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Guide to Cleaner Technologies

Cleaning and Degreasing Process Changes

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GUIDE TO
CLEANER TECHNOLOGIES

CLEANING AND DEGREASING PROCESS CHANGES

Office of Research and Development
United States Environmental Protection Agency
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NOTICE

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This *Guide to Cleaner Technologies: Cleaning and Degreasing Process Changes* has been subjected to U.S. Environmental Protection Agency peer and administrative review and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency.

This document identifies new approaches for pollution prevention in cleaning and degreasing processes. Site-specific selection of a technology will vary depending on shop and manufacturing process applications. It is the responsibility of individual users to make the appropriate application of these technologies. Compliance with environmental and occupational safety and health laws is the responsibility of each individual business and is not the focus of this document.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the U.S. EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

Reducing the utilization or generation of hazardous materials at the source or recycling the wastes on site is one of EPA's primary pollution prevention goals. Economic benefits to industry may also be realized by reducing disposal costs and lowering the liabilities associated with hazardous waste disposal.

This *Guide to Cleaner Technologies: Cleaning and Degreasing Process Changes* summarizes information collected from U.S. Environmental Protection Agency programs, peer-reviewed journals, industry experts, vendor data, and other sources. The cleaner technologies are categorized as commercially available or emerging. Emerging technologies are technologies that are in various stages of development, and are not immediately available for purchase and installation. For each technology, the *Guide* addresses its pollution prevention benefits, operating features, application, and limitations. Elimination or reduction in use of hazardous solvents applied in cleaning processes is the main focus of the technologies covered in the *Guide*.

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SECTION 1
OVERVIEW

What Is Cleaner Technology?

A *cleaner technology* is a source reduction or recycling method applied to eliminate or significantly reduce hazardous waste generation. *Source reduction* includes product changes and source control. *Source control* can be characterized as input material changes, technology changes, or improved operating practices.

Source reduction precedes recycling in the hierarchy of pollution prevention options.

Pollution prevention should emphasize source reduction technologies over recycling but, if source reduction technologies are not available, recycling is a good approach to reducing waste generation. Therefore, recycling should be used where possible to minimize or avoid the need to treat wastes that remain after viable source reduction options have been evaluated and/or implemented.

The cleaner technology must reduce the quantity and/or toxicity of the waste produced. It is also essential that final product quality be reliably controlled to acceptable standards. In addition, the cost of applying the new technology relative to the cost of similar technologies needs to be considered.

Why Clean and Degrease?

Cleaning and degreasing processes are applied in a variety of industries to remove dirt, soil, and grease (often referred to together as soil). Cleaning and degreasing are done as a final step in manufacturing a product, as a preliminary step in preparing a surface for further work (e.g., electroplating), or as a cleaning step for forms or equipment between uses.

In preparing metals for finishing, the cleaning process is the most important. Finishing processes depend on a clean surface as a foundation. In selecting a cleaning operation, the process to be performed as well as the type of metal and contaminant are important considerations.

Cleaning processes are used in product finishing, dry cleaning, and electronics manufacturing industries.

Many parts manufacturers clean their own products, whereas others send them out to companies whose sole business is parts cleaning. Currently, the common cleaning processes for metals include liquid solvent cleaning (cold cleaning) and vapor degreasing. Liquid solvent cleaning usually is done in large tanks containing solvent solutions in which the parts are immersed. This usually is an automated process. Vapor degreasing generally involves chlorinated solvents such as methylene chloride, 1,1,1-trichloroethane, trichloroethylene, or perchloroethylene. Parts are immersed in the vapors of these solvents for degreasing. In the dry cleaning industry, perchloroethylene is commonly used for washing clothes.

In the electronics industry, parts generally are cleaned after soldering to remove contaminants. These contaminants originate from the fluxes used to promote the wetting necessary for good solder joints to be formed. The flux residue can interfere with future processes and reduce the aesthetics and reliability of a part. Traditionally, chlorinated, fluorinated, and other halogenated solvents have been used to remove these residues.

Pollution Problem

Cleaning and degreasing technologies generally involve applying some form of a solvent to a part. Solvents are used in virtually every industry to some extent. During the cleaning process, there is often an environmental problem with air emissions from the solvents. After the cleaning process, a waste stream—composed of the solvent combined with oil, debris, and other contaminants—is left for disposal.

Halogenated solvents have been chosen in the past for their stability, ease of drying, and effectiveness in removing oils. Some of the same characteristics that make these solvents effective in cleaning processes have detrimental environmental effects. Solvent evaporation has been investigated for its role in stratospheric ozone depletion, global warming potential, and ground smog formation.

Using halogenated solvents to clean and degrease not only generates hazardous solvent wastes but also creates work conditions that may be detrimental to the health and safety of workers. Questions concerning safety and health issues include chronic and acute effects, carcinogenicity, and teratogenicity.

Many industries have begun to reduce or eliminate the use of halogenated solvents.

Because environmental laws restrict the use of such solvents, many industries are attempting to reduce or eliminate their use of halogenated solvents. Additional restrictions can be expected in the future.

Potential Solutions

Cleaner technologies now exist or are being developed that would reduce or eliminate the use of solvents for many cleaning and degreasing operations. There are two main focuses in describing cleaner technologies for cleaning and degreasing:

- Alternative cleaning solutions (e.g., aqueous-based) replace solvents. These alternatives could be used in existing processes that currently use solvents.
- Process changes use different technologies for cleaning or eliminate the need for cleaning. The capital costs may be greater for process changes, but the reduced cost of buying and disposing of solvents often makes up for this.

This application guide focuses on those cleaner technologies that involve process changes. Process changes can either eliminate the need for cleaning or apply techniques that eliminate or reduce the use of solvents.

Another possibility is to combine the above two methods. Sometimes the cleaning effectiveness of a solvent substitute is not adequate, and a process change can improve the effectiveness of the substitute. In such a case, a process change is combined with solvent substitution to create a cleaner technology. In other cases, the process change may involve reducing the amount of solvent or making it amenable to recycling. Alternative cleaning solutions are described in the companion U.S. EPA publication, *Guide to Cleaner Technologies: Alternatives to Chlorinated Solvents for Cleaning and Degreasing.* Both alternative cleaning solutions and process changes may have limitations that should be carefully evaluated by potential users for their specific applications.

What's In This Guide?

This application guide describes cleaner technologies that can be used to reduce waste in cleaning and degreasing operations. Its objectives are to help identify potentially viable cleaner technologies that can reduce waste by modifying the cleaning and degreasing process. This guide also provides resources for obtaining more detailed engineering information about the technologies. The following specific questions are addressed:

- What alternative cleaning and degreasing process changes are available or emerging that could significantly reduce or eliminate pollution being generated from current operations?
- Under what circumstances might one or more of these process changes be applicable to your operations?
- What pollution prevention, operating, and cost benefits could be realized by adapting the technology?

Other Questions Affecting Investment Decisions

These other considerations affect the decision to explore one or more cleaner technologies:

- Might new pollution problems arise when implementing cleaner technologies?
- Are tighter and more complex process controls needed?
- Will product quality and operating rates be affected?
- Will new operating or maintenance skills be needed?
- What are the overall capital and operating cost implications?

To the extent possible, these questions are addressed in this guide. The cleaner technologies described in this guide are applicable under different sets of product and operating conditions. If one or more are sufficiently attractive for your operations, your next step is to contact vendors or users of the technology to obtain detailed engineering data and make an in-depth evaluation of its potential for your plant.

Who Should Use This Guide?

This application guide has been prepared for plant process and system design engineers and for personnel responsible for process improvement. Process change descriptions within this guide allow engineers to evaluate options and major plant expansions, so that cleaner technologies can be considered for existing plants and factored into the design of new cleaning and degreasing operations.

Sufficient information is presented to select one or more candidate technologies for further analysis and in-plant testing. This guide does not recommend any technology over any other. It presents concise summaries of applications and operating information to support preliminary selection of cleaner technology candidates for testing in specific processes. Sufficient detail is provided to allow identification of possible technologies that can be applied immediately to eliminate or reduce waste production.

The keywords listed below will help you quickly scan the available and emerging technologies covered in this guide.

Summary

The cleaner technologies described in this guide are divided into two groups based on their developmental maturity:

- Commercially available technologies
- Emerging technologies.

Pollution Prevention Strategy, Section 4, discusses the impact of regulations on the potential for cleaner technologies. The Cleaner Technology Transfer Considerations, Section 5, discusses the various technical, economic, and regulatory factors that influence the selection and use of a cleaner technology.

Keywords

Cleaner Technology
Pollution Prevention
Source Reduction
Source Control
Recycling
Cleaning
Degreasing
Vapor Degreasing
Metal Finishing
Defluxing
Add-on Controls to Existing Vapor Degreasers
Completely Enclosed Vapor Cleaner
Automated Aqueous Cleaning
Aqueous Power Washing
Ultrasonic Cleaning
Low-Solids Fluxes
Inert Atmosphere Soldering
Vapor Storage Technology
Vacuum Furnace
Laser Cleaning
Plasma Cleaning
Fluxless Soldering
Replacement of Tin-Lead Solder Joints

SECTION 2
AVAILABLE TECHNOLOGIES

How to Use the Summary Tables

Seven available cleaner technologies for cleaning and degreasing are evaluated in this section:

- Add-on controls to existing vapor degreasers
- Completely enclosed vapor cleaner
- Automated aqueous cleaning
- Aqueous power washing
- Ultrasonic cleaning
- Low-solids fluxes
- Inert atmosphere soldering.

Tables 1 and 2 summarize descriptive and operational aspects of these technologies. They contain evaluations or annotations describing each available cleaner technology and give users a compact indication of the range of technologies covered to allow preliminary identification of those technologies that may be applicable to specific situations.

Descriptive Aspects

Table 1 describes each available cleaner technology. It lists the **Pollution Prevention Benefits, Reported Application, Operational Benefits,** and **Limitations** of each.

Operational Aspects

Table 2 shows key operating characteristics for the available technologies. The qualitative rankings are estimated from descriptions and data in the technical literature and are based on comparisons to typical technologies that cleaner technologies would replace.

Process Complexity is qualitatively ranked as "high," "medium," or "low" based on such factors as the number of process steps involved and the number of material transfers needed. **Process Complexity** is an indication of how easily the technology can be integrated into existing plant operations. A large number of process steps or input chemicals, or multiple operations with complex sequencing, are examples of characteristics that would lead to a high complexity rating.

The **Required Skill Level** of equipment operators also is ranked as "high," "medium," or "low." **Required Skill Level** is an indication of the relative level of sophistication and training required by staff to operate the new technology. A technology that requires the operator to adjust critical parameters would be rated as having a high skill requirement. In some cases, the operator may be insulated from the process by complex control equipment. In such cases, the operator skill level is low but the maintenance skill level is high.

Table 2 also lists the **Waste Products and Emissions** from the available cleaner technologies. It indicates tradeoffs in potential pollutants, the waste reduction potential of each, and compatibility with existing waste recycling or treatment operations at the plant.

The **Capital Cost** column provides a preliminary measure of process economics. It is a quantitative estimate of the initial cost impact of the engineering, procurement, and installation of the process and support equipment. Costs are given for a specific unit or plant that has implemented the process change. Costs will vary for each facility due to the diversity of data and the wide variation in plant needs and conditions. Cost analyses must be plant specific to adequately address factors such as the type and age of existing equipment, space availability, production volume, product type, customer specifications, and cost of capital.

The **Energy Use** column provides data on energy conversion equipment required for a specific process. In addition, some general information on energy requirements is provided.

The last column in Table 2 cites **References** to publications that will provide further information about each available technology. These references are given in full at the end of the respective technology sections.

Table 1. Available Technologies for Cleaning and Degreasing: Descriptive Aspects

Cleaning/ Degreasing Technology	Pollution Prevention Benefits	Reported Application	Operational Benefits	Limitations
Add-on Controls to Existing Vapor Degreasers	• Reduce solvent air emissions	• Retrofitted on existing vapor degreasers	• Allow gradual phase-in of emission controls • Major process modifications not required • Cleaning principle remains the same • Relatively inexpensive	• Reduce but cannot eliminate air emissions • Performance depends on other features of existing degreaser • Dragout on parts cannot be eliminated
Completely Enclosed Vapor Cleaner	• Virtually eliminates solvent air emissions	• Same as conventional open-top vapor degreasers	• Virtually eliminates air emissions and workplace hazards • Cleaning principle remains the same; user does not have to switch to aqueous cleaning • Significant recovery of solvent • Reduced operating costs	• High initial capital cost • Slower processing time • Relatively higher energy requirement
Automated Aqueous Cleaning	• Eliminates solvent use by using water-based cleaners	• Cleaning of small parts	• Eliminates solvent hazards • Reduces water consumption • Cleaning chemicals are reused • Easy to install and operate	• May not be able to replace vapor degreasing for some delicate parts, and requires more space than vapor degreasing • Wastewater treatment required • Relatively higher energy requirement
Aqueous Power Washing	• Eliminates solvent use by using water-based cleaners	• Cleaning of large and small parts	• Eliminates solvent hazards • Reduces cleaning time	• Pressure and temperature may be too great for some parts • Wastewater treatment required
Ultrasonic Cleaning	• Eliminates solvent use by making aqueous cleaners more effective	• Cleaning of ceramic, aluminum, plastic and metal parts, electronics, glassware, wire, cable, rods	• Eliminates solvent hazards • Can clean in small crevices • Cost effective • Faster than conventional methods • Inorganics are removed • Neutral or biodegradable detergents can often be employed	• Part must be immersible • Testing must be done to obtain optimum solution and cavitation levels for each operation • Thick oils and grease may absorb ultrasonic energy • Energy required usually limits parts sizes • Wastewater treatment required if aqueous cleaners are used
Low-Solids Fluxes	• Eliminates need for cleaning and therefore eliminates solvent use	• Soldering in the electronics industry	• Eliminates solvent hazards • Little or no residue remains after soldering • Closed system prevents alcohol evaporation and water absorption	• Conventional fluxes are more tolerant of minor variations in process parameters • Possible startup or conversion difficulties • Even minimal residues are unacceptable in many military specifications
Inert Atmosphere Soldering	• Eliminates need for flux and therefore eliminates solvent cleaning	• Soldering in the electronics industry	• Eliminates solvent hazards • Economic and pollution prevention benefits from elimination of flux	• Requires greater control of operating parameters • Temperature profile for reflow expected to play more important role in final results

Table 2. **Available Technologies for Cleaning and Degreasing: Operational Aspects**

Cleaning/ Degreasing Technology	Process Complexity	Required Skill Level	Waste Products and Emissions	Capital Cost	Energy Use	References
Add-on Controls to Existing Vapor Degreasers	Low	Low	• Spent solvent • Water in water separator • Air emissions	Varies depending on type of control and size of existing degreaser	• Varies depending on controls	U.S. EPA, 1989
Completely Enclosed Vapor Cleaner	Medium	Low	• Spent solvent • Water in water separator	Approximately $200,000 for a unit with 560 lb/hr processing speed for steel parts	• Approximately 22 kW for a unit with 560 lb/hr processing speed for steel parts (includes 480-V AC electric hookup and 75 psi compressed air)	Gavaskar et al., 1993 Townsend, 1993
Automated Aqueous Cleaning	Medium	Low	• Spent cleaning solution	$180,000 approximately for a unit with 1,000 lb/hr processing speed for steel parts	• 6 motors (1 of 5 hp, 4 of 3 hp, and 1 of 1.5 hp) for a 1,000-lb/hr unit • Gas heat for dryer (15 cu ft/hr)	Gavaskar et al., 1992 Scapelliti, 1993
Aqueous Power Washing	Low	Low	• Spent cleaning solution	$12,000 approx. for 1000-lb capacity, 4' x 4' chamber	• 220 V, 1 to 3 phase, 37 to 69 A (1.5 to 30 hp pump motor and 6 to 25 kW heat source)	Evers and Olfenbuttel, 1993
Ultrasonic Cleaning	Medium	Low	• Spent cleaning solution	Approximately $10,000 for console w/ 25" x18" x 15" chamber	• Generator — converts AC, 60 Hz to DC 20 kHz (200 to 600 W output) • Transducer is 600 to 1000 W	Burstein, 1989 Fuchs, 1989 Magnapak, 1988 Scott, 1989 U.S. EPA, 1991
Low-Solids Fluxes	Medium	Low	• No waste products	No additional capital cost	• None, unless spray applicator is used	Hwang, 1990 U.S. EPA, 1990 U.S. EPA, 1991
Inert Atmosphere Soldering	High	Medium	• No waste products	Varies widely	• Oven capable of utilizing an inert atmosphere	Hwang, 1990 Morris and Conway, 1991 Trovato, 1991 Tuck, 1991

The text further describes pollution prevention benefits, reported application, operational benefits, and limitations for each available technology. Technologies in earlier stages of development are summarized to the extent known in Section 3, Emerging Technologies.

Add-on Controls to Existing Vapor Degreasers

Pollution Prevention Benefits

Up to 90% or more of the solvent in a conventional open-top vapor degreaser may be lost due to air emissions.

The single largest use of halogenated solvents in the United States is for vapor degreasing. This includes batch-type open-top vapor cleaners (OTVCs) and continuous-type in-line cleaners. As much as 90% (or more) of the solvent used in conventional open-top vapor degreasers is lost due to air emissions. Controlling these air emissions from vapor degreasers is therefore of fundamental interest from a pollution prevention point of view. Air emissions from an OTVC occur during startup/shutdown, working, idling, and downtime. During startup, losses occur as the solvent in the sump is heated and a vapor layer is established in the open tank. Shutdown losses occur as this vapor layer subsides when the unit is switched off. Downtime losses occur due to normal evaporation of the solvent when the OTVC is not in use. Idling losses occur by diffusion from the vapor layer in the period between loads.

Movement of the work load in and out of the vapor degreaser is the main cause of air emissions.

By far the most important losses are the working losses or work load-related losses. As long as there are no disturbances at the vapor-air interface in the OTVC tank, air emissions occur but are limited by existing features such as freeboard height above the vapor interface and primary (water-cooled) condensing coils on the freeboard. Most vapor degreasers maintain a freeboard ratio (FBR), i.e., the ratio of the freeboard height to the width of the tank, of 0.75. However, as the work load (basket of soiled parts) is inserted into the tank or taken out after cleaning, this interface is disturbed and considerable amounts of solvent vapor escape to the ambient air by forced convection. Also, a large amount of solvent condensate is dragged out on the cleaned parts as the work load is removed from the tank. This solvent residue evaporates from the parts over time, leading to considerable air emissions.

Additional controls can be incorporated into an existing OTVC to reduce these air emissions. These add-on controls are an important way of reducing solvent emissions without changing the cleaning operation dramatically.

How Do They Work?

Add-on controls are features that can be incorporated into an existing degreaser to reduce air emissions. These process changes include the following:

- Operating controls
- Covers
- Increased FBR
- Refrigerated freeboard coils
- Reduced room draft/lip exhaust velocities.

Operating Features

The add-on controls limit air emissions through changes in operating practices or through equipment modifications. Operating controls are practices that reduce work load-related losses. These can be easily incorporated into the operating procedure, but their impact on emission reduction is significant. Air emissions can be reduced by slowing down the rate of entry of the work load into the OTVC tank. The more quickly the work load is lowered into the tank, the greater the disturbance or turbulence created at the vapor-air interface and the greater are the air emissions as the interface tries to reestablish itself. When the work load is lowered manually into the tank it is difficult to achieve a slow, steady rate of entry. Installing an electric hoist above the OTVC allows greater control on the rate of entry or removal of the work load. Reducing the area of the horizontal face of the basket in proportion to the area of the OTVC tank opening is another way of reducing turbulence at the interface; this will however, adversely affect the production rate.

Solvent condensate dragout can be reduced in several ways.

Facilitating parts drainage also is an important operating control. Parts that have recesses in which solvent condensate could accumulate must be placed in the basket in such a way that the condensate drains out of and not into the recesses. Thus, the amount of condensate dragged out as the basket is removed from the OTVC tank is limited, reducing subsequent air emissions. Another way of reducing dragout is to install electric-powered rotating baskets. The rotation allows condensate to drain out of the recesses in the parts.

A simple flat or rolling cover can be installed on the top of the OTVC tank to reduce air emissions. A cover reduces drafts in the freeboard that may cause disturbances. A cover also reduces diffusion losses during startup/shutdown, downtime, or idling. Covers should slide gently over the top of the opening to reduce disturbances. Automatic biparting covers that enclose the tank while the work load is in the process of being cleaned also are available. Covers can reduce working air emissions from an OTVC by as much as 35 to 50% (U.S. EPA, 1989). The variations in the percent reduction reflect different initial design and operating conditions of the OTVCs tested.

Increasing the freeboard height reduces air emissions.

Increasing the FBR from 0.75 to 1.0 or 1.25 can reduce air emissions significantly. Increasing the freeboard height—that is, the height of the tank above the vapor-air interface—reduces the susceptibility of the interface to room drafts and also increases the distance over which diffusion has to occur. Raising the freeboard on an existing OTVC may, however, reduce a worker's accessibility to the tank. But a raised platform next to the OTVC or an electric hoist can alleviate the problem. Raising the FBR from 0.75 to 1.0 reduces working air emissions by up to 20%. Increasing the FBR from 1.0 to 1.25 reduces emissions by another 5 to 10% (U.S. EPA, 1989). Under idling conditions, air emissions can be reduced by up to 40% when the FBR is increased from 0.75 to 1.0.

Refrigerated coils on the freeboard reduce air emissions.

Air emissions through diffusion can be reduced by installing refrigerated coils on the freeboard above the primary condenser coils. The refrigerated coils may be designed to operate either above or below freezing temperatures. Although theoretically the below-freezing coils should work better, in practice, the below-freezing coils have to be operated on a timed defrost cycle to prevent ice from building up on the coils. This periodic defrosting cycle reduces the efficiency of the coils to some extent. Working emissions are reduced by approximately 20 to 50% for above-freezing coils and by approximately 30 to 80% for below-freezing coils (U.S. EPA, 1989). Under idling conditions, emissions with below-freezing coils were reduced by approximately 10 to 60%. Some systems operate with the primary condenser coils themselves refrigerated, instead of having separate refrigerated coils.

Room drafts caused by plant ventilation can cause an increase in air emissions by sweeping away solvent vapors that diffuse into the freeboard region, leaving behind a turbulence that promotes greater emissions. Reducing room drafts can reduce these emissions. One interesting case is when lip exhausts themselves cause emissions. Lip exhausts are lateral exhausts installed on the perimeter of the OTVC opening to reduce solvent concentrations in the region where workers are exposed. However, this very feature increases diffusion and solvent diffusion losses from the OTVC sometimes are almost doubled. Although most of the diffusing solvent is captured by the lip exhaust and may be recovered later by carbon adsorption, some vapor escapes to the ambient.

Application

The attractiveness of these add-on controls is that they can be applied to almost any vapor degreaser without having to change the process completely. The basic degreasing principle does not change. These controls can be phased in gradually, improvements being made one at a time.

Existing OTVCs can be retrofitted with add-on controls at a reasonable cost. Table 3 shows examples of costs for retrofitting additional controls on typical small or large OTVCs. Actual costs can vary from these averages depending on the types of features obtained and the design of the existing OTVC. These costs indicate that these controls are viable options for small or medium-sized plants.

Table 3. Estimated Capital Cost of Add-ons to Existing Vapor Degreasers

Add-on	Cost for a small degreaser[a] ($)	Cost for a large degreaser[b] ($)
Automated work load handling	2,000-3,000	3,000-4,000
Bi-parting cover	8,000-9,000	10,000-12,000
Increasing FBR to 1.0	1,000-2,000	1,500-2,500
Refrigerated coils	5,000-7,000	8,000-12,000

[a] A small degreaser would have a 4- to 5-ft^2 opening.
[b] A large degreaser would have a 15-ft^2 opening.

Benefits

The benefits of these add-on controls are

- They can be retrofitted onto existing vapor degreasers.
- Simple add-ons such as a cover can reduce air emissions significantly.
- Reduced air emissions mean reduced solvent consumption and hence reduced operating cost.
- Add-on controls are relatively inexpensive.
- They are easy to install and operate.
- Using add-on controls requires no additional labor or skills.

Limitations

The limitations of add-on controls are

- The performance of any one add-on control is dependent on the design features already available on the OTVC. For example, the control efficiency of refrigerated coils varies depending on the temperature and efficiency of the existing primary condenser.
- Air emissions can be reduced considerably but not eliminated by using multiple controls. For example, if adding a cover alone reduces air emissions by 50% and adding refrigerated coils alone reduces air emissions by 50%, adding both the cover and the refrigerated coils will not give 100% reduction.
- Work load-related losses can be reduced but not eliminated.
- Dragout of solvent with the work load cannot be eliminated using add-on controls. Some residual solvent will escape from the parts to the ambient air.

Reference

U.S. Environmental Protection Agency. 1989. *Alternative Technology Control Documents — Halogenated Solvent Cleaners.*. August.

Completely Enclosed Vapor Cleaner

Pollution Prevention Benefits

The add-on controls described previously can significantly reduce air emissions, but the completely enclosed vapor cleaner (CEVC) virtually eliminates them. Tests have shown over 99% reduction in solvent emissions by using the CEVC. This technology was first developed in Germany, where vapor degreasers are regulated as a point source. Some companies have recently started selling this technology in the United States.

How Does It Work?

In a CEVC, the work load is placed in an airtight chamber, into which solvent vapors are introduced. After cleaning is complete, the solvent vapors in the chamber are evacuated and captured by chilling and carbon adsorption. Once the solvent in the chamber is evacuated, the door of the chamber is opened and the work load is withdrawn. The cleaned work load is also free from any residual solvent and there are no subsequent emissions.

Operating Features

> *The CEVC remains enclosed during the entire cleaning cycle.*

Figure 1 shows the CEVC unit configuration. Approximately 1 hour before the shift begins, a timer on the CEVC unit switches on the heat to the sump. When the solvent in the sump reaches vapor temperature, the vapor is still confined to an enclosed jacket around the working chamber. The parts to be cleaned (work load) are placed in a galvanized basket and lowered by hoist from an opening in the top into the working chamber. The lid is shut, the unit is switched on, and compressed air (75 psi) from an external source hermetically seals the lid shut throughout the entire cleaning cycle.

> *Vapors in the cleaning chamber are evacuated before the work load is withdrawn.*

Table 4 shows the cleaning cycle stages. First, solvent vapors enter the enclosed cleaning chamber and condense on the parts. The condensate and the removed oil and grease are collected through an opening in the chamber floor. When the parts reach the temperature of the vapor, no more condensation is possible. At this point, fresh vapor entry is stopped and the air in the chamber is circulated over a cooling coil to condense out the solvent. Next, the carbon is heated up to a temperature where most of the solvent captured in the previous cleaning cycle can be desorbed. The desorbed solvent is condensed out with a chiller. The carbon adsorbs the residual solvent vapors from the air in the cleaning chamber. As shown in Figure 2, the adsorption stage continues until the concentration in the chamber is detected by a sensor to fall below a preset level (usually around 1 g/m^3). When the concentration goes below this level, the seal on the lid is released and the lid can be retracted to remove the work load. Upon retraction, a tiny amount of residual solvent vapor escapes to the atmosphere, the only emission in the entire cycle. Tests have shown that the CEVC reduces solvent emission by more than 99% compared with an OTVC (Gavaskar et al., 1993).

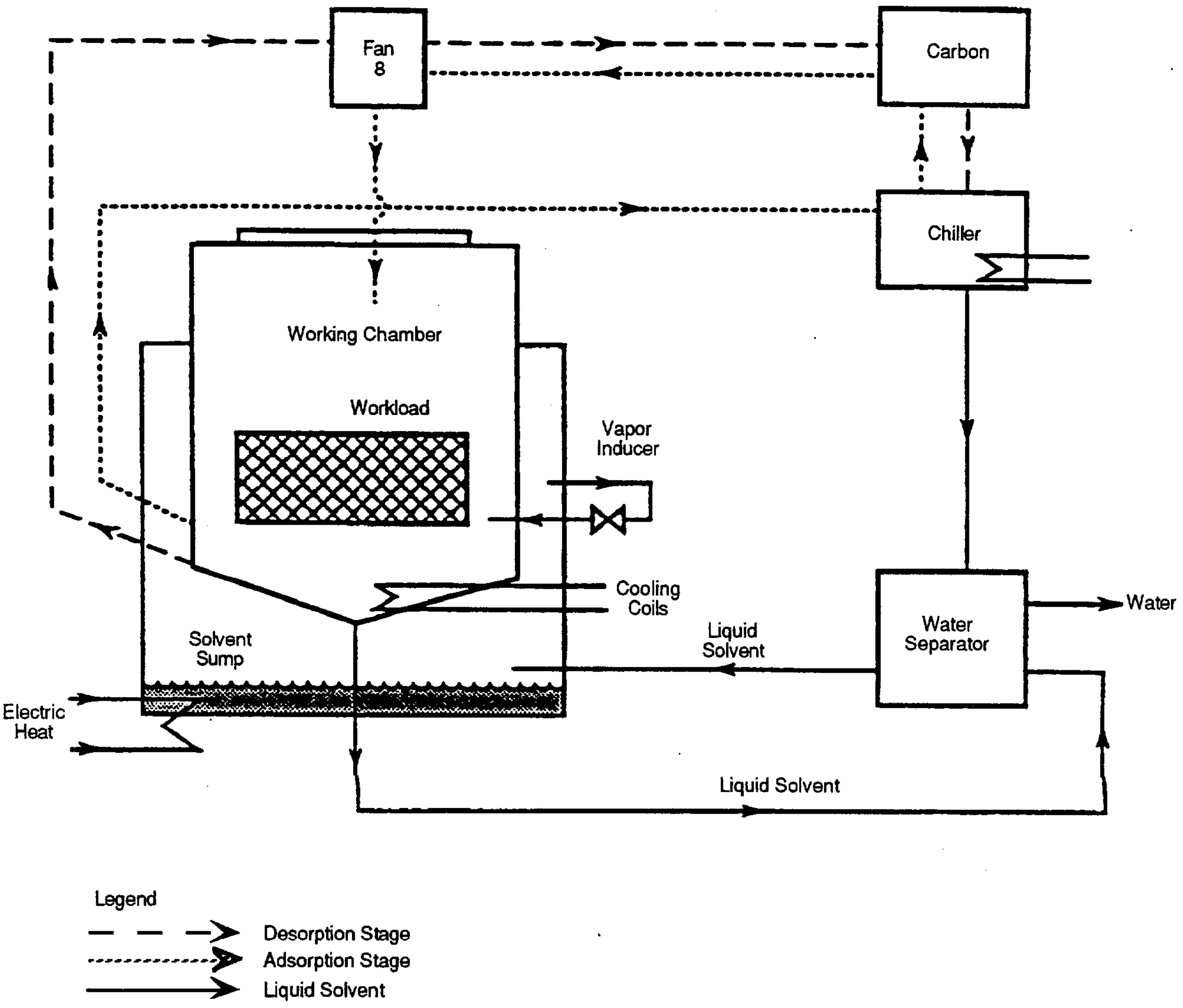

Figure 1. **Completely enclosed vapor cleaner.**

Unlike a conventional degreaser, there are no significant idling losses between loads or downtime losses during shutdown. The CEVC can be operated as a distillation unit to clean the liquid solvent in the sump. To distill, the unit is switched on without any work load in the chamber. After most of the solvent is converted to vapor, the residue in the sump is drained out and the vapors in the chamber are condensed in the chiller to recover the solvent. CEVC thus provides a good alternative for meeting pollution prevention objectives.

Energy requirements of the CEVC are relatively high.

Energy requirements of the CEVC are higher compared with a conventional degreaser. The CEVC operates on a 480-V AC electric supply and consumes approximately 22 kW of power. The higher energy is required to generate, condense, and move the vapor during each load.

One significant difference between a conventional degreaser and the CEVC is that, in the conventional degreaser, there is always a solvent vapor layer present in the degreasing tank. This layer is continuously replenished with solvent vaporizing from the sump. The work load therefore reaches vapor temperature very soon and the cleaning is completed. The CEVC, on the other hand, goes through several stages to evacuate and introduce vapors. Although most of the stages have a relatively fixed time requirement, the vapor-fill stage time varies. The vapor is introduced anew near the bottom of the working chamber with each work load. The vapor slowly works itself up through the work load bringing each successive layer of parts in the basket to vapor temperature. The time taken for the entire load to reach vapor temperature is

Table 4. CEVC Cleaning Cycle

Stage	Vendor-Recommended Time Settings
Solvent heatup (once a day)	Variable[a]
Solvent spray (optional)	10-180 sec
Vapor fill	Variable[b]
Degreasing	20-180 sec
Condensation	120 sec
Air recirculation	120 sec
Carbon heatup	Variable[c]
Desorption	60 sec
Adsorption	60-240 sec[d]

[a] Normally requires approximately 1 hour on days following overnight shutdown when sump solvent temperature drops to 70°C. After weekend shutdowns, when sump solvent temperature drops to 20°C, it may take 1 1/2 hours for solvent to reach vapor temperature. Time on unit allows automatic heat-up prior to beginning of shift.

[b] Varies according to mass of work load and type of metal. Generally varies between 8 to 40 min.

[c] Carbon heatup took approximately 22.5 min during testing.

[d] At 60 sec, if monitor shows that chamber concentration is above 1 g/m^3, then the adsorption stage proceeds to the full 240-sec stage. This sequence repeats if necessary.

described as the vapor-fill stage in Table 4. This vapor-fill time, however, is highly dependent on the total mass and type of metal in the work load. The factor that governs the variation based on type of metal is the thermal diffusivity of each metal. The thermal diffusivity itself is a function of the thermal conductivity, specific heat, and density of the metal.

Cleaning cycle time varies with the type of metal in the work load.

Based on a CEVC unit that is rated at 560 lb of steel parts per hour (1 cleaning cycle per hour), the total cycle time required for various work load metals and masses is shown in Figure 3. For any of the metals, as the mass of the work load increases, the total cycle time increases (mainly due to an increase in the vapor-fill stage time). Parts made out of copper or aluminum require a lower cycle time compared to steel. Aluminum, though, has a much lower density, and there is a limit as to the mass (or weight) of parts that can fit into the basket for one cycle. Additional parts have to be run through the next batch or cleaning cycle. Because of the fixed portion of the cycle time involved in running a fresh batch, the line for aluminum (Figure 3).shows a jump after 375 lb of parts.

Application

The CEVC can be applied wherever vapor degreasing currently is being used. The degreasing principle is the same; the pollution prevention features set this unit apart from conventional OTVCs. This unit is an excellent option for plants that want to eliminate solvent emissions but are unwilling to change over to aqueous cleaning.

The CEVC has a relatively higher capital cost.

Given the longer vapor-fill time, carbon heatup, desorption, and adsorption stages of the CEVC, a much larger cleaning chamber capacity (or batch volume) is required to maintain the same processing rate as with a conventional degreaser. This and other emission control features make the capital cost of the CEVC significantly higher than that of an OTVC. A commercially available CEVC with a capacity of 560 lb/hr of steel parts costs approximately $200,000 (Townsend, 1993). Savings in solvent consumption offset the initial investment.

The CEVC reduces operating costs.

Compared to a conventional OTVC with the same production capacity, the CEVC results in operating savings of $25,000/yr from reduced labor costs (due to larger, unattended batch sizes) and lower solvent requirement (due to solvent recovery) based on a 40-hr work week (Gavaskar et al., 1993). The CEVC does not require much of the auxiliary equipment that may be required for a standard conventional vapor degreaser, if the user is aiming to reduce workplace emissions to meet or anticipate increasingly stringent environmental and worker safety regulations. Additional control devices for standard conventional degreasers (e.g., increased freeboard ratio, refrigerated coils, and room ventilation control) would add considerably to capital and operating costs. In contrast, the CEVC is a self-contained unit that would require no additional facility modifications to achieve significant emission reduction.

Benefits

The CEVC has the following benefits:

- It reduces solvent emissions by over 99% compared to a conventional OTVC.
- Users who do not want to switch to aqueous cleaning can still achieve significant pollution prevention by using the CEVC.
- Labor and skill level requirements are similar to those for a conventional OTVC.
- The CEVC lowers operating costs by reducing solvent losses.
- No additional facility modifications are needed to meet OSHA requirements for plant ambient solvent levels.
- The CEVC has fully automated cycles and runs unattended except for loading and unloading.

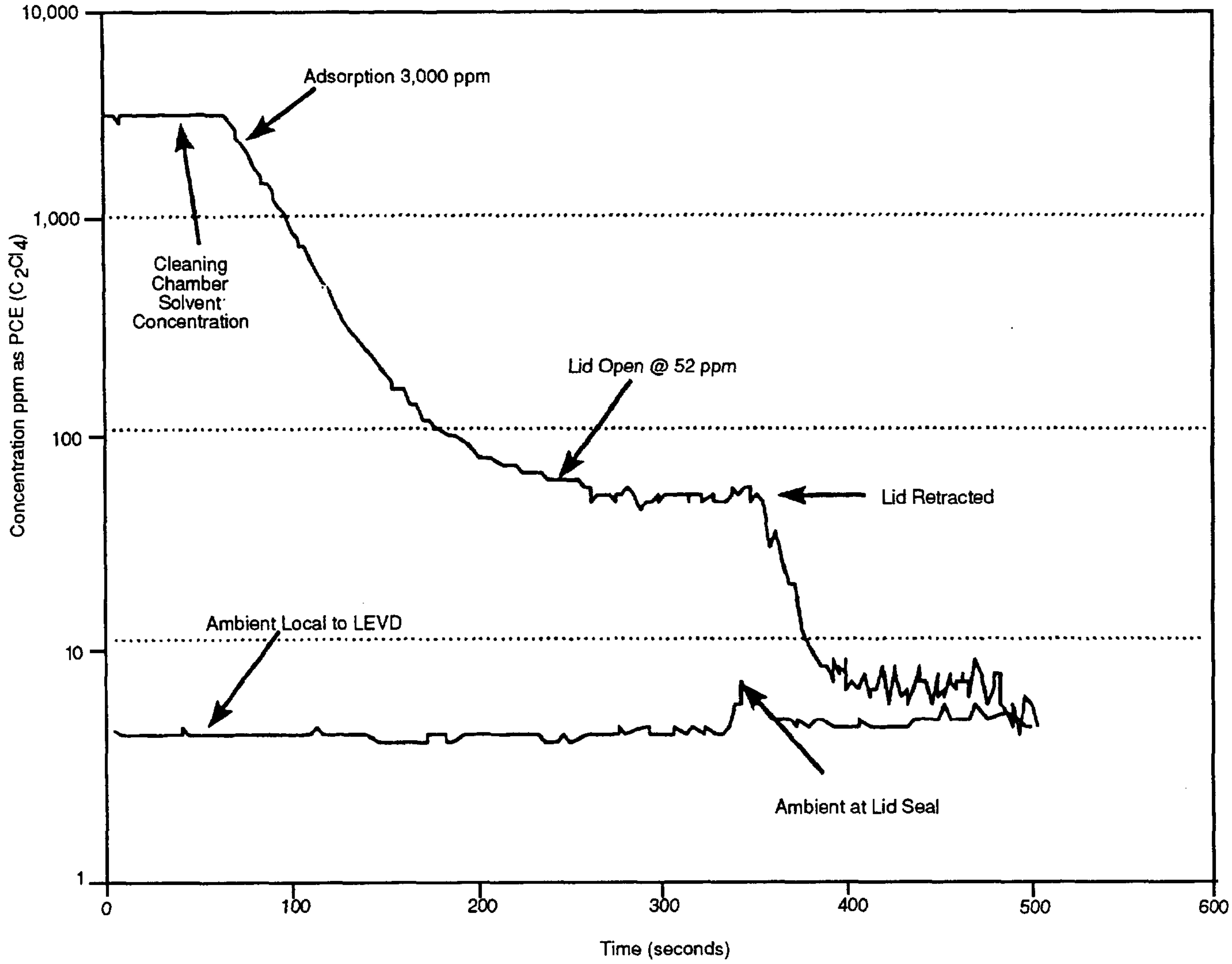

Figure 2. **Adsorption stage at the end of a cleaning cycle on the CEVC.**

The unit adjusts automatically to any type of work load and unseals the working chamber when the cycle is complete.

Limitations

- The CEVC has relatively high capital cost compared to a conventional OTVC.
- The CEVC has longer cleaning cycles for the same capacity.
- It has a relatively higher energy requirement because of the alternating heating and cooling stages.

References

Gavaskar, A. R., R. F. Olfenbuttel, and J. A. Jones. 1993 (in press). *On-Site Solvent Recovery.* U.S. Environmental Protection Agency Project Summary.

Townsend, D. 1993. Personal communication from Dave Townsend of Durr Automation, Inc. in Davisburg, Michigan, to Arun Gavaskar of Battelle, Columbus, Ohio. January.

Automated Aqueous Cleaning

Pollution Prevention Benefits

Automated aqueous cleaners use aqueous cleaning solutions instead of solvents to achieve high-quality

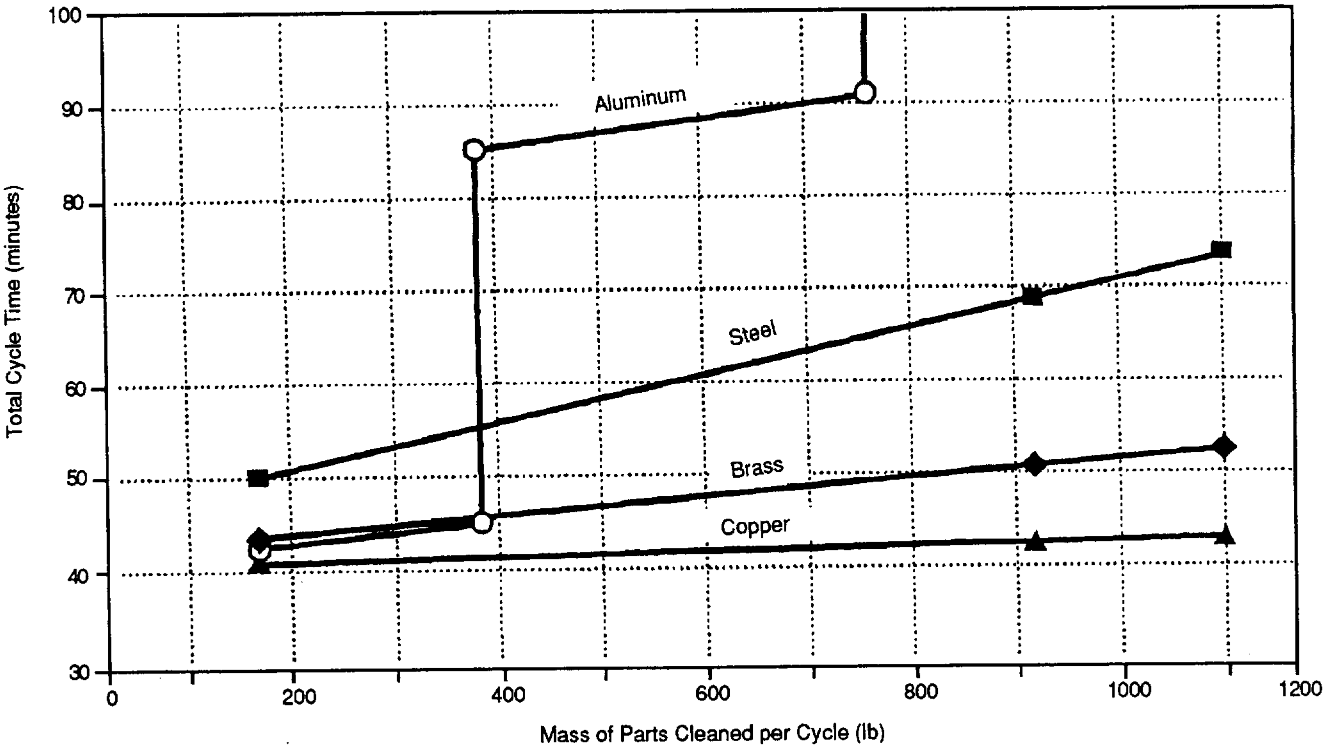

Figure 3. Variation of cycle time for various metals in the CEVC.

cleaning. This available technology replaces the hazardous solvent waste stream with a much less hazardous wastewater stream. These automated machines also have features for significantly reducing the amount of wastewater generated. These machines remove some of the contamination that comes out from the parts being cleaned into the cleaning solution. The cleaning solution can then be recirculated for cleaning several times.

How Does It Work?

Small machined parts often are cleaned in batches of thousands by immersion into a solvent solution or a solvent vapor. Instead, the automated aqueous washer sprays an aqueous solution across the parts to remove oil and debris. Parts travel through a series of chambers, each with different concentrations of cleaning and rinsing solutions. Excess sprayed solution is recovered and reused. Similar automated cleaners are also available for semi-aqueous cleaning solutions.

Operating Features

> *The configuration of the system promotes good contact between cleaning solutions and the parts.*

Figure 4 shows a typical configuration of the automated washer. Not all users require the multitude of compartments shown in the figure, and simpler versions of this unit can be manufactured. The process unit shown in the figure consists of a series of five compartments through which the soiled metal parts are transported. The parts are transported from one compartment to the next by a helical screw conveyor. The parts are sprayed successively with solutions from five holding tanks (one for each compartment). The first compartment sprays hot water on the parts. Because many residual machining fluids on the parts are oil-water emulsions, the hot water helps to break the emulsion. The second and third compartments spray detergent solutions at two different concentrations on the parts. The fourth compartment is for a clean water rinse. The fifth and final compartment sprays a rust inhibitor solution if required. The fifth compartment is followed by a dryer that vaporizes any water droplets remaining on the parts. The cleaned parts drop out of the dryer onto a vibrating conveyor from which they are collected.

The automated aqueous washer also makes use of a "closed loop" system, whereby the used solutions are not disposed of daily but can be recirculated for a week of relatively continuous operation. The cleaning solutions are recaptured after use and sent to the separator tanks shown in Figure 4. One such separator tank is provided for each compartment. In these tanks, the oil floats to the surface and is skimmed off by a pump. Dirt and suspended particles settle down at the bottom of

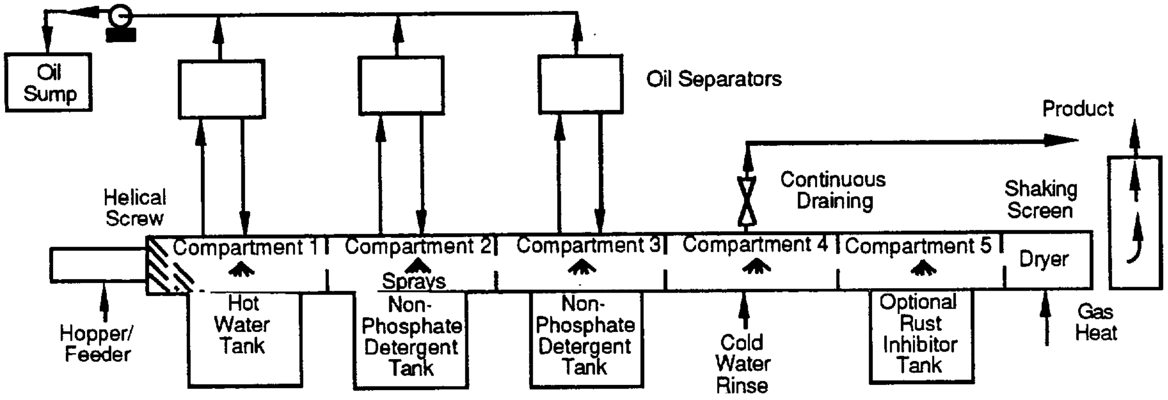

Figure 4. Automated aqueous rotary washing process.

the tank. The bulk of the solution is recirculated back to the holding tanks for reuse. Some makeup solution is needed periodically to replace losses from evaporation and dragout. Detergent chemicals are replenished periodically.

The closed-loop system eliminates daily disposal of spent solutions.

The same cleaning solution can be recirculated and used for a week without changing. At the end of the week (or whenever the contaminants reach a certain level), the holding tanks are emptied and fresh solutions are made up. Because recovery and reuse of the cleaning solution is automatic, the unit requires very little operator attention. In contrast to vapor degreasing or traditional batch aqueous cleaning processes, the continuous operation of this conveyorized unit enables production efficiency. The only operator involvement is for unloading a barrel of soiled parts into the hopper that feeds the parts to the compartments.

Several variations of the washer shown in Figure 4 are now commercially available. Different types of filters, oil-water separators, and sludge thickeners are some of the features offered. The main principle in this new line of washers however is the same—improved contact between the part surface and the cleaning solution and several recovery and reuse cycles of the cleaning solution. Some new units claim zero wastewater discharge, with fresh water added only to make up for evaporation in the drier (Scapelliti, 1993).

Application

Automated aqueous washing provides a comparable level of cleaning quality for most parts that normally would be run through a vapor degreaser. This technology eliminates the need for using solvents. It also provides a cleaning quality comparable to that from traditional aqueous cleaning processes such as alkaline tumbling or hand-aqueous (manual) washing. These traditional processes have the disadvantage of generating large amounts of wastewater. The automated washer, on the other hand, allows for recovery and reuse of the cleaning solution. Wastage of both water and cleaning chemicals is prevented without compromising cleaning effectiveness.

One company expanded plant capacity without increased solvent use.

Quality Rolling and Deburring (QRD) Company, Inc., a medium-sized metal finishing company in Thomaston, Connecticut, has been using an automated aqueous washer similar to the one shown in Figure 4 since February 1990. QRD added the automated washer to accommodate a growth in production. Therefore, the traditional processes (vapor degreasing, alkaline tumbling, and hand-aqueous washing) are still available in the plant, although much of the new work is run through the automated washer. QRD was thus able to expand the plant capacity without increasing solvent consumption.

The reaction of QRD employees and customers to the new washer has been positive. Cleaning quality is comparable to that of the traditional processes (Gavaskar et al., 1992). At the same time, additional capacity has not resulted in additional solvent purchases or significant increases in wastewater. The automated washer was found to be using 90% less water compared with alkaline tumbling and 80% less water compared to hand-aqueous washing. The additional wastewater generated through the expansion in capacity was easily handled by QRD's existing wastewater treatment plant. Table 5 shows the waste volume reduction resulting from the use of the automated washer at QRD.

With automated aqueous cleaning, consumption of cleaning chemicals is lower.

Table 5. Waste Volume Reduction by Using the Automated Aqueous Washer

Conventional Cleaning Waste stream	Volume Generated (gal/yr)	Automated Washing Waste stream	Volume Generated (gal/yr)
Vapor Degreasing[a]		**Automated Washing**[a]	
Wastewater in separator	200	Wastewater	143,000
Still bottom sludge	1,440	Oily liquid	962
Alkaline Tumbling[b]		**Automated Washing**[b]	
Wastewater	1,010,880	Wastewater	85,800
		Oily liquid	577
Hand-Aqueous Washing[c]		**Automated Washing**[c]	
Wastewater	296,400	Wastewater	57,200
		Oily liquid	385

[a] Based on 5,200 barrels/yr run on automated washer instead of vapor degreaser.
[b] Based on 3,120 barrels/yr run on automated washer instead of alkaline tumbler.
[c] Based on 2,080 barrels/yr run on automated washer instead of hand-aqueous washer.

Because cleaning solution is recovered and reused in the automated washer, consumption of cleaning chemicals (and their loss through wastewater) was considerably lower. Chemical costs for the automated washer were 40% lower compared to alkaline tumbling and 95% lower compared to hand-aqueous washing.

The automated washer has relatively higher energy requirements compared to vapor degreasing.

The energy requirement of the automated washer was found to be comparable to that of the traditional aqueous cleaning processes (tumbling and hand-aqueous washing), but was higher than the energy requirement of the vapor degreaser for equivalent production. The automated washer used by QRD (Figure 4) consumes energy for a 5-hp motor for the helical screw (conveyor), four 3-hp motors on the circulation pumps on the holding tanks, a 1.5-hp motor for the oil skimming pump, and 150 cu ft of LPG gas for the drier. The drying required after aqueous cleaning appears to drive the energy requirement of the automated washer above that of the vapor degreaser. The vapor degreaser does not require a drier because excess solvent residual on the cleaned parts evaporates off to the ambient over time. However, this feature is one of the main sources of emissions from vapor degreasing.

Labor requirement of the automated washer was equivalent to that of the vapor degreaser but much lower than for the alkaline tumbler or hand-aqueous washer. The only labor required for the automated washer was for unloading the parts to be cleaned into the hopper once every 20-25 minutes. The hand-aqueous washer had the highest labor requirement because one person had to be in constant attendance to move the barrel of parts from one cleaning tank to the next with an overhead hoist.

The automated aqueous washer had higher operating costs compared to a vapor degreaser, but lower operating costs compared with conventional aqueous processes.

By installing an automated washer instead of a vapor degreaser or a traditional aqueous process, annual savings of $60,000 were realized. The automated washer shown in Figure 4 cost QRD approximately $200,000 to purchase and install. The high initial investment is therefore expected to be recovered in a relatively short period. Note that the cost saving is realized only when the automated washer is compared to all three existing processes at QRD—vapor degreasing, tumbling, and hand-aqueous washing. When compared with the vapor degreaser alone, the automated washer has higher operating costs, mainly due to higher energy (drying) requirements.

This technology may not be suitable for all types of parts.

Some special jobs are still run through the old processes of alkaline tumbling, vapor degreasing, or hand-aqueous washing. For example, QRD still uses the vapor degreaser for very delicate parts. Parts that are particularly difficult to clean (for example parts with a lot of crevices) are sent to the hand-aqueous washer. For certain types of parts that tend to slide over each other to form a close fit, QRD avoids aqueous processes completely, because the surface tension of water at the interface tends to hold the parts together and prevent good cleaning access. However, except for such special jobs, most types of parts are processed through the automated washer.

Benefits

The automated washer described above has several benefits:

- Improved contact between cleaning solution and parts being cleaned enables most types of parts to be aqueous cleaned instead of solvent cleaned.
- Solvent usage at a metal finishing plant can be drastically reduced or eliminated.
- Cleaning effectiveness is comparable to vapor degreasing or conventional aqueous cleaning processes (alkaline tumbling or hand-aqueous washing).
- The amount of wastewater generated is very low compared to the amount generated by traditional aqueous processes. In some types of units, wastewater is claimed to be completely eliminated with fresh water added only to make up for evaporation.
- The automated aqueous washer is easy to install and operate. The labor and skill requirements are low.
- This technology has lower cleaning chemicals consumption compared to traditional aqueous processes.
- Continuous operation of the automated aqueous washer enhances plant efficiency.
- The technology realizes operating cost savings compared to traditional aqueous processes.

Limitations

The limitations of the automated washer are as follows:

- Wastewater generated has to be treated and discharged.
- Some types of parts cannot be cleaned as effectively in the automated aqueous washer as in a vapor degreaser or with a conventional aqueous process.
- The technology has a high energy requirement compared to vapor degreasing, mainly due to the energy required for drying.
- The automated aqueous washer technology has a relatively high initial capital requirement.
- Drying can leave spots on aqueous-cleaned parts if rinsing is inadequate or if rinsewater contains a high level of dissolved solids.

References

Gavaskar, A. R., R. F. Olfenbuttel, and J. A. Jones. 1992. *An Automated Aqueous Rotary Washer for the Metal Finishing Industry.* EPA/600/SR-92/188, U.S. Environmental Protection Agency Project Summary.

Scapelliti, J. 1993. Personal communication from J. Scapelliti of Durr Automation, Inc., Davisburg, Michigan, with A. R. Gavaskar of Battelle, Columbus, Ohio.

Aqueous Power Washing

Pollution Prevention Benefits

The aqueous power washer is similar to the automated aqueous washer in that it combines innovative process technology with the use of an aqueous (or semi-aqueous) cleaning solution. Both technologies eliminate the use of solvents for cleaning. When combined with a "closed-loop" technology, in which the cleaning solution is recirculated, aqueous power washing also reduces water and cleaning solution disposal requirements.

How Does It Work?

Unlike the automated washer which has a continuous operation, most power washers are batch units. Some continuous (conveyorized) units also are available. Whereas the automated washer is more suitable for smaller parts, the power washer is suitable for larger parts. In a power washer, a large part or a group of smaller parts is placed in a closed chamber and blasted from all sides with water or cleaning solution.

Parts to be cleaned are placed inside the power washer unit on a turntable (Figure 5). As the turntable rotates, the parts are blasted from all angles with water at high-pressure (180 psi) and elevated temperature (140°F to 240°F). The force of the spray jets, the heat, and the detergent combine to strip oil, grease, carbon, etc. The cycle time varies from 1 to 30 minutes depending on the type of part.

Operating Features

Power or jet washers are available from a variety of vendors with varying options and in various sizes. One option available is a closed-loop system. The water is collected and sent through a filtration or sedimentation unit or another method of contaminant removal and then sent back to the unit for reuse. This can reduce wastewater treatment and disposal requirements as well as water consumption. Although most systems are simple single-compartment batch units, they are available also as multiple-stage cleaning units or as conveyorized automated systems.

Energy requirements are simple. Most units run on 220 V electrical power. Aqueous power washers are stand-alone units and are available in a range of sizes to fit even in crowded plants. Depending on the type of parts to be washed, an aqueous cleaner can be selected for use in a power washer.

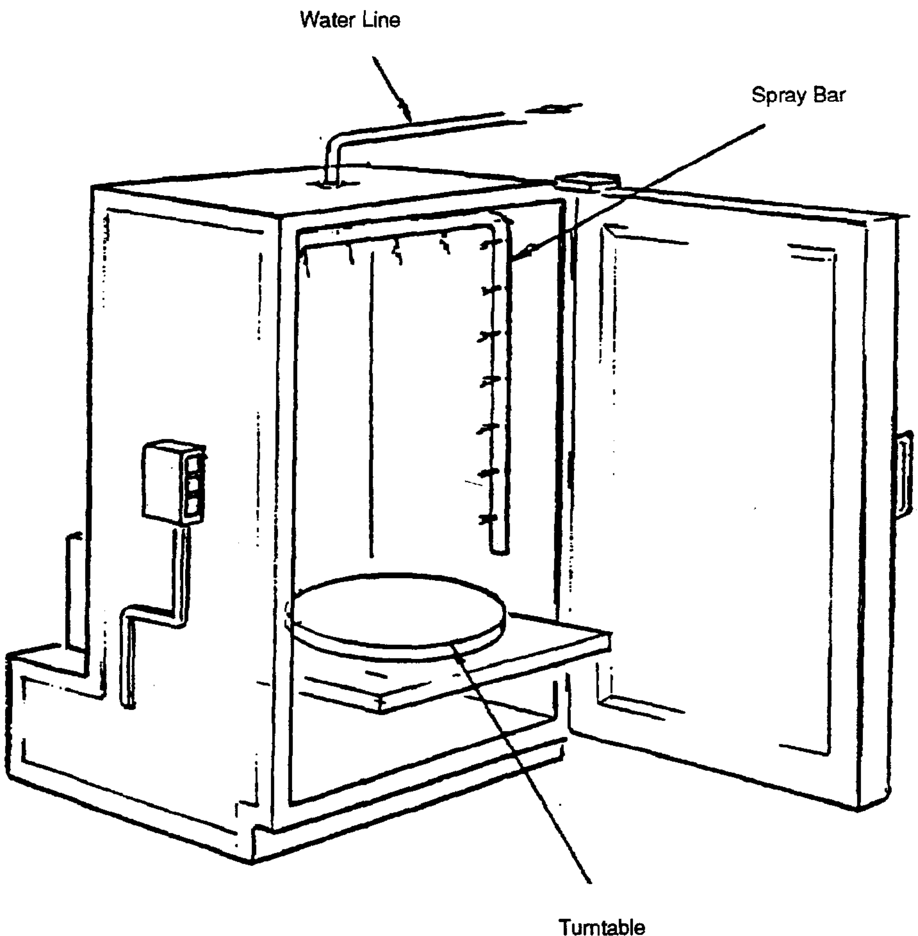

Figure 5. Aqueous power washer.

Like the equipment, the actual operating steps are quite simple. The machine is loaded and the wash cycle timer set. The operator can then leave the equipment while the parts are cleaned.

The aqueous power washer is useful for parts that normally would be run through a vapor degreaser, alkaline tumbler, or hand-aqueous processes. Power washing, with the correct selection of detergents, is safe for metals, plastics, varnish coatings, etc. A power washer also can be used for deburring and chip removal of metal parts.

Costs vary widely depending on the size of the unit and options selected. One firm is spending approximately $70,000 to install a unit that can clean 6,000 pounds of material at one time; the energy load for this unit also is quite high. An average unit might cost about $12,000 and clean 1000 pounds of parts per batch in 10 minutes with fairly low energy requirements. Still smaller are portable units that clean 500 pounds per batch.

Application

Power washers are being used in a variety of industries to clean jet engines, electric motors, metal stampings, diesel engines, etc. The Seattle Metro Garage in Seattle, Washington, uses a power washer to clean parts removed from buses during overhaul and maintenance (Evers and Olfenbuttel, 1993). Previously, they used a combination of solvent baths/wash stations and alkaline steam spray with the washing system. A smaller system is to be put into operation at the same plant for parts from cars and trucks. These units eliminate solvent cleaning for the parts. The discharges from the unit pass through an oil/water separator and then to the Seattle sanitary sewer system. This type of unit eliminates the cost of hazardous or oily waste disposal.

Benefits

The benefits of the aqueous power washer are as follows:

- Aqueous cleaners can be used in applications where solvent cleaning was used previously.
- Aqueous cleaners provide more efficient cleaning compared to manual aqueous tank cleaning.
- Cleaning times are reduced.

- The most common unit is a compact machine with one chamber as opposed to several tanks or compartments.
- The small units are available also as portable units.

Limitations

Aqueous power washers have certain limitations:

- Wastewater generated has to be treated and discharged.
- Some parts, such as electronic sensors or diaphragms, may not be able to withstand the high pressure or temperature of the sprays.
- It is also possible that jet washers will not be able to remove baked-on dirt that cannot be removed by scrubbing.
- Drying can leave spots on aqueous-cleaned parts if rinsing is inadequate or if the rinsewater contains a high level of dissolved solids.

Reference

Evers, D. P., and R. F. Olfenbuttel. 1993 (in press). *Power Washer with Wastewater Recycling Unit.* Technology Evaluation Report prepared by Battelle under Contract No. 68-C0-0003 for the Pollution Prevention Branch of the U.S. Environmental Protection Agency, Risk Reduction Engineering Laboratory.

Ultrasonic Cleaning

Pollution Prevention Benefits

Ultrasonic cleaning makes use of cavitation in an aqueous solution for greater cleaning effectiveness. The efficiency of the technology greatly reduces or eliminates the need for strong solvents. Although solvents can be used with ultrasonic technology, an aqueous or semi-aqueous solution can be substituted for solvents, thereby eliminating solvents from the waste stream. The wastewater generated can then be treated on site and discharged.

How Does It Work?

In ultrasonic cleaning, high frequency sound waves are applied to the liquid cleaning solution. These sound waves generate zones of high and low pressures throughout the liquid. In the zones of negative pressure, the boiling point decreases and microscopic vacuum bubbles are formed. As the sound waves move, this same zone becomes one of positive pressure, thereby causing the bubbles to implode. This is called cavitation and is the basis for ultrasonic cleaning. Cavitation exerts enormous pressures (on the order of 10,000 pounds per square inch) and temperatures (approximately 20,000°F on a microscopic scale). These pressures and temperatures loosen contaminants and perform the actual scrubbing of the ultrasonic cleaning process.

Operating Features

Ultrasonic energy usually is applied to a solution by means of a transducer, which converts electrical energy into mechanical energy. The positioning of the transducers in the cleaning tank is a critical variable. The transducers can be bonded to the tank or mounted in stainless steel housings for immersion in the tank. The number and position of immersible transducers are determined by the size and configuration of the parts, the size of the batch, and the size of the tank. It is preferable to locate the transducers so that the radiating face is parallel to the plane of the rack and the ultrasonic energy is directed at the workpieces. Figure 6 shows the cleaning tank.

The part being cleaned must be immersible in a liquid solution. For best cleaning results, testing must be done with each set of parts to obtain the optimum combination of solution concentration and cavitation levels.

Temperature has the most effect on ultrasonic cleaning.

Temperature is the operating feature that has the most effect on the cleaning process (Fuchs, 1991). Increased temperature results in higher cavitation intensity and better cleaning. This is true provided that the boiling point of the chemical is not too closely approached. Near the boiling point, the liquid will boil in the negative pressure areas of the sound waves, resulting in no effective cavitation.

How parts are loaded into an ultrasonic cleaner also is an important consideration. For instance, a part with a blind hole or crevice can be cleaned effectively if it is placed so that liquid fills this hole and is therefore

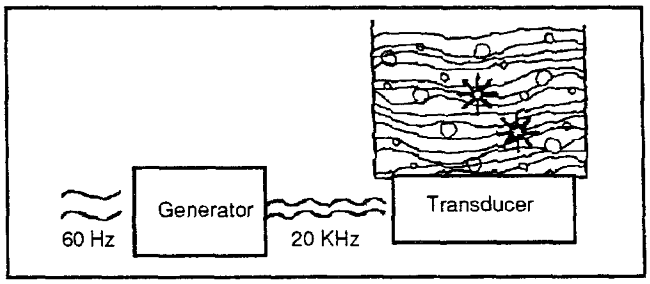

Figure 6. Ultrasonic cleaning tank.

subjected to cavitation action. If this hole is inverted into a liquid with the opening of the hole facing downward, it will not fill with liquid and will not be cleaned. Overloading baskets with small parts can sometimes result in ultrasonic energy being absorbed by the first several layers of parts. Large volumes of small parts can be more effectively cleaned a few at a time with relatively short cycles.

The actual basket design is another important consideration. It should ensure that transmission of ultrasonic energy will be attenuated as little as possible. An open racking method is best whenever possible.

Three Stages of Ultrasonic Cleaning

1. *Presoak.*
2. *Scrubbing and cleaning through cavitation.*
3. *Rinsing.*

There are three basic stages in ultrasonic cleaning. The first is the presoak stage, which is vital to the efficiency of the system. In this stage, the part is placed in the heated cleaning solution which removes all chemically soluble soil and gross contaminants. The second stage is the primary stage of ultrasonic cleaning, in which scrubbing and cleaning are performed through cavitation in the solution. The third stage is rinsing of the cleaned part. Ultrasonics also can be applied in this stage for increased efficiency.

The primary ultrasonic cleaning system has three components: a liquid solution tank, an ultrasonic generator which is the power source for electrical energy, and a transducer which converts electrical energy to mechanical energy. Most generators accept standard AC input at 60 Hz and then convert it to DC. Sizes range from 200-W tabletop units to large 1000-W units. The optimum transducer frequency for most applications has been found to be approximately to 20 kHz. Transducers can be bonded to the tank, or an immersible transducer can be used. Immersible transducers are convenient when a transition is being made to ultrasonic cleaning and existing tanks are to be used.

The use of ultrasonic equipment does not require any special knowledge. The equipment can be selected with the aid of the manufacturer and is simple to operate. Additional discussion of ultrasonic cleaning can be found in Burstein (1989), Magnapak (1988), and Scott (1989).

Application

Ultrasonic cleaning uses conventional equipment available from a wide variety of vendors. There are two basic types of ultrasonic equipment available. Electrostrictive ultrasonics use a ceramic crystal to produce sound vibrations while magnetostrictive ultrasonics use metallic elements.

Ultrasonic cleaning can be applied to almost any parts. Materials such as ceramic, aluminum, plastic, and glass, as well as electronic parts, wire, cables, and rods and detailed items that may be difficult to clean by other processes, are ideal candidates for ultrasonic cleaning.

40 kHz equipment is now available for the electronics industry.

Printed circuit boards and other electronic components can also be cleaned using ultrasonics. While there have been complaints that the 20 kHz equipment can damage fragile products such as electronic equipment, there is now available 40 kHz equipment which is more applicable to the electronics industry. This also reduces the noise level associated with ultrasonic cleaning.

Although most available ultrasonic cleaning equipment is designed for batch tanks, equipment does exist in cylindrical form. A horizontal cylindrical tube or pipe is fitted with peripheral transducers. The resonant-tuned circuit focuses energy along the in-line centerline to allow noncontact cleaning except for the cleaning solution. It has a concentrated high power which results in reduced cleaning times. It generally is used for cleaning wire, strip, tube, cable, and rod configurations. The cylindrical form allows items to feed through without bending and is easily adaptable to varying customer line speeds.

Existing tanks can be modified to use ultrasonic cleaning.

Because of the simplicity of the equipment and the decreased cleaning time, there is a savings in labor costs when using ultrasonics. This savings along with that from decreased solvent purchase and disposal costs, offsets the capital cost of the equipment in a short time. Although costs vary for specific equipment, the cost for an ultrasonic cleaner console with a 25"x18"x15" chamber is approximately $10,000. A rinse console and dryer console would add about $4,000 each. Of course, smaller units can be obtained and existing tanks often can be used if a transducer is added.

The Ross Gear Division of TRW Inc.—a manufacturer of hydraulic motors, hydrostatic steering units, and manual steering gears—has been using an ultrasonic cleaner since December, 1987 (U.S. EPA, 1991).

TRW uses an intensive machining process known as *lapping* to improve the surface finish of parts. Lapping uses an abrasive material that must be completely removed after finishing. Prior to installation of the ultrasonic cleaner, TRW used a solvent (trichloroethylene, TCE) vapor degreasing system to remove the compound. In 1987, this resulted in approximately 14,090 lb of TCE still bottoms, 3,740 lb of filtration powder, and 50,300 lb of fugitive and stack emissions.

Disposal costs and health hazards associated with solvents can be significantly reduced by using ultrasonic aqueous cleaning.

By using a three-stage ultrasonic system washer, TRW has eliminated the use of TCE. The alkaline solution is sent to an ultrafiltration unit to remove oils and then is discharged to the sanitary sewer. This has resulted in a 50% reduction in the quantity of hazardous waste generated at the plant, and thus a significant decrease in disposal costs. Ultrasonic cleaning also has eliminated the potential health hazards associated with TCE.

A military avionics overhauler has converted several processes to use ultrasonics. In one metal-cleaning operation, the use of 1000 gallons of 1,1,1-trichloroethane and Freon 113 was eliminated. The ultrasonic process uses 200 gallons of recoverable water and results in savings of over $8,000 per month. In another process, rings and gaskets were cleaned manually. This labor-intensive method was replaced by ultrasonic cleaning, resulting in a savings of more than 1800 labor hours per year.

Benefits

The ultrasonic technology offers many advantages:

- Ultrasonic cleaning can reach into crevices and small holes where conventional methods may not reach.
- Ultrasonics removes inorganic particles as well as oils.
- Processing speed can be increased.
- Health hazards are greatly reduced.
- A lower concentration of cleaning solution can be used and possibly fewer toxic agents such as neutral or biodegradable detergents can be employed.
- Although capital costs may be higher with ultrasonic cleaning, reduced solvents expense can often pay for a system in a short period of time.

Limitations

The ultrasonic technology has several potential limitations:

- Wastewater generated has to be treated and discharged.
- Ultrasonic cleaning requires that the part be immersible in the cleaning solution.
- Dryers may need to be employed to obtain a dry part.
- Testing must be performed to obtain the optimum combination of cleaning solution concentration and cavitation level.
- The electrical power required for large tanks generally limits part sizes that can be cleaned economically.
- The tendency for thick oils and greases to absorb ultrasonic energy may limit their removal.
- Operating parameters have to be more closely monitored.

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U.S. Environmental Protection Agency. 1991. "TRW, Ross Gear Division, Greeneville, Tennessee." *Achievements in Source Reduction and Recycling for Ten Industries in the United States.* Risk Reduction Engineering Laboratory, Office of Research and Development. September.

Low-Solids Fluxes

Pollution Prevention Benefits

Traditionally, environmentally harmful chlorofluorocarbon (CFC) compounds were used in the electronics industry to clean the residue left behind by conventional fluxes. Using low-solids fluxes (LSFs) prior to soldering leaves little or no visible residue on printed circuit boards (PCBs). Therefore, cleaning with solvents is not needed.

How Does It Work?

Fluxes are used to promote the wettability needed to produce a good solder joint. They also reduce the effect of the inevitable entrapment of air during paste deposition by providing a barrier to the oxidation and reoxidation of metals during the liquefaction stage of soldering. The disadvantage of most fluxes is that they leave residues. These residues can jeopardize the functional reliability of solder joints or circuitry and can interfere with subsequent process steps such as testing or coating, or they may be aesthetically undesirable. A low-solids flux (also known as no-clean flux) leaves minimal residues that generally are considered noncorrosive and have high insulation resistance. Therefore, cleaning is not necessary.

Operating Features

Low-solids fluxes contain only 1 to 10% nonvolatile materials by weight, compared to the 15 to 35% found in conventional fluxes. Low-solids fluxes leave little residue. Any residue that does remain dries rapidly.

Low-solids fluxes are noncorrosive and have high insulation resistance. Therefore, trace residues need not be removed in most cases. However, even trace residues may affect the reliability of certain products. To reduce residues even further and improve the reliability of the component, two processes may be considered: the low-solids flux applicator and inert atmosphere ovens. The low-solids flux applicator is available to electronic manufacturing companies. Inert ovens are widely available, and many manufacturers are now making their standard ovens with options that allow easy conversion to an inert atmosphere. These two processes can be used together or separately.

The LSF applicator is designed to cut down on the amount of flux applied.

The LSF applicator was developed by AT&T. The LSF applicator is designed to apply less flux just prior to wave-soldering than do conventional methods. The applicator contains a spray fixture that can be adjusted very precisely to achieve controlled uniform flux coverage. The spray fixture produces a fine, precisely directed spray pattern and oscillates at a speed determined by the operator or regulated automatically against conveyor-line speeds. The operator controls flux deposition over a wide range by adjusting the air pressure applied to the flux tank.

An inert atmosphere with low-solids fluxes improves solder reliability.

The second method uses an inert atmosphere. Because the small quantity of organic solids in low-residue solder pastes is volatile, reoxidation of exposed surfaces during reflow is a major cause of poor soldering. Eliminating oxygen by creating an inert atmosphere (e.g., nitrogen) improves solder reliability with low-solids fluxes.

One benefit of this technology is that it is relatively easy to convert an existing system. A low-solids flux is substituted for conventional fluxes. In some instances, equipment will need to be added to improve product quality. Examples are the flux applicator described above and the inert atmosphere oven described in the next section.

The use of low-solids fluxes does not require any special knowledge beyond that required for use of conventional fluxes. It does, however, require greater process control, particularly in the area of component cleanliness. Soils on circuit boards and components that were not noticed previously may cause solder defects with low-solids flux. Cleanliness requirements for components should be investigated during the evaluation of this technology. Additional discussion of low-solids fluxes can be found in Hwang (1990) and U.S. EPA (1990 and 1991).

Application

The low-solids flux technology is applicable to the electronics industry where fluxes are needed to promote wettability so that sound solder joints can be formed. The LSF applicator would be applicable for through-hole component circuit boards only.

Equipment may need to be altered to use low-solids fluxes, especially if an inert atmosphere (described in next section) is needed for best results. The purchase and application costs of low-solids fluxes are comparable to those for conventional fluxes. Economic benefits result from eliminating the cleaning step.

The AT&T plant in Columbus, Ohio converted completely to a low-solids flux system in August, 1988. AT&T's system consists of a low-solids flux used with their patented LSF-2000 flux applicator. With this system, the plant has eliminated post-solder cleaning and the use of 30,000 gallons of perchloroethylene (PCE) annually (U.S. EPA, 1991). Using the flux applicator also has reduced the amount of flux material product used by approximately 2,000 gallons per year. Cost savings at the plant are estimated at $145,000 per year as a result of the decreased need to purchase, treat, track, and report on this solvent.

Benefits

Benefits of using this technology are as follows:

- It is easy to convert to this technology.
- Low-solids flux eliminates the need for defluxing and for the use of solvents.

- "Bed of nails" testing on printed circuit board assemblies can be performed immediately after wave soldering, without the problems created by the presence of rosin residues.
- This technology has low capital costs.

Limitations

The limitations of low-solids fluxes are

- Special equipment, such as an LSF applicator, may be required in some cases.
- Even limited residues are unacceptable in many military specifications.
- The activity of these fluxes is usually limited to a short dwell time.
- Lack of adhesion caused by the washing effect of a jet wave sometimes leaves too little active flux at the exit point in the wave to achieve acceptable soldering results. Use of a spray fluxer and a single surface-mount solder wave application can mitigate these problems.
- There may be tighter cleanliness requirements for components and circuit boards.

References

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U.S. Environmental Protection Agency. 1990. "Low-Solids Fluxes/'No-Clean' Assembly." *Manual of Practices to Reduce and Eliminate CFC-113 Use in the Electronics Industry.* March.

U.S. Environmental Protection Agency. 1991. "AT&T Bell Laboratories/AT&T Network Systems, Princeton, New Jersey/Columbus, Ohio." *Achievements in Source Reduction and Recycling for Ten Industries in the United States.* Risk Reduction Engineering Laboratory, Office of Research and Development. September.

Inert Atmosphere Soldering

Pollution Prevention Benefits

Traditionally, environmentally harmful chlorofluorocarbon (CFC) compounds have been used to clean the residue left behind by the fluxes in the electronics industry. An inert soldering atmosphere can eliminate the need for flux and, consequently, for cleaning (no-clean soldering). Without the cleaning process, solvents are not needed. Due to the volatile nature of even low-solids fluxes, reoxidation of exposed surfaces during reflow is a major cause of poor soldering. One solution is to eliminate oxygen.

How Does It Work?

When the solder station is placed in an oxygen-free environment, there is no need for traditional flux to keep the solder wave oxide-free. This approach requires an inert atmosphere. Because of its availability and low cost, nitrogen often is used.

Operating Features

The function of an inert atmosphere in the no-clean process is to create a solder wave upon which no permanent oxide film can form. The inert atmosphere thus eliminates the need for flux to clean the surface of the wave. There are two no-flux machine concepts on the market: open and closed. The open-concept machine, which employs flaps leading into a tunnel, will not reach the desired oxygen rate of under 10 ppm by continuous nitrogen flow alone. This system uses formic acid to reduce the oxygen level. Although this system has the advantage of mechanical simplicity, formic acid is potentially hazardous, and therefore is undesirable or, in some companies, prohibited. A closed system can prevent oxidation without the use of aggressive chemicals.

In a closed system, there are vacuum chambers at the entrance and exit of the process area, which is constantly flushed with nitrogen to keep the oxygen level within limits. This concept also uses a tunnel, but this tunnel is absolutely sealed to the outside environment. The vacuum chambers allow a continuous flow of PCBs through the system while maintaining a nitrogen atmosphere.

Gas consumption depends on the design and operating parameters of the reflow equipment. The key operating parameters for atmosphere in a furnace are gas flow rate, oxygen level, water-vapor level, belt speed, and temperature profile.

Inert atmosphere soldering can yield exceptional results.

Most no-clean applications will yield exceptional results in the 500- to 1,000-ppm range. Zoned forced-convection reflow soldering ovens can efficiently maintain inert atmospheres below 500 ppm oxygen and approaching 250 ppm. Achieving oxygen levels below 250 ppm requires the use of nitrogen volumes so large that they negate any potential cost benefit. Additional discussion on inert atmosphere soldering can be found in Hwang (1990), Morris and Conway (1991), Trovato (1991), and Tuck (1991).

Application

This technology is applicable in the electronics industry. The use of nitrogen is beneficial in some applications, particularly with fine-pitch assemblies and certain no-clean formulations. A large number of new furnaces are now available that have inert gas capability, including the popular forced-convection type. It may also be possible to use existing or retrofitted equipment.

The operator skill level is somewhat higher than that needed for existing operations because the operating parameters require greater control. Costs vary widely depending on existing operations. If existing or retrofitted equipment cannot be used, it may be necessary to purchase a new oven capable of maintaining an inert atmosphere.

> *When deciding on inert atmosphere soldering, costs must be compared.*

Tradeoffs can be seen in terms of cost. When the need for cleaning is eliminated, costs are reduced because there is no need for costly solvents or for time spent on cleaning. In addition, there is no solder waste through oxidation and possibly no need for flux. These costs are offset by the cost of nitrogen. Industrial nitrogen with less than 3 ppm oxygen costs around $0.15/m^3. Consumption is approximately 10 to 20 m^3/hr, depending on the production rate.

Another consideration is oxygen level and nitrogen consumption rate. The better enclosed the oven and the higher the gas flow rate, the lower the overall oxygen content. These levels affect the quality of the finished product as well as the economics of the system.

> *The inert atmosphere technology combined with low-solids fluxes is becoming more common.*

Rather than complete elimination of flux, the use of an inert atmosphere combined with low-solids fluxes is somewhat common. For example, as of July, 1991, AT&T had five production lines capable of reflowing no-clean paste under a nitrogen blanket, and that figure was expected to double by the end of the year.

The use of an inert atmosphere to eliminate flux is still undergoing evaluation by many plants. One such company performed tests on 500 production boards to compare soldering in an inert atmosphere to conventional soldering. Short circuits and solder bridging on small outline integrated circuit (SOIC) leads decreased in inert atmosphere soldering. The bridging between closely spaced metal electrode faces (MELFs) increased due to the higher surface tension of the solder in the presence of nitrogen. Bridging could be avoided by improving the board layout.

Benefits

Inert atmosphere soldering has the following benefits:

- Eliminating flux eliminates the need for solvent cleaning.
- Eliminating both the use of flux and cleaning results in a simpler process, resulting in economic and process time savings.
- Eliminating flux also eliminates any flux residue that may cause reliability problems.
- Reduced solder dross may be achieved.

Limitations

The limitations of inert atmosphere soldering are as follows:

- Compared to conventional methods, the no-clean alternative requires tighter control and higher precision in the reflow process. The temperature profile, gas flow rate, and other operating parameters have to be controlled closely.
- A preparation fluid containing adipic acid additive is sometimes required to achieve wetting. This is similar to the use of a low-solids flux, except that only a small amount of the organic acid is needed. It is believed that this will be washed off by the solder wave, therefore eliminating the need for solvent cleaning. Of course, it may still be necessary to meet military specifications for cleaning.
- A slightly higher skill level is required for operation.
- Inert atmosphere soldering may involve an initial capital outlay for a new furnace.

References

Hwang, J. S. 1990. "No-Clean Soldering and Solder Paste." *Circuits Manufacturing,* September, pp. 41-46.

Morris, J. R., and J. H. Conway. 1991. "No-Clean Reflow Process Implementation." *Circuits Assembly,* August, pp. 28-35.

Trovato, R. A., Jr. 1991. "Inerting the Soldering Environment." *Circuits Assembly,* April.

Tuck, J. 1991. "A New No-Clean World?" *Circuits Assembly,* July, pp. 18-19.

SECTION 3
EMERGING TECHNOLOGIES

How to Use the Summary Tables

Six emerging cleaner process changes for cleaning and degreasing are evaluated in this section:

- Vapor storage technology
- Vacuum furnace
- Laser cleaning
- Plasma cleaning
- Fluxless soldering
- Replacement of tin-lead solder joints.

Tables 6 and 7 summarize descriptive and operational aspects of these technologies. The tables contain evaluations or annotations describing each emerging technology and give a compact indication of the range of technologies covered to allow preliminary identification of those that may be applicable to specific situations.

Descriptive Aspects

Table 6 describes each emerging cleaner technology. It lists the **Pollution Prevention Benefits, Reported**

Table 6. Emerging Technologies for Cleaning and Degreasing: Descriptive Aspects

Emerging Technology Type	Pollution Prevention Benefits	Reported Applications	Benefits	Limitations
Vapor Storage Technology	• Reduces amount of solvent used	• Vapor degreasing • Dry cleaning	• Decreases potentially hazardous emissions from vapor degreasers	• Does not eliminate solvent use
Vacuum Furnace	• Eliminates solvent use for cleaning	• Removal of oils from metals	• One-step process • Newer processes collect the oil for recycling; therefore waste stream is eliminated	• Typical processes do not allow for oil recycling. If oil is not collected, it can degrade the diffusion pumps; so frequent cleaning would be necessary
Laser Cleaning	• Eliminates solvent use for cleaning	• Cleans metallic or nonmetallic surfaces	• Can clean with high spatial selectivity • Cleaning process is fast and energy-efficient	• Requires a special cleaning chamber
Plasma Cleaning	• Eliminates solvent use for cleaning	• Cleans metallic or nonmetallic surfaces	• Performs ultrafine cleaning	• Requires a special cleaning chamber • Relatively slow process
Fluxless Soldering	• Reduces solvent use in cleaning • Reduces hazardous fluxes	• Electronics industry	• Reduces process steps	• Some materials could be degraded by certain fluxless processes
Replacement of Tin-Lead Solder Joints	• Eliminates solvent cleaning and hazardous fluxes	• Electronics industry	• Reduces process steps • Eliminates hazards of lead compounds	• May replace hazards of lead compounds with hazards of silver

Table 7. Emerging Technologies for Cleaning and Degreasing: Operational Aspects

Emerging Technology Type	Process Complexity	Required Skill Level	Waste Products and Emissions	References
Vapor Storage Technology	Medium	Medium	Residual air losses and still bottom residues	Hickman and Goltz, 1991
Vacuum Furnace	Medium	Medium	Oils, or if recycling is used, no waste products	Mitten, 1991
Laser Cleaning	Medium	Medium	Only the contaminants removed from the part	Allen, 1991 Allen et al., 1992 Küper and Brannon, 1991 Lee et al., 1992 Peebles et al., 1990 Peebles et al., 1991 Tam et al., 1992 Walters et al., 1993 Watanabe and Bison, 1992 Zapka et al., 1991, 1992
Plasma Cleaning	Medium	Medium	Only the contaminants removed from the part	Baker, 1980 Brunner, 1992 Coburn, 1991 Horwath and Moore, 1983 IBM, 1986 Kominiak and Mattox, 1977 Liston, 1989 O'Kane and Mittal, 1974 Ward and Buss, 1992
Fluxless Soldering	Varies	Varies	No waste products	Hosking, 1990
Replacement of Tin-Lead Solder Joints	Medium	Low	No waste products	Werther, 1990

Application, Operational Benefits, and **Limitations** of each.

Operational Aspects

Table 7 shows key operating characteristics for the emerging technologies. The qualitative rankings are estimated from descriptions and data in the technical literature.

Process Complexity is qualitatively ranked as "high," "medium," or "low" based on such factors as the number of process steps involved and the number of material transfers needed. **Process Complexity** is an indication of how easily the technology can be integrated into existing plant operations. A large number of process steps or input chemicals, or multiple operations with complex sequencing, are examples of characteristics that would lead to a high complexity rating.

The **Required Skill Level** of equipment operators also is ranked as "high," "medium," or "low." **Required Skill Level** is an indication of the level of sophistication and training required by staff to operate the new technology. A technology that requires the operator to adjust critical parameters would be rated as having a high skill requirement. In some cases, the operator may be insulated from the process by complex control equipment. In such cases, the operator skill level is low, but the maintenance skill level is high.

Table 7 also lists the **Waste Products and Emissions** from the emerging cleaner technologies. It indicates tradeoffs in potential pollutants, the waste reduction potential of each, and compatibility with existing waste recycling or treatment operations at the plant.

The last column in Table 7 cites **References** to publications that will provide further information about each emerging technology. These references are given in full at the end of the respective technology sections.

The text further describes operating characteristics, application, benefits, and limitations for each technology. Technologies in more advanced stages of development are discussed in Section 2, Available Technologies.

Vapor Storage Technology

Vapor storage technology uses an air lock to temporarily store solvent vapors.

Vapor storage technology uses an air lock and airtight equipment to temporarily store solvent vapors from an existing vapor degreaser and return the vapors for reuse (Hickman and Goltz, 1991). The air lock is used when moving parts into and out of the cleaning chamber. After being cleaned in the vapor degreaser, the parts are moved back into the air lock. The solvent-laden air in the air lock is then cooled and circulated through a bed of adsorbent until the desired solvent concentration is reached in the air lock (depending on the design and the number of adsorbent beds used). The parts are then removed, and the air lock can be reloaded for the next cleaning cycle. Next, the adsorbent bed is thermally desorbed by circulating heated air from the air lock through the bed and back to the air lock. The new parts are then moved into the cleaning chamber, and the process is repeated. Figure 7 shows the equipment used in the process.

An air lock can be added to existing cleaning equipment.

This technology is similar to the completely enclosed vapor cleaner (CEVC) technology described in Section 2, Available Technologies, except that the air lock can potentially be added on to existing vapor cleaning machines. As in conventional vapor degreasing, the condensed solvent in the degreaser would still be collected and distilled to remove contaminants. This results in some solvent in the still bottom waste stream. This amount is small compared to the amount of solvent lost to the air. Use of vapor storage technology significantly reduces the amount of solvent lost to the environment. This technology currently is being explored for dry cleaning (clothes cleaning) application.

Reference

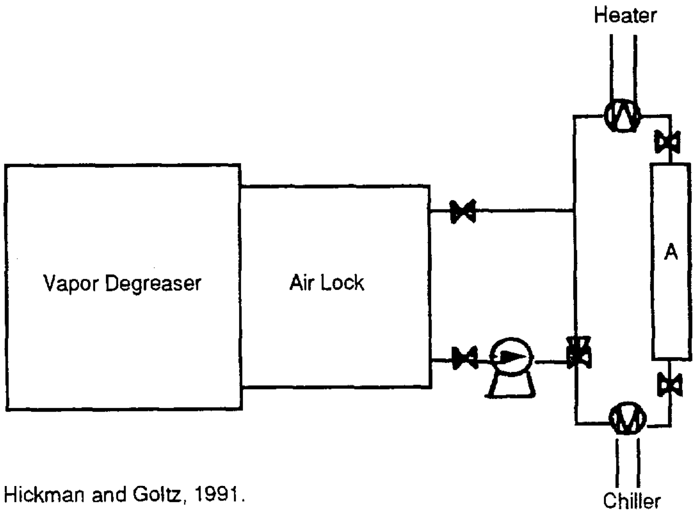
Hickman, J. C., and H. R. Goltz. 1991. "Temporary Vapor Storage Technology." *Conference Proceedings of the International CFC and Halon Alternatives Conference sponsored by the Alliance for Responsible CFC Policy.* December, 1991.

Vacuum Furnace

A vacuum furnace vaporizes oils from parts.

A vacuum furnace uses heat and vacuum to vaporize oils from parts. The cycle time depends on the mass of the load and the vapor pressure of the oil being removed. Time and heat determinations are based on material properties such as the emissivity, the cross-section, and the mass. Most equipment is closed to eliminate emissions, and to facilitate backfilling the chamber with nitrogen and/or air to cool the parts prior to removal. The parts are cooled to ensure operator safety.

In a typical system, a load of parts is heated in a vacuum to vaporize all oils present. With newer de-



Source: Hickman and Goltz, 1991.

Figure 7. **Equipment used in vapor storage technology.**

signs, these vapors are then condensed and collected for later removal to be reprocessed or recycled. This is essentially a one-step process. Another recent design of the vacuum furnace for deoiling is a hot-wall design that eliminates furnace wall oil deposits caused by condensation. There is no condensation because the walls are at a temperature above that which will condense the vapor.

The time and temperature depend on properties of the part being cleaned and the oil being removed.

The temperature and time requirements are based on the parts material and the oil being removed. Operating temperatures range from 210 to 650°F, and the vacuum range is 100/20,000 μ. A typical cycle time is approximately 15 to 20 min. The operator loads the parts into the chamber, selects the cycle based on the type of parts and oil, and then removes the cleaned parts. Periodically, the operator must defrost the condenser and drain the oil for recycling.

The use of a vacuum furnace to deoil metal parts produces a small waste stream consisting only of the oil removed from the part. With the proper equipment, the oil can be recycled and reused or sold. Either option would result in no waste stream. The pollution prevention benefits of such a technology are great. Both a solvent waste stream and a contaminant waste stream are eliminated.

Vacuum furnaces are available from a variety of vendors. However, newer equipment, especially that designed for deoiling parts, is less common but is available from some vendors.

Vacuum deoiling can be applied where vapor degreasing typically is used.

Vacuum furnace deoiling can be applied where vapor degreasing typically is used to clean metal parts. Other typical applications include removal of paint solvents; drying of ink/paint designs; and precleaning for brazing, plating, or heat treating. The technology also can be used to remove oil from nonmetallic parts.

One study (Mitten, 1991) conducted an economic comparison of vacuum furnace deoiling with vapor degreasing. Although capital costs for vacuum furnace deoiling were higher, the estimated operating costs were lower, resulting in a payback of approximately 2 years for a 4,000 hr/yr operation. The capital cost for vacuum deoiling was $192,000 for a system that would accept a work load with dimensions 30"W 36"H 48"L, and the operating cost was estimated at $5.20/hr.

A number of companies already use vacuum furnace deoiling to clean metal parts. However, newer versions of the technology are available. For example, newer oil collection and recycling equipment as well as new hot wall design techniques that eliminate problems associated with condensation on the walls are now on the market.

Parts do not have to be dried after cleaning in the vacuum furnace.

The major benefits of vacuum furnace deoiling over vapor degreasing are the pollution prevention benefits and the health and safety benefits resulting from solvent elimination. Another benefit of vacuum furnace deoiling compared to other cleaner technologies is that the cleaned parts do not become water soaked and therefore do not need to be dried after the cleaning process.

One limitation is that the processing time and temperature depend on the material to be cleaned and the oil to be removed. Therefore, adjustments may be needed for each new material, oil, or combination thereof. Also, the part must be able to withstand the required temperature and vacuum pressure.

Reference

Mitten, W. 1991. "Vacuum Deoiling for Environmentally Safe Parts Cleaning." *Metal Finishing, 89*(9):29-31.

Laser Cleaning

The use of laser cleaning to clean material surfaces is being explored by Sandia National Laboratories in Albuquerque, New Mexico. Short pulses of high-peak-power laser radiation are used to rapidly heat and vaporize thin layers of material surfaces. These layers of surface material form a dense cloud of hot vapors that will condense and recontaminate the surface if not removed immediately. To prevent recontamination, the vapors are removed by entrainment into a flowing gas stream. Laser cleaning must be carried out in an inert gas environment to avoid further contamination.

Laser cleaning requires neither solvents nor aqueous solutions.

Localized cleaning is an operational advantage of laser cleaning. With this technology, a small area can be cleaned without affecting the entire part. Laser cleaning contributes directly toward meeting waste minimization goals—no solvents or even aqueous solutions are needed. The only waste is the small amount of material removed from the surface of the item being cleaned.

Laser cleaning has been contemplated since the 1960s, but has been implemented in only a limited number of applications. Most notably, lasers have been used, and continue to be used, for cleaning statuary and aging paintings. Also, lasers have been used to strip paint from metal and composite substrates and to strip insulation from conductors.

One form of laser cleaning, laser ablation, vaporizes thin layers of contaminants.

Laser cleaning can be performed on either metallic or nonmetallic surfaces. There are at least two mechanisms in laser cleaning of metallic surfaces: laser ablation of absorbing contaminants and laser-driven blowoff of transparent contaminants. Laser ablation vaporizes thin layers of contaminants at the air-contaminant interface. Efficient use of this requires that the contaminant be strongly absorbing at the laser wavelength. Typically, in the absence of a strong absorption peak, far ultraviolet (UV) wavelengths are preferred because broadband adsorption occurs in most materials in the far UV wavelength region. Also, more efficient contaminant removal is found for short-pulse-width, high-peak-power lasers.

Another form of laser cleaning, blowoff of particles, actually gets under the particles and pops them off with a microexplosion.

The blowoff mechanism occurs when the material is mostly transparent to the laser beam, which passes through the contaminant and initiates a microexplosion at a subsurface site, either at small absorbers within the contaminant or at the metal surface. The trapped, expanding vapors generated from the microexplosion pop off relatively large pieces of contaminants. The blowoff mechanism is, in general, more efficient than ablation because less energy goes into the heat of vaporization to remove the same mass of material.

A third possible mechanism has been conjectured by Walters et al. (1993) that is believed to be responsible for a cured epoxy removal process discovered recently. In this process, the semitransparent epoxy material transmits enough of the pulsed laser beam to heat the metal substrate. Differential thermal expansion leads to a debonding of the material in one pulse. No damage to the substrate occurs, and no significant effluent is generated.

A pulsed laser can be used to advantage in fluxless soldering.

The most common contaminants found in the literature consist of oxide films that have been effectively removed using a pulsed yttrium aluminum garnet (YAG) laser. This type of laser can be used to advantage in reducing chemical usage in processes such as fluxless soldering (Peebles et al., 1991), which is discussed in this Emerging Technology section. The threshold for efficient film removal varies only slightly with film composition, but typically is about 1 J/cm^2 in all cases reviewed. Laser cleaning typically is done in a cleaning chamber that is either evacuated or pressurized with an inert gas such as helium or argon, with the laser beam introduced through a window. However, it is feasible to perform cleaning in a clean room with a fume hood and a flowing inert gas.

The bulk of literature on laser cleaning of nonmetallic surfaces has been directed toward the cleaning of semiconductor materials. The primary semiconductor contaminants that have been laser cleaned are oxide films and absorbed metal ions. Over the past 25 years, ruby, Nd:YAG, alexandrite, and CO_2 lasers have been used for cleaning, but more recently, excimer lasers have been the focus of most laser cleaning of semiconductor substrates.

UV wavelength lasers clean more efficiently than other laser wavelengths.

Because of the lack of high surface reflectivity of many nonmetallic substrates, the only laser cleaning mechanism identified in the literature reviewed is the ablation process discussed above. Consequently, UV lasers, such as krypton-fluoride excimers, have been used most for this cleaning application (Küper and Brannon, 1991; Watanabe and Bison, 1992). UV wavelengths can clean more efficiently than other laser wavelengths because the absorption depth into oxides is much smaller (typically about 10 nm) in the UV region.

Another variation is benign-liquid-assisted laser cleaning.

Liquid-assisted laser cleaning is a variation in the use of lasers for cleaning. Many repair and maintenance tasks require final cleaning of the surfaces in a clean room environment using methods that achieve very low numbers of residual particles on the part surface. These micron-size particles are extremely difficult to remove because the binding forces (Van der Waals, capillary, and electrostatic) holding them on the surface are much greater than gravitational and inertial forces at this particle size. Traditionally, a filtered Freon™ wash performed in a laminar flow clean station is used for this step. A similar problem arises in semiconductor device microfabrication, where micron-size particles cause defects on the same scale as that of the microstructure being produced in the process. Two groups have developed benign-liquid-assisted laser-cleaning techniques that have successfully achieved particulate removal without Freon™ or harsh solvents. It is important to note that the liquid does not reside on the surface for longer than a second or so.

Zapka and colleagues at IBM (Tam et al., 1992; Zapka et al., 1991 and 1992) have developed a technique wherein a very thin volatile liquid layer (water, ethanol, methanol, isopropanol, and mixtures thereof) is formed on the surface to be cleaned just before delivery of a short laser pulse. The liquid works its way under the particles by capillary action and is explosively evaporated by conduction of heat from the substrate which is heated directly by the laser pulse. The IBM researchers conducted most of their research on silicon surfaces exposed to 16-ns laser pulses from a KrF excimer laser (0.248 µm wavelength). They consider the process a dry-cleaning process because of the short residence time of the liquid on the surface.

In similar work at the University of Iowa, Allen and colleagues (Allen, 1991; Allen et al., 1992; Lee et al., 1992) have cleaned micron- and submicron-size particles from silicon substrates using a slightly different approach. They use a laser wavelength that is absorbed directly in the liquid that is deposited as the assist layer rather than in the substrate itself. Water was found to be the best liquid and the CO_2 TEA laser (100-ns pulse, 1-µs tail) with 9.6- and 10.6-µm wavelengths was used in most of their research. Both this method and the IBM approach appear to work well in most cases.

There are several advantages of laser cleaning:

- The area to be cleaned can be highly selective and sharply defined.
- The process generally is very fast and energy efficient.
- No foreign atoms are introduced to the surface as in ion bombardment techniques.
- If cleaning is done in vacuum, the vacuum is not compromised because the laser source can be located outside of the cleaning chamber.
- Thermal diffusion of bulk impurities to the surface is avoided because of the extremely large quenching rate afforded by very short pulses available.
- The removal rate can be easily controlled by changing the beam fluence or pulse repetition rate.
- Laser cleaning is amenable to "dry" effluent control through cover gas filtering.
- Liquid-assisted laser cleaning removes micron-size particles.

The blowoff mechanism is more efficient that ablation, but the blowoff cleaning process is self-limiting at laser wavelengths that are reflected by the metal surface, provided that the beam fluence is below the damage threshold of the substrate. Self-limiting behavior has been observed by Peebles et al. (1991) using a YAG laser to clean oxide from stainless steel (SS) 304, but the limiting behavior should be dependent only on the reflectivity of the substrate to the laser wavelength and generally is applicable.

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Plasma Cleaning

Plasma cleaning is a batch process.

Plasma cleaning is one type of surface processing, among several, that depends on production of a low-pressure steady-state plasma in a special vacuum chamber. These processes include sputter deposition, ion plating, plasma-enhanced chemical vapor deposition, etching, cleaning, and surface modification. These techniques are fairly well developed and are used widely in industry. Plasma cleaning is, by its nature, a batch process and has a relatively low cleaning rate that is most appropriate to removal of thin contaminant films. A review article by Coburn (1991) presents a good basic overview of plasma surface processing and a guide to terminology used in the field.

In typical plasma processing arrangements, the excitation of the gas may be from a direct current (DC), radiofrequency (RF), or microwave power source. A simple DC low-pressure glow discharge can clean effectively if electrodes can be permitted in the discharge chamber. If contamination from electrode sputtering is a concern, inductive or capacitive coupling from an RF circuit can produce an electrodeless plasma discharge that will clean a part surface. The typical frequency for the RF discharge is 13.56 MHz. Additional processing control can be achieved by separating the plasma generation function from the surface interaction control function as in the microwave plasma generation approach. All of these geometries may be used to clean surfaces, but selection of one or another will depend on the substrate material (conductor, insulator, etc.) and the nature of the contaminant.

The principles of plasma cleaning are the same as those used in plasma etching.

Plasma cleaning works by the same principles as etching. If an inert gas is used, the ions and neutrals in the plasma bombard the surface to be cleaned and sputter off the contaminant film molecule by molecule, in a purely physical manner. By using a reactive gas in the plasma, the bombarding ions also may react with the contaminants and form gaseous species that evaporate from the surface. For energetic ions, the process known as reactive ion etching is used in microfabrication as well as in cleaning. Examples of plasma cleaning processes for metallic and nonmetallic surfaces are discussed in the following paragraphs.

Plasma cleaning has been used since 1968, when it was found to be effective in guidance system component cleaning. Initial research in this area reported an investigation of the effectiveness of glow discharge cleaning of gas-bearing gyros. The researchers were interested in increasing the adhesion of a lubricating film to the gyro's shaft and rotor, which required furnishing a clean surface to the lubricant. The main alternative to glow discharge cleaning of a gyro surface was to employ organic solvent, detergent, and water baths followed by a light abrasive buffing to prepare bearing surfaces for the lubricant. This time-consuming process involved days to complete. By contrast, glow discharge could clean bearing surfaces in minutes. In the cleaning tests, an argon plasma produced in an industrial plasma cleaner was used. Typically, the contamination layer to be removed was only 1 to 3 molecules in depth.

Radiofrequency (RF) plasma cleaning can be more effective than solvent cleaning.

O'Kane and Mittal (1974) compared traditional solvent cleaning with RF plasma cleaning for preparing rhodium and iron-cobalt surfaces to receive a vapor-deposited polymer film. They used water wettability and Auger electron spectroscopy to measure the cleanliness of the surfaces. Their results showed that argon or helium-oxygen plasma cleaning was more effective than solvent cleaning in removing sulfur and carbon contamination. No damage to the magnetic properties of the surface was observed.

In another study motivated by the need for good adhesion and interface bonding in depositions (in this case an aluminum deposition), Kominiak and Mattox (1977) found that a reactive plasma cleaning was most effective for their titanium, SS-304, Kovar, and Ni-Co steel substrates. Using soft X-ray appearance potential spectroscopy to check cleanliness, they obtained the best results in carbon residue reduction with low-voltage RF sputtering (300 V) with an Ar-HCl mixture forming the plasma.

Baker (1980) studied the reactive plasma cleaning of copper, aluminum alloy, and Inconel 625 with DC and RF discharges in argon-oxygen mixtures. He used a mass spectrometer set on CO_2 to monitor carbon evolution from the surface and calibrated the measurement by etching a pure carbon film. Baker found that reactive plasma cleaning was most effective at removing the deeply bonded carbon when the workpiece was at cathode potential to enhance the ion impact energy.

Plasma cleaning is a good waste minimization tool.

The plasma technology incorporating parallel plate electrodes with RF excitation greatly increases plasma cleaning speed.

Of critical importance is the work of Ward and Buss (1992), who recently studied plasma cleaning as a waste minimization tool. They experimentally investigated the effect of the process parameters on the plasma removal of thin films (1.5 to 7 µm) of polymethyl-methacrylate (PMMA) and poly-2-vinylpyridine from a substrate located in a research chamber using parallel plate electrodes with RF excitation. They found that by using a 40% SF_6/O_2 plasma that had an optimized plasma pressure (250 Torr) and power density, a removal rate of approximately 5 nm/sec (19 µm/hr) for PMMA could be obtained. This was an enhancement of two orders of magnitude over the removal rates of commercial plasma cleaners. By contrast, an optimized argon plasma produced a removal rate of only 0.08 nm/s.

Additional experiments addressed the removal of A-9 aluminum cutting fluid oil from substrates. The A-9 was a mixture of hydrocarbon solvents, waxes, fatty acids, fragrances, and dyes. In their report they did not specify the amount of oil present in the substrates that were tested. Using a 40% SF_6/O_2 plasma they were able to obtain a removal rate of 7.5 nm/s.

Plasma cleaning can be used to clean circuit boards.

Recent research indicates that plasma cleaning also can be of value in cleaning circuit boards. IBM researchers (Horwath and Moore, 1983; IBM, 1986) discovered that RF reactive cleaning with oxygen-carbon tetrafluoride may be used to remove epoxy/glass particle/copper drill smears in drilled through-holes in printed circuit boards. Both nonreactive and reactive plasma cleaning have been studied as a means to prepare hybrid integrated circuits prior to wire bonding (Brunner, 1992; Liston, 1989). Performance exceeding that of standard solvent cleaning in removing adhesive vapor residues has been achieved as measured in terms of wire bond yields. Plasma cleaning accomplishes ultrafine cleaning.

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Fluxless Soldering

In the electronics industry, conventional soldering requires fluxing to promote wetting and to remove oxidation from surfaces to be soldered. Halogenated solvents must then be used to remove the flux residues. Sandia National Laboratories (SNL) in Albuquerque, New Mexico, is exploring methods of fluxless soldering. With this approach, no flux residue is created, and the cleaning step is eliminated. Therefore, no solvent is needed.

Under contract to the U.S. Department of Energy (DOE) for the DOE weapons complex, SNL is developing four technologies that could eliminate the need for flux (Hosking, 1990). These technologies reduce or prevent surface oxidation prior to or during soldering, which is the main function of flux.

Fluxless Technologies

- *Controlled atmosphere soldering*
- *Thermomechanical surface activation soldering*
- *Metallization technology*
- *Inhibitor technology*

Controlled atmosphere soldering is discussed under Inert Atmosphere Soldering in Available Technologies, Section 2. Besides inert atmospheres, SNL is exploring reactive plasma and a dilute acid vapor-inert gas mixture that functions as either a protective or a reducing cover during processing.

Thermomechanical surface activation soldering uses kinetic or directed thermomechanical energy to spall or ablate the surface oxide and facilitate wetting. Laser, solid-state diffusion, and ultrasonic soldering are typical ways to accomplish this. These processes can be done in air or in a controlled atmosphere.

Metallization technology involves using silver as a nonoxidizing, readily wettable surface. The application of silver is an exacting process and must be controlled precisely. A thick layer generally is required to guarantee complete coverage and wettability. However, extra silver will produce a brittle solder joint. The approach is to apply a thinner layer of silver, although this has the risk that the coating will be porous, exposing the underlying metallic surface to oxidation and degrading wettability. Methods of inhibiting these effects are being investigated.

Inhibitor technology involves protecting these porous metallizations by applying inhibitors. SNL, in conjunction with the State University of New York at Stony Brook, is studying the bonding behavior of organic inhibitors on metallic surfaces and their effect on subsequent solder wetting.

Possible limitations of these technologies include incompatibility with processes and other materials as well as potential underperformance of the finished product.

Reference

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Replacement of Tin-Lead Solder Joints

One electronics manufacturer has developed a method of replacing tin-lead for soldering with a combination of organic polymers (epoxies, thermoplastics, or silicones) and conductive fillers (carbon, copper, or silver). This replacement would eliminate the need for fluxes and, consequently, the need to remove flux residues (Werther, 1990). Because the electronics industry is the largest user of Freon™-based cleaning solvents, fluxes, and (possibly) lead, this approach would have significant pollution prevention benefits.

By replacing tin-lead with organic polymers and conductive fibers, the use of flux and solvent cleaning would be eliminated.

An indication of the potential magnitude of the pollution prevention benefits can be seen at Interconnect Systems Incorporated (ISI), an electronics manufacturer. Current production levels at ISI require that approximately 5 million solder joints be made annually. With tin-lead soldering, this would require several thousand grams of solder paste, several dozen gallons of flux, and more than 50 gallons of Freon™ per year. By replacing tin-lead with organic polymers and conductive fibers, the use of flux and Freon™ would be eliminated.

ISI is currently examining the feasibility of this replacement in terms of functional qualities such as the electrical resistance in the joint, the mechanical and electrical integrity of the joint over time, the physical form of the adhesives, and the cost-effectiveness of the replacement.

Reference

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SECTION 4
POLLUTION PREVENTION STRATEGY

The main federal environmental regulations influencing the application of new cleaning technologies are the Clean Air Act Amendments (CAAA), the Resource Conservation and Recovery Act (RCRA), the Right to Know provisions of the Superfund Amendment and Reauthorization Act (SARA), and the emphasis on eliminating pollution at the source in the Pollution Prevention Act of 1990. Solvent cleaners also increase the potential workplace exposures to volatile organic compounds (VOCs) regulated under the Occupational Safety and Health Act (OSHA). There are a wide variety of state and local limits on VOC, hazardous, and aqueous wastes that also are of concern.

RCRA regulations make processes that generate significant solvent waste streams unattractive.

The requirements for cradle-to-grave management for solvent waste established by RCRA create several incentives to seek solvent-free alternatives. Disposal of RCRA wastes (including solvent waste) is costly and carries continued liability. RCRA also requires the waste generator to maintain a waste minimization program. Converting all possible plant applications to a cleaning technology that eliminates or reduces solvent use helps to demonstrate an effort to minimize hazardous waste.

Hazardous solvent emissions have to be reported under Title III of SARA.

Since 1988, manufacturing facilities have been reporting emissions of more than 300 chemicals or chemical categories. The reporting requirements are established under Title III of SARA. The toxic chemical release reporting usually is referred to as the Toxics Release Inventory (TRI). The reporting rule requires annual data on direct releases to all environmental media. Facilities meeting the following conditions must file TRI data:

- A Standard Industrial Classification (SIC) code in the range of 20 to 39
- 10 or more employees
- Manufacture or processing of more than 25,000 pounds or use of more than 10,000 pounds of a chemical on the TRI list.

The reporting requirements were expanded to include data on recycling as required by the Pollution Prevention Act. The effort required to track and report chemical usage as required by these legislations is significant. For plants that exceed the reporting threshold, reducing chemical use below the threshold eliminates the requirement to prepare a report for the chemical. Commonly used cleaning solvents—1,1,1-trichloroethane (TCA), trichloroethylene (TCE), methylene chloride (MC), and perchloroethylene (PCE)—also are TRI chemicals. Therefore, reducing or eliminating the use of any such solvent will eliminate the need to complete a TRI reporting form for that solvent.

Many solvents used in cleaning processes are part of a list of 17 priority toxic chemicals in the 33/50 Program targeted for early reduction.

The EPA also encourages the voluntary reduction of 17 priority toxic chemicals identified in the 33/50 Program for early pollutant reductions (U.S. EPA, 1991, 1992). Several cleaning solvents are on the list of priority toxic chemicals identified by the EPA Administrator for early reduction in the 33/50 Program. Switching from conventional solvent cleaning to a cleaner technology will assist in meeting the reduction goal.

OSHA regulations for solvent air emissions in the workplace are becoming increasingly stringent.

Another consideration is that the organic solvents used in cleaning may result in sufficient vapor concentrations to cause concern for workers in the area. The National Institute for Occupational Safety and Health (NIOSH) recommends that occupational exposure to carcinogens be limited to the lowest feasible concentration. OSHA regulations for workplace emissions are also becoming increasingly stringent.

Title III of the CAAA requires adoption of Maximum Achievable Control Technologies (MACT) for control of 189 hazardous air pollutants (HAPs). Cleaning processes using solvents are considered major sources of HAPs and are subject to MACT standards. Vapor degreasing is the single largest use for solvents, followed by dry cleaning (clothes cleaning) and cold cleaning (liquid solvent cleaning). Based on 1987 U.S. EPA estimates, approximately 25,000 to 35,000 batch vapor degreasers and 2,000 to 3,000 continuous cleaners were used in the United States.

The Pollution Prevention Act establishes source reduction as the preferred method for pollutant management.

The Pollution Prevention Act establishes pollution prevention as the preferred method for pollutant management. The processes described in this document provide promising alternatives to conventional processes for potential users, i.e., the metal-finishing, dry-cleaning, electronics, and any other industry that uses cleaning processes. Under programs such as the U.S. EPA's 33/50 Program, industries are encouraged to reduce pollutants voluntarily in anticipation of future regulations, which are expected to become increasingly stringent. The CAAA of 1990 allows the U.S. EPA to grant a 6-year compliance extension on the MACT compliance date to any existing source of air toxics that reduces emissions voluntarily by 90% (95% for particulates) below 1987 levels before January 1, 1994.

MACT standards will be issued by the U.S. EPA for new and existing sources, using the best controlled similar sources as a measure. MACT can include control equipment, process changes, material substitutions, equipment design modifications, work practices, or operational practices. All sources in a source category or subcategory will have to implement MACT. Unless the owner of the source is eligible for the 6-year extension (for 90% reduction), all industrial sources are expected to be in compliance within 3 years of promulgation of the MACT standards. A 5-year compliance extension also may be granted for prior installation of Best Available Control Technology (BACT) or Lowest Achievable Emissions Rate (LAER).

Under CAAA, MACT standards can be expected for halogenated solvent cleaners.

Under Title III of the CAAA, the U.S. EPA on July 16, 1992 (*Federal Register*, 1992) added halogenated solvent cleaners as an area source category. Thus, halogenated solvent cleaners are considered a major source category emitting at least 10 tons/year of any one air toxic or 25 tons/year of any combination of air toxics. Therefore, MACT standards can be expected to be promulgated for these cleaners. Vapor degreasing constitutes the single largest use of solvents in the United States, and therefore is an important area targeted for pollution prevention.

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SECTION 5
CLEANER TECHNOLOGY TRANSFER CONSIDERATIONS

Pollution prevention involves either using new processes that significantly reduce solvent emissions or switching to aqueous or semi-aqueous cleaning.

Alternative cleaning technologies are important for users who want to meet or anticipate new regulations. Such users have two options:

- Use new equipment that significantly reduces solvent emissions.
- Use a semi-aqueous or aqueous cleaner.

The latter option is more attractive from the pollution prevention standpoint, but for a variety of technical or economic reasons, the user may choose to go with the former. A third option, using processes that eliminate the need for cleaning, may also be viable.

Multiple add-on controls can significantly reduce air emissions from a vapor degreaser.

In the metal-finishing industries with conventional open-top vapor cleaners (OTVCs), the user could implement an incremental approach to pollution prevention. Such an approach would involve gradual phasing in of add-ons such as installing OTVC covers, increasing free-board height, changing from water-cooled to refrigerated coils (assuming that a non-CFC refrigerant is being used), and controlling room ventilation or exhausts. It could be possible to achieve 90% reduction with a combination of these standards. If the eventual MACT standard promulgated is limited to these add-ons to existing OTVCs, the user would then be in compliance. If the MACT standard turns out to be more stringent (enclosed vapor degreasing), the user could still be eligible for the 6-year extension if the add-ons were implemented before January 1, 1994.

Savings in operating costs make the CEVC technology cost effective over the long term.

There currently is no indication that the completely enclosed vapor cleaner (CEVC) would immediately become the MACT, especially given the high capital cost of the CEVC. However, on the assumption that environmental regulations become more stringent over time, the user could consider investing in a CEVC. The CEVC brings about savings in operating costs that would offset the higher capital cost over time. Some European countries regulate vapor degreasers as point sources, and CEVC is the required technology in those countries. Future models of the CEVC are expected to incorporate two carbon beds (instead of the one bed in the current model) so that one can be desorbed while the other is adsorbing. The extra bed would eliminate carbon heatup and desorption stage times and increase processing speed significantly for greater operating savings.

New aqueous and semi-aqueous washers are more efficient compared with conventional aqueous cleaning processes.

The above considerations assume that the user wants to retain vapor degreasing in some form and not switch over to aqueous or semi-aqueous cleaning. Industries have been reluctant to eliminate vapor degreasing completely because of its advantage with certain types of parts or simply because of tradition and ease of operation. However, aqueous and semi-aqueous cleaning technologies have advanced in recent years in terms of both the type of cleaning chemicals used and the type of equipment used. A fairly broad range of equipment such as the automated washer (for smaller parts) and the power washer (for larger parts) is commercially available. These washers are much more efficient compared to the traditional aqueous cleaning processes of alkaline tumbling and hand-aqueous washing. Ultrasonics affords another method for improving cleaning efficiency in hard-to-reach places of the workpiece. Because many aqueous washers involve either high-pressure sprays or tumbling action to expose all surfaces of the workpiece, users often prefer vapor degreasing for delicate parts. A combination of aqueous cleaning and ultrasonic cleaning holds a lot of promise for such applications.

Most of the cleaner technologies discussed in this guide result in reduced operating costs, and users can expect a payback on their initial investment. However, the reluctance to switch over to a new cleaning technology results from an understandable concern over the cleaned product quality. Will the new process provide the same cleaning effectiveness as the conventional technology for the desired range of applications?

Pilot testing of the new technology can be done to evaluate its effectiveness.

Vendors can help in the selection process.

Before switching to a new cleaning technology, users must first ensure that the new technology is suitable for their particular application. This may involve testing a pilot unit at the plant or at the vendor's location. Many vendors have test units at their manufacturing locations, where typical soiled parts can be cleaned to evaluate the effectiveness of the technology. Some users switch one of their traditional cleaning lines (vapor degreasing, alkaline tumbling, etc.) to new aqueous cleaning methods as a means of gradually phasing in the technology. If the new technology is found to be unsuitable for certain types of parts, the user can still clean those parts using traditional processes. Plants that plan to increase their existing capacities could consider adding new cleaning technologies instead of traditional ones, as a step toward gradual phase in.

When evaluating the effectiveness of a new cleaning technology, the user must often evaluate how clean the part is after washing. Evaluating the cleanliness of the workpiece can involve anything from simple visual observation to sophisticated surface analysis depending on the requirements of the application. For example, many metal finishing industries use a relatively simple test called the water-break test to evaluate a clean surface. The test involves dipping the cleaned workpiece or a cleaned test panel into a beaker of water and pulling it out. If the water film forms a continuous layer on the workpiece surface that can be sustained for about a minute, the surface is considered clean enough for further product finishing steps such as electroplating. Evaluating the cleanliness of an irregularly shaped part with crevices or blind holes may be more difficult.

Switching to a CEVC does not change the cleaning principle.

Unlike switching to aqueous processes, switching to a CEVC has the advantage that the cleaning effectiveness can be expected to be similar to that of the OTVC that it replaces, because the basic process is the same. The process similarities eliminate the detailed cleaning effectiveness testing that may be required when switching over to an aqueous process and thus alleviate product quality concerns. Vendors, however, can work with users to design suitable aqueous cleaning equipment. When cleaning effectiveness of aqueous systems falls below expectations, the vendor often can bring about improvements by making design modifications. For example, in aqueous cleaning, just changing the angle of the sprays can sometimes improve the cleaning effectiveness dramatically. Aqueous cleaning systems also can be custom designed for a particular application.

Most dry cleaning establishments already incorporate some form of closed-loop equipment.

In the dry cleaning industry, most establishments already incorporate some form of closed-loop equipment. Solvent vapors in the cleaning chamber typically are evacuated and recovered by either refrigeration or carbon adsorption, so that only a very tiny amount of solvent vapor is emitted at the end of the cycle. Research in this area is focused on developing better adsorbents that can remove this tiny fraction by capturing more of the solvent from the circulating air stream then is possible with refrigeration or carbon adsorption.

In the electronics industry, chlorinated solvents and CFCs traditionally have been used to remove the flux residue during soldering. One option is to use organic fluxes that can be washed off with water. However, a highly acidic solution may be required to avoid tin and lead hydroxide deposition, and this can lead to corrosion. Also, unlike conventional rosin fluxes, water-soluble organic fluxes do not encapsulate impurities resulting in electromigration.

Alternatively, several users have switched over to using water fortified with surfactants to clean conventional rosin fluxes. Although this is an important step in eliminating solvent use, the surfactant may not always be able to remove all the flux. Aqueous cleaning and ultrasonics can be used together for difficult cleaning applications, but as in all aqueous cleaning, drying is required. Also, the wastewater generated must be treated before discharge.

The low-solids flux (LSF) technology is increasingly being used during soldering to eliminate solvent use. New options being developed range from controlled atmospheres to alternative solder alloys. Here again, the industry is taking a cautious approach of in-house testing and gradual phase-in of technologies for pollution prevention.

Secondary pollution sources is an issue that needs to be addressed in the future.

One concern about cleaner technologies that has not yet been sufficiently addressed is the impact of secondary pollution sources on pollution prevention. Sometimes, pollution prevention technologies have higher energy requirements than the conventional technologies that they replace. For example, both the automated aqueous washer and the completely enclosed vapor cleaner (CEVC) described in Section 2 were found to have higher energy requirements than a conventional vapor degreaser. In the case of the automated aqueous washer, the higher energy requirement arose from the need for drying the parts after cleaning. In the case of the CEVC, the higher energy requirement arose from the consecutive heating and cooling cycles needed to generate and recover solvent vapors. The issue of higher energy consumption versus in-plant reduction or elimination of a hazardous pollutant is an issue that needs to be addressed in the future.

SECTION 6
INFORMATION SOURCES

Table 8 shows the trade associations and the technology areas they cover. Readers may contact these trade associations and request their assistance in identifying one or more companies that could provide the desired technological capabilities.

Table 8. Trade Associations and Technology Areas

Trade Association	Technology Areas Covered	Contact
AT&T Manufacturing Tech Group (MTG)	Low-solids flux applicator	Magit Elo-Gunther/Head of MTG (Developer) tel. (609) 639-2238
American Electroplaters' and Surface Finishers' Society	Metals finishing	12644 Research Parkway Orlando, FL 32826 tel. (407) 281-6441
Institute of Metal Finishing	Metals finishing	Exeter House Holloway Head Birmingham B1 1VQ England tel. (021) 622-7388
National Association of Metal Finishers	Metals finishing	111 E. Wacker Drive Chicago, IL 60601 tel. (312) 644-6610
Electronics Industry Association	Electronics industry	1711 "I" Street N.W., Suite 3000 Washington, DC 20006

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