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Waste Minimization in Metal Parts Cleaning

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This booklet provides information on ways to reduce wastes associated with metal parts cleaning operations. It was published by EPA's Office of Solid Waste and Emergency Response and is part of EPA's waste minimization program under the 1984 RCRA amendments.

Other EPA Waste Minimization Publications

Waste Minimization Benefits Manual
Manual for Waste Minimization Opportunity Assessments
Guide to Waste Minimization for the Paint Manufacturing Industry
Guide to Waste Minimization for the Pesticide Formulating Industry
Guide to Waste Minimization for the Commercial Printing Industry
(The latter three publications were developed jointly by EPA's Risk Reduction Engineering Laboratory and the California Department of Health Services.)

Disclaimer

This guide is advisory only. It is intended to be used by industrial personnel responsible for metal parts cleaning operations in order to help them develop approaches for minimizing wastes. Compliance with environmental and occupational safety and health laws is the responsibility of each individual business and is not the focus of this document. Mention of any product, service, or process in this document is for educational purposes only and should not be considered an endorsement by the U.S. Environmental Protection Agency.

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"The Congress hereby declares it to be the national policy of *the United States that, whenever feasible, the generation of hazardous waste is to be reduced or ‘eliminated as expeditiously as possible." HSWA 1984.*

1. INTRODUCTION

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The Hazardous and Solid Waste Amendments of 1984 to the Resource Conservation and Recovery Act (RCRA) establish as a national policy that hazardous wastes are to be reduced or eliminated as expeditiously as possible. To help accomplish this goal, the U.S. Environmental Protection Agency (EPA) will provide technical materials and guidance to companies through its waste minimization technology transfer program. As part of EPA's program, this booklet was prepared to provide waste minimization options to companies with parts cleaning operations.

Parts cleaning is an important process for a large variety of organizations involved in the manufacture, repair, and maintenance of parts and equipment. From large metal fabrication plants to captive maintenance shops of industrial facilities, parts cleaning operations are essential to doing business.

The reason for focusing attention on minimizing waste in parts cleaning operations is because the solvents and other chemicals used in parts cleaning often result in significant air emissions, wastewater discharges, and the generation of hazardous wastes. Waste minimization offers a significant and often cost effective opportunity to reduce the emissions and discharges of toxic pollutants into the environment.

This booklet is organized as follows. This introduction covers basic definitions and concepts of waste minimization, and it outlines incentives for minimizing waste. A general strategy for minimizing waste is presented. An approach for applying this waste minimization strategy to parts cleaning operations is provided in Section Two, which begins with an overview of parts cleaning operations. Section Three presents waste minimization options in solvent cleaning, aqueous-based cleaning, and abrasive cleaning applications. A discussion of options implementation follows; then conclusions, waste minimization information sources, and a bibliography close the document.

This booklet is intended to provide the reader with key concepts and establish a good point of departure in the search for viable waste minimization techniques. Examples are provided throughout the text to help the reader obtain more detail or specifics for an option being discussed. However, this booklet is not intended to replace in-depth references or provide detailed information that may be needed to fully evaluate the feasibility of a specific option.

Where this information is available, the examples provided in this booklet include the economics of implementing a waste minimization option. However, the economics of making changes in an operation are often facility-specific; the scale of an operation may have a great deal to do with whether new capital outlays can be justified, for example. Because of differences between facilities, generalizations are difficult and the reader is advised to consider site specifics in determining whether a waste minimization option is economically feasible. In addition to the conventional capital and operating costs that are part of profitability analysis, waste minimization projects should be considered for their less tangible but beneficial consequences, such as avoided regulatory compliance costs, liability avoidance, improved health and environment and resulting improved public image. The reader is referred to EPA's Waste Minimization Benefits Manual for additional information (USEPA, 1988C)

1.1 What is Waste Minimization?

Waste minimization can be accomplished either through source reduction or recycling of hazardous wastes that are generated or subsequently treated, disposed of, or stored (Figure 1). Although much of the current focus of waste minimization is on hazardous waste, EPA encourages and promotes the minimization of all wastes released into air, water, and land.

Source reduction is the in-plant reduction of waste, usually and preferably within the process that generates it. Recycling is the use, reuse, or reclamation of waste material. Treatment of hazardous waste is not considered by EPA to be waste minimization, unless it is performed as a necessary step to render the waste recyclable. The reduction of waste toxicity by dilution, or of waste volume by dewatering (or more generally, by the removal of an inert innocuous component) are not considered alone and by themselves to be viable waste minimization options.

One approach to waste minimization is source reduction. The in-plant source reduction approach relies on changes to input materials, to the physical plant (or technology), or to the operating practices component of the manufacturing process. Of all three methods of source reduction, the improvement of operating practices is often the easiest, least costly, and most effective waste minimization approach, especially in the initial stages of a waste minimization effort.

Source reduction is generally preferable to recycling because waste generation is directly curtailed or avoided in the first place. Recycling should be conducted wherever possible, for wastes that cannot be eliminated or reduced by making changes in the process.

Figure 1. WASTE MINIMIZATION DEFINITIONS

WASTE MINIMIZATION

The elimination or reduction, to the extent feasible, of hazardous waste that is generated and would otherwise be subsequently treated, stored or disposed of. It includes any source reduction or recycling activity undertaken by a generator that results in either (1) the reduction of total volume or quantity of hazardous waste or (2) the reduction of toxicity of the hazardous waste, or both, so long as such reduction is consistent with the goal of minimization present and future threats to human health and the environment (USEPA 1986).

SOURCE REDUCTION

Any activity that reduces or eliminates the generation of hazardous waste at the source, usually within a process (USEPA 1986).

RECYCLING

A material is "recycled" if it is used, reused, or reclaimed (40 CFR 261.1(c)(7). A material is "used or reused" if it is either (1) employed as an ingredient (including its use as an intermediate) to make a product; however a material will not satisfy this condition if distinct components of the material are recovered as separate end products (as when metals are recovered from metal containing secondary materials) or (2) employed in a particular function as an effective substitute for a commercial product (40 CFR 261.1(c)(5). A material is "reclaimed" if it is processed to recover a useful product or if it is regenerated. Examples include the recovery of lead values from spent batteries and the regeneration of spent solvents (40 CFR 261.1(C)(4).

1.2 Incentives For Minimizing Waste

There are numerous economic, regulatory, legal, and other incentives for minimizing waste. A summary of these incentives is provided in Table 1.

It is worth noting that, unlike traditional end-of-pipe treatment approaches, waste minimization offers real potential for reducing manufacturing cost and thus can successfully compete with other plant improvement projects for funding.

1.3 Waste Minimization Assessments

Specific waste minimization options can be identified and developed by conducting a waste minimization assessment. The assessment process (Figure 2) is a set of procedures for investigating waste streams, generating waste minimization options, evaluating their feasibility and implementing those that are found to be feasible. The reader is referred to the EPA's Waste Minimization ***Opportunity Assessment Manual*** (USEPA 1988B) for details on how to execute the assessments and other components of the overall waste minimization program. The most successful programs in industry include a strong management and employee commitment to reduce waste and save money.

Table 1. Incentives for Waste Minimization

Economics
- Increased land disposal costs.
- Savings in raw material and manufacturing costs.
- Avoidance of costly alternative treatment technologies.

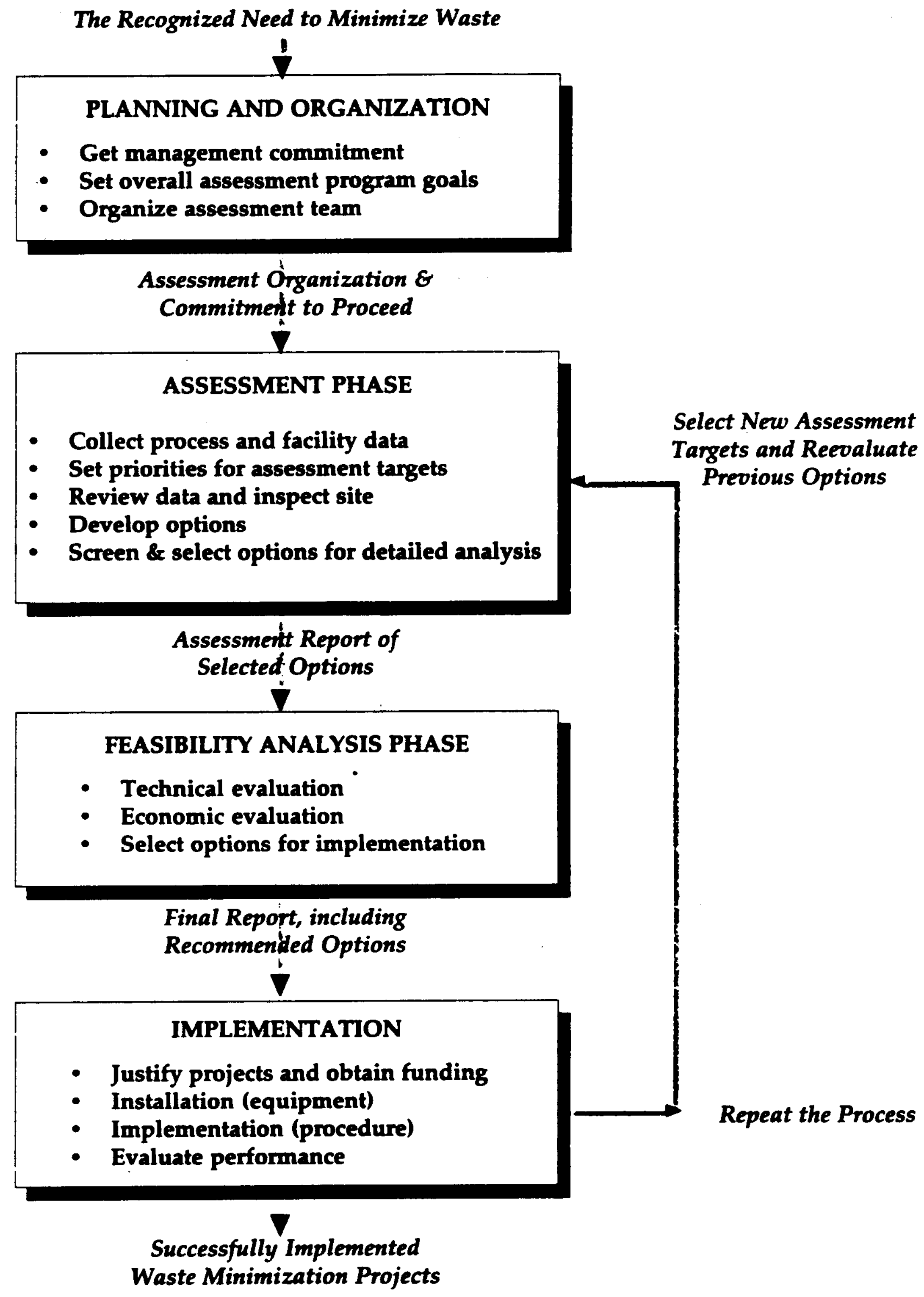
Regulations
- Certification of a waste minimization program on the hazardous waste manifest.
- Biennial waste minimization program reporting.
- Land disposal restrictions and bans.
- Increasing permitting requirements for waste handling and treatment.

Liability
- Potential reduction in generator liability for environmental problems at both onsite and offsite treatment, storage, and disposal facilities.
- Potential reduction in liability for worker safety.

Public Image and Environmental Concern
- Improved image in the community and among employees.
- Reduced impact on the environment.

Source: USEPA, 1988B.

Figure 2. The Waste Minimization Assessment Procedure



2. WASTE MINIMIZATION IN PARTS CLEANING OPERATIONS

2.1 Overview of Parts Cleaning

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Parts cleaning is an integral process operation for industries that repair, maintain, or manufacture parts and equipment. Examples of such industries are automobile repair, equipment repair, and transportation maintenance industries (trucks, trains, ships, and aircraft). Manufacturing groups include furniture manufacturers, metal fabricators, machinery manufacturers, electric and electronic equipment manufacturers, and instrument manufacturers, among many others.

While the science of parts cleaning is very complex, the aim of cleaning is relatively simple -to avoid the generation of rejects during subsequent use or processing steps by removing contamination (i.e. soil) from the surface of the parts being cleaned. Removal of soils can be achieved by way of detergency, solvency, chemical reaction, or mechanical action. Each of these actions, or a combination of actions, can be employed in a cleaning operation.

Organic solvents, the most widely used class of cleaners, are used primarily for removing organic or oil-based contaminants. The types of solvents commonly used for commercial cleaning applications are shown in Table 2 along with other cleaning media, listed by their cleaning action. Table 3 provides a summary of cleaning methods or means of applying a particular cleaning medium.

Aqueous cleaners can contain acids, alkalies or chelating agents. Acid cleaners such as sulfuric, nitric, and hydrochloric acids are used to remove oxidation scale and rust from metal surfaces. Alkaline cleaners are solutions of inorganic salts often used in heated soak tanks to remove heavy oily soils and some solid soils. Caustic solution is often employed as a paint stripping agent. For both acid and alkaline aqueous cleaners, rinse water plays an important part in the cleaning operation.

Abrasives are designed to remove rust, oxides, and burrs to create a smooth surface. Common abrasives are sand, aluminum oxide, or silicon carbide mixed with an oil- or water-based binder.

Detailed review and discussion of parts cleaning can be found in several references in the bibliography, including Spring, 1963 and 1974; Dumey, 1984, and the American ***Society*** for ***Metals' Metals Handbook,*** 1988.

Table 2. Cleaning Media, Listed by Action

Detergency

(1) Alkaline salts and caustics
(2) Surfactants (soaps and synthetic soaps)
(3) Alkaline cleaners (1 and 2 combined)
(4) Emulsion cleaners (solvents and surfactants)

Solvency

(1) Aliphatic hydrocarbons: naphtha, kerosene, diesel fuel
(2) Aromatic hydrocarbons: benzene, toluene, xylene
(3) Non-flammable solvents (halogenated hydrocarbons: TCA, TCE, PCE, methylene chloride, chlorofluorocarbons)
(4) Polar solvents (ketones, alcohols, esters, ethers, terpenes, amines)
(5) Emulsifiable solvents (flushed away with water)
(6) Diphase cleaners (solvent and aqueous layered media)

Chemical Reaction

(1) Acidic baths (pickling) yield soluble salts by reaction with oxides, sulfides, etc.
  (a) Mineral acids: sulfuric, hydrochloric, phosphoric acids
  (b) Passivating acids: nitric, chromic
  (cl Organic acids
  (d) Specialty acids containing surfactants for wetting-out action or a foam blanket or pickling inhibitors to prevent excessive attack on the metal
(2) Alkaline baths
  (a) Alkaline de-rusters containing organic sequestrants which solubilize metal oxides and also remove soils
  (b) Molten alkali with or without hydride (reductant) or nitrate (oxidant) or electric current; also removes soils
(3) Chelating agents react with soils to form soluble complexes
(4) Electropolishing (reverse current cleaning), electrodissolution of metal substrate at the anode
(5) Oxidizing or reducing agents to chemically render the soil soluble

Mechanical Action

(1) Turbulence/agitation
(2) Abrasives
(3) Deformation
(4) ultrasonic cleaning
(5) Heat
(6) Electrocleaning (direct current hydrogen scrubbing at the cathode)

Source: Adapted from Spring, 1963.

Table 3. Cleaning Methods

- Wiping
- Wire brushing
- Grinding or machining
- Sandblasting or abrasive blasting
- Shot blasting
- Liquid blasting (hydroblast)
- Hydroblast with abrasives
- Blasting with softer material, e.g. plastic bead blasting
- Cryogenic paint stripping
- Physical distortion
- Molten salt bath
- Wipe on, wipe off
- Immersion
- Circulation of cleaner
- Air sparging (aqueous cleaners only)
- Spray cleaning
- Tumbling in barrels
- Ultrasonic cleaning
- Steam cleaning or stripping
- Vapor degreasing (solvents only)
- Electrocleaning (aqueous cleaners only)
- Flame or hot air impingement
- Centrifugal wheel

2.2 Waste Minimization Strategy for Parts Cleaning

The recommended strategy for developing effective waste minimization options for parts cleaning operations relies on systematic exploration of the following <u>sequence</u> of steps:

1. Avoid the need to clean.
2. Select the least hazardous medium for cleaning.
3. Maximize cleaning efficiency.
4. Segregate cleaning wastes.
5. Maximize recycling and reuse.

This strategy is consistent with the multi-media approach and general emphasis of reducing the waste at the source. Each step is discussed in the following sections.

Can cleaning be avoided?

In many instances, by controlling the factors that contribute to surface contamination of the parts, the need for cleaning can be reduced or eliminated altogether. Control of part contamination starts with a study of contarmination sources. Sources can be incoming soils applied by metal vendors or soils applied in house (i.e., coolants, stamping fluids, drawing compounds, rust inhibitor, etc.). Some frequently encountered sources and types of contamination are shown in Table 4.

Upon identifying the type and origin of the contamination, it is worthwhile to examine whether cleaning can be avoided or its extent reduced. For example, protective coatings of grease or paint (which require solvents for removal) can be replaced with peel coatings or shrink-wrapping of items with polymeric sheeting. Moisture which can lead to rust can often be reduced or eliminated by allowing the parts to dry more thoroughly between operations or by storing them indoors to avoid condensation and/or rain.

Also of importance is the location of cleaning operations in manufacturing sequence. Articles to be cleaned prior to finishing should only be cleaned at the point in time when they are ready for coating. Parts should not be cleaned and conversion-coated and then warehoused or staged for subsequent batch coating. During storage, the parts can become contaminated by air-borne oils or by handling. These contaminants will interfere with ultimate finish quality and increase the rate of rejects.

Examination and subsequent control of contamination sources may lead to reduction or elimination of cleaning requirements, as illustrated above. However, it is also important to note that an unwarranted relaxation of cleaning requirements may have an opposite effect of increasing waste generation associated with rework of the rejects, e.g. due to poor coating quality. Any proposed changes to the cleaning process require careful evaluation of potential waste generation in downstream operations.

Select the least hazardous medium

The choice of cleaning medium for a given parts cleaning operation is determined by a number of factors:

- physical and chemical properties of contaminants, substrate surface, and cleaning media.
- the amount of contaminant to be removed
- the required degree of cleanliness and product quality
- size, shape, and complexity of part to be cleaned
- volume or number of parts to be cleaned per unit time
- costs of raw materials, equipment, and labor
- worker protection
- environmental protection

Shrink-wrapping

Oil is often used to coat metal parts before shipment in order to prevent rust, which forms on exposure to air and moisture. Similar protection can be achieved by a removable plastic coating, such as polyethylene shrink-wrapping. At the receiving facility, the use of vapor degreasing to remove the oil is no longer necessary.

Removal of oil contaminants prior to welding

The welding of metal parts which have residual oils present on or near the weld leads to the formation of carbonaceous deposits due to pyrolysis of organics at high temperatures. Such deposits are extremely difficult to remove. Cleaning the parts prior to welding greatly reduces the subsequent cleaning requirements.

Table 4. Types and Sources of Surface Contamination

Contaminant	Composition	Origin/Use
Pigmented metal drawing compounds	Oil with friction reducing pigments (talc, chalk, lithopone, sulfur, graphite or lime)	Press and punch operations
Non-pigmented metal drawing compounds	Mineral oils and highly chlorinated synthetic oils, mineral oils and greases, vegetable or animal oil and/or fats, aliphatic esters, and emulsifiable synthetic oils	Press forming, bending (tubes)
Polishing and buffing compounds	Greases, metallic soaps, abrasives and waxes	Polishing and buffing
Cutting and grinding fluids	Plain and sulfonated mineral and fatty oils, chlorinated mineral oil soaps, salts and saturated fatty alcohols	Machining operations
Oxidation and scale	Rust (metal oxides), heavy metal salts, water scale	Corrosion oxidation deposition welding
Quenching oils		Heat treatment
Rust protection oils		Storage
Lube oils and hydraulic fluids		
Paint and inks	Pigment with binder	Surface protection, identification
Moisture	Water	Exposure to water, condensation
Fingerprints	Body oils, particulates	Manual handling
Particulate matter	Metal chips, dust, carbonaceous deposits	Dusty environment, coking
Fluxes	Rosin, terpenic compounds	Soldering

The relative importance of these factors can change considerably over time. For example, both benzene and carbon tetrachloride (former standards in industry) have been found to be carcinogenic and were regulated out of use as metal cleaners because of heightened concern over worker exposure. This same concern, and increased disposal costs, have caused some major automotive manufacturers to phase out solvent cleaners in favor of aqueous cleaners.

In looking for a new cleaning medium or procedure, a company should consider the least toxic or most environmentally acceptable medium, then, if this is not satisfactory, progress to more toxic or less environmentally desirable alternatives. This pattern dictates that cleaning media be evaluated in the following order:

- water or air
- abrasive media with water or air as carrier
- aqueous detergent solutions
- alkaline solutions
- acids
- solvents

Ideally, the cleaning method of choice would involve the shortest cleaning sequences, employing the least toxic cleaning medium, generating the least amount of wastes, and still providing the necessary minimum level of cleaning to the part at minimum cost. For facilities attempting to change from one cleaning medium to another, the impact on subsequent operations must be considered. Any proposed changes to the cleaning process requires careful evaluation of potential effects of the cleaner on the substrate that might affect the integrity of downstream processes (anodizing, plating, painting, etc.). The impact of cleaner drag-out on the lifespan of downstream process solutions should also be addressed.

Maximize cleaning efficiency

If a cleaning step cannot be eliminated, and the least hazardous cleaning material that is effective is already being employed, then it should be used as efficiently as possible. From a waste reduction point of view, this means using the least amount of cleaning medium to achieve an acceptable level of cleanliness. Examples of ways to improve cleaning efficiency are cited in later sections of this booklet for solvent cleaners, aqueous-based cleaners, and abrasives, respectively.

Recycle and reuse waste

The cleaning waste that cannot be eliminated through substitution or more efficient use should be considered for recycling or reuse. The segregation of different types of cleaning waste may be required for such recycling or reuse. Specific examples of recycling and reuse are discussed for specific cleaning media in later sections of this pamphlet.

3. WASTE MINIMIZATION APPROACHES FOR SPECIFIC CLASSES OF CLEANING MEDIA

In the following sections, waste minimization strategies that are effective for specific cleaning media are presented. The order of presentation - solvents, aqueous-based, and abrasive cleaners - reflects the need to replace or reduce the use of the most hazardous materials first. Also, a greater amount of information is presented regarding ways to minimize solvent use than is provided for aqueous or abrasive cleaners, since solvents are a greater concern both environmentally and from a health standpoint.

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Although organic solvents have excellent cleaning properties, many of them are considered hazardous to human health and the environment. The negative environmental and health-related attributes of solvents, particularly halogenated ones include:

- toxicity
- flammability
- ability to dissolve or penetrate polymeric landfill liners
- high diffusivity through porous strata
- ability to dissolve and serve as a carrier to other toxic organics
- high volatility
- photochemical reactivity
- long half-life
- toxic degradation products
- resistance to biodegradation
- depletion of stratospheric ozone

Solvent wastes were among the first to be banned from land disposal by EPA. The 1984 RCRA amendments specify five categories of solvent waste (F-001 to F-005) which are banned from land disposal effective November 1986 (RCRA 3004 (e)(l)). Due to the diverse problems associated with solvent use, solvents should be used only when no other cleaner is suitable for the job. The major ways to avoid or reduce the generation of solvent waste include eliminating the need to use solvent; finding adequate substitutes for solvents; minimizing losses associated with solvent use; and segregation, recycle, and reuse of waste solvents.

3.1 Eliminate the Need for Solvents

The first priority in efforts to reduce solvent waste is to examine the cleaning steps that require solvent. Such examination should aim to avoid solvent use by eliminating or modifying the cleaning step. Special attention must be given to the origin of soil and its composition.

Eliminate cleaning step

AT&T Technologies, Inc. of Union, N. J., report that simple changes made in a testing operation enabled the company to eliminate a cable-end cleaning step that had employed l,l,l-trichloroethane (waste Reduction-The Untold Story, 1985).

3.2 Substitution Alternatives for Solvents

Many firms have been successful in substituting less toxic cleaning media for solvents. The alternatives include:

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- substitution of toxic solvents with less toxic solvents
- substitution of solvents with aqueous cleaners
- substitution of solvents with emulsion cleaners
- substitution of solvents with mechanical and/or thermal methods

Discussion of each substitution approach is provided below. Most emphasis is given to aqueous cleaners, since this is the major and often most effective alternative.

In the case of halogenated solvents, media substitution will often require a switch from vapor degreasing to cold tank cleaning with possible addition of mechanical or ultrasonic agitation. A preliminary analysis of possible substitutes for chlorinated solvents & available (US EPA 1983).

Use less toxic solvents

Substituting one solvent for another in cleaning applications has an extensive history. Trichloroethylene (TCE) is being replaced by l,l,l-trichloroethane (TCA). Benzene and other toxic aromatic solvents were replaced by less toxic aliphatic solvents such as Stoddard solvent and naphthas. Possible solvent alternatives to halogenated compounds include:

- aliphatic hydrocarbons (e.g. naphthas)
- terpenes
- N-methyl-2-pyrrolidone
- dibasic acid esters

Although photochemically reactive, terpenes (derived from citrus plank and pine trees) are "generally recognized as safe" substances (Hayes, 1988). However, carcinogenicity of terpenes and other cycloalkenes has not been well explored. The terpene cleaners are available commercially in neat form or as water solutions with surfactants, emulsifiers, rust inhibitors, and other additives. T&penes tested very favorably as substitutes for halogenated solvents for removal of heavy greases, oily deposits, and carbonized oils. Terpenes are being actively tested as alternatives to chlorofluorocarbons in electronic park cleaning.

Reported disadvantages of terpenes include inability to separate long chain aliphatic oils for recycle of the cleaning solution both in neat form and in aqueous emulsions. Ultrafiltration to remove oil is not viable for recycle and is only useful for treating dilute emulsions prior to wastewater treatment. Recovery by distillation is impractical since terpenes boil around 340^{0}F, which means that many light oils would be carried over with the solvent. Energy cost for distillation recovery, even with vacuum assist, would be high. Difficulties in rinsing residues from parts surfaces have been cited. Also, terpenes cost three to five times more than traditional chlorinated and hydrocarbon solvents. (Evanoff, 1988).

Other substitutes for halogenated solvents include N-methyl-2-pyrrolidone (Taylor 1988), and dibasic acid esters (Lucas 1988). These substitutes are considered to be safer and environmentally preferable to halogenated solvents due to their low volatility and biodegradability. For additional information, the reader should contact manufacturers of these products directly. It is recommended that solvent/cleaner recyclability be thoroughly investigated along with cleaning properties, volatility, toxicity, cost, and other attributes.

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Aqueous cleaners

Historically, aqueous cleaners have been used extensively throughout the industry. In recent years, their use has increased as environmental concerns and regulatory restrictions placed solvent cleaners under more scrutiny.

The simplest aqueous cleaner is water, which can be used in conjunction with mechanical or ultrasonic agitation. Hot water high pressure spray systems are quite effective at removing caked-on dirt and grime. Where hard water deposits may result in staining, use of demineralized or deionized water is recommended. Use of demineralized water in a reuse bath preceding a plating or process bath can help avoid the build-up of calcium and magnesium contaminants in the bath. For example, hot deionized water has been successfully tested as a replacement for CFC-113 in certain critical cleaning applications in the manufacture of disk drives in the electronic industry.

The cleaning action of aqueous cleaners relies mainly on displacement of soils rather than dissolving them as is the case with organic solvent. Two classes of aqueous cleaners, alkaline and acidic cleaners, are usually distinguished bawd on pH. Application methods include soak cleaning, spraying, ultrasonic cleaning, electrocleaning, and steam cleaning.

Alkaline cleaning solutions contain builders (sodium salts of phosphate carbonates, silicates, and hydroxides) and surfactants (detergents and soap) Other additives may include anti-oxidants and stabilizers as well as small amounts of solvents. Acidic cleaning solutions may contain mineral acid (nitric, sulfuric, phosphoric, or hydrochloric), organic acids (sulfamic, oxalic, or citric), detergents, chelating agents, and occasionally small amounts of solvents.

Use water in place of solvents
Certain electronic filter circuits are housed in aluminum casings. The casings are manufactured by an outside sheet metal contractor who cleans the parts prior to shipment. Since delivered parts had occasional visible stains, methyl alcohol was used to remove them. A simple investigation showed that hot deionized water was equally effective WE, 1985).

Replace solovent with aqueous cleaning medium
An electronic manufacturing facility of a large corporation originally cleaned printed circuit boards with solvents. The company found that by switching from a solvent-based cleaning system to an aqueous-based system the same operating conditions and workloads could be maintained. The aqueous-based system cleaned 6 times more effectively. This resulted in a lower product reject rate, and eliminated a hazardous waste (USEPA, 1983).

It is important to evaluate the wastewater quality issues and recyclability aspeck when selecting an aqueous cleaner. Generally, selection of non-emulsifying cleaners which promote oil separation will enhance recyclability. Process equipment involves a heated tank equipped with oil skimmer and mechanical agitation, spraying, or ultrasonic devices. The cleaning step is usually followed by water rinsing and air drying.

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Quite often, solvent is employed for cleaning because an attempt to utilize an aqueous cleaner was unsuccessful. Before committing to solvent, one should investigate the compounds requiring removal. High melting temperature compounds are often used in forming compounds, lubricants and preservatives, making removal with aqueous cleaners difficult. Suppliers of metal processing chemicals can recommend substitutes that can be cleaned with aqueous cleaners thus eliminating solvent and emulsion cleaners. General studies are available (Briggs, 1976; Wagner, 1984; USEPA, 1983; Evanoff, 1988); however, each application is highly specific and generalizations are difficult. Testing of a number of potential substitutes is recommended (see Table 5). The reader is advised to contact aqueous cleaner manufacturers for specific recommendations. A comprehensive list of manufacturers and trade names can be found in recent issues of Metal Finishing's "Guidebook & Directory" or other standard buying guides.

Emulsion cleaners Emulsion cleaners combine solvent cleaning with aqueous cleaning so that water-immiscible solvent is dispersed in the aqueous phase with the aid of emulsifiers, surfactants, and coupling agents. The large surface area of the dispersed solvent phase often allows the attainment of results achievable with direct solvent cleaner. Solvent vapor pressure and evaporation losses are suppressed.

Emulsion cleaners are used for immersion or spray cleaning in cold baths predominantly in metal fabrication facilities. Disadvantages include residual oil film on the park (which necessitates an additional cleaning step in applications where a high degree of cleanliness is required), relatively low saturation capacity, and difficulties in recycling by separation of oil and reconstituting the cleaner. Emulsion cleaning is no longer a widespread technology and is being quickly replaced by aqueous cleaners. For more information on emulsion cleaners, the reader is referred to USEPA, 1983.

Replace solvent with alkaline cleaning media

The Torrington Company in Walhalla, SC, was using vapor degreasers containing l,l,l-TCE to clean metal bearings for the automotive industry. Because of concern about worker health and increasing solvent prices, the company installed an alkaline degreaser that employed a two-stage washer and hot air drier. The waste water from this system can be discharged directly to the sewer system because the alkaline cleaner is considered non-hazardous (Kohl, 1984).

Reduction of solvent USe

A company that reduced TCE use is the Hamilton Beach Division of Scovill, Inc. in Clinton, N.C., which manufactures small electric appliances. Scovill found that a water-soluble synthetic cleaner manufactured by Cincinnati Milacron Co. could be used in place of the TCE organic solvent degreaser for some applications, reducing TCE use overall by 30 percent. This saved $12,000 per year. (Huising, et al. 1985).

Mechanical/thermal methods

In addition to aqueous cleaners, mechanical and/or thermal methods are quite effective at eliminating the need for solvents. Solvents are often used to dry park following a water rinse operation. As an alternative, air blast systems utilize a high velocity air jet that-blows water droplets and other contaminants from glass, metal, or wood park. Abrasive blast cleaning methods use a plastic blast media to clean and strip park. Dry stripping and cleaning can reduce disposal costs and water usage and have been shown to reduce labor costs significantly. The plastic media are recycled.

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Table 5. Selection of an Aqueous Cleaner[1]

1. Review cleaner composition. Hazardous or undesirable components are identified on material safety data sheets. Many candidate cleaners can be eliminated on this basis.
2. Identify contaminants to be cleaned from park, and obtain samples of each.
3. Apply each contaminant to representative metal panels and immerse in each candidate cleaner in laboratory scale cleaning tanks. Use manufacturer's recommendations for concentration and temperature, and provide mechanical agitation. After periods of 5, 10, and 15 minutes, remove panels from bath, rinse, and evaluate cleanliness. Cleanliness can be ascertained by (a) water break, (b) fluorescence under UV light (applicable for soils that fluoresce), and (c) by immersing in a cupric chloride solution and observing uniformity of copper deposited.
4. If a contaminant was cleaned (from Step 3), lower the temperature and re-test until the minimum effective temperature is identified. Also determine the minimum effective cleaner concentration in a similar manner. If the contaminant from Step 3 was not cleaned, increase temperatures and concentrations to identify minimum effective parameters. These data will permit selecting the optimum operating conditions for any contaminant or mixtures thereof of any of the cleaners evaluated.
5. Using a series of standard tests, determine etch rates, staining characteristics, effects on coatings' adhesion, and corrosion characteristics.
6. Evaluate cleaner performance including tank maintenance, recyclability, and disposal requirements in a pilot plant-scale tank prior to full scale implementation.

[1] Selection process developed by General Dynamics/Fort Worth Division (Evanoff et al 1987).

Abrasive substitutes for solvents in paint stripping
Conventional paint stripping of aircraft may use 8,000 gallons per aircraft of such solvents as methylene chloride or hot caustic. Hill Air Force Base in Ogden, Utah, has successfully employed plastic beads propelled by high pressure air jets (bead blasting) to remove paint from aircraft exteriors. Besides not generating hazardous waste, the use of bead blasting improved personnel working conditions, was easier to perform than solvent paint stripping, and cost less and used less raw material.

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To replace the use of chlorinated solvents in paint stripping operations, heat or flame cleaning ovens are becoming more common. Heat cleaning ovens burn off paint and other organic compounds from metal park. Specifically, these techniques have been successful in cleaning paint hangers and hooks. A disadvantage of heat cleaning ovens is the production of combustion emissions.

3.3 Minimize Solvent Losses

Once it has been determined that the use of solvent cannot be avoided, all efforts to reduce solvent use in a facility should be made. The following options are grouped according to their application (general, cold cleaning, and vapor degreasing).

General options Waste minimization options that apply to solvent use in general are discussed below. These options include standardizing solvent use, consolidating solvent cleaning operations, maintaining solvent quality, increasing cleaning efficiency, and reducing solvent evaporation.

Standardize solvent use

Standardization means using the least number of different solvents in the facility. A reduced inventory helps track solvent consumption, reduces the risk of cross contamination, and eases waste handling. In addition to simplifying cleaning operations, standardization also helps promote the potential for downgrading or recycling waste solvents. Using fresh solvent for the most critical cleaning applications and reusing solvent sequentially for less de-. manding cleaning operations can reduce overall solvent consumption and waste production.

Consolidate cleaning operations into one centralized degreasing operation

Centralization helps in the effort to standardize solvent use. It also eases the effort it would take to supply many solvent users dispersed throughout a facility. A centrally-located solvent issue and waste collection station was found to be useful in solvent control and in proper waste handling in the multiuser facility (SFE Technologies, 1985).

Maintain solvent quality

By maintaining solvent quality, the need for solvent replacement and disposal is reduced. Ways to achieve this goal include contamination avoidance, equipment maintenance, solvent monitoring, proper solvent addition, and prompt sludge removal. These approaches are discussed below.

Staged solvent use and standardization of solvent

A Massachusetts electronics firm switched from using three different solvents - mineral spirits for degreasing machine park, perchloroethylene for computer housings, and a fluorocarbon-methanol blend for printed circuit boards - to a single solvent mixture. The mixture of l,l,l-trichloroethane and alcohol is used for all three applications in a staged system. Fresh solvent is used for the printed circuit boards, then is reused to degrease the computer housings and, last, the machine park. Besides reducing solvent consumption and waste, this practice has eliminated potential cross contamination of solvents, generated a single waste stream that can be recycled, simplified safety and operating procedures, and increased purchasing leverage (Traverse, 1984).

Contamination avoidance

Park should be checked for undue contamination, including moisture, before being cleaned. Often, park stored outside will pick up a large amount of condensation. The introduction of water from condensation into a bath of chlorinated solvent can acidify the solvent. When this occurs, the solvent must be replaced and all equipment in contact with the solvent thoroughly flushed and rinsed. Another problem is that water contamination can lead to increased air emissions because of azeotrope formation. To avoid this problem, the parts should be stored indoors. Precleaning inspections can help point out potential problems that are due to upstream operations.

Another purpose of precleaning inspections is to promote workload segregation. In some situations, a given bath of solvent is more than adequate for cleaning the normal production workload but it fails to thoroughly clean heavily soiled pieces. As these pieces pass through production and yield rejects, the solvent bath is blamed for inadequate cleaning. Rather than having to replace the bath due to an occasional heavily soiled object, it is better to segregate these objects and to preclean or spot-clean them before the bath.

Material and/or process substitution can be another effective way of avoiding undue bath contamination. Use of newer, water emulsifiable metal forming lubricants that require less material, and spray/mist application devices will minimize the amount of material applied (Evanoff, 1988).

Equipment maintenance

Racks and barrels should be maintained so as not to introduce corrosion products (such as rust) into the solvent. Corroded racks can also remove liquid from the bath by way of capillary action.

Solvent monitoring

The military is currently developing solvent test kits (Joshi et al., 1988) for cleaning operations using Stoddard solvent (PD-680) and chlorinated solvents (l,l,l trichloroethane, methylene chloride, trichloroethylene, and perchloroethylene). The purpose of these kits is to provide operators with simple, reliable and repeatable testing means for determining when solvent is'spent. Due to the often arbitrary nature in which the need for solvent replacement is now determined, much solvent may be disposed of prematurely. The most reliable tests developed to date include light transmittance @ 500nm, electrical conductivity, and specific gravity for PD-680 and acid acceptance value, light transmittance, and electrical conductivity for the chlorinated solvents.

SOLVENTS

After establishing a proper monitoring program, work should be undertaken to correct identified problems. Chlorinated solvents contain stabilizers to prevent acid forming reactions with water, metal, heat, and oil. When an acid acceptance test indicates that the solvent is near the point of "going acid," the solvent is either disposed of or fresh solvent is added in an attempt to boost stabilizer levels. Addition of fresh solvent is a poor solution since it results in the degradation of the fresh solvent. A better solution is to analyze the solvent and add only the specific components required (see example below). Since each type of solvent may employ a different mix of stabilizers, the solvent manufacturer should be contacted before any additions are made.

Carefull solvent addition

Care should be taken whenever solvent is added to the tank to ensure that proper solvent is being added. For example, as little as 0.1% TCA mistakenly added to a tank of TCE can cause an acid condition requiring disposal of the entire contents.

Sludge removal

Metal fines can catalyze reactions that lead to decomposition of the solvent. Paint chips can absorb solvent and swell, forming a viscous sludge. Routine maintenance should be performed to remove sludge. Continuous filtering is often helpful.

Increased cleaning efficiency

As the level of contamination increases, the rate of solvency slows down While cold cleaning operations can be successfully performed at up to 10%; contamination, solvent baths are often replaced due to slow cleaning action. when the contamination level reaches 2 to 3%. A simple way to increase cleaning efficiency is to employ manual brushing. Manual brushing is extremely effective at removing caked-on soils and is a very common precleaning technique. Disadvantages include exposure of workers to solvents, high labor costs, and the need for high ventilation rates to protect workers. High ventilation rates can, in turn, lead to excessive solvent evaporation.

Maintaining solvent qualify

The Ogden Air Logistic Center generates about 6500 gallons of waste l,l,l trichloroethane (TCA) from 21 vapor degreasing operations. In an effort to reduce this waste, the chemical laboratory personnel determined that the TCA was being disposed of because it did not meet an acid acceptance value of 0.10 weight percent NaOH. Oil contamination levels were less than 10 percent at the time of disposal, far less than the expected 30 percent level. To restore acid acceptance levels, 1,2 butylene oxide was added to the solvent. No adverse reactions or detectable problems were observed when the butylene oxide was added to the vapor degreasers. Ogden Air Logistics Center expects to reduce disposal volumes by 4000 gallons (60 percent) and save $30,000 per year (Christensen, 1988).

SOLVENTS

Cleaning efficiency can also be increased by increasing the degree of agitation in the bath. Methods include use of mechanical agitators, ultrasonic devices, liquid sprays, and liquid jet pumparound arrangements. Great care should be taken with these methods to ensure that undue splashing does not occur. Systems are available that provide a raising and lowering (or pumping) action of the parts trays inside the bath while the unit is closed. Increased temperature may be employed to increase cleaning efficiency but this method leads to larger evaporative losses.

Cleaning speed can be maintained effectively at high contamination levels using ultrasonic agitation. High frequency sound waves are transmitted through the solvent, causing formation and collapse of small vapor bubbles at solid surface (micro-cavitation). The agitation assists in the removal of insoluble soils. This supplementary cleaning action is not expensive, and it can prevent the need for hand cleaning and reduce the number of rejects. Ultrasonic transducers may be added to existing equipment, and they can be used in both vapor degreaser and cold cleaning applications.

Control of evaporative losses

The first step in controlling evaporative losses is the selection of the proper location for cleaning operations. The area should be free from drafts and away from any heat source, which can cause large evaporative losses. These large losses can result in problems elsewhere in a facility.

The second step in controlling evaporative losses is through the proper use of lids. Tank lids, even on cold tanks, are very effective in reducing solvent loss. For vapor degreasers, roll-type covers are recommended over hinged covers because they are less disturbing to the vapor zone.

Other methods that are effective in controlling evaporative emissions from all solvent cleaning operations are the proper monitoring of temperature (if the solvent is heated) and avoiding the use of porous items such as ropes or bags for handling parts. Additional air emission control methods are discussed in the subsequent sections.

Cold cleaning

Of the total number of cold cleaner soak tanks in use, it has been estimated that 70 percent are used for maintenance operations. Typically, most tanks hold 30 or more gallons of solvent and have about four square feet of open area. Cold tanks used in manufacturing operations range from desktop sized units used for cleaning small parts to units designed to clean large sections of aircraft. Maintenance cleaning usually employs mineral spirits (petroleum distillates such as Stoddard solvent) while manufacturing operations employ a wider variety of solvents.

Locate solvent rank properly

One manufacturer placed a tank of chlorinated solvent near his paint cure oven. Heat from the oven caused excessive emissions which were picked up by the oven's combustion fan. The emissions were burned, forming hydrochloric acid, which ruined the finish on the painted parts in the oven. The manufacturer had to strip, clean, and repaint all of the parts. All of the waste (not to mention the cost) associated with this event could have been avoided if the tank was properly located (Dumey, 1984).

SOLVENTS

Some waste minimization options specific to cold cleaningsoak tank operations include reducing the degree of drag-out and using a counter-current cleaning arrangement. In addition to these methods, the reader should review **all of the general options discussed in the preceding section.**

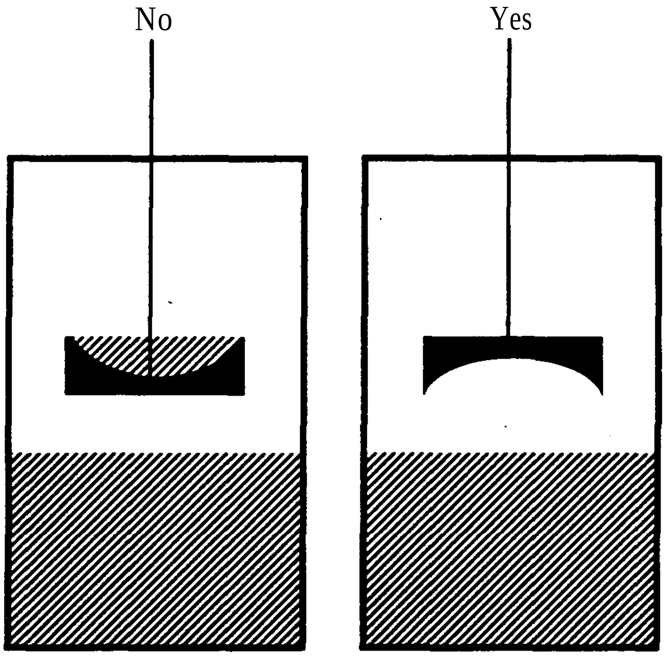
Reduce drag-out

Drag-out is the term applied to the liquid that comes along on the part as it is removed from the tank. Excessive drag-out can result in increased solvent replenishment costs, increased air emissions, and upset of downstream processes. Methods for reducing drag-out include proper racking, increased drainage, and installation of drain boards.

Proper racking

Careful attention should be given to the design of work baskets and to methods of racking so as to ensure that a minimum amount of solvent will be trapped either in the work or in the baskets (Figure 3).

Figure 3. Racking For Maximum Drainage



Increase drainage

Parts should always be allowed to drain inside the tank before being removed. The installation of a rest shelf inside the tank allows the operator to better drain the parts, especially heavy ones. Depending on the size, shape, and function of the part, some fabricators design the part to include inconspicuous drainage holes.

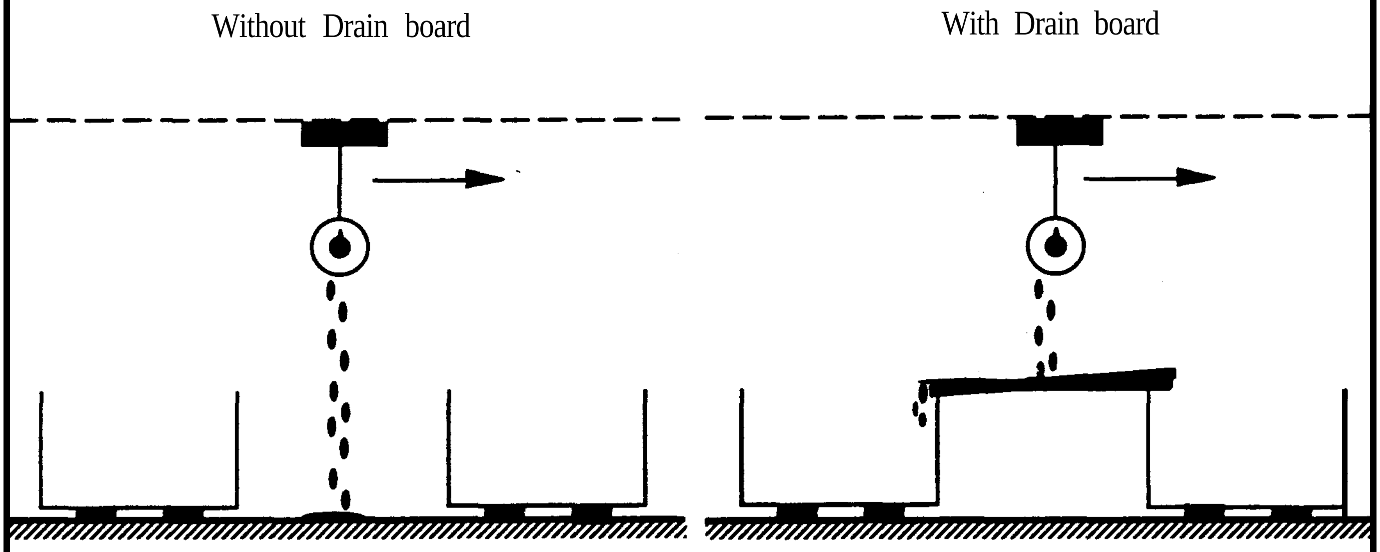
Install drain boards

Drain boards are often helpful in recovering solvent that drips from a part. Drain boards which extend from one tank to the next help to keep the area between tanks clean (Figure 4).

Use counter-current cleaning

Parts should be passed through a series of cleaning tanks or compartments. The first tank consists of used solvent, the last rinse consists of very clean solvent. When the first tank of solvent is spent, it can be pumped out for disposal and each subsequent tank pumped into the previous tank. For facilities with limited space, existing tanks can be segmented. Staging will reduce the amount of solvent use by maintaining solvent quality for a longer period.

Figure 4. Installing Drain Boards Conserves Solvent, Keeps Floor Clean.



Vapor degreasing

In industries that perform a large amount of cleaning, vapor degreasing systems are common. Available sizes for open-top units range from 1 x 2 feet, up to 6 x 100 feet. The typical unit size is approximately 3 x 6 feet. Open-top units are commonly employed in the electroplating and electronics industries where easily handled parts are cleaned. Conveyorized (or fully automated) units are more common in the aerospace and large appliance product coating industries.

Vapor degreasing systems usually consist of a tank of halogenated solvent that is heated to the solvent's boiling point. Parts to be cleaned are placed in a basket or on a rack and lowered into the vapor zone. As the solvent condenses, the contamination is dissolved and the parts are rinsed and cleaned. To increase cleaning efficiency, the parts may be immersed into the solvent bath or a solvent spray unit may be employed. When the temperature of the parts finally reaches the temperature of the solvent vapor, condensation of the vapor onto the part ceases. The parts can then be removed from the unit clean and dry.

Solvent use in vapor degreasing can be minimized by many of the general options discussed previously and by the options listed below:

Limit entrance/exit speeds

Solution and vapors are removed from the tank when a part is inserted or withdrawn too quickly. Avoid speeds greater than 11 feet per minute to limit excessive dragout.

Limit workload size

The use of baskets having an area of less than 50% of the degreaser opening will limit vapor dragout due to piston effect (Figure 5).

Avoid work shock

Work shock occurs when a heavy load is introduced into the degreaser, resulting in collapse of the vapor blanket and infiltration of air into the cleaning unit (Figure 6). The solvent-saturated air will be expelled from the unit when the vapor layer is reestablished.

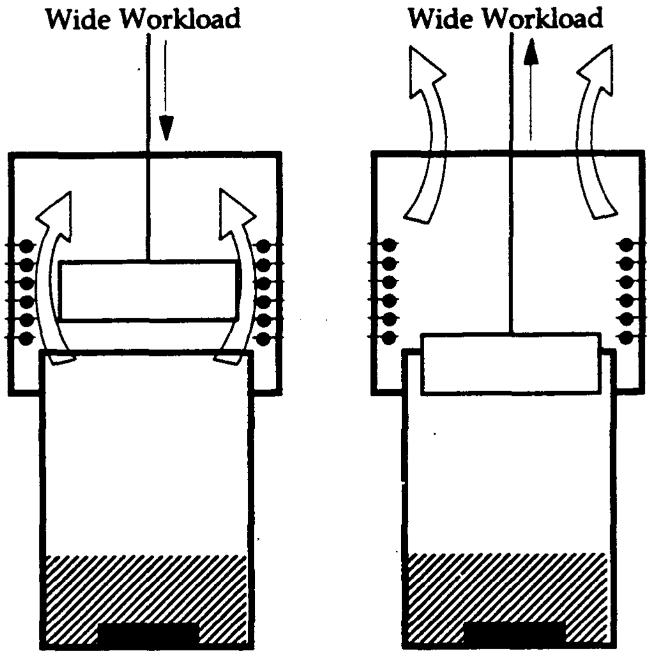
Maintain temperature of solvent

The temperature of the solvent in the degreaser should be maintained at a level adequate for vapor production, to ensure that the degreaser functions efficiently.

Allow sufficient time in the degreaser

Ensure that parts have reached the temperature of the vapor so that condensation has ceased.

Figure 5. Piston Effect



Spray only below the vapor zone

The spray pattern should be a solid stream, not a fine mist.

Maintain proper solvent level in sump

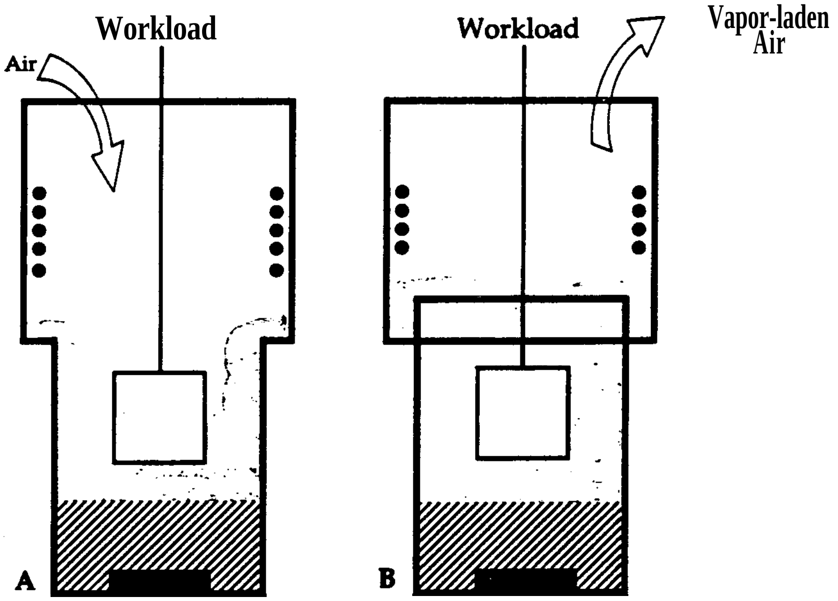
In addition to excessive water contamination, a major cause of chlorinated solvents going acidic is exposure of the heating coils to the solvent vapor. Exposure causes localized overheating which results in decomposition of the solvent. These items can be kept in check by inspecting the parts for excessive water and by regularly checking the operation of the water separator and solvent level controls.

Minimize vapor diffusion

Vapor diffusion, which results in air emissions, can be reduced through the following means:

- Check parts for excessive water contamination.
- Cover water separator to prevent vapor loss.
- Check water jacket for proper water flow and temperature on outside of degreaser.

Figure 6. Work Shock



A 1. Work introduced
2. Rapid condensation on work
3. Vapor blanket collapses
4. Air pulled in

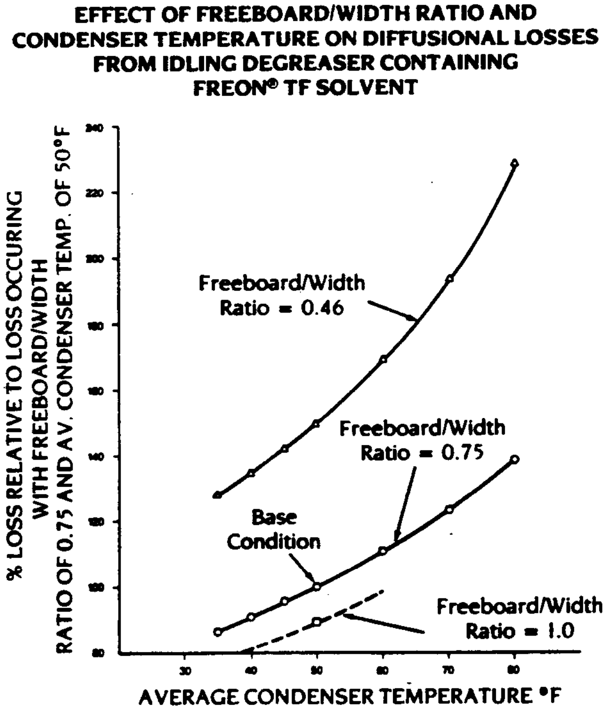
B 5. Condensation on work stops
6. Vapor blanket m-established
7. Vapor-laden air expelled

SOLVENTS

- Extend freeboard. Increasing the freeboard/width ratio of a vapor degreaser can reduce solvent air emissions (see Figure 7).
- Use cold traps above freeboard chillers.
- Locate the degreaser away from drafts or use baffles to prevent upset of the vapors. Proper location can reduce solvent loss by 30 percent

For additional information on ways to reduce emissions associated with vapor degreasing, the reader should contact the solvent supplier. Most if not all of the major chlorinated solvent manufacturers have information available on the proper way to utilize, maintain, and eventually dispose of their products.

Figure 7. Effect of Changes in Freeboard/Width Ratio (Figure courtesy of Du Pont)



3.4 Solvent Segregation and Recycling/Reuse

SOLVENTS

In addition to the savings in solvent that result from minimizing losses during use, overall solvent consumption can be reduced by segregating solvent wastes and recycling or reusing them. EPA estimates that up to 50% of all solvent wastes are currently being segregated and managed for energy recovery, reclamation or recycling.

To simplify waste solvent handling and to make recycling feasible, the following procedures should be followed (Kohl, 1984 and California DHS, 1986):

Keep solvents segregated

In the recycling process, it is much easier to separate a solvent from its impurities than to separate two solvents. Specific recommendations are always to segregate:

- Chlorinated from non-chlorinated solvent wastes.
- Aliphatic from aromatic solvent wastes.
- Freon from methylene chloride.
- Water waste from flammable waste.

SOLVENTS

Keep waste solvents as free from water, solids, and garbage as possible

Label the container clearly, keep the container closed and, if possible, sheltered from rain. Drums should be covered to prevent contamination with water.

Label the chemical content on each waste container

Record the exact composition and method by which the solvent waste was generated.

Recycling Where recycling of solvent waste is viable, the choice between on-site versus off-site recycling must be made. Major factors that may influence a decision are shown in Table 6.

Table 6. Factors Influencing the Decision to Recycle Solvent Wastes on Site

Advantages	Disadvantages
Less waste leaving the facility.	Capital outlay for recycling equipment.
Owner's control of reclaimed solvent's purity.	Liabilities for worker health, fires, explosions, leaks, spills, and other risks as a result of improper equipment operation.
Reduced liability and cost of transporting waste offsite.	Possible need for operator training.
Reduced reporting (manifesting).	Additional operating and maintenance costs.
Possible lower unit cost of reclaimed solvent.	
Perceived Benefits	Reported Difficulties
Favorable economics for recovery (e.g. reduced solvent requirements).	Loss of solvent during distillation process.
Reduction in disposal costs.	Low solvent recovery efficiency.
Reduction in reporting (manifesting)	Installation problems.
Lower liability.	Maintenance problems.

Source: California DHS, 1986.

SOLVENTS

On-Site Recycling

On-site recycling is economical when approximately 8 gallons of solvent waste is generated per day (Schwartz, 1986). The simplest form of solvent reuse is termed "downgrading," which is the use of a solvent that has become contaminated through initial use for a second cleaning process. For example, precision bearings need very high purity solvents for cleaning. The solvent acquires very little contamination in usage and can be downgraded or used for less demanding cleaning operations.

More effort is required to recycle solvent that has become heavily contaminated, and the possibilities for both on-site and off-site recycling or reclamation need to be explored. In vapor degreasing and cold cleaning, the soil removed accumulates in the equipment. Eventually the solvent becomes too contaminated for further use and it must be reclaimed or disposed of via incineration. For on-site recycling, many different separation technologies are available. Commonly used separation technologies for contaminated solvents include gravity separation, filtration, bath distillation, fractional distillation, evaporation, and fuel use.

Gravity separation

The use of settling to separate solids and water from solvent often permits the reuse of solvent. For example, paint thinners may be reused many times if solids are allowed to settle out.

Filtration

Filters can be used to remove solids from many solvents thus extending solvent life.

Batch distillation

A batch still vaporizes the used solvent and condenses the overhead vapors in a separate vessel. Solids or high boiling residues (>400^{0}F) remain in the still as a residue. Solvent stills range in size from 5 gallon to 500 gallon capacity. A vapor degreaser can be used as a batch still for recycling solvent. This is often done by employing proper boil-down procedures. Detailed discussion of these procedures is available from major solvent suppliers.

In many applications, it is necessary to keep the water content of the recovered solvent to less than 100 ppm. This can often be accomplished by distilling off the solvent-water azeotrope, decanting the water, and then drying the remaining solvent with a molecular sieve, or other desiccant. The water removed in this operation must then be either treated or drummed for disposal.

On-site recycling

A company that used trichloroethylene in degreasing was able to cut its solvent waste from 20 drums a month to five drums a month -a 75 percent reduction. Virgin solvent consumption was reduced by 15 drums a month. Formerly, the company removed solvent waste from degreasers into a storage tank every other day. The stored waste was transferred to drums for disposal. Now, the solvent waste is pumped into a holding tank; every two weeks this collected waste is redistilled to recover as much solvent as possible, leaving only 5 drums per month requiring off-site disposal (USEPA 1988 A).

(For a survey of small still manufacturers and other technical information, the reader is referred to “Guide to Solvent Waste Reduction Alternatives” available from the State of California Department of Health Services (Calif. DHS, 1986).

SOLVENTS

Fractional distillation

Fractional distillation is carried out in a refluxed column equipped with either trays or packing. Heat is supplied by a reboiler located at the bottom of the column while heat is removed at the top of the column by a condenser.. Fractional distillation allows for separation of multi-component mixtures or mixtures of solvent and oils with very similar boiling points.

Evaporation

Evaporation can be employed for solvent recovery from viscous liquids, sludges, or still bottoms resulting from distillation. Scraped or wiped-film evaporators utilize revolving blades which spread the liquid against a heated metal surface. The vapors are recovered by means of a condenser. Another type of system, a drum dryer, employs two heated counter-rotating drums through which the liquid feed must pass. While both systems can handle viscous wastes, the drum dryer is more tolerant of polymerizable contaminants.

Off-Site Recycling

If recycling of waste solvent on site is impractical, several off-site recycling schemes are available. One should consider or investigate all of the items listed in Table 7 when selecting an off-site recycling scheme. Some viable off-site

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Recycling solvents efficiently

Segregating solvent wastes is usually an essential step prior to recycling. IBM Corporation reported that segregation may also-increase recycling efficiency; segregating non-chlorinated from chlorinated solvents resulted in 15 to 20 percent greater yields (Waste ***Reduction - The Untold Story, 2985).***

Mobile solvent degreasing units

Automobile repair shops in California can lease fully-contained degreasing systems from Safety Kleen Inc. Safety Kleen provides a batch-tolling service for degreasing solvents; it leases its mobile units, including solvents, as one system. Safety Kleen periodically replaces the spent solvent with fresh solvent, and recycles the spent solvent at a separate facility.

Waste exchanges

Waste exchanges generally exchange some 20 to 30 percent of the wastes they list (Banning, 1983,1984). At present, the most common wastes listed are solvents and metal wastes. Other wastes listed include acids, alkalis, other inorganic chemicals, organics and solvents, and metals and metal sludges.

recycling arrangements include toll recyclers, and waste exchange/brokerage.

Toll recyclers

Toll recyclers offer services to generators by supplying solvent wash equipment and solvent and waste recycling services. The solvent wash equipment is maintained by these companies and the solvent is replaced periodically. The used solvent is recycled at an off-site facility. Costs for these services range from 50-90% of new solvent cost.

Waste exchange and brokerage

This is not a technology but an information service. A waste exchange can match a generator of waste with a facility that can use the waste as a raw material. Commercial waste brokerage services are also available. A waste generator is matched with a potential waste user who can utilize the waste as a feedstock. Matching generators and users is based on the knowledge of raw material inputs and wastes and product outputs of individual industries and firms.

Table 7. Facility Characteristics to Be Considered in Choosing an Off-Site Recycler

Permits held by the facility.
Types of solvent wastes managed.
Ability to meet solvent purity specifications if solvent is to be returned to the generator.
Availability of registered trucks to transport the solvent wastes.
Distance to the recycling facility and associated transportation costs.
Available laboratory facilities and analytical procedures.
Record keeping practices.
Availability of custom recycling services. (e.g., vendor-owned recycling units that can be operated on the generator's property).
Expertise on in-plant waste management strategies and process controls.
insurance for recycling/treatment/disposal operations.
Disposal procedures for still bottoms and solvents that cannot be recycled.
State regulatory agency's compliance records on the facility.
Current customers' comments on the facility.
Facility's financial stability.

Source: Radimsky, 1984.

AQUEOUS

Aqueous cleaning comprises a wide range of water-based cleaning methods that use water, detergents, acids, and alkaline compounds to displace soil rather than dissolving it in organic solvent. Aqueous cleaning has been found to be a viable substitute for many parts cleaning operations currently using solvents. Its principal disadvantage is that the parts are wet after cleaning and ferrous parts easily rust in this environment. (However, the use of warm (140-150°F) air for drying is less costly than the cost associated with solvent usage and disposal and there are additives available to prevent short term rusting). Also, aqueous cleaning may not be suitable for electronic components since it may leave conductive residue.

Waste mmimization techniques for reducing wastes from aqueous cleaning include substitution alternatives, use of less hazardous compounds, and maintaining solution quality.

3.5 Substitution Alternatives for Aqueous Cleaners

Abrasives, water, or steam are less hazardous than acid or alkaline cleaners, and may be equally or more effective. An example in which an abrasive cleaning system was successfully substituted for an alkaline cleaner is provided below.

3.6 Use of Less Hazardous Acid or Alkaline Compounds

The aluminum processing industry widely uses deoxidizers and desmutters based on chromic acid which is highly toxic and a possible carcinogen. By substituting a nonchromated deoxidizer, use of a hazardous product can be eliminated. The latter products are based on ferric sulfate which is easily treated for disposal (Weast 1988).

3.7 Maintain Solution Qualify

As was discussed under general waste minimization options for solvent use, maintaining solution quality reduces the need for replacement and disposal. Ways to achieve this goal include precleaning inspection, avoiding unnecessary loading, providing continuous heating, proper solution make up, removing sludge promptly, and monitoring cleaning solution strength.

Precleaning inspection All parts entering the tanks should be free of solvents and other cleaners. For parts that are first mechanically cleaned, water-based abrasives and cutting oils should be used to reduce the cleaning load. Precleaning of the parts in a hot water bath is often effective in reducing the load on the cleaner. This initial precleaning stage can often be made up from the last rinse stage of the cleaning ***operation*** and should employ demineralized water.

Substituting an abrasive cleaning system for an alkaline bath

A manufacturer of fabricated metal products cleaned nickel and titanium wire in an alkaline chemical bath prior to using the wire in its product. In 1986, the company began to experiment with a mechanical abrasive system. The system worked, but required passing the wire through the unit twice for complete cleaning. In 1987 the company bought a second abrasive unit and installed it in series with the first unit. This system allowed the company to completely eliminate the chemical cleaning bath (USEPA, 1988B).

Precleaning inspections of the parts may also help in establishing the proper temperature and concentration at which to operate the bath. Quite often, bath temperatures and/or concentrations are increased in an attempt to improve efficiency. While this works in many cases, some soils can become set at higher temperatures and concentrations. When bath oils and solids are present on a part, the rapid removal of the oil due to higher bath temperature creates a difficult-to-remove solid. Proper cleaning may require a lower temperature, longer soak time, and some form of agitation.

Avoid unnecessary loading

When using an alkaline cleaner, alkalinity may be reduced by the acidity of the soils removed, reaction of the alkali with carbon dioxide in the air used for agitation, and reaction of the cleaner components with hard water salts (Spring, 1963). In some applications, the detrimental effects of carbon dioxide and hard water can be as significant as the effect of soil loading. Quite often, 10 to 25 percent of the cleaner can be consumed due to water softening.

In addition to consuming expensive cleaner, large amounts of solids form in the bath which may then interfere with cleaning. These solids can also form scale on the heating tubes and reduce heat transfer efficiency. Cleaner consumption can be very high when heated cleaning baths are used and large amounts of hard water are added as evaporation makeup. Solutions to these problems include use of mechanical agitation instead of air and use of softened, demineralized, or deionized water.

Provide continuous heating

For tanks containing alkaline cleaner that are well insulated, properly covered, and located where ambient temperatures are not too low, there are benefits to be gained if the tank is not allowed to cool overnight. Derived benefits include reduced absorption of carbon dioxide (i.e. less reduction of alkalinity) and fewer rejects during production start-up due to inadequate temperature. Occasional cooling of the tank should be performed to allow for the split out and removal of oil. Proper heating and cooling cycles will depend on the types of air encountered, the types of cleaning agents used, and the workload on the system.

Proper solution make-up

Great care should be exercised when making up cleaning solutions. If the water is too hot, boil over can occur due to the heat of solution. If the water temperature is too low, the liquid or solid cleaner will sink to the bottom and not mix properly. With cleaners that contain inhibitors, failure to allow for complete mixing can lead to attack of metal parts or the tank itself. A helpful procedure is to formulate baths at the end of a shift so that the components have time to dissolve and mix before the start of production. For systems without good mixing controls, the use of liquids should be favored over solids or powders.

Good mixing is achieved by adding a mixing system to the tank. By installing a three way valve on the main header of the pump exit, solution can be re-diverted to the chemical entry area instead of through the spray nozzles. This provides for easier dissolution of chemicals through a greater number of turnovers (less pressure drop means higher pumping rates), and elimination of potential plugging of the nozzles when dissolving solids.

AQUEOUS

Remove sludge and soils promptly

Removing sludge and soils from aqueous cleaning soak tanks will reduce chemical use by increasing the permissible time interval between dumping and total cleanout of the tank.

Alkaline cleaners are available which allow the separation of excess oily soil from the cleaner. These formulations involve the use of surfactants that are good detergents but poor emulsifiers. Agitation of the bath during the work shift causes a temporary emulsification which keeps the soil in suspension. After a prolonged period of inactivity (usually overnight), the oily soils float to the surface where they are skimmed off. This method is quite effective with mineral oil-type soils but is less so with fatty oils.

Monitor cleaning solution strength

Analytical checks of solution strengths should be made on a routine basis. The correction of solution strength by making small and frequent additions is much more effective than making a few large additions. Analytical checks can be performed by the operator utilizing simple titration techniques (does the addition of a given amount of reagent to a known volume of cleaner and indicator result in a color change?). Full scale titration tests may be performed by the lab on a less frequent basis. An accurate log of all tests and cleaner additions should be kept at all times. Occasional testing of the reagents should also be performed.

Equipment maintenance

As discussed under solvent cleaning, rack systems should be maintained in good condition, free from cracks, rust, and corrosion. Metal tanks should be properly coated with protective finishes both ‘inside and out. Plastic linings should be used in deionized water rinse tanks since these tanks tend to rust rapidly. Use of plastic tanks can eliminate this problem. Spray nozzles should be inspected regularly to avoid clogging.

Reducing chemical use and waste in a bath cleaning system

Liquid-Life makes a 100-gallon per minute separator unit that operates in conjunction with a cleaning bath (solvent, alkaline or acid). The separator unit continuously removes sludge and particulate matter from the bath. A pump, hydrocyclone, and sludge retention tank make up the unit. Waterloo Industries Inc., of Waterloo, Iowa, installed the Liquid-Life unit for its alkaline cleaning system, used to clean the steel cabinets it manufactures prior to phosphatecoating the cabinets. The Liquid-Life unit has enabled Waterloo to reduce its chemical costs by 20 percent, clean out its alkaline bath system every 13 weeks instead of every four weeks, and do less maintenance on the cleaning operation since the pump is the only moving part in the system (Anonymous, March 1982).

Aqueous

Another important item to maintain regularly is the float valve that supplies make-up water to tanks of heated cleaning solution. Float valves are used to maintain the level in the tank so that the heating coils/elements do not become exposed. While maintaining an adequate level is extremely important, it is also important that the valve does not leak and result in dilution of the cleaner. In addition to maintenance, making frequent analytical checks is a good way to detect slow leaks.

Reduce drag-out

If possible parts should be racked so that surfaces are nearly vertical and the longer dimensions are horizontal. (For example, a rectangular part should be racked so that while its planes are vertical, its long axis is horizontal.) If the lower edge is tilted, the run-off will occur at a comer rather than the entire edge. As shown in Table 8, proper racking can reduce solution drag-out. Backing parts so that their planes are vertical is preferable to racking the planes horizontally (i.e., oriented like the top of a table). Drag-out can also be reduced by draining parts thoroughly, installing drain boards, reducing the concentration of cleaner, and by increasing solution temperature.

Increase the degree of rinsing efficiency while reducing water use

Rinse tanks should be agitated for maximum rinsing efficiency. Heating the water may also be effective but care should be taken that the soils present do not become set. Ways to further increase efficiency while reducing water usage include:

Use of demineralized water

Following a final rinse, the contaminants contained in the rinse will remain on the workpiece. As the parts dry, spotting or rusting may occur. For items on which minor residues cannot be tolerated, the use of demineralized water is standard. Using demineralized water will also reduce the amount of sludge generated during wastewater treatment and may allow the direct reuse of rinse water as make-up to the cleaning bath.

Reducing drag-out

Parts that have recesses or cavities may carry significant amounts of cleaning solution with them when they are removed from a bath. Improved rack design, including proper tilting of long horizontal bars, reduced the amount of drag-out from a cleaning bath associated with an electroplating operation, according to a report by Pioneer Metal Finishing Inc., of Franklinville, New Jersey. Other drag-out reducing measures include tilting a part during withdrawal, or drilling small holes in the part to provide for drainage during removal.

Using deionized water rinse

It has been reported (Spring 1963; Brown, Spring, and Hennessy 1955) that many in the steel fabricating industry were troubled with the pinpoint rusting of steel "blackplate." Experiments showed that a residual amount of alkaline cleaner residue plus hard water produced this type of rusting during storage at slightly humid conditions. Lab tests showed that this type of rusting only occurred when hard water and alkaline salts were present. Rinsing in hard water only resulted in heavy streak rust while use of deionized water produced trace or no rust. A final rinse in distilled water was utilized to prevent rusting.

AQUEOUS

Table 8. Drag-Out for Various Rack Configurations

Item	Drag-out, gal/100 ft2
Vertical parts, well drained	0.4
Vertical parts, poorly drained	2.0
Vertical parts, very poorly drained	4.0
Horizontal parts, well drained	0.8
Horizontal parts, very poorly drained	10.0
Cup-shaped parts, very poorly drained	8.0 to > 24.0

Source: Durney, 1984.

Table 9. Flow Rates for Five Rinsing Systems

System	Flow (gpm)
Single rinse	10.0
Two rinses in series, equal flow of fresh rinse water to each tank	0.6
Three rinses in series, equal flow of fresh rinse water to each tank	0.3
Two counterflow rinses, fresh water feed to second tank only	0.3
Three counterflow rinses, fresh water feed to third tank only	0.1

Source: Durney, 1984.

AQUEOUS

Counterflow rinsing

Counterflow rinse systems should always be used to reduce overall water consumption and subsequent treatment requirements. A comparison of 5 rinse systems is illustrated in Table 9.

Spray rinsing

Rinsing efficiency can be increased by installing spray systems. Spraying parts with fresh water as they are raised above the rinse equals the equivalent of 1/2 of a counterflow bath.

Installation of fog nozzles

Fog nozzles use much less water than conventional spray systems. Fog nozzles also benefit aqueous cleaned parts by covering the parts, thus preventing solution from drying on parts. Solution drag-out is reduced.

Employ closed loop systems

For pickling applications, consider a closed loop acid pickle system as shown in Figure 8. This system consists of four essential items (Krofchak and Stone 1975):

A synthetic fiber fume filter to recover acid vapors

Unlike wet scrubbers, these filters do not produce large volumes of waste water and the recovered acid can be returned directly to the bath.

- **Use of indirect heating (instead of live steam** injection) **and** agitation **to maintain cleaning efficiency and acid concentration.**

- **Employment of a multistage counter-current rinsing sequence**

  Rinse water from the first stage can be used as make-up to the acid tank. This avoids the need for treating a stream that contains 70 to 80 percent of the dragged-out acid. Rinse water from subsequent stages-can be used as makeup for preceding stages.

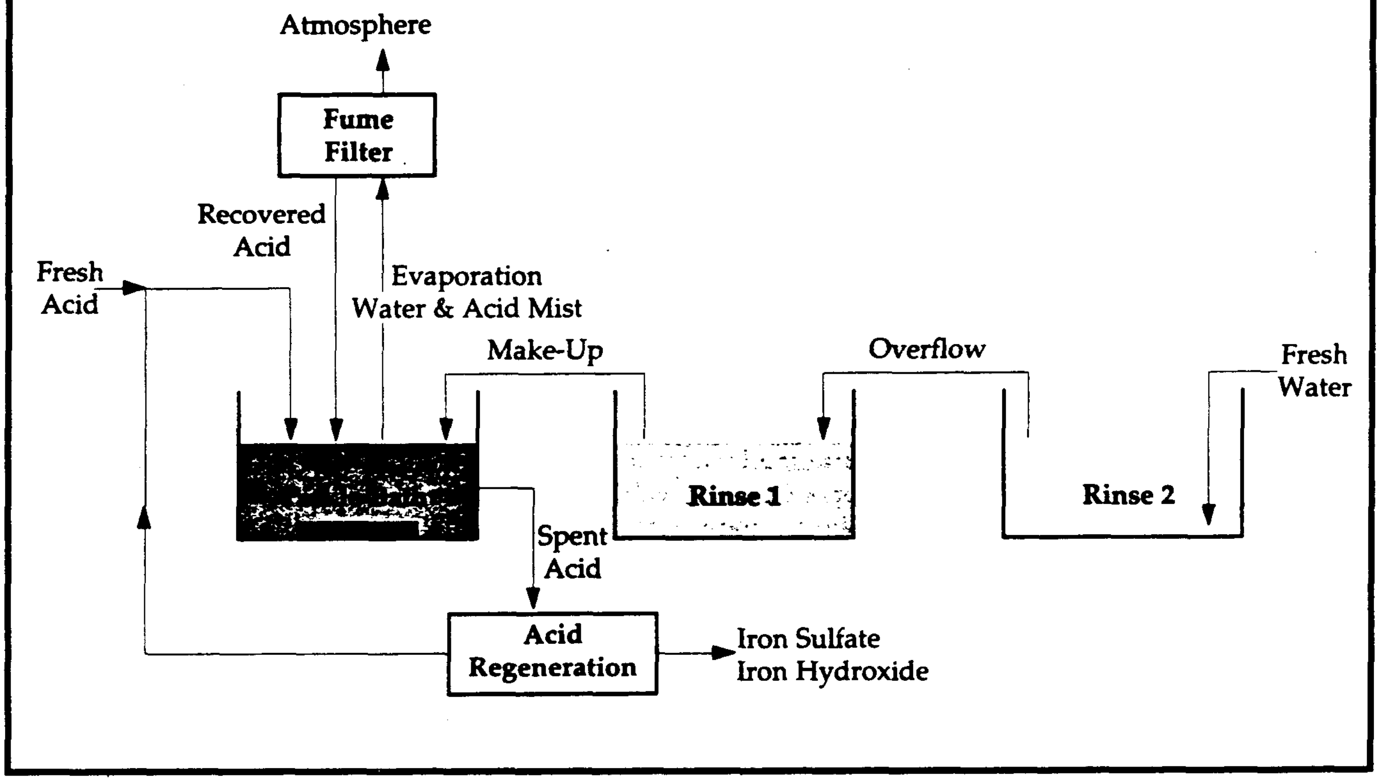
- **Use of a cooling or evaporative crystallizer to recover ferrous sulfate from spent sulfuric acid baths**

  For facilities employing hydrochloric acid, proven commercial processes can be employed to recover iron and hydrochloric acid.

Proper parts drying

After a water rinse, it is quite common to dry the parts using compressed air. Unless great care is taken to ensure the removal of oil, water, and dirt from the air stream, resoiling of the parts will almost certainly occur. Automated drying ovens might be a more viable alternative.

Figure 8. Acid Pickle Closed-Loop System



Abrasives can be used in tumbling barrels or applied to a buffing wheel or machine. Other mechanical abrasive cleaning methods include air-assisted or water-assisted blasting, brushing, vibratory processes, centrifugal barrel finishing (CBF), centrifugal disc finishing, spindle finishing, and use of natural

Waste from buffing operations consists of worn out cloth wheels saturated with abrasives, metal particles, binder, and various oxides. Waste from liquid-based mass finishing operations consists of abrasives, metal particles, and water and oxides dispersed in a slurry. Alkaline and acid cleaners are sometimes added to abrasive slurries in order to improve cleaning action. These slurries are discharged when the abrasive has undergone a given amount of attrition.

Options for reducing wastes associated with abrasive cleaning include:

Use of greaseless or water-based binders for buffing or polishing

When oil-based binders are used, the frictional heat generated during buffing can cause the binders -to bum. This in turn leads to the requirement for additional cleaning with alkaline soaks. When properly used, greaseless compounds produce parts that leave the wheel clean and dry. Greaseless compositions also tend to adhere to the surface of the wheel so that wheel life is extended.

Use of liquid spray compositions

Liquid spray abrasive systems are usually water-based abrasives that are applied directly to the buffing wheel. Wheel wear due to compound deficiency, compound waste due to over-application, and post-cleaning requirements are all significantly reduced or eliminated when a spray gun with liquid abrasive spray is used.

Control water level in mass finishing equipment

Mass finishing operations are carried out in aqueous solutions using abrasives or non-abrasive compounds. Water level control is extremely important in order to achieve maximum efficiency in mass cleaning operations. If not enough water is used, parts leaving the equipment will be dirty. Too little water will increase the attrition rate of the abrasive and increase replacement frequency.

4. IMPLEMENTATION

After promising waste minimization measures for a parts cleaning operation have been identified, they should be evaluated for technical and economic feasibility and, if found satisfactory, they should be implemented. For those methods that are found to be economically infeasible, additional analysis including consideration of "hidden " cost, liability, public image and other components (USEPA, 1988C) should be performed before dropping an option.

Adopting specific waste minimization measures may not be easy or straightforward. A number of factors (Table 10) may affect the readiness of an organization to implement measures that require changes in procedures, equipment, or employee responsibilities. Developing a strategy to overcome these barriers should be an integral part of waste minimization planning. This strategy should include establishment of a working group of personnel representing the affected departments: Health and Safety, Production, Maintenance, Process Control, Purchasing, and Facilities, for example. (USEPA), 1988B)

5. CONCLUSIONS

As increased regulation raises the cost of waste treatment and disposal, efforts to decrease waste volumes and toxicity become more economically justifiable. Implementing waste minimization techniques to reduce cleaning waste can produce treatment and disposal cost savings which more than offset the expenditure. In addition, material costs, regulatory compliance, and other costs can be cut since the life of the cleaning solutions will be lengthened.

Most of the measures discussed in this pamphlet would involve minimal capital outlays. For example, proper equipment operation requires only that management thoroughly train the employees using the equipment and that the equipment be correctly maintained. These low-cost measures generally have a fast payback and are among the first a firm should implement. Making employees aware of the cost of waste generation due to cleaning operations and involving them in identifying solutions may encourage the design of more efficient production processes.

With the adoption of efficient production processes and the waste-minimizing measures presented here, companies with parts cleaning operations should be able to reduce their waste disposal costs and liabilities, and reduce their contribution to the environmental problems associated with waste disposal.

Table 10. Some Barriers to Waste Minimization

Production

A new operating procedure will reduce waste but may also be a bottleneck that decreases the overall production rate.

Production will be stopped while the new process equipment is installed.

A new piece of equipment has not been demonstrated in a similar service. It may not work here.

Facilities/Maintenance

Adequate space is not available for the installation of new equipment.

Adequate utilities are not available for the new equipment.

Engineering or construction manpower will not be available in time to meet the project schedule.

Extensive maintenance may be required.

Quality Control

More intensive QC may be needed.

More rework may be required.

Client Relations/Marketing

Changes in product characteristics may affect customer acceptance.

Inventory

A program to reduce inventory (to avoid material deterioration and reprocessing) may lead to stockouts during high product demand.

Finance

Inadequate cost evaluations or coordination with financial department.

Purchasing

Existing stocks (or binding contracts) will delay the replacement of a hazardous material with a nonhazardous substitute.

Environmental

Accepting another plant’s waste as a feedstock may require a lengthy resolution of regulatory issues.

Waste Treatment

Use of a new nonhazardous raw material will adversely impact the existing wastewater treatment facility.

Source: USEPA, 1988B.

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7. SOURCES OF INFORMATION ON WASTE MINIMIZATION

Associations That Can Provide Information and Direction Relating to Waste Minimization in Parts Cleaning

Abrasive Engineering Society (AES)
1700 Painters Run Rd.
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Aerospace Industries Association of America (AIA)
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Washington, DC 20036
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Air Pollution Control Association (APCA)
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American Chemical Society
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American Electronics Association (AEA)
2600 El Camino Real
Palo Alto, CA 94306
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American Electroplaters Society (AES)
1201 Louisiana Ave.
Winter Park, FL 32789
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American Society for Metals (ASM)
Metal Parks, OH 44073
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American Society for Testing and Materials (ASTM)
1916 Race St.
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Association for Finishing Processes (AFP)
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Chemical Coaters Association (CCA)
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Chemical Manufacturers Association (CMA)
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Chemical Specialties Manufacturers Association (CSMA)
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Electrochemical Society (ECS)
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Fabricating Manufacturers Association (FMA)
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Federation of Societies for
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Halogenated Cleaning Solvents
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Institute for Interconnecting and
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Semiconductor Equipment
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Mountain View, CA 94043
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Semiconductor Industry
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