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CLOSED LOOP AQUEOUS CLEANING

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Closed Loop Aqueous Cleaning:

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TOXICS USE REDUCTION INSTITUTE

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1. INTRODUCTION

Traditionally, metal parts and electronics components were cleaned with chlorinated solvents. However, concern over the depletion of the ozone layer has led to a phase-out in the production of some of these solvents, while the use of others is being curtailed or eliminated due to adverse health effects. In an effort to efficiently clean parts and assemblies without the use of chlorinated solvents, companies are turning to aqueous cleaning. Filtration techniques to "close loop" the aqueous cleaning processes are being used to make these processes even more economical and environmentally friendly.

The following report serves as an introductory guide to closed loop aqueous cleaning. Section 2 provides the basics of aqueous cleaning, while section 3 presents the various components of closed loop systems. In section 4, necessary maintenance of closed loop systems is outlined. Section 5 discusses the economic viability of these systems. The Appendix provides detailed information about fifteen vendors of alkaline cleaner recovery units, which are the integral part of any closed loop aqueous cleaning system.

2. AQUEOUS CLEANING

2.1. AQUEOUS CLEANERS

In general terms, aqueous cleaning combines a water-based cleaning solution with mechanical cleaning action. In particular, alkaline cleaners are viewed as the most viable substitute for chlorinated solvents because they are capable of removing nearly any type of contaminant. Acid and neutral cleaners are also used for certain cleaning applications. Components of these cleaners may be divided into three general categories: surfactants, builders, and additives.

Surfactants are molecules which are preferentially absorbed at the water-hydrocarbon interfaces. They are comprised of both a hydrophilic (water-soluble) and lipophilic (oil-soluble) group, and may be classified as anionic or nonionic depending upon the charge of the hydrophilic group. Surfactant properties include wetting, emulsifying, dispersing, foaming, and anti-foaming.

Builders are inorganic alkaline salts which enhance the effects of the surfactants. Their functions may include saponification of fatty soils, control of water hardness and other ions, deflocculation of contaminants, and maintenance of cleaner alkalinity by providing both reserve alkalinity and buffering. Different types of builders include phosphates, carbonates, hydroxides, zeolites (crystalline hydrated aluminosilicates), and silicates, which also inhibit corrosion of ferrous substrates.

Additives, which may overlap builders in function, act primarily as contaminant dispersants, water softening agents, detergent fillers, and corrosion inhibitors. Examples include ethylenediaminetetraacetate (EDTA), amine compounds, and various polymers.

2.2. AQUEOUS CLEANING METHODS

The selection of the most appropriate aqueous cleaning method is dependent upon the nature of the contaminants and the desired level of cleanliness. Factors affecting the cleaning process include cleaning temperature and time, type of mechanical action, fixturing of the parts, and the cleaner concentration and additives. The three methods for providing mechanical energy are immersion, spray, and ultrasonic, operated in either a batch or continuous mode. In addition, all three methods may be designed to operate in a closed loop manner such that contaminants are removed from the process water. This allows for extended recycling and reuse of a given volume of both cleaning solution and rinse water in the aqueous cleaning system.

Immersion cleaning involves submerging the parts in a bath and providing mechanical agitation (air agitation, turbulation, brushing) as necessary to achieve the desired cleaning level. Spray cleaning uses a wash stream under pressure to provide a greater level of mechanical agitation, and thus a greater contaminant removal rate. This method is often more effective at removing contaminants from blind holes and crevices than immersion cleaning. Ultrasonic cleaning subjects an immersion cleaning tank to high frequency (40-100 kHz) sound waves, resulting in a phenomena known as cavitation. Cavitation results in the formation of tiny bubbles, which upon implosion impart very high levels of mechanical agitation on the parts. Ultrasonic energy enhances cleaning more than any other method. A trend in this type of "sonic" cleaning has been to go to even higher frequencies (800-900 kHz), especially in the manufacture of semiconductors. This method is referred to as megasonic cleaning.

Following cleaning, the parts may be rinsed with water. Rinsing is typically performed with a series of countercurrent cascading rinse tanks. The countercurrent configuration uses a series of rinse tanks, each one progressively "cleaner" than the one before. This configuration minimizes water use and insures that the final rinsing stage contains the "cleanest" rinse water. Large amounts of water may be wasted if closed loop rinsing systems are not employed.

After rinsing, the parts are dried. An exception is when the next step is aqueous based (e.g., plating, phosphating, or anodizing). In such cases, drying is sometimes omitted. Drying can be a very energy-intensive process, and it is in this stage that much of the cost associated with aqueous cleaning is incurred. Drying methods and devices include compressed air blow-off, infrared lamps, air circulating fans, ovens (air and vacuum), centrifuges, sawdust tumbling, cloth wiping, and solvent displacement. The last method, solvent displacement, involves immersing the wet part in a solvent that is immiscible with water.

2.3. CONTAMINANTS

Contaminants must be removed from parts and assemblies to prevent interference with further use or processing of the parts. Many of these contaminants can be removed using a mild alkaline cleaner in conjunction with some type of mechanical cleaning action. Once contaminants are removed from the parts, it may be desirable to remove them from the cleaning solution in order to extend the cleaning bath life. It is important to note that hydrocarbon oils may exist either in an emulsion within an aqueous solution due to the presence of surfactants, or as a separate phase (tramp oil). Tramp oils typically are suspended on the surface of the cleaner bath and can be removed from the bath simply by skimming. However, tramp oils may become temporarily dispersed within the bath through mechanical means. When this occurs, only the more elaborate separation techniques required for the removal of emulsified oils (such as membrane separation) will remove the dispersed tramp oils. Table 1 lists contaminants commonly encountered in metal and electronics cleaning[1].

Table 1. Common Contaminants of Metal and Electronic Parts

Metal Parts	Electronic Parts
hydrocarbon oils silicone oils organic solvent buffing compounds mold-release agents metallic complexes metal oxides trace metals particulates scale salts	resins rosins fluxes conductive residues particulates salts

3. CLOSED LOOP SYSTEMS

3.1. SEPARATION TECHNIQUES

As stated, closed loop aqueous cleaning involves the removal of contaminants from both the cleaner bath and the rinse water. In removing contaminants from the cleaner bath, the useful life of the cleaner is extended and the quantity of waste disposed is minimized. A variety of separation methods exist for removing contaminants from aqueous solution. Methods selected for a particular application are often chosen on the basis of contaminant size. Particulates may be removed using settling tanks, chip baskets, media filtration, or canister filters. Tramp oils are collected using skimmers and coalescers. The majority of the remaining contaminants can be removed using membrane filtration techniques (micro and ultrafiltration). Microfiltration uses a membrane with pore sizes in the range of 0.1 to 10 microns, while ultrafiltration pore sizes range from 0.001 to 0.1 microns. Ultrafiltration membrane pore sizes are also specified by molecular weight cut-offs (MWCOs). Contaminants with a diameter greater than the membrane MWCO will be rejected (i.e., "filtered out"). Both micro and ultrafiltration are pressure driven processes. Neither type of membrane will reject salts, which eventually may lead to elevated salt concentrations within the cleaner bath. High salt concentrations may adversely affect bath performance and make bath disposal necessary. Thus, it is important to monitor the salt content of both the recycled bath and the water used to create fresh baths. High salt concentrations in the rinse water is avoided through the use of other technologies (e.g., reverse osmosis and ion exchange).

Membrane filtration is suitable for use in a closed loop cleaning system for two major reasons. Experimental results indicate that the proper selection of membrane pore size for a particular cleaning chemistry can selectively remove bath contaminants (i.e., emulsified oil and other relatively large molecules), while simultaneously permitting the majority of cleaner components to pass through. Selection of the proper membrane pore size is reduced to a tradeoff between retention of emulsified oil and passage of cleaner components. In addition, membrane techniques utilize a crossflow configuration (see Figure 1) which splits the cleaner solution into an (almost) oil-free permeate stream and an oil-rich retentate (or reject) stream. In crossflow filtration, surface filtration (or seiving) rather than depth filtration is the dominant separation mechanism. With seiving, the membrane acts as a porous wall or barrier to bath contaminants, which are rejected based on their size. The crossflow configuration maximizes flow capacity and minimizes membrane fouling, allowing for the processing of high volumetric flowrates of contaminated cleaner solution and rinse water. Previously, this type of filtration was limited to lower temperature and neutral pH operation, but recent advances in membrane technology have extended operating ranges.

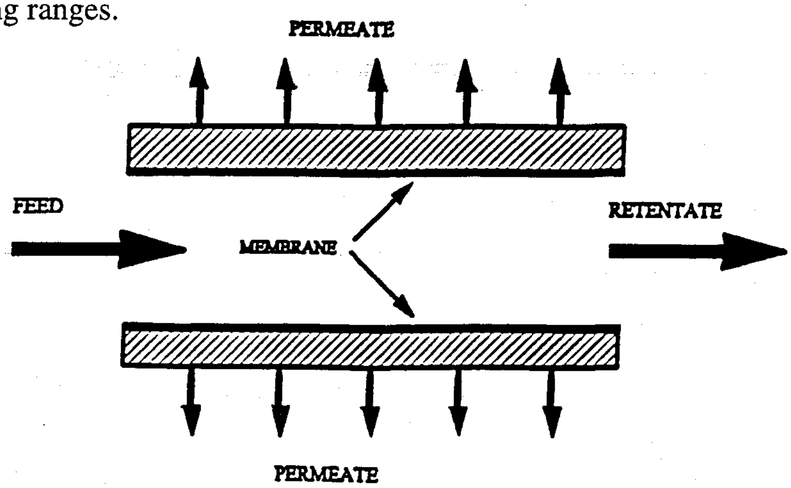

Figure 1. Schematic Representation of Crossflow Filtration

Closed loop rinsing systems are designed to purify rinse water to a level which leaves the rinsed parts able to meet company-specified cleanliness standards. Besides using particle, micro, and ultrafiltration, these systems may use reverse osmosis (RO). RO is able to remove all contaminants (including salts) from rinse water, but requires pressure driving forces much higher than those associated with micro and ultrafiltration. In addition, RO requires pretreatment of the rinse water by microfiltration to protect the RO membranes. Other separation methods include activated carbon, which is able to remove the majority of organic contaminants, and ion exchange, which uses specially designed resins to capture "undesirable" cations and anions (e.g. chlorine, heavy metals, calcium, and magnesium), exchanging them for hydrogen and hydroxide ions which then combine to form water. When spent, these resins are considered hazardous waste and must be shipped back to suppliers for regeneration.

3.2. MEMBRANE CONSTRUCTION

Microporous membranes are made from a variety of materials. Most commonly used for this particular application are ceramic and polymeric membranes. Ceramic membranes are usually constructed of zirconia or alumina oxide. Polymeric membranes used for closed loop systems are typically constructed of polyvinylidene fluoride (PVDF), polypropylene (PP), polyacrylonitrile (PAN), and cellulose-based polymers. Ceramic membranes are prepared by sintering (heating under pressure), while polymeric membranes may be formed by sintering, stretching, track etching (bombardment with nuclear particles and subsequent treatment with solvent), or phase inversion (precipitation of the membrane from solution using a nonsolvent). A fairly recent development is the carbon fiber-carbon composite membrane. Both the carbon and the ceramic membranes are able to tolerate wider pH ranges and higher temperatures than the polymeric membranes. This often makes them better suited for use in the recovery of aqueous cleaners since the cleaning is often performed at high temperature and pH conditions.

Polymeric membranes may be further classified as symmetric or asymmetric. Symmetric membranes have a fairly uniform pore diameter throughout the thickness of the membrane. Asymmetric membranes consist of a very thin selective "skin" layer deposited on a thick, highly porous substructure. Asymmetric membranes are highly selective, yet maintain high filtration rates because of their superior porosity. Thus, they are well-suited for use in micro and ultrafiltration.

Membranes are incorporated into module systems to optimize membrane surface area and feed flowrate. In this manner the maximum permeate flow through the surface area of the membrane (or flux) is achieved. The most common configurations used in closed loop cleaning membrane modules are tubular, spiral wound, and hollow fiber. Figure 2 illustrates the three types. Ceramic membranes are limited to the tubular configuration.

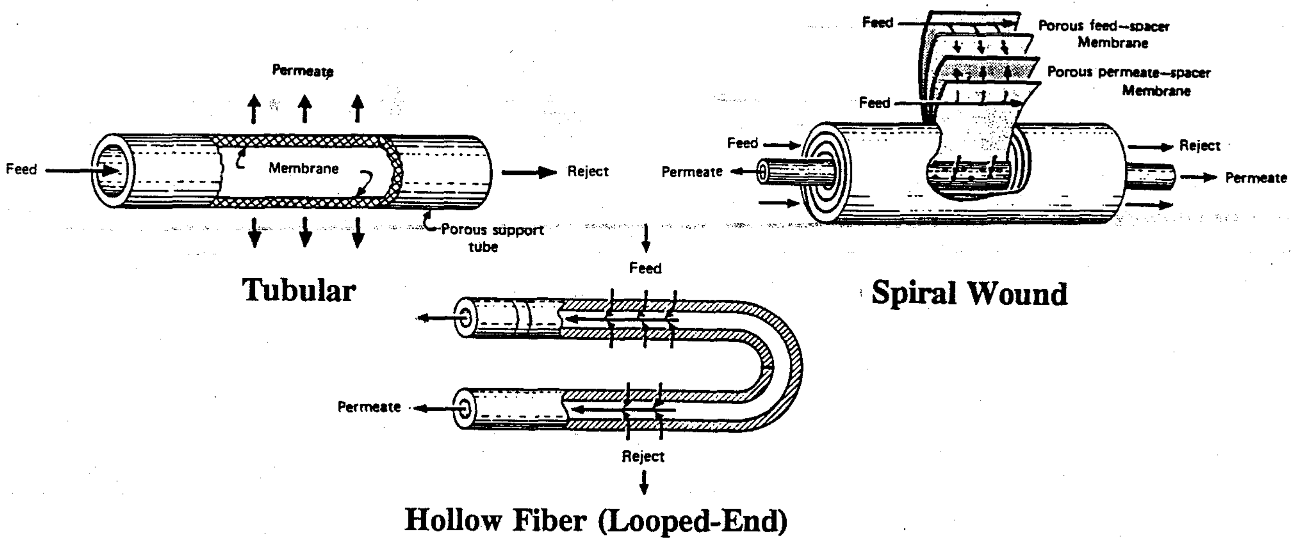

Figure 2. Membrane Configurations Used in Closed Loop Cleaning Membrane Modules[2]

3.3. SYSTEM DESIGN

A simplified closed loop aqueous cleaning system is shown in Figure 3. This configuration incorporates recycling for both the cleaner bath and rinse water. The parts are initially immersed in the cleaner bath. The contaminated cleaner solution is continuously pumped through a particulate filter to a process tank where tramp oils are skimmed. The solution is then passed through an ultrafiltration module, which removes emulsified oils and other contaminants. The permeate containing the cleaner components is recycled to the original cleaner bath, while the contaminant-laden retentate is sent back to the process tank.

The closed loop system for the rinse section is more extensive. Because the rinsed part must be left as clean as possible, the rinse water must be as free of contaminants as possible. To achieve this level of water purity, this loop incorporates coarse filtration, carbon adsorption, and ion exchange. The resulting rinse water contains no contaminants aside from small concentrations of salt. This closed loop rinse water configuration is well-established and results in the production of highly purified rinse water. Depending upon the particular requirements, this configuration can be modified to reduce capital costs.

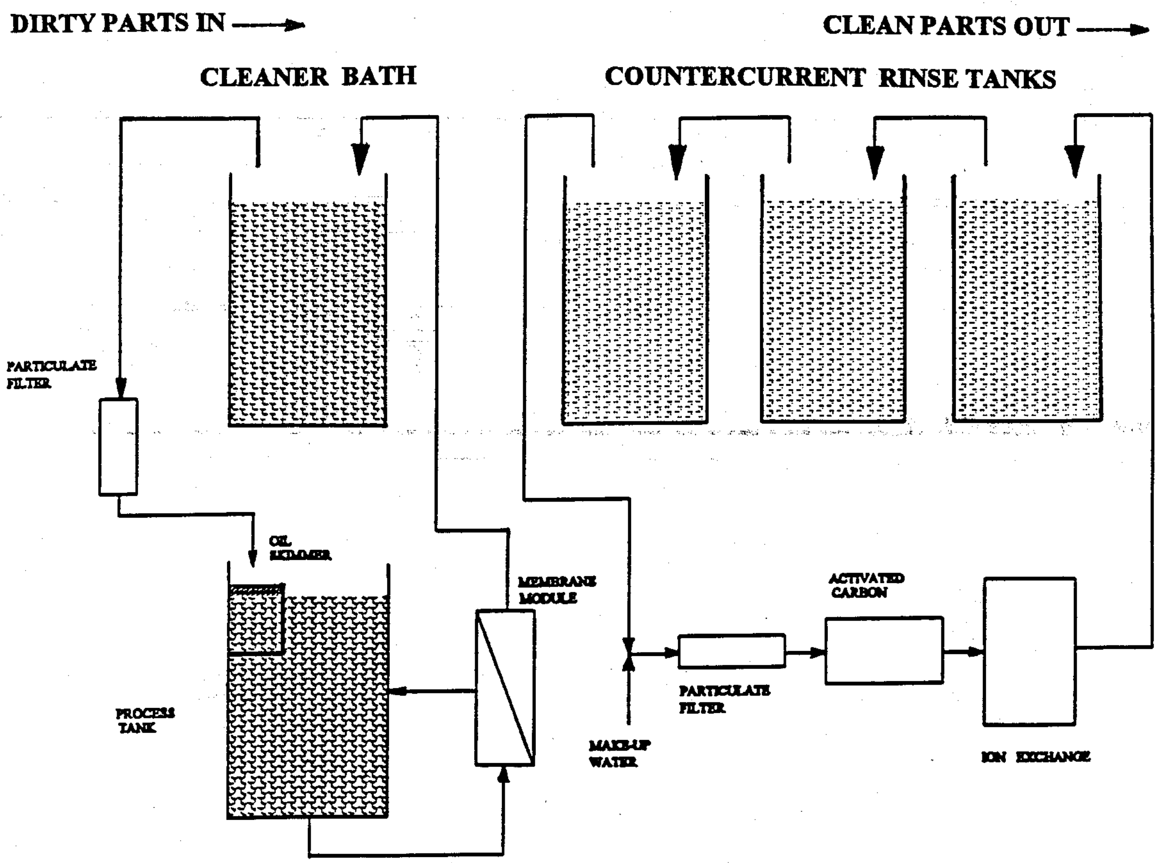

Figure 3. Simplified Closed Loop Aqueous Cleaning System

4. SYSTEM MAINTENANCE

The proper operation and cleaning of the membrane is essential for prolonging the life of the membrane and the reliable, predictable operation of the closed loop system. Crossflow filtration techniques depend upon a high flow rate to maintain turbulent flow through the filter module. Turbulent flow provides the agitation necessary to minimize (but not prevent) concentration polarization at the surface of the membrane. Concentration polarization is the tendency of the solutes to collect at the wall of the membrane, thus decreasing flux by increasing the osmotic pressure. A higher concentration at the wall also may lead to a lower membrane rejection rate and accelerated fouling. Fouling occurs through two different mechanisms, which may occur separately or in series. Fouling may be ascribed to a slowly consolidating gel layer at the membrane surface which acts as an additional semipermeable membrane, or to the adsorption of solute molecules onto pore walls within the membrane[3,4]. A hydrophilic membrane is more resistant to fouling by oily contaminants, and will maintain higher average flux rates.

Operators must be sure to clean the membranes as stipulated by an established maintenance schedule to prevent fouling and/or permanent damage to the membrane. Cleaning may need to be performed daily, weekly, or monthly, depending on the bath contaminant loading. A typical cleaning process includes purging the system of all contaminated cleaner bath, circulating a cleaning solution, removing this solution and flushing with water, testing the flux using fresh water, and finally bringing the system back into operation[5]. Strong acid and caustic solutions may also be used to clean ceramic and carbon membranes. Back-flushing can seriously damage many membranes, and should only be used in systems where it is designed as part of regular maintenance. Polymeric membranes should not be allowed to dry, as this can lead to permanent and irreversible fouling.

In addition to cleaning the membrane, the cleaner bath must also be maintained. Makeup water must be added to compensate for evaporative losses, and cleaner additive packages may need to be added to maintain acceptable cleaning bath performance. However, eventually the cleaner bath itself must be disposed. Reasons for bath disposal may be the buildup of salts and other contaminants within the bath or an unacceptable level of biological growth (and odor). Alternatives for handling the spent bath may include on-site waste treatment and disposal to drain, concentration by evaporation, or on-site batch treatment. Each of these alternatives require an outside hauler to transport and dispose of the resulting sludge. This sludge may be considered hazardous waste depending on its composition.

5. ASSOCIATED COSTS & SAVINGS

5.1. COST COMPARISON

Total capital costs and operating costs have been estimated for a variety of systems. From discussions with industry, D'Ruiz[6] estimated costs for four "typical" aqueous cleaning systems (see Table 2). These systems include varying degrees of "closed looping". Disposal costs are assumed for instances where the waste water must be treated as a hazardous waste. However, depending upon the capacity and complexity of the aqueous cleaning system, capital costs alone may exceed $200,000. Operating costs are comparable to those of a similar sized vapor degreaser[6].

The figures contained in Table 2 are generalized. They are intended only to introduce the major costs associated with a switch to aqueous cleaning. Following are case studies verifying the economic viability of implementing closed loop aqueous cleaning.

5.2. CASE STUDY #1 (Karrs and McMonagle)

Superior Plating, Inc. in Minneapolis compared the paybacks for the replacement of a 1,1,2-TCE vapor degreaser with an immersion aqueous cleaning system. The line originally cleaned 15,500 sq.ft. of plated surface per week. Without cleaning solution recovery, the payback period for the aqueous cleaning equipment based on operating savings ($13,288/yr) was 1.13 years. When a cleaner recovery system incorporating a ceramic filter was installed, the annual operating savings increased to $26,719. The payback period for the total system (immersion tank and recycler) was only 1.35 years.

Table 2. Annualized Aqueous Cleaning System Costs

Configuration	Capital & Operating*	Disposal**
manual roller conveyor immersion	$38,354	$24,000
small batch immersion	$40,247	$6,000
manual roller conveyor ultrasonic	$41,731	$39,600
conveyorized spray	$44,533	$20,000

* Original 1991 cost figures adjusted to 4th quarter 1994 cost using Marshall & Swift equipment cost index
** Assume $10 per gallon disposed[7]

5.3. CASE STUDY #2 (TURI)

H.C. Starck Inc. (HCST) of Newton, MA is a primary metals company which processes tantalum and niobium from the refining stage to the production of finished parts. HCST used 1,1,1-trichloroethane (TCA) in-house for part vapor degreasing, manual sheet cleaning, and as a full strength machining coolant. The mandated phase-out of TCA as an ozone-depleting substance in conjunction with the Labelling Law legislation prompted HCST to begin replacing TCA in 1993. TCA was replaced with oil-based lubricants for machining processes and alkaline cleaners and non-ozone depleting solvents for cleaning processes. Another major factor prompting the switch from TCA was the issue of worker health and safety. By implementing these alternative technologies, HCST has eliminated approximately 40,000 pounds per year of TCA. In addition, the use of ultrafiltration units (spiral wound and hollow fiber) on their cleaning lines has reduced their cleaner purchases from 6,000 pounds per year to 2,000 pounds per year. The payback period for the transition from TCA to the alternative technologies was approximately 9 months.

5.4. CASE STUDY #3 (TURI)

The PresMet Corporation of Worcester, MA manufactures a variety of powdered metals parts. Because of environmental concerns with the use of vapor degreasing, PresMet worked on developing an alternative cleaning method. In late 1990, they successfully implemented an aqueous-based cleaning system that eliminated the use of perchloroethylene (perc). In October 1994, as part of their continuous improvement activities, they purchased an ultrafiltration unit for the recovery and recycling of their aqueous cleaner. This cleaner is used primarily in part deburring as a lubricant and rust inhibitor, but also removes various contaminants. The closed loop cleaning system installed at PresMet processes their used plant water, and includes a settling tank, skimmer, centrifuge, and hollow fiber ultrafiltration unit. By implementing aqueous cleaning, PresMet has eliminated 24,000 pounds per year of perc. In addition, the use of the ultrafiltration unit has decreased annual cleaner expenditures from $60,000 to about $7,500 and the daily volume of deburring effluent discharged to drain from 2,000 gallons to about 75 gallons. The payback on the closed loop system is estimated at 2 years.

6. CONCLUSIONS

The current regulatory climate is causing both large and small companies to reconsider their current cleaning methods. Metal and electronics parts cleaning using chlorinated solvents is quickly becoming a thing of the past. And although some companies are awaiting a "drop-in" replacement for chlorinated solvents, a more practical alternative for most applications is a switch to aqueous cleaning. Many companies in Massachusetts have already converted to aqueous cleaning, and now are looking to further modernize and contain their cleaning process by implementing "closed looping".

Although many companies are using closed loop rinsing systems, only a few companies have implemented closed loop aqueous cleaning processes at this time. However, water use and discharge regulations will only continue to become more stringent, prompting companies to decrease their use of water through process improvements. Closed loop aqueous cleaning is a proven technology, found to be effective at further reducing waste volumes by both concentrating the sludge accumulated in the cleaning process and extending the life of the cleaner bath by an average of seven to ten times. In addition, annual operating costs associated with aqueous cleaning can be significantly reduced.

As stated, closed loop aqueous cleaning is a proven technology which can increase process efficiency and decrease the generation of waste. Many companies are coming to understand that the implementation of such systems should not be based solely on a short-term economic evaluation, but must also include environmental and regulatory considerations. By incorporating closed loop aqueous cleaning to reduce chemical use and waste generation, companies will position themselves at the forefront of both cleaning technology and current government regulations. In the long run, such a position will be more economically beneficial than trying to remain one step ahead of the ever evolving regulations surrounding parts cleaning.

When all the factors are weighed, the change to closed loop aqueous cleaning becomes a very attractive alternative.

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APPENDIX: Vendor Information

This appendix contains information intended to serve as a guide to assist industry in the selection of an alkaline cleaner recovery unit, which is an integral part of any closed loop cleaning system. Closed loop rinsing systems were not included because they are already well established within industry. The manufacturers included were chosen after reviews of advertisements in trade journals and discussions with membrane manufacturers. Initially, about twenty-five manufacturers were contacted for product line information. Eventually, the list of manufacturers was reduced to fifteen based on criteria established by TURI. These criteria included the separation techniques offered, number of successful installations for this particular application, and willingness to participate in the project.

The appendix includes an introductory page which defines abbreviations and a list of general facts and information concerning alkaline cleaner recovery systems. Following this page is a table listing manufacturer name, address, and phone number, the types of separation unit(s) offered by the manufacturer and their suggested operating ranges (pH and temperature), the flow capacities and sizes (volume or footprint) of various units, and generalized cost estimates for the listed units. The final page of the appendix lists additional information provided by the manufacturers.

Hopefully the information contained within this appendix, when combined with the associated technical report, will provide companies with enough background knowledge to understand the benefits of closed loop aqueous cleaning and lay the ground work in their search for an alkaline cleaner recovery unit.

ABBREVIATIONS AND ADDITIONAL NOTES

Abbreviation Key:

MF= microfiltration	UF=ultrafiltration
PVDF= polyvinylidene fluoride	PP= polypropylene
PAN= polyacrylonitrile	N/A= not available
CF-CC= carbon fiber-carbon composite	

Notes:

1. The information in the table represents the most commonly used system configurations. Many of the companies can offer additional technologies and flow capacities.

2. The life of polymeric membranes and their pH ranges are very temperature dependent (at higher temperatures, the expected life and range will typically decrease). The life of some ceramic membranes may be decreased by the use of silicated cleaners.

3. Expected membrane lives are 1-3 years for polymeric and up to 10 years for ceramic and carbon-based.

4. All of the companies offer extensive product support packages, which typically include pilot testing, warranty on parts and labor, user training, and continued technical support (phone and/or visiting staff). The installation and start-up is typically performed by the purchaser.

5. The price quotes are extremely generalized. For a more accurate cost estimate for your particular needs, please contact individual manufacturers.

6. All of the units are designed to retrofit into existing alkaline cleaning systems.

Table 3. Vendor Information

COMPANY NAME ADDRESS PHONE NUMBER	SEPARATION METHODS AND OPERATING RANGES	REPRESENTATIVE SYSTEM FLOWRATES AND DIMENSIONS IN FT. (volume or footprint)	REPRESENTATIVE SYSTEM COSTS
MANCHESTER CORP. P.O. Box 317 280 Ayer Rd. Harvard, MA 01451 508 772-2900	MF using tubular ceramic membranes pH range: 0-14 temp: <BP of cleaner bath	100 gpd: 4x4x4 8600 gpd: 4x4x9	\$5,000-\$10,000 \$80,000
WHEELABRATOR ENGINEERED SYSTEMS INC. -- MEMTEK 28 Cook St. Billerica, MA 01821 508 667-2828	MF using tubular PVDF and ceramic membranes pH range: 8-12(PVDF) / 0-14(ceramic) temp: <140F(PVDF) / <200F(ceramic)	720 gpd: 3.7x2.8x5.6	\$25,000
SEPARATION TECHNOLOGISTS 100 Griffin Brook Park Methuen, MA 01844 508 794-1170	UF using spiral wound PVDF, polysulfone, and polyamide membranes pH range: 1-13 @ 77F temp: <160F	100 gpd: 4x3x5 1000 gpd: 6x4x6 10000 gpd: 8x4x6	\$6,000-\$12,000 \$10,000-\$18,000 N/A
ECO RESOURCES INC. 25 Commercial Dr. Suite 7 Wrentham, MA 02093 508 384-1477	MF using tubular ceramic membranes pH range: 0-14 temp: <200F	1000 gpd: 3.3x2.0x5.1 2000 gpd: 6.1x2.2x6.7	low \$20,000's mid \$30,000's
KOCH MEMBRANE SYS. INC. 850 Main St. Wilmington, MA 01887 508 657-4250	UF using tubular PVDF and other polymeric membranes pH range: 2-10.5 @ 150F temp: <180F	50 gpd: 2 sq.ft. 1500 gpd: 15 sq.ft. 10000 gpd: 35 sq.ft.	\$3,500 \$28,000 \$100,000

COMPANY NAME ADDRESS PHONE NUMBER	SEPARATION METHODS AND OPERATING RANGES	REPRESENTATIVE SYSTEM FLOWRATES AND DIMENSIONS (ft.) (volume or footprint)	REPRESENTATIVE SYSTEM COSTS
MSC LIQUID FILTRATION CORP. 10 Dusthouse Rd. Enfield, CT 06082 203 749-8316	MF using tubular ceramic membranes pH range: 0-14 temp: <BP of cleaner bath	100 gpd: 3x3x6 500 gpd: 4x4x7 2000 gpd: 4x4x8	$7,000-$12,000 $13,000-$15,000 $30,000-$40,000
COMPLIANCE SYSTEMS, INC. 124 Heritage Ave. Portsmouth, NH 03801 603 436-2535	MF/UF using tubular CF-CC and ceramic membranes pH range: 0-14 temp: <BP of cleaner bath	100 gpd: 3x2x6 500 gpd: 3x3x6 1000 gpd: 4x3x6	$8,500 $16,000 $25,000
RINSEPURE TECHNOLOGIES, INC. 797 Danielson Pike N.Scituate, RI 02857 401 647-3692	UF using spiral wound PVDF membranes pH range: 4-11 temp: <140F	120 gpd: 1.5x1.5x4.2 500 gpd: 1.5x1.5x4.2	$3,650 $5,000
INFINITEX INC. P.O. Box 383 10100 Main St. Clarence, NY 14031 716 759-6983	UF using spiral wound PVDF and other polymeric membranes pH range: 2-11 @ 135F temp: <165F	55 gpd: 1.7x0.8x1.7 150 gpd: 1.8x1.5x3.3 250 gpd: 1.8x1.5x3.3 3000 gpd: 5.0x5.0x6.0	$4,000 $5,800 $9,000 $47,000
MEMBREX, INC. 155 Route 46 West Fairfield, NJ 07004 201 575-8388	UF using spiral wound UltraFilic® PAN membranes MF/UF using tubular ceramic membranes pH range: 2-13(PAN) / 0-14(ceramic) temp: <170F(PAN) / <200F(ceramic)	300 gpd: 1.5x1.0x3.0 4500 gpd: 6.8x3.0x4.3 50000 gpd: 20.0x7.3x8.9	N/A N/A N/A

COMPANY NAME ADDRESS PHONE NUMBER	SEPARATION METHODS AND OPERATING RANGES	REPRESENTATIVE SYSTEM FLOWRATES AND DIMENSIONS (ft.) (volume or footprint)	REPRESENTATIVE SYSTEM COSTS
TREATMENT PRODUCTS CORP. P.O. Box 444 Thorndale, PA 19372 610 269-5324	MF using tubular PP membranes UF using tubular PVDF membranes pH range: 0-14(PP) / 7-12(PVDF) temp: <160F(PP) / <120F(PVDF)	700 gpd: 5.6x1.5x6.0(MF) 5.5x2.0x7.0(UF) 5000 gpd: 16.0x2.0x6.5(MF) 14.0x4.0x8.0(UF)	$10,000 $10,000 $40,000 $40,000
U.S. FILTER CORP. 181 Thorn Hill Rd. Warrendale, PA 15086 412 772-0044	MF/UF using tubular ceramic membranes pH range: 0-14 temp: <BP of cleaner bath	150 gpd: 3.8x3.0x5.1 1000 gpd: 4.8x3.0x6.3 10000 gpd: 6.7x4.0x8.7	$19,000 $29,200 $115,000
SEPARATION DYNAMICS INT'L, LTD. 23801 Industrial Park Dr. Studio Center Farmington Hills, MI 48335 810 478-7910	diffusion using hollow fiber cellulose membranes pH range: 5-11 temp: <190F	250 gpd: 15 sq.ft. 3000 gpd: 24 sq.ft. 50000 gpd: 100 sq.ft.	$15,000 $25,000 N/A
UNITECH INDUSTRIAL INC. P.O. Box 330 16 South Ave. Wappingers Falls, NY 12590 800 277-5522	hydromechanical pH range: 0-14 temp: <BP of cleaner bath	1500 gpd: 16 sq.ft. 140000 gpd:120 sq.ft.	$7,500 $70,000
ALFA LAVAL SEPARATION INC. 955 Mearns Rd. Warminster, PA 18974 215 443-4030	centrifuge pH range: 2-14 temp: <BP of cleaner bath	100 gpd: 2x2x2 5000 gpd: 6x6x6 30000 gpd: 10x10x10	$15,000 $80,000 $150,000

ADDITIONAL INFORMATION PROVIDED BY THE COMPANIES

Manchester Corp.: Have almost 20 years of experience in wastewater treatment and recycling

Wheelabrator Engineered Systems Inc. -- Memtek: Offer 3 year warranty on PVDF membranes; stainless steel construction

Separation Technologists: 1994 EPA Award for "Leadership in Closed-Loop Water Recycling"

ECO Resources Inc.: Equipment rental program available

Koch Membrane Systems Inc.: Pioneer in membrane separations with over 25 years of experience

MSC Liquid Filtration Corp.: Specialize in manufacture of smaller systems (<1000 gpd)

Compliance Systems, Inc.: Offer exclusive two year performance guarantee

Rinsepure Technologies, Inc.: Specialize in manufacture of small systems (<500 gpd)

Infinitex Inc.: Smaller systems offer superior portability

Membrex, Inc.: Offer patented Ultrafilic® hydrophilic polymeric membranes which are highly resistant to fouling by oils

Treatment Products Corp.: Offer "try-buy" agreement: If within 30 days unit does not perform as promised, can return it

U.S. Filter Corp.: Hold U.S. patent for use of ceramic membranes for recycling aqueous cleaners

Separation Dynamics Int'l, Ltd.: Offer Extran™ system based on exclusive cellulose membrane technology

Unitech Industrial Inc.: Bring experience from European markets; no moving parts in separator

Alfa Laval Separation Inc.: Larger company provides excellent product support; does not incorporate membrane technology