Pollution Prevention Technology Profile
Closed-Loop Aqueous Cleaning

June 17, 2003

Introduction

The purpose of this Technology Profile is to provide information about closed-loop aqueous cleaning technologies in order to raise awareness of their potential to increase the useful life of cleaning agents and significantly reduce water use and wastewater generation. This profile focuses on the potential benefits of closed-loop aqueous cleaning systems when compared to traditional aqueous cleaning systems. This profile is not intended to detail the potential benefits of aqueous cleaning over halogenated solvent cleaning, although these benefits are sometimes mentioned. The Profile provides information about four main categories of closed-loop aqueous cleaning technologies: simple bag and cartridge filter; coalescer/skimmer; thin film oil separator; and membrane systems. The Profile contains the following sections:

It should be noted that this Technology Profile is not intended to be an "approval" of these technologies. The appropriateness of the use of closed-loop aqueous cleaning technologies should be determined on a site-by-site basis. Potential users should contact officials in the state in which the facility is located to determine the state-specific regulatory requirements that could apply. A listing of state contacts is located at the end of this profile.

Background

Metal cleaning and degreasing processes are used in a variety of industries to remove contaminants and unwanted material such as dirt, grease, chips or filings, lubricants, oil emulsions, and dust, as well as grinding and polishing pastes (collectively referred to as "contaminants"). These contaminants can severely interfere with the production process and lower product quality. Surface cleaning and/or degreasing can be performed as the final step in manufacturing a product, as a preliminary step in preparing the surface for further work, or as an intermediate step for forms or equipment between uses. Metal cleaning and/or degreasing occurs in many sectors including metal fabrication, surface coating, metal finishing, and circuit board manufacturing.

For many years, the traditional cleaning method involved chlorinated solvents in vapor degreasers or immersion systems. The chlorinated solvents most frequently used for metal cleaning include the following: 1,1,1-Trichloroethane (1,1,1-TCA), trichloroethylene (TCE), tetrachloroethylene (perchloroethylene), and dichloromethane (methylene chloride). Chlorinated solvents are effective cleaners and were considered safe for workers because they have low flammability. However, their use is now associated with serious adverse environmental and worker health impacts such as increased cancer risk, formation of ground-level ozone and smog, and depletion of the ozone layer.

Due to these concerns and more stringent regulation, companies began searching for less hazardous cleaners and cleaning methods that would effectively and efficiently clean metal parts and electronic components. Aqueous cleaning methods proved to be a viable option for many companies.

Aqueous Cleaning Overview[1,2]

Aqueous cleaning has been used for years to remove salts, rust, scale, and other organic soils from ferrous metals. Aqueous cleaning tends to be more effective at higher temperatures and is generally performed at temperatures above 120^{o}F. In some applications, hot water alone may be sufficient to clean parts. However, aqueous cleaners are typically mixtures of water, detergents, and other additives that promote the removal of organic and inorganic contaminants from hard surfaces. Generally, in order to be categorized as aqueous cleaning, the cleaner should be approximately 95 percent water by volume. The cleaning step is typically followed by a water rinse. Depending on the cleanliness requirements, there can be more than one rinse step. In most aqueous cleaning systems, more wastewater is generated from the rinse step than the cleaning step.

Each component of an aqueous cleaner performs a distinct function and effects the way the contaminant is removed from a substrate. Alkaline cleaners are generally viewed as the most viable substitute for chlorinated solvents due to their ability to remove most types of contaminants. However, acid and neutral cleaners are utilized for specific cleaning applications.

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[1] Underwood, Christopher and Karen Thomas, *Closed-loop Aqueous Cleaning*, Massachusetts Toxics Use Reduction Institute, September 1995.
[2] U.S. EPA, Guide to Cleaner Technologies, *Alternatives to Chlorinated Solvents for Cleaning and Degreasing*, EPA/625/R-93/016, February 1994.

The primary component of alkaline cleaners is surfactants. Surfactants provide detergency by lowering surface and interfacial tensions of the water so that the cleaner can penetrate small spaces better, get below the contaminant, and help lift it from the substrate. Surfactants are typically combined with special additives such as pH buffers, corrosion inhibitors, saponifiers, emulsifiers, deflocculants, complexing agents, and anti-foaming agents to meet the particular cleaning need.

Aqueous cleaning typically combines the water-based cleaning solution with mechanical cleaning action. Mechanical cleaning action can be provided by pressure spray, or by immersion with agitation and/or ultrasonics. The selection of the most appropriate aqueous cleaning method is based upon the type of contaminant(s) and the level of cleaning needed. Several factors may affect the cleaning process such as cleaning temperature and time, type of mechanical action, configuration of the parts, concentration of the cleaner, and the type(s) of additives used. The following sections briefly describe the three primary aqueous cleaning methods: immersion, pressure spray, and ultrasonic.

Immersion
The immersion method cleans parts and components by immersing them in a solution and using agitation to add the energy needed to displace the contaminants. The contaminants are removed from the metal surface using convection currents created by heating coils or some form of mechanical action such as brushing.

Pressure Spray
Pressure spray cleaning involves forcing a cleaning solution through the spray nozzle at a high pressure to increase the impingement on the part's surface. The pressure can vary from as low as 2 psi to more than 400 psi. Spray cleaning solutions are prepared with low foaming detergents and may be less chemically effective than those used in immersion cleaners, but are still effective at cleaning because of the increased mechanical action. Spray cleaners are typically favored by the manufacturing sector because they can handle a wide range of part sizes and configurations, including parts that would be difficult to fit in an immersion system. Spray cleaners can also come in a variety of configurations, but generally fall under three categories: batch, conveyor, and rotary. Generally, spray systems are enclosed, or partially enclosed and the cleaner is recovered and reused.

Ultrasonic
Ultrasonic cleaning is a special type of immersion that transmits high-frequency sound waves (vibrations) through the solution to produce a scrubbing action. The high-frequency sound waves force the formation and collapse of low-pressure bubbles, referred to as cavitation. The bubbles provide additional mechanical cleaning action and increase the ability of cleaning agents to reach all surfaces of the part or component. This process also creates high temperatures and turbulence on the microscopic scale, further aiding in the cleaning process. Ultrasonic cleaning is very effective when cleaning small parts. The limitations to the applicability of ultrasonic systems include a tendency for thick oils and greases to absorb the ultrasonic energy, high capital costs, high electricity use, and potential difficulties maintaining the immersed transducers.

Cleaner Useful Life
The parts/components emerging from the aqueous cleaner carry with them a layer of the cleaning solution that may need to be rinsed from the surface. When necessary, the parts or components

are rinsed with a volume of water to remove the detergent film. Rinse systems generally involve immersion of the part in a series of tanks, each containing progressively cleaner water. Spray rinse systems are also used. As the cleaner becomes contaminated, typically with dirt and oil, cleaning times increase and greater quantities of rinse water must be used to reach optimum product quality and cleanliness. This continues until the cleaner has reached the end of its useful life. Useful life is generally considered to be the point at which the soil concentration being held by the cleaner overwhelms the ability to hold additional soil or prevent its redeposition on the parts. Therefore, at some point, the cleaner must be disposed of and replaced by a new bath. Each time a new bath is introduced, the manufacturing process may be interrupted and the contaminated water must be disposed of, most likely as a hazardous waste.

Closed-Loop Aqueous Cleaning Overview[3,4]

Aqueous cleaning methods have proven to be an effective and viable alternative to solvent cleaners. However, one of the primary disadvantages of the aqueous cleaning process is the generation of rinse water and/or spent cleaner wastewater streams. Depending on the nature of the contamination removed from the part, this wastewater can contain hazardous material that must be properly disposed of. Therefore, the wastewater can require treatment prior to discharge. Extending aqueous cleaner life through operating changes and/or through recycling may offer an environmentally sound alternative. It may also reduce costs, allowing cleaning solutions to be reused repeatedly.

Searching for techniques to improve upon the limitations of aqueous cleaning methods led researches to develop alternatives that would reduce and sometimes eliminate the wastewater problem, closed-loop aqueous cleaning. Closed-loop aqueous cleaning involves the removal of undesirable contaminants from both the cleaner and the rinse water usually through a process using simple bag and cartridge filters, coalescers/skimmers, and/or membrane systems. The cleaning bath and the rinse waters are recycled in separate systems.

The idea behind closed-loop cleaning systems is not revolutionary. It simply adds an additional step to the current aqueous cleaning process and can usually be readily adapted to fit the specific needs of the company. Implementing a closed-loop aqueous cleaning system can have many benefits. A system can minimize water usage while also reducing operational down time and the costs for replenishing the cleaning detergent.

Regulatory Requirements

Aqueous cleaning systems can generate a significant quantity of rinse water and spent cleaner wastewater that needs to properly managed. Most often, discharge is to a publicly-owned treatment works (POTW). However, sewer discharge permit conditions are increasingly restrictive, often requiring treatment prior to discharge. Discharge to surface water requires a National Pollutant Discharge Elimination System (NPDES) permit a costly process that also requires treatment prior to discharge. Most jurisdictions prohibit the discharge of wastewater, other than from sanitary sources, to below ground systems (e.g. septic system).

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[3] Underwood, Christopher and Karen Thomas, *Closed-loop Aqueous Cleaning*, Massachusetts Toxics Use Reduction Institute, September 1995.
[4] McLaughlin, Malcolm, *Closed-loop Cleaner Recycling*, CleanTech, June 1997.

The cost and technical and regulatory requirements of wastewater management have created a motivation for companies using aqueous cleaning to investigate methods to reduce or eliminate wastewater discharges. Conversely, wastewater management is often cited by companies as a reason to continue to use chlorinated solvents for cleaning.

While closed-loop systems can substantially reduce or even eliminate the need for wastewater management, they do eventually generate some waste. Depending on the characteristics of the material being cleaned, the concentrated sludge generated from a closed-loop aqueous system may or may not be a hazardous waste. The quantity of waste generated from a closed-loop aqueous system is dependent upon the quantity of cleaning performed and how dirty the material being cleaned is, and in general is significantly less than if chlorinated solvents are used. In addition, some jurisdictions could require regulatory approval of wastewater recycling systems, particularly if it is to be added to an existing aqueous cleaning system that currently has a discharge. Therefore, before installing a closed-loop aqueous cleaning system the potential user should contact their state regulatory agency to determine what regulations could apply.

Applicable Industries

Closed-loop systems can be appropriate for virtually all situations where aqueous cleaning is appropriate. The main constraint would be physical space limitations since the system needs to be located at or near the cleaning process. Determining the optimal system design requires examination of the waste stream to be recycled, particularly flow rate, characteristics of the contaminants and their loading, and characteristics of the cleaner. If the current system combines waste streams from several different cleaning operations for treatment at a central wastewater treatment system, they might need to be separated so that each different type of cleaner can be recovered for reuse. However, the facility should first evaluate the viability of using the same cleaner chemistry for multiple applications.

Benefits

There are numerous potential benefits associated with closed-loop aqueous cleaning systems when compared with traditional aqueous cleaning systems, including: significantly reduced cleaner purchases, water consumption and wastewater generation; and improved product quality. There can be additional benefits associated with a particular technology and those are discussed in the technology-specific sections. For the general benefits described below, their magnitude depends upon the characteristics of the cleaning operation and the particular technologies chosen to close the loop.

Reduced Cleaner Purchase Costs: A closed-loop system installed on the cleaner bath purifies the cleaner so it can be reused. Because bath life can be significantly extended, purchases of new cleaner can be reduced by 50 to 90 percent or more.

Reduced Water Consumption: A closed-loop system installed on the rinsewater system purifies the rinsewater so it can be reused, usually cutting water consumption by 95 percent or more. A closed-loop system on the aqueous cleaner bath that operates continuously (not batch) can prevent the build up of contaminants in the cleaner and thereby reduce overall rinsewater requirements by 50 percent or more.

Reduced/Eliminated Wastewater Management: In traditional aqueous cleaning, spent cleaner and rinsewater is typically discharged from the facility as wastewater, often with pretreatment.

The significantly reduced water consumption discussed above translates into significant reductions in wastewater generation. Most systems that close the loop on both the cleaner bath and the rinsewater can eliminate wastewater generation altogether. The only waste generation is the concentrated contaminants that are typically not handled as wastewater - because of the small quantity they are usually drummed for off-site treatment or disposal. In addition, wastewater treatment and/or discharge can entail significant regulatory compliance costs for monitoring, recordkeeping, and permitting. Eliminating a wastewater discharge can reduce the regulatory costs for the facility.

<u>Increased Consistency and Improved Product Quality</u>: Under traditional aqueous cleaning, the cleaner gets progressively dirtier until it is spent. As the quality of the cleaner declines, contamination can remain on the work piece, causing quality problems and increasing rework. Systems that operate continuously as part of the cleaning process (not batch recycling) help keep the cleaner performing at a relatively consistent level which can translate into improved product quality and less rework, reducing labor requirements/cost.

Concerns

There are some potential concerns associated with closed-loop aqueous cleaning systems when compared with traditional aqueous cleaning systems, including: waste generation and system maintenance requirements. There can be additional concerns associated with a particular technology and those are discussed in the technology-specific sections.

<u>Waste Generation</u>: As mentioned above, closed-loop technologies can often eliminate wastewater generation. However, they now create a concentrated waste that does eventually have to be removed. Depending upon its composition, this waste can be subject to regulation as a hazardous waste. However, in most cases the quantity generated is small and the regulatory requirements are not excessive. The quantity of waste and whether it is considered a hazardous waste depend upon the nature of the contamination being removed from the part.

<u>System Maintenance</u>: Closed-loop technologies all entail pieces of equipment that are added to the aqueous cleaning process and require maintenance. In addition, some technologies are more complex than others, requiring additional monitoring and maintenance for proper operation. However, the reduction/elimination of wastewater can decrease monitoring maintenance requirements, particularly for facilities that had treatment systems. Maintenance can also be reduced by in-line (continuous) aqueous cleaner recycling by significantly extending the time period between aqueous cleaner bath tank cleaning.

Closed-Loop Aqueous Cleaning Technologies[5]

A number of separation methods exist for removing unwanted contaminants from an aqueous cleaner solution ranging from skimmers to membrane separation systems. The method selected for an aqueous cleaning closed-loop system is dependent upon a variety of factors such as characteristics of the contaminant(s), level of cleanliness needed, and cost of implementation and maintenance. It is important to note that systems can be combined to achieve differing levels of cleanliness. For sophisticated cleaning situations several methods are often combined, for

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[5] Underwood, Christopher and Karen Thomas, *Closed-loop Aqueous Cleaning*, Massachusetts Toxics Use Reduction Institute, September 1995.

example the solution may pass through a simple filter followed by a skimmer (or visa versa), and then a membrane system. The following discussion is focused mainly on aqueous cleaner recycling; however the concepts and technologies apply to rinse water recycling as well.

Simple Bag and Cartridge Filters

Simple filtration bags or cartridges are utilized primarily to extend cleaner bath life by removing gross contamination and therefore are most appropriate for use where the level of cleanliness is not a major factor. Simple filters are often used as a pre-filtration step prior to membrane separation when higher levels of cleanliness are required. The relatively simple bag and cartridge filtration methods use gravity or a low pressure pump to move the wastewater through the filter to remove suspended particles at 1 to 100 micron levels of filtration. Filters are generally used to remove particulate matter from the wastewater stream. They can also be selected to remove non-emulsified oils, but are not effective for emulsified oils.

Advantages

- Simple, effective method to extend cleaner life in many situations
- Low capital cost
- Low maintenance requirements and low replacement costs

Drawbacks

- If the wastestream is oily, the filters can become coated so quickly that the cost of either replacing or washing the filters might outweigh the financial benefits of extended bath life. Use of a skimmer prior to the filter might be appropriate for oily wastewater. Pilot experimentation with filters may indicate whether or not they can significantly increase bath life for a particular application.
- Cannot remove emulsified oils and small contaminants and therefore, depending on the particular contaminant and cleaner characteristics, might not significantly extend cleaner life if not combined with another technology.
- Filters eventually require disposal – could be a hazardous waste depending on the contaminant characteristics.

Coalescers/Skimmers

When precision cleaning is not necessary and the contaminant being removed is oil, a skimmer alone can be used to prolong the cleaner life. A coalescer is a filter whose configuration helps the oil rise to the surface of the tank where a belt or disc skimmer can be used to remove the floating oil. The oil is diverted to another reservoir where it can be recycled or managed as a waste. For some cleaners, simply cooling the wastestream can increase the separation of the oil and improve efficiency. After a period of time the cleaner will loose its effectiveness and require replacement. However, with the use of a skimmer, cleaner life can often be significantly extended.

Advantages

- Simple, effective method to extend cleaner life when oily contamination is present

- Low capital cost and low maintenance requirements

Drawbacks

- Only oils that have risen to the surface are removed, therefore oil that has not fully separated is not removed. Does not remove emulsified oils.

- Does not remove contaminants that do not rise to the surface. Therefore, if contaminants other than oil are present, cleaner life might not be significantly extended by use of a skimmer alone.

- Cleaner components can be mixed in the oil layer at the surface and skimmed off.

Case Study – Lockheed Martin Defense Systems[6]

Lockheed Martin Defense Systems (LMDS) manufactures precision aerospace products. Parts were cleaned with solvent vapor degreasers. Due to concerns about air emissions, LMDS decided to replace many of the solvent degreasers with aqueous processes, one of which was a closed-loop ultrasonic system. The 100 gallon ultrasonic aqueous cleaner and the rinse tanks were each fitted with a system to continuously filter a portion through coalescing filters after which oil is skimmed off. The wastewater then flows through two cartridge filters, one of 50 micron size and the other of 10 microns before being returned to the ultrasonic system.

Results

- Solvent use eliminated
- Water use and sewer discharge cut by 2 million gallons per year
- Wash and rinse water life are approximately 18 months
- Waste generation reduced to 165 gallons per year

Implementation Issues

- Filters are changed out every six months
- When the cleaner bath was changed out, the rinse water was used to make-up the new cleaner and new rinse water was added.

Costs

- Capital cost: $88,560

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[6] Massachusetts Toxics Use Reduction Institute, *Lockheed Martin Defense Systems, Pittsfield, Massachusetts, Closed-loop Aqueous Cleaning of Mechanical Parts*, Technical Report No. 33, 1996.

- Contributes a portion of the overall facility-wide savings: $497,000 reduction in solvent purchases; $17,500 in waste disposal reduction; $65,000 air emission permitting and recordkeeping requirement reductions
- Annual savings of $3,450 in water and sewer costs specific to the unit.

Thin Film Oil Separator[7]

When oil is the major contaminant of concern, a mechanical separation configuration known as thin-film separation can be appropriate for aqueous cleaner recycling and often offers greater benefits than a coalescer/skimmer system. The thin film oil separator, known as Suparator™ operates continuously with the cleaning system, and therefore, a thick layer of oil never accumulates at the cleaner surface. The oil/cleaner layer is skimmed off the cleaner bath/reservoir and fed to a stainless steel process tank via gravity or a low pressure pump. The oil floats to the top of the process tank where it enters the separation device. The configuration drives the aqueous cleaner downward and causes the oil to concentrate at the surface, as shown in Figure 1. After the oil is removed, the cleaner can be filtered through a simple bag or cartridge filter or possibly a fine mesh screen to remove any remaining particulate. If a pump is used to move the wastestream to the process tank, the filter/screen should be placed prior to it if the particulate loading is significant. This system can be used prior to a membrane separation technique if necessary to meet stringent cleaning requirements.

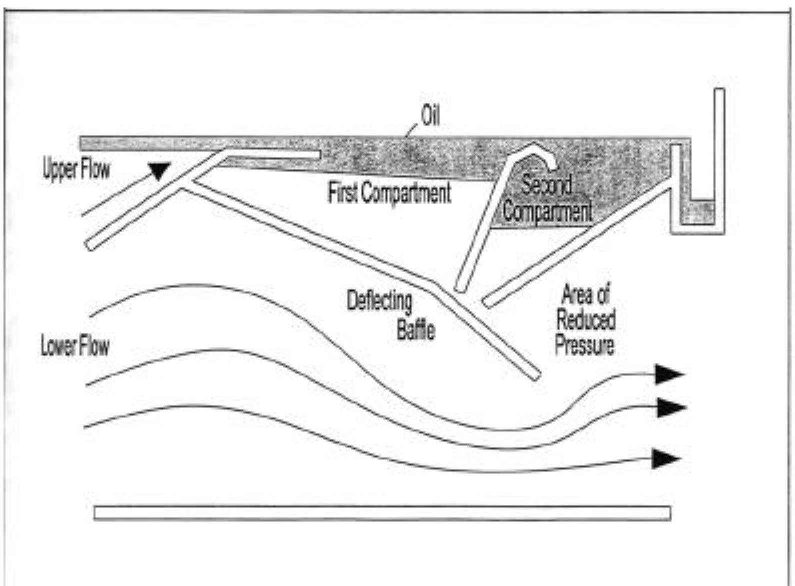

Figure 1: Suparator™ Oil Separation Compartment[8]

[7] Massachusetts STrategic Envirotechnology Partnership (STEP) and the Massachusetts Toxics Use Reduction Institute (TURI), *Pilot of the Pollution Prevention Technology Application Analysis Template Utilizing Suparator™ Thin-Film Oil Recovery System*, September 1999.
[8] Massachusetts STrategic Envirotechnology Partnership (STEP) and the Massachusetts Toxics Use Reduction Institute (TURI), *Pilot of the Pollution Prevention Technology Application Analysis Template Utilizing Suparator Thin-Film Oil Recovery System*, September 1999, Page 1-3.

Advantages

- Removes more oil from the cleaner than skimmers and other mechanical methods, resulting in a purer cleaner.

- The oil removed does not contain cleaner components and has a water content of less than 1 percent. Often the oil can be reused with no or minimal processing. If not reused, the volume of waste oil reduced because the oil collected is more concentrated than from other mechanical methods.

- Simple design with low maintenance requirements.

- Surfactants are separated from the oil and remain in the recycled cleaner and therefore, cleaner make-up chemistry is typically not necessary.

Disadvantages

- Cleaner chemistry is important – the system performs best when an oil-rejecting neutral aqueous cleaner is used, and less efficiently when an emulsifying alkaline aqueous cleaner is used. However, the system does extend cleaner life even for an emulsifying alkaline chemistry.

- Particulate, if present in the wastestream, tends to accumulate at the bottom of the process tank and therefore, requires removal.

- In order for the oil layer to properly contact the system baffles and to create the required pressure differentials in the separator, flow rates cannot drop below design levels. Note that the baffles can be adjusted if wastestream levels permanently rise or fall.

Case Study – Racine Plating Company [9]

The Racine Plating Company specializes in the surface finishing of metal parts, primarily electroplating. Prior to finishing the parts oily contaminants are removed with an emulsifying alkaline aqueous cleaner in an immersion bath followed by an electrocleaning step and then are pickled prior to rinsing. The company operates two cleaning lines. The Suparator™ thin film oil separator was added to each system to extend cleaner life, and not to recover a reusable oil product. The processing tank sizes are 240 liters (63.4 gallons) and the flow rate into each unit is approximately 5.9 gallons per minute.

Results

- 50 percent reduction in rinsewater use due to reduction of oil in the cleaner resulting in less residual oil remaining on parts after cleaning and pickling

[9] Massachusetts STrategic Envirotechnology Partnership (STEP) and the Massachusetts Toxics Use Reduction Institute (TURI), *Pilot of the Pollution Prevention Technology Application Analysis Template Utilizing Suparator Thin-Film Oil Recovery System*, September 1999.

- Improved product quality – reduced rework requirements due to the reduction of residual oil on parts
- 50 percent reduction in aqueous cleaner purchases
- 25 percent reduction in electrocleaner purchases, again due to the reduction of residual oil on parts after aqueous cleaning
- No significant surfactant loss from cleaner
- Recovered oil contained less then 0.5 percent water

Implementation Issues

- System does not recover significant volumes of oil.
- During independent testing the oil and grease concentration of the cleaner did not decrease – however, it remains relatively stable, providing consistency to the cleaner – oil concentrations do not build up quickly as they would without the thin film oil separator.

Cost

- Capital cost $8,650 for the gravity-feed system (including automated overflow protection) and $6,110 for the pump configuration
- Annual operating cost savings per line of $11,600 (reduced aqueous cleaner, electrocleaner, and sulfuric acid (for cleaning) purchases, and reduced water consumption)
- Payback period of 8.9 months for the gravity-feed system and 6.3 months for the pump-feed system.

Case Study – Lindberg Heat Treat Company[10]

Lindberg Heat Treating Company is a commercial heat treater, primarily of steel fasteners. Once the heat treating process is completed, the parts are cooled in an oil quench system. After quenching, oil is removed from the parts in a combination immersion and spray washer. Generally, washing is with water; however, during periods of high production throughput a polymer additive is used. The facility initially used an 8 inch wide belt skimmer to separate the oil from the rinse water (which is recycled). However, the belt skimmer did not adequately remove the oil from the rinsewater. When the parts entered the Tempering Furnace they had a thin coat of oil that burned off in the furnace creating a lot of smoke and an air quality problem. In addition, the recovered oil required processing through an oil conditioning system to remove water and a centrifuge to remove more water and particulate before it could be reused.

A Suparator™ thin film oil separator was purchased to replace the belt skimmer and centrifuge. The processing tank size is 240 liters (63.4 gallons) and the flow rate into the unit is approximately 8.2 gallons per minute.

[10] Massachusetts STrategic Envirotechnology Partnership (STEP) and the Massachusetts Toxics Use Reduction Institute (TURI), *Pilot of the Pollution Prevention Technology Application Analysis Template Utilizing Suparator Thin-Film Oil Recovery System*, September 1999.

Results

- Smoke generation in Tempering Furnace was eliminated
- Quench oil purchases reduced from 18,000 gallons per year to 1,000 gallons (94%)
- Improved product quality – no more surface staining (caused by residual oil in the Tempering Furnace). Results in improved appearance and elimination of need to use an abrasive blast cleaning process at the plating shop that receives the fasteners.
- Eliminated need to dispose of contaminated quench oil (was 18,000 gallons per year)
- Eliminated need to dispose of contaminated water (was 4,950 gallons per year)
- Cleaner additive purchases reduced from 30 gallons per year to 10 gallons (67%)
- Scheduled equipment maintenance reduced from 64 man-hours per year to 12 (81%) and scheduled production downtime reduced from 32 hours to 0 (100%)
- Recovered oil contained less than 0.1 percent water

Implementation Issues

- Metal fines accumulated at the bottom of the process tank, requiring periodic cleaning. Cleaning requires the unit to be taken off line and drained, and then cleaned with a spray water wash, and generally takes approximately 1 hour each month.

Cost

	Belt Skimmer	Thin film oil separator
Operating Costs	$82,010 for quench oil and additive purchases, oil and water disposal, and scheduled maintenance and production downtime	$4,250 for quench oil and additive purchase, and scheduled maintenance
Capital Cost	NA	$8,200
Payback		38 days

Membrane systems[11,12]

A membrane system is a physical separation processes that generally does not affect the chemistry of the cleaning solution. Pressure is applied to one side of a semi-permeable membrane forcing the water and soluble compounds to flow from the spent cleaning solution, or dirty rinse water, through the membrane, while particles and less-soluble compounds, such as oils do not pass through the membrane and are concentrated. The resulting filtered fluid (called permeate or filtrate) can be reused; however, a small amount of the cleaning solution chemistry might need to be added to restore cleaning effectiveness. For example, surfactants can react with oil emulsions or can be prevented from crossing the membrane if it is clogged or fouled. The losses of surfactant must be made up in order for the cleaner to perform.

[11] The University of Rhode Island Center for Pollution Prevention, *Pollution Prevention Technology Application Analysis Utilizing Membrane Filtration Technology*, April 2001.
[12] Rajagopalan, N. and T. Lindsey, Illinois Waste Management and Research Center, and John Sparks, U.S. EPA, *Recycling Aqueous Cleaning Solutions: Using Membrane Filtration to Recycle Aqueous Cleaning Solutions*, PF Online (www.pfonline.com).

Membrane materials for aqueous cleaner recycling are generally classified as organic polymer or inorganic/ceramic. Organic membranes can be used when pH is less than 12 and temperature is less than 140^{o}F. At high pH the cleaner can react with the organic membrane materials. Inorganic membranes are typically made from alumina, zirconia, or sintered steel and are used when a higher pH and/or temperature is required. Membranes can be coated to resist fouling from oils and/or to allow easy cleaning. The selection of membrane material requires consideration of several factors including: pore size; temperature tolerance; surface chemistry of the membrane, including coating; and stability of the membrane when exposed to the wastewater.

There are generally four main types of membrane systems, classified according to pore size:

- nanofiltration
- reverse osmosis
- microfiltration
- ultrafiltration

Nanofiltration relies on membranes with pore sizes of less than 0.001 microns and reverse osmosis on membranes with even smaller pore size. Generally, the exceptionally small pore size of nanofiltration and reverse osmosis membranes make them good for purifying water as virtually all other compounds do not pass. For systems where dionized water is used for rinsing, a reverse osmosis system can be an effective method to recycle rinse water. However, for applications where such pure water is not required, reverse osmosis is generally not appropriate. Nanofiltration can be appropriate when rinse water must be very clean but not totally pure; however it can often be more than needed as well. Nanofiltration and reverse osmosis are also not applicable when recycling cleaning agents is the primary objective as most of the desired cleaning chemicals would not pass through the membrane and would remain in the waste concentrate. Generating the pressure required to drive the liquid through the membrane is energy intensive and nanofiltration and reverse osmosis are associated with higher operating cost than the other membrane systems.

Microfiltration and ultrafiltration can be appropriate for aqueous cleaner recovery, as well as for recycling rinse water. Microfiltration employs a membrane with pore size in the range of 0.05 to 5.0 micron in diameter and is most effective for removing particles. Ultrafiltration membranes have pore sizes in the range of 0.001 to 0.1 microns and are effective for removing both particles and large molecules. The smaller the pore size, the greater the energy required to create enough pressure to force liquid through the membrane. Therefore, ultrafiltration is associated with higher energy cost than microfiltration. Smaller pore size is generally associated with a slower processing rate as well. Therefore, the largest pore size that will perform adequately should be chosen. Generally, membranes used to recycle aqueous cleaners have pore sizes in the range of 0.05 to 0.45 microns.

Once the type of membrane and its pore size are chosen, the module configuration must be determined. There are three primary membrane configurations: tubular, hollow fiber, and spiral wound. Generally, tubular membranes are easier to clean (typically via mechanical means) and do not require pre-filtration of the incoming wastewater stream. However, tubular configurations offer less membrane area per given volume than the other configurations which reduces efficiency. Tubular configurations are most appropriate for small to moderate volume flows with high solids loading. Tubular ceramic membranes can be both backflushed and mechanically cleaned.

Hollow-fiber and spiral-wound membranes often require pre-filtration to prevent plugging of the passageways within the configuration. Hollow-fiber modules can be backflushed for cleaning. Spiral-wound membranes are more susceptible to fouling and are more difficult to clean, however it is usually more cost effective for removing clean oil emulsions. Spiral-wound membranes are most appropriate for high volume flows with low contaminant loading (or after use of pre-filtration).

Membranes require periodic cleaning. The length of time between flushing and/or cleaning is dependent on the characteristics of the waste stream. For systems recycling heavily contaminated flows, filtration prior to the membrane unit, such as with a simple bag filter is advised to remove the largest of particles, reducing the opportunity that the membrane will become clogged and increasing the interval between membrane cleaning and/or replacement.

Commercially available micro- and ultra-filtration systems typically operate in a batch mode in a configuration similar to that shown in Figure 2.

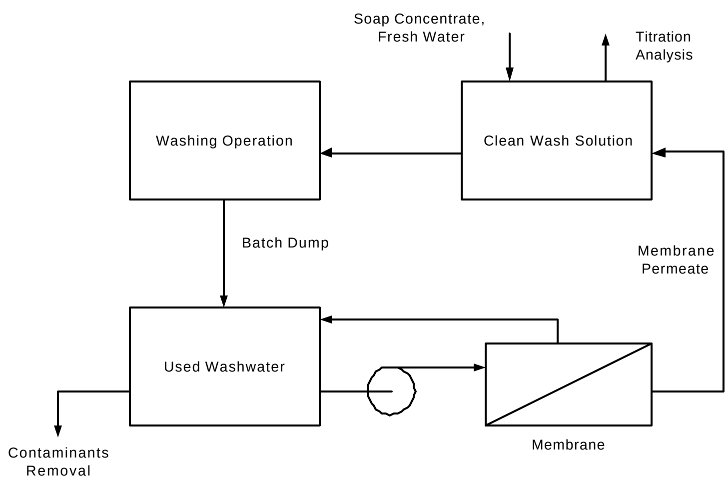

Figure 2: Aqueous Cleaner Recycling – Example Batch System Configuration[13]

Systems can also be designed that continuously bleed off a portion of the cleaner from the wash tank (or reservoir for spray systems) as shown in Figure 3 for purification. The system and membrane unit should be sized to turnover the cleaner solution in about half the time as the life of the cleaner under normal operations without the continuous recycling.

A batch or continuous system can significantly extend cleaner life. However, at some point the cleaner will require replacement. Periodic removal of the concentrated sludge from the process tank is also required. Depending on flow rate and contaminant characteristics and load this interval could range from several months to several years.

[13] The University of Rhode Island Center for Pollution Prevention, *Pollution Prevention Technology Application Analysis Utilizing Membrane Filtration Technology*, April 2001, Page 16.

Advantages

- Can significantly extend cleaner life in most applications.

- Membranes can remove emulsified oils and can be designed to remove virtually all contaminants.

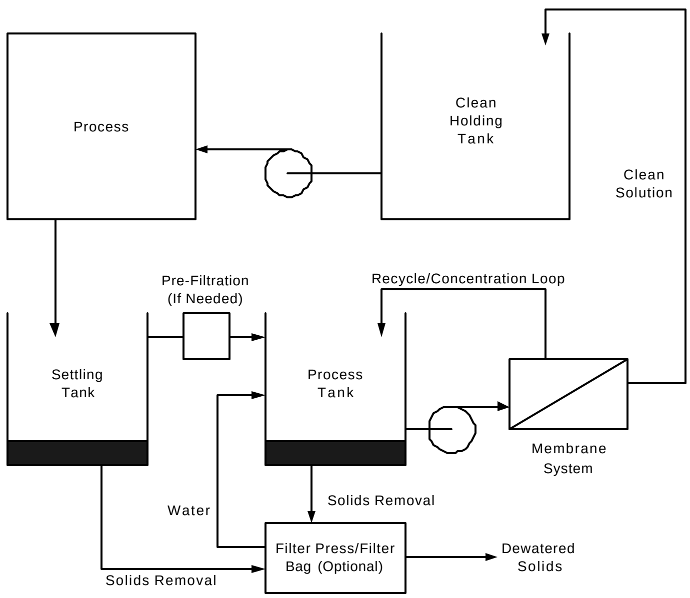

Figure 3: Aqueous Cleaner Recycling – Example Continuous System Configuration[14]

Drawbacks

- Hard water can cause precipitate to form on the membrane, effectively clogging it. The facility's water might need to be softened before use in the aqueous cleaner or as rinse water.

- Membranes (except reverse osmosis membranes) do not reject salts which will continue to accumulate in the cleaner and adversely affect its performance. The salt content of the facility's water and of the cleaner should be monitored.

- The cloud point of a cleaner can impact the effectiveness of a membrane system. The cloud point is determined by raising the temperature of the cleaner until it becomes cloudy (the surfactants are separating from the solution). Membrane systems work most efficiently when the cloud point of the aqueous cleaner occurs at temperature above the operating temperature of the filtration system.

- Limonene and other related (citrus-based) cleaners are not effectively recycled with membrane systems. Citrus-based cleaners are not water soluble and their components

[14] The University of Rhode Island Center for Pollution Prevention, *Pollution Prevention Technology Application Analysis Utilizing Membrane Filtration Technology*, April 2001, Page 6.

remain with the contaminants. Alternative aqueous cleaners that can be recycled might be as effective for the cleaning application and might be more economical.

- Membranes require periodic cleaning or replacement that can require labor as well as production downtime.

- Higher operating costs than for simple filters and skimmers due to electricity needs.

- May require pretreatment using a simple filter and/or skimmer to prevent fouling and/or excessive cleaning needs.

Case Study – Interplex Metals, Inc.[15]

Interplex Metals performs nickel, copper, and tin plating for the electronics industry. Most plating is reel-to-reel, with some barrel and rack plating occurring. The shop initially used 1,1,1-trichloroethane (TCA) for cleaning. Due to health, economic, and regulatory concerns, the shop switched to an ultrasonic aqueous cleaning system. However, they now had a significant quantity of oily wastewater to manage and installed an ultrafiltration system to recycle the cleaning solution. The cleaning solution in the ultrasonic unit loses its effectiveness after approximately one month. The solution is then drained from the ultrasonic unit into the spent solution tank for batch recycling. The wastestream passes through a cartridge filter and then the membrane system where the contaminants are separated from the cleaning solution. Contaminants are returned to the solution tank where they are concentrated and the cleaner is returned for reuse in the ultrasonic cleaning tank.

Results

- The same cleaner solution was reused for over two years with no change in product quality and less than one drum of concentrated oil waste was produced.
- When compared with the old halogenated solvent method, productivity was increased significantly because the line speed could be increased from 10 ft/min (the previous limit due to OSHA requirements) to 30 ft/min.
- When compared with the halogenated solvent system, product quality has increased – the rejection rate was decreased from 6-7 percent to less than 1 percent.
- A total of 1,800 gallons per year of 1,1,1-tricholoroethane use was eliminated.

Cost

	Before	After*
Operating Costs	$17,600 for 1,1,1-tricholoroethane	$900 for soap, cartridge filters, membrane replacement
Capital Cost	NA	$20,000
Payback		1.2 years

* Note that savings associated with increased productivity are not included

[15] The University of Rhode Island Center for Pollution Prevention, *Pollution Prevention Technology Application Analysis Utilizing Membrane Filtration Technology*, April 2001.

Case Study - Werner Company[16]

The Werner Company manufactures fiberglass, aluminum, and wood climbing products. Their cleaning/deburring operation uses a large rotary machine and a small vibratory machine that both use the same cleaning agent. The overflow from these machines generated 1,500 gallons of wastewater per day that was discharged to the local POTW. The company had experience problems meeting its discharge limit for fats/oils/grease. The company installed one ultrafiltration unit to recover the cleaning agent, reduce water use, and eliminate the POTW discharge. The ultrafiltration system is equipped with eight tubular membranes with a total surface area of 17 square feet. The system operates continuously as part of the process.

Results

- cleaning chemical consumption cut from 183 gallons to 13 gallons per month - 93 percent
- water use cut from 1,500 to 15 gpd – 99 percent
- elimination of discharge to POTW
- fats/oil/grease reduced from 340 to 119 ppm
- TSS reduced from 562 to 6 ppm

Implementation Issues

- initially there were problems with the quality of the recycled cleaner due to interference by chemicals used in other processes upstream of the cleaning/deburring operation. The company evaluated the associated lubricants and chemicals and replaced many with more environmentally friendly options. This critical review and replacement reduced material usage and significantly cut fugitive VOC emissions at the facility.
- recycling of the cleaner has not created any issues with quality

Cost

	Before	After
Operating Costs	$23,000	$8,000
Capital Cost	NA	$42,000
Payback		2.8 years

[16] Illinois Waste Management and Research Center (WMRC) Fact Sheet, *In-Process Recycling of Deburring Solution Using Ultrafiltration*, TN01-077, June 2001.

Contacts for More Information

Resources and Vendors

Mention of any company, process, or product name should not be considered an endorsement by NEWMOA, NEWMOA member states, or U.S. EPA.

www.cleanersolutions.org: the website of the Massachusetts Toxics Use Reduction Institute (TURI) Surface Solutions Laboratory has extensive information on alternatives to solvent cleaning, particularly aqueous cleaning.

www.clean.rti.org: the Solvent Alternatives Guide (SAGE) website contains comprehensive pollution prevention information on solvent and process alternatives for parts cleaning and degreasing. SAGE does not recommend any ozone depleting chemicals. SAGE was developed by the Surface Cleaning Program at Research Triangle Institute in cooperation with the U.S. EPA Air Pollution Prevention and Control Division (APPCD).

www.industrialpartswashers.com is an on-line information resource contains web links to numerous vendors of parts cleaning technologies, many of which can provide closed-loop aqueous cleaning systems.

http://dmoz.org/Business/Industrial_Goods_and_Services/Machinery_and_Tools/Cleaning_Equipment/Parts_Cleaners/ is another on-line resource that contains web links to numerous vendors of parts cleaning technologies, many of which can provide closed-loop aqueous cleaning systems.

Suparator™ Thin Film Oil Separation Technology
Aqueous Recovery Resources, Inc. (ARR)
300 Adams Street
Bedford Hills, NY 10507
(914) 241-2827
www.suparator.com

State Technical Assistance Programs

In Connecticut: Kim Trella Department of Environmental Protection 79 Elm Street Hartford, CT 06106 (860) 424-3242	**In Maine:** Peter Cooke Department of Environmental Protection 17 State House Station Augusta, ME 04333 (207) 287-6188
In Massachusetts: John Raschko Office of Technical Assistance 251 Causeway Street, Suite 900 Boston, MA 02114 (617) 292-1093	**In Massachusetts**: Linda Benevides, STEP Program Executive Office of Environmental Affairs 251 Causeway Street Boston, MA 02108 (617) 626-1197
In New Hampshire: Paul Lockwood Department of Environmental Services 6 Hazen Drive Concord, NH 03301 (603) 271-2956	**In New Jersey:** Ruth Foster Department of Environmental Protection 401 East State Street, PO Box 423 Trenton, NJ 08625 (609) 292-3600
In New York: Dennis Lucia Department of Environmental Conservation 50 Wolf Road Albany, NY 12233 (518) 457-2553	**In Rhode Island:** Rich Girasole Department of Environmental Management 235 Promenade Street Providence, RI 02908 (401) 222-4700, ext. 4414
In Vermont: Greg Lutchko Department of Environmental Conservation 103 South Main Street Waterbury, VT 05671 (802) 241-3627	**At NEWMOA:** Jennifer Griffith NEWMOA 129 Portland Street, 6th Floor Boston, MA 02114 (617) 367-8558, ext. 303

The Northeast Waste Management Officials' Association (NEWMOA) is a nonprofit, nonpartisan interstates organization that addresses regional waste and pollution prevention issues. The membership is composed of state environmental agency directors of the hazardous waste, solid waste, waste site cleanup, pollution prevention and underground storage tank programs in Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont. NEWMOA provides a forum for increased communication and cooperation among the member states, a vehicle for the development of unified position on various issues and programs, and a source for research and training.