by using a sludge dryer. Increasing the percent solids content from 35 percent to 95 percent will reduce sludge volume by 60 to 65 percent. Plant B generated 93.5 cubic yards of sludge in 1987. Use of a sludge dryer could reduce the annual sludge generation volume by approximately 60 cubic yards.

Plant B would need to purchase a small dryer to handle the 50 cubic feet of sludge it generates each week. Therefore, the sludge dryer would need to process 10 cubic feet, or 75 gallons, of sludge each day.

PLANT C WASTE MINIMIZATION ASSESSMENT

Plant C specializes in zinc plating and anodizing. The company has been in business since 1977 and employs 30 people, 4 of whom have some responsibility for environmental compliance. Plant C operates two and sometimes three 8-hour shifts per day. The following discussion summarizes the findings of the California audit team.

Process Description

Plant C operates large process baths and rinse tanks and is, therefore, able to process large workpieces.

PROCESS BATHS

Plant C's process tanks range in size from 800 gallons to 4,500 gallons. Approximately 80 percent of the production output involves zinc plating. All process lines are operated by automatic hoists.

Plant C uses several process bath maintenance techniques for its zinc baths. A wetting agent is added to the zinc baths to decrease surface tension. A swimming pool filter removes oil and particulates from the zinc process baths. Each bath is filtered as needed for approximately 24 hours. Copper contaminants are removed from the zinc baths by dummyping, a technique based on low-current electrolytic removal. Zinc anode balls are added to maintain the operating concentration.

The plant replenishes its alkaline cleaning baths by removing a portion of the bath and restoring its volume with fresh chemicals and water. The pH of the alkaline electrocleaner is monitored to determine the need for replenishing. The entire bath is dumped when replenishing becomes too frequent. The alkaline cleaning baths are also filtered to remove particulates and oil.

Workpiece rack handling is performed automatically at Plant C using hoists. The removal rate is preset for all operations and is maintained at approximately 1 foot per second. The drainage time for workpiece racks is controlled by an operator, however, and workpiece racks are allowed to drain until the drag-out stops streaming and begins to drip.

Most of the process tanks used at Plant C are set side by side with no space between where drag-out solution would drain. Drain boards are used on two of the tanks that do have space between them.

Chemical process baths are replaced when they no longer provide the necessary process quality. The frequency of bath disposal at the plant varies with the type of bath and the amount of plating required. The zinc process baths have not been replaced in over 13 years. The acid stripper baths generally last from 3 months to 6 months, the alkaline cleaner baths from 6 months to 12 months, and the remaining baths one or more years. All spent process baths are batch treated on site.

RINSE SYSTEMS

Plant C uses both static rinse tanks and flow-through rinse water tanks. All rinse tanks in the zinc plating line are static tanks and are batch treated on site. Flow-through tanks and static tanks are used on the anodizing line and discharge directly to the sanitary sewer.

The plant uses several water conservation techniques in its zinc plating rinse systems. One tank is used for a rinse bath after both alkaline and acid cleaning operations. Three other tanks are used together as a triple rinse system. Once a week, the rinse water in the initial rinse tank is removed and replaced with the rinse water from the intermediate rinse tank. Rinse water from the final rinse tank is pumped into the intermediate tank, and then is filled with clean rinse water.

Plant C operates both static and flow-through rinse tanks for the anodizing line. The rinse water effluent from the anodizing line is discharged directly to the publicly owned treatment works (POTW) since this rinse water does not contain metals that are regulated under the plant's discharge permit.

Air spargers are used on several of the rinse tanks in both the zinc plating and anodizing lines. Several rinse tanks are not equipped with air spargers,

however, because of concerns for agitating settled contaminants and affecting product quality.

WASTEWATER TREATMENT

Plant C batch treats for its waste rinse water. Rinse water is collected in a number of holding tanks and tested prior to treatment. The holding tanks segregate cyanide waste, chromium waste, and acidic and alkaline waste. Wastewater containing cyanide is treated with sodium hypochlorite to oxidize the cyanide. Wastewater containing chromium is treated with sodium bisulfite to reduce the chromium. Following these processes, caustic is added to the waste for metal precipitation and pH adjustment. Polymer is then added to aid flocculation of the precipitants. Effluent leaving the clarifier is filtered and discharged to the POTW. Sludge is settled in a holding tank and then dewatered in a filter press to increase solids content to approximately 35 percent. Once the sludge is dewatered, it is placed in a storage tank and allowed to accumulate. Plant C generates approximately 16 cubic yards of sludge quarterly and the sludge is transported off site.

Plant C also batch treats its spent baths in a separate treatment tank before adding the waste to the treatment system. These wastes are treated to remove high concentrations of metals prior to the standard treatment process. The sludge generated from the batch treatment is added to the sludge from the wastewater treatment plant, and the supernatant is added to the rinse water influent to the treatment plant.

Waste Reduction Recommendations

Plant C has effectively implemented a number of waste reduction technologies. The company continually monitors its process bath life. Several rinse water reduction techniques are used including multiple tank rinsing, static rinsing, and air spargers. The company also batch treats all spent process baths and segregates waste streams for selective treatment. Nevertheless, several additional opportunities for waste reduction may be available to Plant C to further reduce its hazardous waste generation.

DRAG-OUT LOSS REDUCTION

Drag-out lost between several of the process tanks should be recovered by using drain boards. Plant C has installed drain boards between some of its process tanks to catch drag-out and return it to the process baths. However, the remaining tanks do not have drain boards because plant personnel require access to the space between these tanks to make repairs. Removable or hinged drain boards should, therefore, be installed.

Drag-out loss can be minimized by improving workpiece removal and drainage procedures. Plant C uses an automatic hoist to remove parts from the process baths. The removal speed should be slower. Drain time should also be controlled by a timer. Optimal removal and drain times can be determined by measuring drag-out that has been allowed to drain into a pan after trying different removal speeds and drain times. The automatic hoist can be set at the optimal removal speed, and a timer can be used to help operators use adequate drain time.

Capital costs would include the purchase of timers, possible modifications to the hoist motor to allow for a slower removal rate, and material for constructing drain boards. The company will also need to commit time for personnel to experiment with modified workpiece rack removal and drain procedures.

MATERIAL SUBSTITUTION

Plant C should replace its chelated electrocleaner with a nonchelated or mild chelated cleaner. A nonchelated bath would produce less sludge during treatment.

Plant C should also replace its zinc cyanide baths with a noncyanide zinc plating chemistry. The cyanide baths and cyanide-contaminated rinse water require additional treatment to destroy the cyanide. The company now uses sodium hypochlorite to treat the cyanide wastes. Caustic is used to raise the pH prior to treatment. According to other metal finishers, replacement chemistries are available for zinc baths. By using these chemistries, the plant would not need

to use cyanide treatment and could reduce its waste treatment costs by avoiding the cyanide oxidation treatment step.

The use of nonchelated cleaners may require the process bath to be continually filtered. Filter systems cost between \$400 and \$1,000. Such a system would include a water pump, filters, and associated piping. However, depending on the actual requirements of the cleaning bath, Plant C may be able to operate with only periodic filtering using an existing filter system.

Savings from using nonchelated and noncyanide chemistries include reduced waste treatment and sludge handling costs. Plant C can test alternative process chemistries and batch treat the resultant waste to determine the effect these alternative process chemicals have on reducing sludge volume.

WASTE REUSE

Plant C should reuse spent acid and alkaline baths for waste treatment. The company now batch treats its spent acid and alkaline baths with virgin chemicals. These spent process baths could be used for pH adjustment prior to cyanide destruction and chromium reduction. The company could also use spent acids to neutralize the spent alkaline baths, if the baths are compatible. Plant C should determine which of the acidic and alkaline process baths would be best for pH adjustment prior to chromium reduction or cyanide destruction. The remaining spent acidic and alkaline baths should be used to neutralize each other, if the baths are compatible. The plant may have to synchronize its dump schedules for these baths to ensure availability and to minimize the length of time spent baths would have to be stored prior to reuse.

Costs associated with using process bath wastes for wastewater treatment include the purchase of holding tanks and the time required to test various treatment options. Holding tanks for the spent baths could cost between \$400 and \$600 for 150- to 400-gallon tanks. The effectiveness of the spent process baths for wastewater treatment can be tested on a batch treatment basis in the treatment system. Significant savings can be expected from reusing spent baths for wastewater treatment and will include reduced treatment chemical purchases and sludge generation.

WASTEWATER TREATMENT

Several potential wastewater treatment modifications are available to Plant C that provide opportunities for sludge volume reduction. The company generates over 60 cubic yards of sludge annually. Although no sludge characterization data were available to assess the efficiency of the existing treatment system, it appears that modifications to the system could reduce sludge volume.

The plant treats chromium wastes with sodium bisulfite to reduce chromium. This requires the pH of the waste stream to be between 2.0 and 2.5. The acids used to drop the pH and the caustic used to raise it for metal precipitation contribute to sludge volume. The company should consider reductions with ferrous sulfate, which does not require pH adjustments down to 2.0. Although the resulting ferric ions will precipitate out and contribute to sludge volume, often the contribution is not as great as the pH adjustment chemicals used for bisulfite reduction. Plant C should evaluate its existing chromium treatment process to determine if alternative treatment chemicals could be used to reduce sludge volume.

Plant C should also consider electrolytic recovery of zinc from its spent process bath and rinse solutions. The plant now batch treats its spent zinc solutions to precipitate metals. Some spent solutions contain zinc in concentrations as high as 80,000 parts per million. These solutions could be electrolytically treated to recover the zinc. The company could use an existing plating tank. By inserting numerous metal boards into the spent solution and running a current through it, plant personnel can recover the zinc in the spent solution.

SLUDGE DEWATERING

Plant C can significantly reduce its sludge disposal costs by dewatering its industrial waste treatment sludge. The plant generates approximately 35 cubic feet of sludge per week (7 cubic feet per day). Therefore, a sludge dryer with a treatment capacity of 1.0 to 1.5 cubic feet per hour is appropriate. A continuous feed dryer appears necessary to minimize labor costs. A dryer of this type, which uses either natural gas or propane as a fuel source, would cost approximately

\$27,000, not including the cost for a propane tank. If the unit operated 5 hours a day, 5 days a week, operating costs for a unit fueled by propane would be approximately \$1,500 per year. The operating costs do not include labor.

Plant C currently pays approximately \$16,000 per year to dispose of its industrial waste sludge. However, this figure does not include state and federal hazardous waste taxes, which could increase disposal

costs by \$67 per cubic yard (a \$4,200 increase in Plant C's annual disposal costs). If a dryer achieved a 2.5-to-1 reduction in sludge volume, annual disposal costs would be reduced by approximately \$10,000 (\$12,100 if taxes are considered). After subtracting the annual operating costs, annual savings would be approximately \$8,500. This represents approximately a 3-year payback on investment. The payback time would be 2.5 years if waste taxes are included in the cost of sludge disposal.

Appendix B

WHERE TO GET HELP:

FURTHER INFORMATION ON POLLUTION PREVENTION

Additional information on source reduction, reuse and recycling approaches to pollution prevention is available in EPA reports listed in this section, and through state programs and regional EPA offices (listed below) that offer technical and/or financial assistance in the areas of pollution prevention and treatment.

Waste exchanges have been established in some areas of the U.S. to put waste generators in contact with potential users of the waste. Twenty-four exchanges operating in the U.S. and Canada are listed. Finally, relevant industry associations are listed.

U.S. EPA Reports on Waste Minimization

Facility Pollution Prevention Guide. EPA/600/R-92/088.*

Waste Minimization Opportunity Assessment Manual. EPA/625/7-88/003.*

Waste Minimization Audit Report: Case Studies of Corrosive and Heavy Metal Waste Minimization Audit at a Specialty Steel Manufacturing Complex. Executive Summary. EPA No. PB88-107180.**

Waste Minimization Audit Report: Case Studies of Minimization of Solvent Waste for Parts Cleaning and from Electronic Capacitor Manufacturing Operation. Executive Summary. EPA NO. PB87-227013.**

Waste Minimization Audit Report: Case Studies of Minimization of Cyanide Wastes from Electroplating Operations. Executive Summary. EPA No. PB87-229662.**

Report to Congress: Waste Minimization, Vols. I and II. EPA/530-SW-86-033 and -034 (Washington, D.C.: U.S. EPA, 1986).***

Waste Minimization—Issues and Options, Vols. I-III. EPA/530-SW-86-041 through -043. (Washington, D.C.: U.S. EPA, 1986).***

The Guides to Pollution Prevention manuals* describe waste minimization options for specific industries. This is a continuing series which currently includes the following titles:

Guides to Pollution Prevention: Paint Manufacturing Industry. EPA/625/7-90/005.

Guides to Pollution Prevention: The Pesticide Formulating Industry. EPA/625/7-90/004.

Guides to Pollution Prevention: The Commercial Printing Industry. EPA/625/7-90/008.

Guides to Pollution Prevention: The Fabricated Metal Industry. EPA/625/7-90/006.

Guides to Pollution Prevention for Selected Hospital Waste Streams. EPA/625/7-90/009.

Guides to Pollution Prevention: Research and Educational Institutions. EPA/625/7-90/010.

Guides to Pollution Prevention: The Printed Circuit Board Manufacturing Industry. EPA/625/7-90/007.

* Available from EPA CERI Publications Unit (513) 569-7562, 26 West Martin Luther King Drive, Cincinnati, OH, 45268.

** Executive Summary available from EPA, CERI Publications Unit, (513) 569-7562, 26 West Martin Luther King Drive, Cincinnati, OH, 45268; full report available from the National Technical Information Service (NTIS), U.S. Department of Commerce, Springfield, VA, 22161.

*** Available from the National Technical Information Service as a five-volume set, NTIS No. PB-87-114-328.

Guides to Pollution Prevention: The Pharmaceutical Industry. EPA/625/7-91/017.

Guides to Pollution Prevention: The Photoprocessing Industry. EPA/625/7-91/012.

Guides to Pollution Prevention: The Fiberglass Reinforced and Composite Plastic Industry. EPA/625/7-91/014.

Guides to Pollution Prevention: The Automotive Repair Industry. EPA/625/7-91/013.

Guides to Pollution Prevention: The Automotive Refinishing Industry. EPA/625/7-91/016.

Guides to Pollution Prevention: The Marine Maintenance and Repair Industry. EPA/625/7-91/015.

Guides to Pollution Prevention: The Metal Casting and Heat Treating Industry.

Guides to Pollution Prevention: Mechanical Equipment Repair Shops.

Guides to Pollution Prevention: The Metal Finishing Industry.

U.S. EPA Pollution Prevention Information Clearinghouse (PPIC): *Electronic Information Exchange System (EIES)—User Guide, Version 1.1.* EPA/600/9-89/086.

Waste Reduction Technical/ Financial Assistance Programs

The EPA Pollution Prevention Information Clearinghouse (PPIC) was established to encourage waste reduction through technology transfer, education, and public awareness. PPIC collects and disseminates technical and other information about pollution prevention through a telephone hotline and an electronic information exchange network. Indexed bibliographies and abstracts of reports, publications, and case studies about pollution prevention are available. PPIC also lists a calendar of pertinent conferences and seminars, information about activities abroad, and a directory of waste exchanges. Its Pollution Prevention Information Exchange System (PIES) can be accessed electronically 24 hours a day without fees.

For more information contact:

PIES Technical Assistance
Science Applications International Corp.
8400 Westpark Drive
McLean, VA 22102
(703) 821-4800

or

U.S. Environmental Protection Agency
401 M Street S.W.
Washington, D.C. 20460

Myles E. Morse
Office of Environmental Engineering and
Technology Demonstration
(202) 475-7161

Priscilla Flattery
Pollution Prevention Office
(202) 245-3557

The EPA's Office of Solid Waste and Emergency Response has a telephone call-in service to answer questions regarding RCRA and Superfund (CERCLA). The telephone numbers are:

(800) 242-9346 (outside the District of Columbia)

(202) 382-3000 (in the District of Columbia)

The following programs offer technical and/or financial assistance for waste minimization and treatment.

Alabama
Hazardous Material Management and Resource
Recovery Program
University of Alabama
P.O. Box 6373
Tuscaloosa, AL 35487-6373
(205) 348-8401

Department of Environmental Management
1751 Federal Drive
Montgomery, AL 36130
(205) 271-7914

Alaska

Alaska Health Project
Waste Reduction Assistance Program
431 West Seventh Avenue, Suite 101
Anchorage, AK 99501
(907) 276-2864

Arizona

Arizona Department of Economic Planning and
Development
1645 West Jefferson Street
Phoenix, AZ 85007
(602) 255-5705

Arkansas

Arkansas Industrial Development Commission
One State Capitol Mall
Little Rock, AR 72201
(501) 371-1370

California

Alternative Technology Section
Toxic Substances Control Division
California State Department of Health Services
714/744 P Street
Sacramento, CA 94234-7320
(916) 324-1807

Pollution Prevention Program
San Diego County Department of Health Services
Hazardous Materials Management Division
P.O. Box 85261
San Diego, CA 92186-5261
(619) 338-2215

Colorado

Division of Commerce and Development Commission
500 State Centennial Building
Denver, CO 80203
(303) 866-2205

Connecticut

Connecticut Hazardous Waste Management Service
Suite 360
900 Asylum Avenue
Hartford, CT 06105
(203) 244-2007

Connecticut Department of Economic Development
210 Washington Street
Hartford, CT 06106
(203) 566-7196

Delaware

Delaware Department of Community Affairs &
Economic Development
630 State College Road
Dover, DE 19901
(302) 736-4201

District of Columbia

U.S. Department of Energy
Conservation and Renewable Energy
Office of Industrial Technologies
Office of Waste Reduction, Waste Material
Management Division
Bruce Cranford CE-222
Washington, DC 20585
(202) 586-9496

Pollution Control Financing Staff
Small Business Administration
1441 "L" Street, N.W., Room 808
Washington, DC 20416
(202) 653-2548

Florida

Waste Reduction Assistance Program
Florida Department of Environmental Regulation
2600 Blair Stone Road
Tallahassee, FL 32399-2400
(904) 488-0300

Georgia

Hazardous Waste Technical Assistance Program
Georgia Institute of Technology
Georgia Technical Research Institute
Environmental Health and Safety Division
O'Keefe Building, Room 027
Atlanta, GA 30332
(404) 894-3806

Environmental Protection Division
Georgia Department of Natural Resources
205 Butler Street, S.E., Suite 1154
Atlanta, GA 30334
(404) 656-2833

Guam

Solid and Hazardous Waste Management Program
Guam Environmental Protection Agency
IT&E Harmon Plaza, Complex Unit D-107
130 Rojas Street
Harmon, Guam 96911
(671) 646-8863-5

Hawaii

Department of Planning & Economic Development
Financial Management and Assistance Branch
P.O. Box 2359
Honolulu, HI 96813
(808) 548-4617

Idaho

IDHW-DEQ
Hazardous Materials Bureau
450 West State Street, 3rd Floor
Boise, ID 83720
(208) 334-5879

Illinois

Illinois EPA
Office of Pollution Prevention
2200 Churchill Road
P.O. Box 19276
Springfield, Illinois 62794-9276
(217) 782-8700

Hazardous Waste Research and Information Center
Illinois Department of Energy and Natural Resources
One East Hazelwood Drive
Champaign, IL 61820
(217) 333-8940

Illinois Waste Elimination Research Center
Pritzker Department of Environmental Engineering
Alumni Memorial Hall, Room 103
Illinois Institute of Technology
3201 South Dearborn
Chicago, IL 60616
(312) 567-3535

Indiana

Environmental Management and Education Program
School of Civil Engineering
Purdue University
2129 Civil Engineering Building
West Lafayette, IN 47907
(317) 494-5036

Indiana Department of Environmental Management
Office of Technical Assistance
P.O. Box 6015
105 South Meridian Street
Indianapolis, IN 46206-6015
(317) 232-8172

Iowa

Center for Industrial Research and Service
Iowa State University
Suite 500, Building 1
2501 North Loop Drive
Ames, IA 50010-8286
(515) 294-3420

Iowa Department of Natural Resources
Air Quality and Solid Waste Protection Bureau
Wallace State Office Building
900 East Grand Avenue
Des Moines, IA 50319-0034
(515) 281-8690

Waste Management Authority
Iowa Department of Natural Resources
Henry A. Wallace Building
900 East Grand
Des Moines, IA 50319
(515) 281-8489

Iowa Waste Reduction Center
University of Northern Iowa
75 Biology Research Complex
Cedar Falls, IA 50614
(319) 273-2079

Kansas

Bureau of Waste Management
Department of Health and Environment
Forbes Field, Building 730
Topeka, KS 66620
(913) 269-1607

Kentucky

Division of Waste Management
Natural Resources and Environmental Protection
Cabinet
18 Reilly Road
Frankfort, KY 40601
(502) 564-6716

Kentucky Partners
Room 312 Ernst Hall
University of Louisville
Speed Scientific School
Louisville, KY 40292
(502) 588-7260

Louisiana
Department of Environmental Quality
Office of Solid and Hazardous Waste
P.O. Box 44307
Baton Rouge, LA 70804
(504) 342-1354

Maine
State Planning Office
184 State Street
Augusta, ME 04333
(207) 289-3261

Maryland
Maryland Hazardous Waste Facilities Siting Board
60 West Street, Suite 200 A
Annapolis, MD 21401
(301) 974-3432

Massachusetts
Office of Technical Assistance
Executive Office of Environmental Affairs
100 Cambridge Street, Room 1904
Boston, MA 02202
(617) 727-3260

Source Reduction Program
Massachusetts Department of Environmental
Quality Engineering
1 Winter Street
Boston, MA 02108
(617) 292-5982

Michigan
Resource Recovery Section
Department of Natural Resources
P.O. Box 30028
Lansing, MI 48909
(517) 373-0540

Minnesota
Minnesota Pollution Control Agency
Solid and Hazardous Waste Division
520 Lafayette Road
St. Paul, MN 55155
(612) 296-6300

Minnesota Technical Assistance Program
1313 5th Street, S.E., Suite 207
Minneapolis, MN 55414
(612) 627-4646
(800) 247-0015 (in Minnesota)

Mississippi
Waste Reduction & Minimization Program
Bureau of Pollution Control
Department of Environmental Quality
P.O. Box 10385
Jackson, MS 39289-0385
(601) 961-5190

Missouri
State Environmental Improvement and Energy
Resources Agency
P.O. Box 744
Jefferson City, MO 65102
(314) 751-4919

Waste Management Program
Missouri Department of Natural Resources
Jefferson Building, 13th Floor
P.O. Box 176
Jefferson City, MO 65102
(314) 751-3176

Nebraska
Land Quality Division
Nebraska Department of Environmental Control
Box 98922
State House Station
Lincoln, NE 68509-8922
(402) 471-2186

Hazardous Waste Section
Nebraska Department of Environmental Control
P.O. Box 98922
Lincoln, NE 68509-8922
(402) 471-2186

New Jersey
New Jersey Hazardous Waste Facilities Siting
Commission
Room 514
28 West State Street
Trenton, NJ 08625
(609) 292-1459
(609) 292-1026

Hazardous Waste Advisement Program
Bureau of Regulation and Classification
New Jersey Department of Environmental Protection
401 East State Street
Trenton, NJ 08625
(609) 292-8341

Risk Reduction Unit
Office of Science and Research
New Jersey Department of Environmental Protection
401 East State Street
Trenton, NJ 08625
(609) 292-8341

New Mexico
Economic Development Department
Bataan Memorial Building
State Capitol Complex
Santa Fe, NM 87503
(505) 827-6207

New York
New York Environmental Facilities Corporation
50 Wolf Road
Albany, NY 12205
(518) 457-4222

North Carolina
Pollution Prevention Pays Program
Department of Natural Resources and Community
Development
P.O. Box 27687
512 North Salisbury Street
Raleigh, NC 27611-7687
(919) 733-7015

Governor's Waste Management Board
P.O. Box 27687
325 North Salisbury Street
Raleigh, NC 27611-7687
(919) 733-9020

Technical Assistance Unit
Solid and Hazardous Waste Management Branch
North Carolina Department of Human Resources
P.O. Box 2091
306 North Wilmington Street
Raleigh, NC 27602
(919) 733-2178

North Dakota
North Dakota Economic Development Commission
Liberty Memorial Building
State Capitol Grounds
Bismarck, ND 58505
(701) 224-2810

Ohio
Division of Hazardous Waste Management
Division of Solid and Infectious Waste Management
Ohio Environmental Protection Agency
P.O. Box 0149
1800 Watermark Drive
Columbus, OH 43266-0149
(614) 644-2917

Oklahoma
Industrial Waste Elimination Program
Oklahoma State Department of Health
P.O. Box 53551
Oklahoma City, OK 73152
(405) 271-7353

Oregon
Oregon Hazardous Waste Reduction Program
Department of Environmental Quality
811 Southwest Sixth Avenue
Portland, OR 97204
(503) 229-5913
(800) 452-4011 (in Oregon)

Pennsylvania
Pennsylvania Technical Assistance Program
501 F. Orvis Keller Building
University Park, PA 16802
(814) 865-0427

Center of Hazardous Material Research
Subsidiary of the University of Pittsburgh Trust
320 William Pitt Way
Pittsburgh, PA 15238
(412) 826-5320
(800) 334-2467

Puerto Rico

Government of Puerto Rico
Economic Development Administration
Box 2350
San Juan, PR 00936
(809) 758-4747

Rhode Island

Hazardous Waste Reduction Section
Office of Environmental Management
83 Park Street
Providence, RI 02903
(401) 277-3434
(800) 253-2674 (in Rhode Island)

South Carolina

Center for Waste Minimization
Department of Health and Environmental Control
2600 Bull Street
Columbia, SC 29201
(803) 734-4715

South Dakota

Department of State Development
P.O. Box 6000
Pierre, SD 57501
(800) 843-8000

Tennessee

Center for Industrial Services
University of Tennessee
Building #401
226 Capitol Boulevard
Nashville, TN 37219-1804
(615) 242-2456

Bureau of Environment

Tennessee Department of Health and Environment
150 9th Avenue North
Nashville, TN 37219-5404
(615) 741-3657

**Tennessee Hazardous Waste Minimization Program
Tennessee Department of Economic and Community
Development**

Division of Existing Industry Services
7th Floor, 320 6th Avenue, North
Nashville, TN 37219
(615) 741-1888

Texas

Texas Economic Development Authority
410 East Fifth Street
Austin, TX 78701
(512) 472-5059

Utah

Utah Division of Economic Development
6150 State Office Building
Salt Lake City, UT 84114
(801) 533-5325

Vermont

Economic Development Department
Pavilion Office Building
Montpelier, VT 05602
(802) 828-3221

Virginia

Office of Policy and Planning
Virginia Department of Waste Management
11th Floor, Monroe Building
101 North 14th Street
Richmond, VA 23219
(804) 225-2667

Washington

Hazardous Waste Section
Mail Stop PV-11
Washington Department of Ecology
Olympia, WA 98504-8711
(206) 459-6322

West Virginia

Governor's Office of Economics and Community
Development
Building G, Room B-517
Capitol Complex
Charleston, WV 25305
(304) 348-2234

Wisconsin

Bureau of Solid Waste Management
Wisconsin Department of Natural Resources
P.O. Box 7921
101 South Webster Street
Madison, WI 53707
(608) 267-3763

Wyoming
Solid Waste Management Program
Wyoming Department of Environmental Quality
Herschler Building, 4th Floor, West Wing
122 West 25th Street
Cheyenne, WY 82002
(307) 777-7752

Waste Exchanges

Alberta Waste Materials Exchange
Mr. William C. Kay
Alberta Research Council
P.O. Box 8330
Postal Station F
Edmonton, Alberta
CANADA T6H 5X2
(403) 450-5408

British Columbia Waste Exchange
Ms. Judy Toth
2150 Maple Street
Vancouver, B.C.
CANADA V6J 3T3
(604) 731-7222

California Waste Exchange
Mr. Robert McCormick
Department of Health Services
Toxic Substances Control Program
Alternative Technology Division
P.O. Box 942732
Sacramento, CA 94234-7320
(916) 324-1807

Canadian Chemical Exchange*
Mr. Philippe LaRoche
P.O. Box 1135
Ste-Adele, Quebec
CANADA J0R 1L0
(514) 229-6511

Canadian Waste Materials Exchange
ORTECH International
Dr. Robert Laughlin
2395 Speakman Drive
Mississauga, Ontario
CANADA L5K 1B3
(416) 822-4111 (Ext. 265)
FAX: (416) 823-1446

Enstar Corporation*
Mr. J. T. Engster
P.O. Box 189
Latham, NY 12110
(518) 785-0470

Great Lakes Regional Waste Exchange
400 Ann Street, N.W., Suite 204
Grand Rapids, MI 49504
(616) 363-3262

Indiana Waste Exchange
Dr. Lynn A. Corson
Purdue University
School of Civil Engineering
Civil Engineering Building
West Lafayette, IN 47907
(317) 494-5036

Industrial Materials Exchange
Mr. Jerry Henderson
172 20th Avenue
Seattle, WA 98122
(206) 296-4633
FAX: (206) 296-0188

Industrial Materials Exchange Service
Ms. Diane Shockey
P.O. Box 19276
Springfield, IL 62794-9276
(217) 782-0450
FAX: (217) 524-4193

Industrial Waste Information Exchange
Mr. William E. Payne
New Jersey Chamber of Commerce
5 Commerce Street
Newark, NJ 07102
(201) 623-7070

Manitoba Waste Exchange
Mr. James Ferguson
c/o Biomass Energy Institute, Inc.
1329 Niakwa Road
Winnipeg, Manitoba
CANADA R2J 3T4
(204) 257-3891

*For-Profit Waste Information Exchange

Montana Industrial Waste Exchange
Mr. Don Ingles
Montana Chamber of Commerce
P.O. Box 1730
Helena, MT 59624
(406) 442-2405

New Hampshire Waste Exchange
Mr. Gary J. Olson
c/o NHRRA
P.O. Box 721
Concord, NH 03301
(603) 224-6996

Northeast Industrial Waste Exchange, Inc.
Mr. Lewis Cutler
90 Presidential Plaza, Suite 122
Syracuse, NY 13202
(315) 422-6572
FAX: (315) 422-9051

Ontario Waste Exchange
ORTECH International
Ms. Linda Varangu
2395 Speakman Drive
Mississauga, Ontario
CANADA L5K 1B3
(416) 822-4111 (Ext. 512)
FAX: (416) 823-1446

Pacific Materials Exchange
Mr. Bob Smee
South 3707 Godfrey Boulevard
Spokane, WA 99204
(509) 623-4244

Peel Regional Waste Exchange
Mr. Glen Milbury
Regional Municipality of Peel
10 Peel Center Drive
Brampton, Ontario
CANADA L6T 4B9
(416) 791-9400

RENEW
Ms. Hope Castillo
Texas Water Commission
P.O. Box 13087
Austin, TX 78711-3087
(512) 463-7773
FAX: (512) 463-8317

San Francisco Waste Exchange
Ms. Portia Sinnott
2524 Benvenue #35
Berkeley, CA 94704
(415) 548-6659

Southeast Waste Exchange
Ms. Maxie L. May
Urban Institute
UNCC Station
Charlotte, NC 28223
(704) 547-2307

Southern Waste Information Exchange
Mr. Eugene B. Jones
P.O. Box 960
Tallahassee, FL 32302
(800) 441-SWIX (7949)
(904) 644-5516
FAX: (904) 574-6704

Tennessee Waste Exchange
Ms. Patti Christian
226 Capital Boulevard, Suite 800
Nashville, TN 37202
(615) 256-5141
FAX: (615) 256-6726

Wastelink, Division of Tencon, Inc.
Ms. Mary E. Malotke
140 Wooster Pike
Milford, OH 45150
(513) 248-0012
FAX: (513) 248-1094

U.S. EPA Regional Offices

Region 1 (VT, NH, ME, MA, CT, RI)
John F. Kennedy Federal Building
Boston, MA 02203
(617) 565-3715

Region 2 (NY, NJ, PR, VI)
26 Federal Plaza
New York, NY 10278
(212) 264-2525

Region 3 (PA, DE, MD, WV, VA, DC)
841 Chestnut Street
Philadelphia, PA 19107
(215) 597-9800

Region 4 (KY, TN, NC, SC, GA, FL, AL, MS)
345 Courtland Street, N.E.
Atlanta, GA 30365
(404) 347-4727

Region 5 (WI, MN, MI, IL, IN, OH)
230 South Dearborn Street
Chicago, IL 60604
(312) 353-2000

Region 6 (NM, OK, AR, LA, TX)
1445 Ross Avenue
Dallas, TX 75202
(214) 655-6444

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Region 10 (AK, WA, OR, ID)
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Seattle, WA 98101
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Industry & Trade Associations

National Association of Metal Finishers (NAMF)
111 East Wacker Drive, Suite 600
Chicago, IL 60601
(312) 644-6610

American Electroplaters and Surface Finishers Society
(AESF)
12644 Research Parkway
Orlando, FL 32826-3298
(407) 281-6441

Metal Finishing Suppliers' Association (MFSA)
801 North Cass Avenue
Westmont, IL 60559
(708) 887-0797

Videos

Management Training in Pollution Prevention and
Control in the Metal Finishing Industry
Environment Canada, 1991
Canadian Water and Wastewater Association
24 Clarence Street, 3rd Floor
Ottawa, Ontario, Canada K1N 5P3
(613) 238-5692

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