Making Decisions about Water and Wastewater for Aqueous Operation

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Chapter 2.17
Handbook for Critical Cleaning
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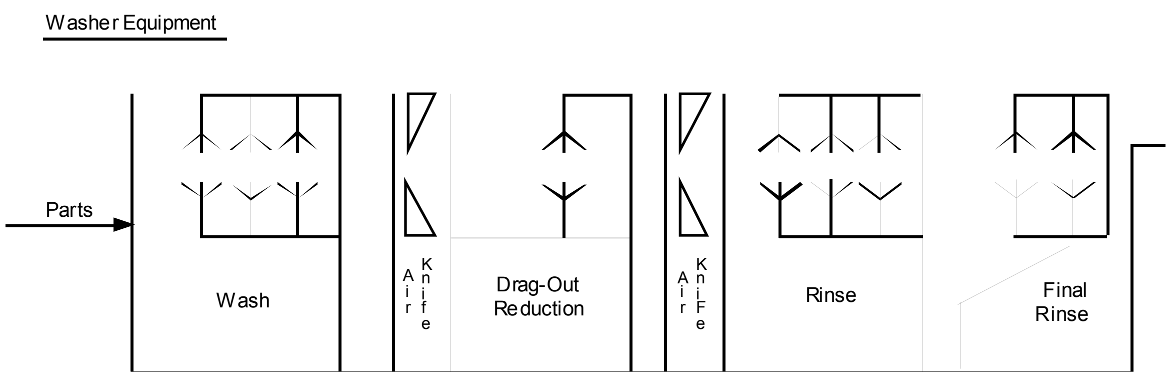
INTRODUCTION

Water is the essential liquid in aqueous cleaning processes. Purity of the water is an integral part of the cleaning process. With water, one must be concerned about the condition of the water at each stage of the process to finish with a usable product. Also of concern is the condition of the water at the end of the process, i.e., the wastewater. This chapter discusses water purification and conditioning techniques both for the cleaning process itself and for the wastewater. In many cases, the wastewater from one stage of an operation is the source water for another stage. It is notable that discussions of water source treatment processes are often integrated with those from wastewater since, in many cases, the principles and techniques are the same.

Usually this subject is discussed by describing several general water treatment systems. But the author has decided to take the user's viewpoint to make this chapter a more usable reference. Even with minimal knowledge of water processes, the reader can refer to the section "Operational Situations of a Typical User," review the specific area of interest, and devise a plan of action.

As new technologies are introduced, users have more options in source water and wastewater treatment than ever before. This adds to the complexity of decision making, especially if the most cost-effective solution is necessary. Typical water treatment terms are defined and various water processes are explained and compared. The main objective of this chapter is to introduce new users to the water treatment field and to serve as a quick, easy-to-use reference guide for experienced users

Fig. 1 Conveyorized Washer Schematic



Note: The above schematic represents a conveyorized washer. It can also be visualized as a multistage cabinet washer where all of the parts remain stationary and are subjected to each cleaning step or a dip tank cleaning process where the parts are moved manually or automatically from one cleaning step to another.

TYPICAL CLEANING SYSTEM

Essentially all cleaning operations use one or more of the sequence of operations shown in Figure 1 (washer only). The schematic shows a parts washing unit where The parts move along a conveyor to different stages of washing, rinsing, and drying. Also, this same schematic can be visualized as a cabinet washer in which the parts remain stationary while they are subjected to one or more of the same cleaning stages as in a conveyorized washer. Many of the following discussions apply to this schematic.

OPERATIONAL SITUATIONS OF TYPICAL USER

There are seven general, operational situation considerations:

1. Determining the water purity requirement
2. Determining the wastewater volume produced
3. Source water treatment
4. No-wastewater discharge options
5. Wastewater discharge options
6. Determining the wastewater treatment for a new process
7. Overcapacity of the current wastewater treatment system

In most cases, a user may have to consider more than one of the above situations. The first two are the most critical and greatly affect the others. It is not unusual for minor differences in conditions between one user and another to have a major impact on a user's final decision.

Determining the Water Purity Requirements

In some cases, determining the water purity requirements is not easy and some investigation is necessary. Information from trade associations, competitors, or related processes is helpful. If these sources are inadequate, the user may have to experiment on a small scale or make the determination during the actual production process. The latter decision has a downside risk of too many part failures. The user may then have to rent a system on short notice to reduce the failure rate. In certain cases, purchasing new equipment with a vendor buyback if the equipment is later found to be unnecessary is a good option.

Measuring Water Purity

In many applications the user must be concerned about measuring those characteristics of source water (tap water) from a lake, river, well, or from wastewater that affect the quality of the parts being cleaned. In the great majority of cases, two characteristics are measured: undissolved and dissolved contaminants.

Undissolved Contaminants

Undissolved contaminants are contaminants in water that do not affect its electrical properties. These contaminants can be measured by different methods, depending upon specific requirements, and any or none of these might have to be monitored. Fat, oil, grease (FOG) measurements are used to determine whether a user complies with the discharge regulations of municipal sewer districts, called publicly owned treatment works (POTWs).

Total suspended solids (TSS) is a measure usually of the amount of suspended particles with sizes over 0.45 µm. Fat, oil, grease (FOG) is a measure of any compound (vegetable or animal fats, petroleum and synthetic oils, lubricants and some sulfur compounds) extracted by a fat-soluble solvent.

Dissolved Contaminants

Dissolved contaminants such as ionic compounds including sodium chloride, calcium carbonate, and many others that form ions in water, are measured by a total dissolved solids (TDS), conductivity, or resistivity meter. Dissolved contaminants such as sugar, starches, and other water-solubilizing organic compounds are not ionic, do not conduct an electrical current, and are not detected by electrical measurements. These measurements are not usually used by POTWs to determine compliance with discharge regulations but can interfere with some cleaning processes if not detected and removed.

Typically, measurement of dissolved contaminants is made with a TDS meter to make a quick approximation of the capacity of ion-exchange resins and reject capability of nanofilter and reverse osmosis (RO) membranes. The readings are in ppm (parts per million) of ions in water. Each meter manufacturer might use a different algorithm to convert the electrical measurement to a TDS reading so it is possible that different meters might give different results. Without this measurement, a user would need a complete water analysis, which is time-consuming and expensive. Such an analysis is done primarily when a high degree of accuracy is required.

The higher the dissolved ionic content of the water, the higher the conductivity. Source water (tap water) typically has a conductivity from 40 to 1000 µS/cm. A conductivity meter is the measurement instrument of choice for water typically above about 10µS/cm. Conductivity readings of about 1 µS/cm are near the limit of accuracy for this type of measurement.

For a conductivity meter to be useful as a TDS meter, the conductivity reading has to be converted to an approximate amount (ppm) of ions in the water. The conversion factor (0.4 to 0.6) was determined by averaging the readings calculated from a complete water analysis of many samples of well, river, or lake water supplies throughout the United States. For wastewater, which may contain ions that differ substantially from natural water supplies, this conversion range might be less accurate. For simplicity, all TDS readings used in this chapter are determined by multiplying the conductivity readings by a conversion factor of 0.5 (e.g., a conductivity of 1000 µS corresponds to approximately 500 ppm of TDS).

Undissolved and Dissolved Contaminants

There are several measurements that are made on water for both undissolved and dissolved contaminants.

Total organic carbon (TOC) is a measure of the total amount of oxidizable organic matter (oxidized by ultraviolet radiation).

Biological oxygen demand (BOD) is a measure of the amount of oxygen that bacteria need to oxidize biodegradable organic matter over a given period of time.

Chemical oxygen demand (COD) is a measure of the amount of oxygen required to oxidize reducing compounds such as sulfides, salts of metals, etc. and organic compounds into carbon dioxide and water.

TOC measurements are usually used for critical high-purity water applications. BOD and COD measurements are usually used to determine whether a user complies with discharge regulations of POTWs.

Other Conditions

pH is a measure of the acidity, neutrality, or basicity of water and is expressed as the negative log of the hydrogen ion concentration, or -log $[H^+]$. A pH reading below 7 is an acid condition, 7 is a neutral condition, and above 7 is a basic condition. The pH of source (tap) water for certain wash chemical preparations and of rinse water in certain applications can be very important.

Determining the Wastewater Volume Produced

Determining the amount of wastewater produced by a cleaning process is very important because it has a major influence on the user's strategy and decision making. For example, for small volumes, cleaning processes generating less than about 25 to 75 gals/week, it is probably best to haul away the wastewater unless there is an existing treatment system. Depending upon the cost, some form of evaporation, like solar evaporation, might be less expensive. A determination of whether the wastewater is hazardous or not is required to comply with federal, state, and local regulations. Hauling a hazardous waste can cost as much as $1000/55-gal drum, whereas for a nonhazardous waste the cost it can be less than $50/55-gal drum. For large volumes, other wastewater reuse processes should be employed and are discussed in later sections.

Source Water Treatment

All aqueous processes require a minimum initial charge of water from a well, river, lake, or a transported supply of water (bottled or from a tanker truck). Many operations might need a continuous supply. Typically, a closed-loop system uses the lowest amount of makeup water, while a cleaning process without any water reuse requires the largest amount of water.

There are five typical options in general order of decreasing amounts of suspended solids and dissolved minerals:

1. No treatment
2. Mechanical, adsorptive and oxidation
3. Water softening
4. Reverse osmosis (RO)
5. Deionization (DI)

There are exceptions to this ranking, for example, a water supply with no treatment could be as good as another water supply that is softened. In some cases, a source water could be even better than river water treated with RO, if the criterion is ionic content. Also, the amount of particles passing through an RO is far less than from DI, but the ionic content from DI can be far less than RO.

No Treatment

In some cases the source (tap) water is of sufficient quality that no treatment is necessary If a water purity specification is not available, the required purity might be determined by testing on a small or a pilot production scale. If a pilot scale is not practical, it may be necessary to go to a full production scale with a backup plan to treat the source water as quickly as possible should this option prove to be insufficient.

Removal by Mechanical Filters, Adsorptive Filters, and an Oxidation Method

Mechanical filters depend on a physical barrier for contamination removal. Adsorptive filters use large surface areas to remove contamination. An oxidation method uses oxygen to convert dissolved ions into particles that are removed mechanically.

Mechanical Filters

Mechanical filtration is one of the most common methods used to remove particles from water and wastewater in cleaning processes. They are ranked from coarse to fine removal with some overlap of removal capability of one method with another. See Table 2 for a chart of the different types of contaminants and the separation technology used to remove each one.

Granular media filters are composed of single media or multimedia with various grades of sand and other minerals, used primarily to remove suspended particles from 20 to 40 μm (micrometers or microns) in size, but can remove finer particles as well. As a reference point, a grain of table salt is about 125 *μm*. *Bag filters* are manufactured from felt like materials both woven and nonwoven and typically have a higher contaminant loading and a lower cost per pound of contamination removal than cartridge filters. *Cartridge filters* are commonly used filters made from a wide variety of plastic and natural fibers, such as polypropylene and cotton, in a large variety of designs such as molded, fiber wound, and pleated papers.

Generally, cartridge filters are most often used for lower flow rates and higher-efficiency applications, whereas bag filters are used for lower-efficiency and high flow rate applications. For high-flow-rate and high-volume applications, granular filters are most often used first, then frequently followed by the other two methods.

Membrane filters are manufactured from a variety of plastic and inorganic materials with different shapes (flat sheets, tubes, spiral wound tubes). They are designed to remove very small particles and organic molecules from a liquid stream. Microfilters (MFs) are rated at about 0.05 to 1.0 μm. Ultrafilters (UFs) essentially remove all particles and molecules from about 10,000 to 1,000,000 Da (daltons, unit of measurement for molecular weight) from water.

There is neither an industry-wide micrometer rating that demarcates microfilters and ultrafilters nor an industry-wide filtration efficiency rating standard. So it is not uncommon for a microfilter from one manufacturer to be called an ultrafilter by another manufacturer. To compare one membrane with another, a user must determine from the manufacturer the test method for the rating. This rating problem can be extreme, for example, a membrane manufactured from a plastic material, such as polysulfone, polypropylene, or nylon, rated at 0.2 Am can reject 99.9999%+ of all bacteria, whereas a ceramic membrane with the same rating may have a far lower removal efficiency.

Neither of these types of membranes removes ions from water, but they do remove colloids and other high-molecular-weight ; substances such as surfactants. Microfilter membranes have holes and are coarser than ultrafilters, and both are used to recycle wash chemicals (alkaline cleaners). Ultrafilter membranes do not have physical holes and are even more effective than microfilters in removing large organic molecules and low-molecular-weight petroleum products.

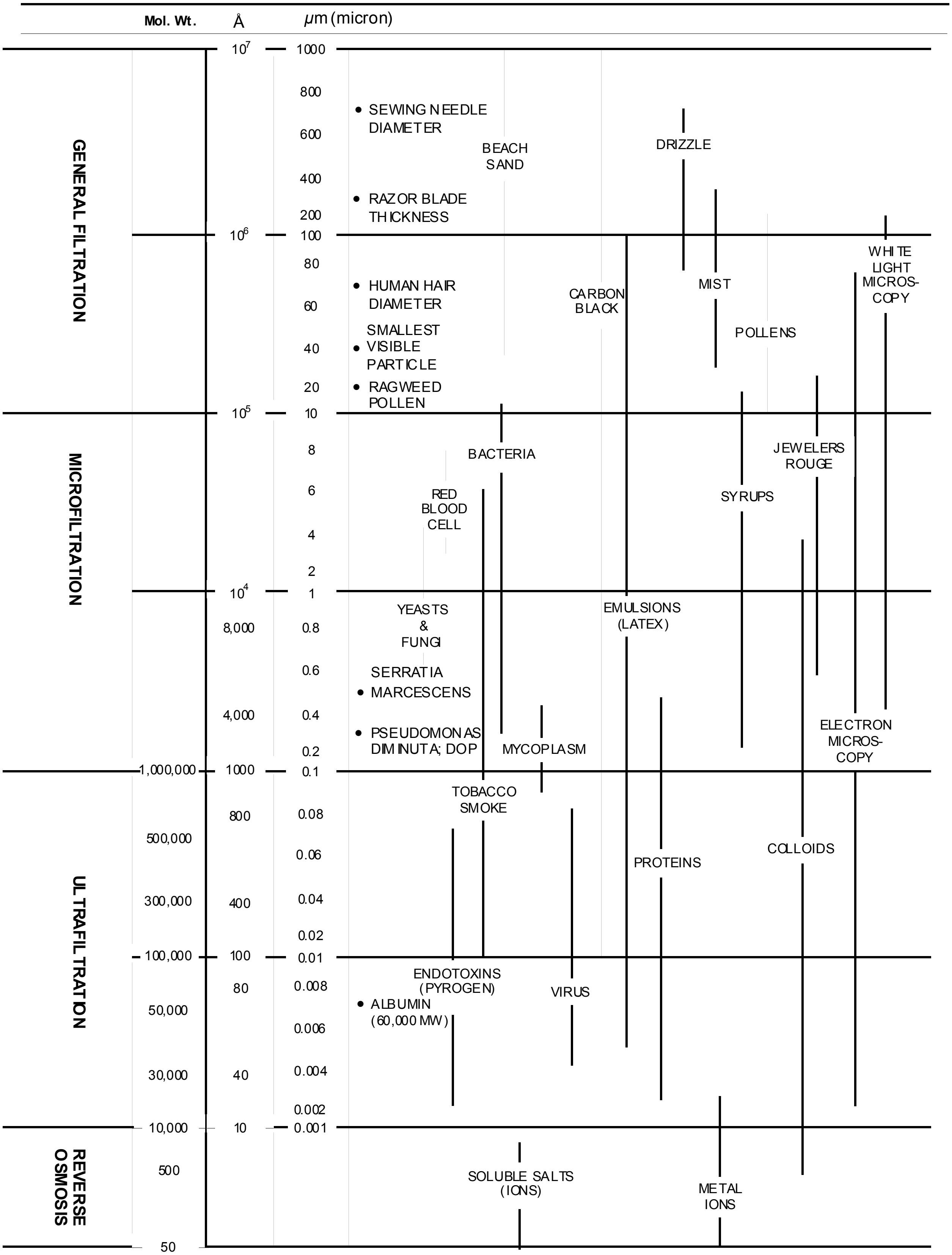
Adsorptive Filters

Activated carbon is a granular medium made by heating carbon-containing materials, such as coal, coconut shells, and similar substances, in the absence of air, producing a porous material with a large surface area. This large surface area allows the attachment of large organic molecules. Typically, it is used as a pretreatment method to remove chlorine and long-chained organic molecules prior to ion-exchange resins and some RO systems. It acts as a catalyst to eliminate the oxidizing power of the chemicals by reducing them to other ions. It is also used to remove low levels of oil and grease (petroleum and synthetic) products.

Oxidation Method

Oxidation is a chemical process that changes the state of the dissolved species, such as iron or manganese, to a particulate form that is removed by mechanical filtration. This is an important pretreatment process before RO or ion-exchange resins for iron- and manganese-bearing water. Oxidation is sometimes used alone to treat water just before a cleaning process. The oxidation is achieved by a chemical or air.

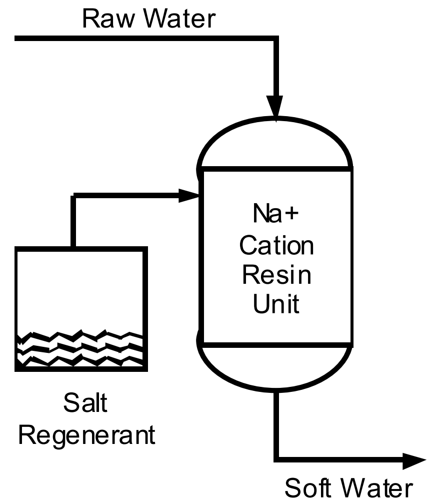
Table 2 Relative Size of Small Particles



Differential pressure increases with reduced micron ratings; dirt-holding capacity and relative flow rates decrease with reduced micron ratings. A, Angstrom = 10 ecm; lum, micrometer (micron)=10' A; 1 mil = 0.001 in. _ 25.4 μm.
Note: Nanofilters, a newer technology, is between reverse osmosis and ultrafiltration.

Source: Gelman Sciences, Ann Arbor, MI, ©1987.

Fig. 2 Water Softener



Water Softening

Water softening is a process of removing hardness minerals such as calcium and magnesium cations from water without reducing the TDS content of the water. The key component of a water softener is the *ion-exchange resin* contained inside a tank. The tank can have manual or automatic controls to regenerate the ion-exchange resin (Figure 2).
Ion-exchange resin is manufactured from polystyrene that is cross-linked with divinylbenzene. It consists of small plastic spheres about the size of the head of a common pin. The resin has positively charged sodium cations held on the resin surfaces by electrostatic charges. The sodium cations are exchanged for cations of calcium, magnesium, and dissolved iron in the water. Once all of the sodium cations are exchanged, the resin is exhausted. It must be replaced with new resin or be regenerated (reversing the process) by flowing concentrated sodium chloride brine through the resin during a multistage process, performed manually or automatically, within the tank. Even though ions are being exchanged for other ions, there is essentially no change in the TDS of the water as measured by a conductivity or TDS meter.

Water Softener Capacity Calculation

Water treatment chemists can predict the probable number of gallons of soft water a water softener will produce. For example, the "ppm" (expressed as $CaCO_3$) of the water has to be converted to grains per gallon because most ion-exchange resins are rated on the basis of grains expressed as $CaCO_3/ft^3$. The term "grain" is an old unit of weight measurement, originally referring to grains of wheat, and is used in the water industry. There are 7000 grains per pound and 1 gr/gal = 17.1 ppm. To convert a reading, for example, 100 ppm of hardness to grains/gal of hardness, the following proportion is used:

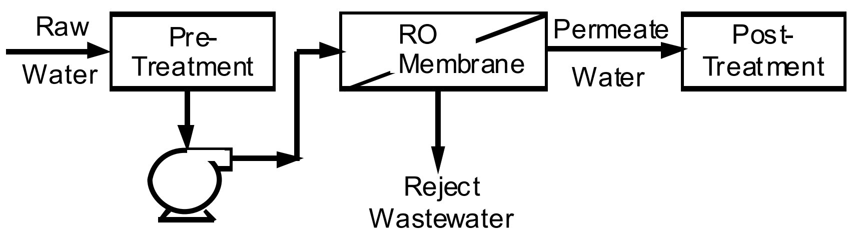
$$\frac{1\ \text{gr/gal}}{17.1\ \text{ppm}} \qquad \frac{X}{100\ \text{ppm}} \qquad X = 5.8\ \text{gr/gal}$$

Most water softeners with cation resin have a capacity of about 30,000 gr (expressed as $CaCO_3/ft^3$) of resin. If water supply has a total hardness of 5.8 gr/gal, a user can expect a softener with 1 ft' of cation resin to produce close to 5172 gal/ft^3 (30,000 gr/ft3 - 5.8 gr/gal = 5172 gal) of soft water before the cation resin has to be regenerated again. There are factors such as regenerant concentration, iron fouling of the resin, and others that can significantly influence the actual capacity of the resin.

Dissolved Solids and Ionic Removal

The most common industrial processes used for reducing dissolved solids and ions in water are *deionization* (DI) and *reverse osmosis (RO). Nanofiltration (NF),* a membrane process very similar to RO, can remove dissolved solids and ions to a much lesser extent, and is used in far fewer applications than RO. While RO removes dissolved solids and ions down to about 200 Da, NF removes down to about 300 Da. *Distilled water is* not as economical to use unless it is purchased in low volumes. *Electrodeionization,* a newer ion-exchange process, produces high-purity water of less than about 0.4 ppm (>1 Mfl-cm resistivity) as sodium chloride without the use of chemical regeneration.

Fig. 3 Single-Pass RO



Reverse Osmosis Process

RO is a membrane process that removes essentially all particles, and most molecules and ions about 200 Da and larger from water. RO (Figure 3) is a process in which a pump is used to force water through a membrane barrier to produce water with a lower dissolved solids content. The key component of an RO unit is the membrane, which is made from a thin film of plastic, most often in the form of a spiral or "jelly roll." Membranes vary in size from 2 in. diameter X 10 in. long up to about 12 in. diameter and about 5 ft long. Water pressure up to 1000 lb/in^2 forces water through the membrane. A complete RO system can consist of a pretreatment stage using mechanical filter (cartridge or multimedia filter), adsorptive media (activated carbon), and/or antiscaling (chemical, pH treatment, water softening), a high-pressure pump, RO membrane, storage tank (optional), and post-treatment (ultraviolet light, repressurization pump, and deionization). The selection of these processes depends upon a source water analysis and the specific objectives of the user. A double-pass RO is an RO followed by another RO.

The RO membrane separates the water into two streams: contaminants into a reject stream (wastewater to a sewer) and lower-ionic-content water into a permeate stream (usable for process). About 25 to 85% of the total water in a single-pass RO becomes a reject stream containing all of the contaminants. Therefore, 15 to 75% of all source water becomes permeate water ready for use in the process. This percentage range is the practical limit for a single-pass RO and the actual percentage depends upon the RO design and a water analysis.

The membrane removes essentially all particles including microorganisms and rejects 70 to 99+% of the dissolved solids and ions down to about 200 Da. It rejects essentially the same percentage of ions whether the incoming stream has thousands or hundreds of parts per million of dissolved solids. For example, if the TDS of the wastewater to the RO doubles, the TDS of the permeate water will about double, and if ion-exchange is used as posttreatment after the RO, the ion-exchange cost will about double. The ionic weight, shape, and amount of the charge determine the degree of rejection.

The water purity of the permeate (usable) water typically ranges from 50,000 to 600,000 fl-cm and can be estimated with a source water analysis. As the membrane ages, its ability to reject dissolved solids decreases, resulting in a practical life of the membrane of about 3 years. Higher-purity water, which has a lower TDS and higher resistivity, can be attained with a double-pass RO (replacing the single-pass RO), DI, or electrodeionization of the RO product water being required. DI or electrodeionization is necessary as a post-treatment process to RO whenever the user requires a higher water purity than 1 MΩ-cm resistivity.

Deionization Process

DI is a process using ion-exchange resin to remove ionized solids (cations and anions) from water. The key component of a DI unit is the ion-exchange resin. A two-bed deionizer consists of two tanks in series: a tank with cation resin followed by a tank with anion. The cation resin is the same as the resin 'used in a water softener except that it has hydrogen cations instead of sodium cations on the functional groups of the ion-exchange resin. Another type of deionizer, a mixed-bed, has both cation and anion resins intimately mixed in one tank.

There are three basic deionizer designs:

1. Two-bed
2. Mixed-bed
3. Tri-bed (two-bed followed by a mixed-bed)

Usually there are three basic operating options:

1. Disposable resin
2. Regenerable resin (rental or owned)
3. On-site regenerable deionizers

For the disposable resin option, the resin is used once and discarded. For the rental or owned resin option, the user rents or owns the tanks with resin and the vendor takes the exhausted tanks back to its facility and regenerates the resins with strong acid and caustic chemicals. For the on-site regenerable deionizer option, the resins are regenerated inside the tanks with the same chemicals used in the rental or owned tank option, but the user might have to treat the wastewater produced by the regeneration process for pH and/or heavy metals.

When resin is regenerated repeatedly, its capacity to remove ions after each regeneration decreases. The rate of this decrease depends upon a number of variables, such as the type and amount of foulants, oxidizing power of the contaminants, temperature, and other factors in the water. The capacity decrease rate is usually greater for wastewater applications than for source water (tap water) treatment.

With the disposable and rental or owned tank options, there is no waste stream to treat at the user's facility since the contaminants are held on the resin beads. An RO system, by comparison, always has a wastewater stream that goes to a sewer. This is the key reason resin systems lend themselves more easily to closed-loop treatment, whereas membrane systems generally do not.

Occasionally, DI is referred to as *demineralization,* an older term used infrequently today. Technically, deionized water is any water treated by a deionizer from which dissolved solids are removed and the water resistivity increases. There is no specific water purity measurement that defines the term *deionized.* DI removes ions, positively charged cations and negatively charged anions, from water using ion-exchange resins in the hydrogen and hydroxyl form. Even though RO removes dissolved solids similar to DI and often can produce similar water with resistivity below 1 MΩ-cm, it is not referred to as deionized water, but RO water.

Ion-exchange resins have specific capacities, that is, the ability to remove ions from a given number of gallons of water and it is inversely proportional to the TDS of the water. For example, if tripling the TDS, the capacity of the resin will be decreased to about one third of its capacity. If the TDS is too high, the cost of replacing or regenerating the resin can be uneconomical.

Table 3 Types of Deionizer Designs vs. Water Characteristics

Water Characteristics	Type of Deionizer Design			
	Two-Bed Weak Base	Two-Bed Strong Base	Mixed-Beds[a]	Tri-Bed
Purity (MΩ-cm)[b]	0.02-0.6	0.1-0.9	**1.0-18.2**	(see previous column "Mixed-Bed")
pH	6 or lower	8.0+	5.5-8.5	
Carbon dioxide and silica removal	No	Yes	Yes	
BOD and COD reduction		Essentially none		

[a] A mixed-bed followed by one or more mixed-bed tanks is used when (1) a polisher is necessary to remove residual ions that might get through only one mixed-bed tank and when 18.2 MΩ-cm water purity (highest water purity available) is required and (2) added capacity is required; the higher the water purity, the closer the pH is to 7.0

bThese are typical ranges for each process.

Source: Otten, G., American Laboratory, July 1972.

Sometimes the only way to make deionization economical is to use an RO membrane as pretreatment for the deionizer (discussed below with closed-loop systems). The type of ions, ionic charge, and the concentration of each ion can affect the capacity of the resin differently.

Mixed-bed ion-exchange resin has a nominal capacity of approximately 10,000 grains/ft^3 to an end point of 1 MΩ- cm resistivity. The actual capacity of the resin depends upon a number of factors such as amount of chemical used to regenerate the resin, the type and concentration of each ion in the water, the amount and type of foulants in the water, the flow rate, the cross-sectional area of the resin surface in the tank, the depth of the resin in the tank, and the temperature of the water.

For a two-bed deionizer, the resin capacity is calculated from the capacity of the cation and anion resin. The cation resin has a nominal capacity of 30,000 grains/ft^3 and a strong base anion resin at about 20,000 grains/ft'. A weak-base anion resin (another option) has a capacity 50 to 100% greater than a strong base because it does not remove dissolved carbon dioxide and silica.

Table 3 shows the key differences between the performance of four types of deionization systems.

DI or RO or Both

Generally, DI is

- Preferred when wastewater has a TDS less than about 100 ppm because operating costs are lower;
- Required when higher water purity is needed than an RO alone can produce;
- Able to maintain the same water purity even if the feed water quality varies substantially;
- A simpler system to operate for low-flow-rate applications using rental tanks.

Generally, RO is

- Preferred when wastewater has a TDS above about 100 ppm because operating costs are lower;

- Preferred when lower water purity is required, unless low flow rates are used;
- Not able to maintain the same water purity if the feed water quality varies substantially unless DI post-treatment is used;
- A more complicated system to operate for low-flow-rate applications.

Even though these reasons are typical for choosing DI or RO, there are exceptions:

- Even though the initial cost of an RO system and its operating costs are significantly higher than DI in a low-TDS case, the capability of an RO system to remove microorganisms and other fine particles might be more desirable.
- The required use of strong acids and caustics when using a regenerable unit at the user's site may be too hazardous.
- Even though RO may be preferable in a higher-TDS application, the simplicity of renting a DI system with minimal operating costs may be preferred.

In summary, both of these technologies are used together whenever the water purity required is higher than an RO can produce and the TDS of the wastewater is too high to make DI alone cost-effective. When comparing closed-loop and zero-discharge wastewater 'treatment systems, it is important to consider that RO always has a reject stream, whereas DI might have a wastewater stream.

Other Methods

The following methods have limited use in providing high-purity water for cleaning Operations.

- *Distillation is* a process that heats water until it vaporizes and condenses into water with a purity up to about 1 MΩ-cm. Distillation is capable of removing dissolved and undissolved minerals and some organics, but is not generally used for industrial water purification of tap water. As compared with RO and DI, it has a higher operational cost because it is an energy-intensive process. However, it is an inexpensive source for low-volume applications if purchased in bottled quantities. Using bottled water is an economical way of testing what water purity is required by a cleaning process.
- *Electrodeionization is* an ion-exchange process that uses an electrical current on a membrane barrier embedded with ion-exchange resin. This process, usually requiring pretreatment of a source water with a membrane process like RO, can increase the resistivity of the water purity to 1 MΩ-cm and as high as 15+ MΩcm. This is a newer technology primarily used to eliminate safety hazards from using strong acids and caustics when regenerating mixed-bed deionizers on site. Flow rates can range from low to high volume.

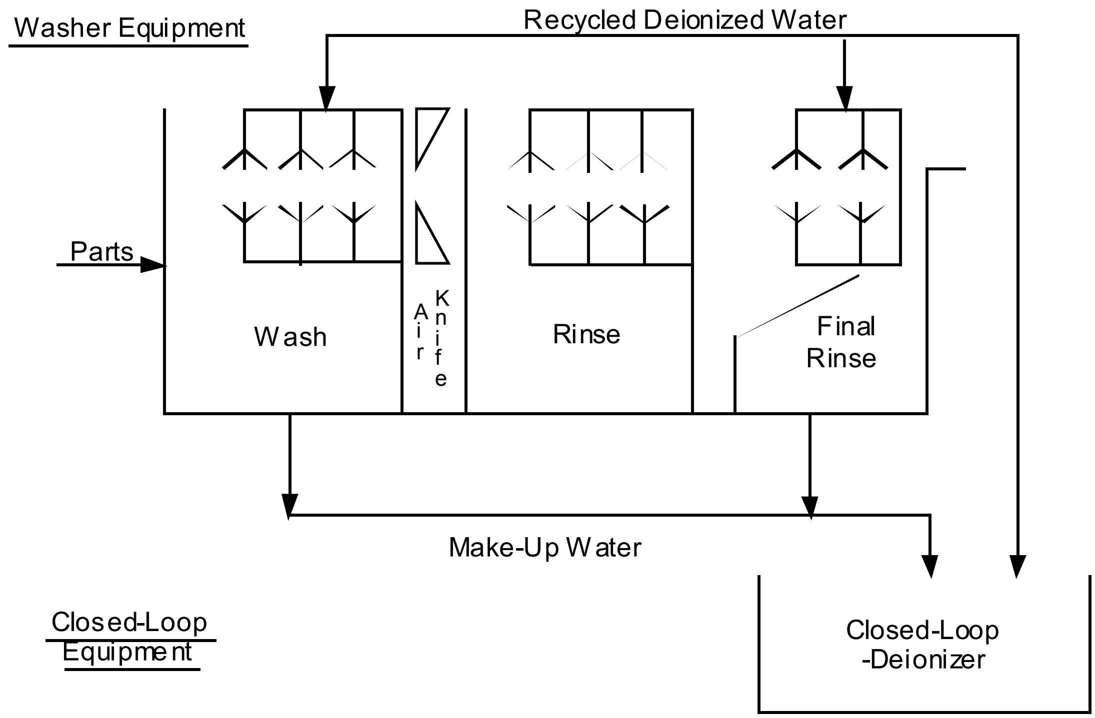
No-Wastewater-Discharge Options

The key to any "no-wastewater-discharge" option is the reuse of the wastewater. Sometimes wastewater from one application can be considered as acceptable source water for another process. Cascade counterflow rinses are used very often and are a good example of wastewater reuse in the same process. In this method, the purest water is used to rinse at the end of the process and the wastewater, flows opposite to the parts being cleaned as it cascades to the previous step in the process. As many as four cascade rinses are not unusual. Each time the wastewater is reused, the overall cost of water for the process decreases as compared with using new water for each rinse stage.

A user may decide not to discharge any wastewater because:

- There is a desire or policy to reduce the chance of future liability for contamination.
- The local community prohibits discharge of any industrial wastewater.
- There is a high cost of monitoring contamination to a septic system and/or a pro
- hibitive cost of possible future remediation of the groundwater.
- There is uncertainty of water availability.

Fig. 4 Washer and Closed-Loop Wastewater System Interface Schematic



Closed-Loop Method

A closed-loop process can be defined as a wastewater treatment process that has no wastewater discharged to a sewer, with the wastewater recycled to the same or another process. A closed-loop is not easily attained, but for some processes it is the most cost-effective, ideal solution.

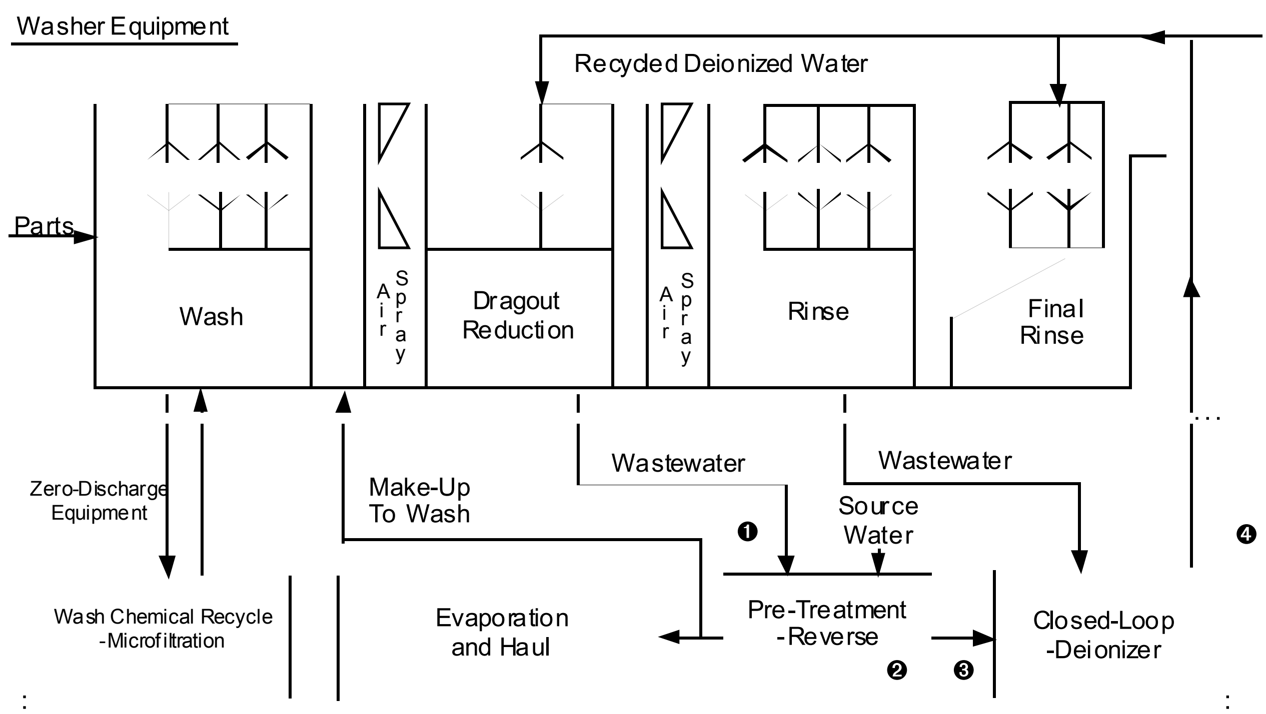
This is the design standard for the electronics assembly cleaning industry (see Figure 4). In this application, the capital cost for a closed-loop system is about 20% more than a non-closed-loop system that discharges all the wastewater to a sewer. However, the operating cost for a closed-loop system is usually so favorable that it has a positive operating cash flow. The low TDS, below about 20 ppm, is the key to making this process economical. The lower the TDS, the greater the return on the user's investment. For many non-electronic-assembly applications, the capital cost difference might be similar but the operating cost for a closed-loop may be prohibitive because of the high dissolved solids in the wastewater.

Several aspects of the electronics assembly application might be applicable to other user applications. In this application, a manufacturer takes printed circuit boards, inserts a variety of electronic devices on the boards, fluxes the boards, and then solders the devices onto the board. The flux might be left as is on the board or sometimes is removed with either source water or DI water and the wastewater discharged to a sewer or treated with a closed-loop system. This closed-loop process accomplishes the following:

- No water pollution (no wash or rinse water goes down the drain)
- No wastewater tests, permits, inspections, and reports
- Reduction of energy and water usage by at least 90%
- Essential elimination of the continuous need for water
- Water purity ranging from low to high depending upon the process requirements
- Solid waste contaminants that are not hazardous except in unusual cases
- Wastewater converted to hot, deionized water
- Wastewater that can be recycled indefinitely
- Pretreatment of water performed by equipment

The typical electronics assembly closed-loop design uses a combination of particulate removal, organic removal media, and ionic removal media to allow the water to be completely reused. Water purity levels start at 15 MO-cm and higher and, as the contaminants accumulate on the ion-exchange resin, the water purity decreases to the minimum acceptable water purity. This process operates economically whenever the water purity is allowed to decrease to about 1 Mfl-cm. However, the operating costs would be about half as much if the water purity were allowed to decrease to 1000 to 20,000 S2-cm. This latter design has the highest potential positive cash flow as compared with a non-closed-loop system. Once the particulate, granular organic, and ionic removal media are exhausted, the solid waste generated is usually nonhazardous, according to the federal Toxic Characteristic Leaching Procedure (TCLP) test.

Figure. 5 Washer and Zero-Discharge Wastewater System Interface Schematic



Zero-Wastewater-Discharge Method

Even though the closed-loop process is the ideal process because it has the greatest probability of yielding the largest return on investment, it can be used only in limited applications. For applications where it is not feasible, a zero-discharge method can be used. This design allows no wastewater to be discharged to the drain and uses a combination of microfiltration and reverse osmosis membrane, ion-exchange (closed-loop), and evaporation. When comparing this design with a closed-loop recycling, the additional capital equipment is about double and it is more expensive to operate than a closed-loop system.

Figure 5 shows a possible zero-discharge design that represents the cleaning stages of a typical conveyorized or batch-type cleaner (parts remain stationary). In this design, the wash chemical might be recycled with a microfiltration membrane system. Most often, the final rinse water from the same cleaning process cannot be recycled economically in an ionexchange closed-loop system because of the excessive TDS, usually above about 75 ppm. This is caused by the dragout from the wash tank. If the same ion-exchange closed-loop process discussed above were used, a pretreatment method such as RO would be required; otherwise, the operating costs would be prohibitive. The following paragraphs describe in detail each part of the zero-discharge design and evaluate the user's decision-making factors, starting with the chemical wash (alkaline) stage, from left to right.

Wash Chemical

There are three methods of handling the wash chemical: hauling, evaporation, and recycling.

If the wastewater is not hazardous, it can be *hauled by* a standard commercial vehicle. If it is hazardous, it must be manifested to an authorized facility. This might be used as a temporary measure until other solutions are implemented.

Evaporation may be an alternative, when hauling large volumes of wash chemical is not appropriate and recycling is not cost-effective. The user has more cost-effective options for treating wastewater from a low-volume than a high-volume application. For example, in cleaning processes producing less than about 75 gal/week of wastewater, it is more costeffective to haul the wastewater unless there is an existing wastewater treatment system. For large volumes of wastewater, the hauling option is not usually cost-effective.

Evaporation is an energy-intensive process and the cost of the energy must be considered. It is a method of separating a liquid. from its solids typically by heating the liquid (gas, electricity, solar energy) or by using a vacuum distillation unit. This can greatly reduce the amount of wastewater to be disposed of by 70 to 95%. If there are other processes in a plant producing excess energy, or if solar energy is available, evaporation can be economical for large volumes. After evaporating the volatiles, the remaining contaminant might become a solid waste containing hazardous metals or have a high pH, which makes it a hazardous waste.

For some of these processes, the vapors might be regulated and a permit might be required. The water vapor from any of these evaporative devices might have a distilled water quality (100,000 to 700,000 Ω-cm resistivity) that can be reused in the process. However, in most instances, the cost of condensing the water vapor is greater than treating the source water.

It is noteworthy that the cost of hauling and evaporation usually is not significantly affected by the concentration of dissolved minerals or hazardous metals in the wastewater. In addition to evaporating the spent wash chemical, an evaporator can treat the reject wastewater stream from an RO membrane in the next stage of the treatment process.

Membrane recycling is a relatively new treatment process. As mentioned earlier, all membrane processes have a wastewater reject stream containing all contaminants in a concentrated form that usually goes to a sewer. However, some processes, like membrane recycling of wash chemicals, can reuse the reject stream in a closed-loop manner. When membrane recycling of wash chemicals is used, the contaminants are continuously concentrated and eventually must be processed or disposed.

This membrane recycle process uses microfilters or ultrafilters and permits the reuse of a chemical cleaner by allowing most of it to pass through the membrane, while at the same time removing the fine particles and emulsified oils. The term *oil* refers generically to both petroleum and synthetic products that are oils, greases, lubricants, and similar products. This separation process is imperfect and sometimes some or many of the key ingredients of the cleaner are removed. The critical balance of this membrane recycling process is to achieve the separation of the oil from the wash chemical while not removing too many of the key ingredients of the chemical cleaner. Even in the best-balanced process, some chemical cleaner is removed and the critical ingredients might be replaced periodically with small amounts of additional chemical. Experience from operating such systems has shown that the life of a chemical cleaner can be extended from three to ten times.

There are multiple benefits from this process, including increased life of wash chemical with resulting less chemical consumption, less water used, lower hauling costs, and less labor and downtime. There can also be an increased consistency of wash chemical with a much lower average concentration of emulsified oil and a much lower average particulate level.

Table 4 Zero-Discharge-Wastewater System Designs Using Different TDSs of Wastewater to Produce Low- and High-Purity Rinse Water

Sampling Point	1 TDS of Wastewater[a] (ppm)	2 Pretreatment Equipment	3 Resistivity of Water after Pretreatment(Ω-cm)	4 Resistivity of Final Rinse Water (Ω -cm)
Case A: Low-purity rinse water	Up to about 5000	(1) Single-pass RO (2) Double-pass RO	(1) About 62,000[b] (2) About 900,000	No DI closed-loop; same as column 3
Case B: Low- and high-purity rinse water	Less than about 20	None	Same as column 1	After a DI closed loop, from 1000 to 5,000,000
Case C: High-purity rinse water	Up to about 5000	Dragout reduction[c] With either (1) single-pass RO or (2) double-pass RO	(1) About 30,000 (2) About 1,000,000	After a DI closed loop (1) 15,000,000 (2) 15,000,000

Note: The water sampling points for 1, 2, 3, and 4, are shown in Table 5.

[a]TDS of the wastewater going to drain from the wash chemical tank (excluding wash chemical) and is the wastewater treated by next column. The conversion from TDS (ppm) to conductivity is 0.5 (as calcium carbonate) = 1 μS/cm.

[b]1f 98% reduction is used for the second RO, the calculated resistivity would be 3 M11-cm (3,000,000 fl-cm). However, the water purity is sensitive to any dissolved solids, which can most likely reduce the resistivity to below 1 Mfl-cm.

[c]RO rejecting 98% of the TDS was used for these calculations. The percentage may as high as 99% but not for all dissolved solids. Dragout refers to mechanical methods used to reduce the amount of dissolved solids going to the next process. The dragout could be a prerinse section in the in-line cleaner, or a time delay between two dip tanks to allow drainage of the parts or other similar method.

A user's ability to achieve these benefits depends on a careful evaluation of tt process and suppliers of the cleaning chemical, parts cleaner, membrane u oil/lubricant/grease contaminants.

Once a user is convinced recycling might be cost-effective, a demonstration test shnould be performed on the wash chemical to determine its recyclability and the cleanliness of the recycled product. This would be followed by a pilot test at the user's facility to corroborate the benefits of recycling. Sometimes, other chemicals and micrometer-rated membranes are required to achieve optimum results.

Rinse Water

After the parts are washed, the next step in the cleaning process is rinsing. There are several possible methods to treat the wastewater depending upon the volume of wastewater produced. The designation of a low- and high-volume application is arbitrary, and there can be a large overlap between the two in actual applications.

Hauling (even with evaporation) is usually not economical for processes producing thousands of gallons of rinse wastewater daily. To make hauling cost-effective, reuse methods like RO can reduce the amount of wastewater requiring further treatment by up to about 75%. The RO can provide the additional benefit of treating the source water to make up for any water losses from drying parts or the reject wastewater from the RO.

The last consideration for a zero-discharge-wastewater design is the effect on the design by the user's requirement for either a low- or high-purity rinse water. Low- and high-purity water are arbitrary terms that can have a wide range of meanings depending upon the user industry. For this discussion, water with a resistivity below 1 MΩ-cm is considered low purity and water above 1 MlΩ-cm is considered high purity. RO as pretreatment is required to attain both levels of water purity, unless the TDS is 20 ppm or lower. For low-purity rinse water, a single-pass RO might produce the required water purity. For a high-purity rinse water, a dragout reduction step plus a single-pass RO, or double-pass RO, might be required before a final rinse DI closed loop.

The amount of pretreatment depends upon the TDS of the wastewater being dragged out from the wash chemical tank by the parts being cleaned, racks, conveyor, and other handling equipment used in a dip tank operation, conveyorized in-line cleaner, or a cabinet washer. As a first step for any type of cleaning process, it is important to orient the parts to allow more time to drain off the wash chemical. These pretreatment methods will assure a lower operating cost for a closed-loop system if used to polish the water up to 15.0 MΩ-cm and higher. Table 4 provides a guideline for the kind of pretreatment equipment and the expected water purity for the final rinse. As shown, the lower the TDS of the wastewater, the less extensive the pretreatment equipment required.

Case A: Depending upon the TDS of the wastewater before the RO and the water purity requirement, a single-pass RO alone might achieve a user's goal for a low-purity-water rinse (below 1 MΩ-cm). If the water purity is not sufficient, a double-pass RO will produce a higher water purity than a single-pass RO. To achieve a zero-wastewater-discharge system, the reject wastewater stream from either RO process is hauled or evaporated and hauled.

Case B: As discussed above, no pretreatment is required for the economical operation of a zero-discharge wastewater system if the TDS of the wastewater is below about 20 ppm just before a final rinse DI closed-loop. The key difference between operating a closed-loop system for a low (below 1 MΩ-cm) and high (above 1 MΩ-cm) water purity application is that for a low-purity application the water purity is allowed to degrade to a resistivity of about 1000 to 20,000 Ω-cm, which is about the range of the purity of source water through-out the United States. The control of this process can be accomplished simply with a conductivity or TDS meter. When the maximum conductivity or TDS allowed by the process is reached, the ion-exchange resin is replaced. This reduces the operating costs of the system by one half to one third compared with a high-purity application. For a high-purity application, the higher the minimum water purity required by the process, the higher the operating cost, because the ion-exchange media will have to be replaced more frequently. For some applications, high-purity water may be too corrosive to the parts being cleaned, especially steel, galvanized, or brass parts. A DI closed-loop process produces only granular media disposed of or regenerated at a vendor's plant. The different operating conditions of this closed-loop process might compare more favorably to hauling whenever RO is used.

Case C: When the wastewater TDS of the stream feeding the RO membrane is about 5000, the RO is followed by a final rinse DI closed-loop with a dragout reduction before the RO to reduce the TDS. Dragout reduction refers to mechanical methods used to reduce the amount of contamination dragged out of a wash chemical tank going to the next process. Its purpose is to concentrate the dragout from the wash chemical tank into the smallest volume of water possible to minimize the size of the RO. For an in-line cleaner, the dragout reduction step is usually a prerinse.

For a dip tank, the amount of dragout can be controlled by letting the wash chemical drain from the parts into the wash tank before going to the rinse tank, a brief rinse spray, or by using a still rinse tank of water (even source water might be adequate). For a conveyorized cleaner, a good design is air spray the parts and conveyor belt to blow off excess wash chemical before it enters the dragout reduction step that has a water spray and follow with another air spray to blow off excess water. For the cabinet washer without a conveyor, the most practical way is to let the parts drain off excess wash chemical and, if necessary, have one or more short rinses with a drain-out step.

After the dragout reduction step, the next TDS reduction process is the RO. A doublepass RO without dragout reduction might be an alternative to a dragout reduction with a single-pass RO. To determine which alternative is most cost-effective, compare the cost of installing a dragout reduction in a washer along with a single-pass RO and evaporating the RO reject wastewater with the cost of using a double-pass RO without dragout reduction in a washer and evaporating the RO reject wastewater. The additional benefit of a doublepass RO is that there is a higher probability of achieving a higher water purity that might eliminate the need for a final rinse DI closed-loop.

If the wastewater to the RO has significant amounts of oil or surfactants, the life of the RO membrane can be reduced. To protect the RO, pretreatment such as activated carbon or bag filters for low oil concentration applications or an ultrafilter (UF) or microfilter (MF) membrane for higher concentrations can be used. The activated carbon does not have a reject stream creating more wastewater to handle while a OF or MF membrane process does. There are low-challenge applications for which a OF or MF membrane can be used as a dead-end unit (without any reject stream) and taken off line and cleaned periodically.

In summary, low-purity (below 1 MΩ-cm) rinse water is sufficient for some applications. A single-pass or double-pass RO is adequate to produce this purity. But for higher purity (above 1 MΩ-cm) rinse water, the amount of wastewater treatment depends upon the TDS of the wastewater and the required resistivity of the final rinse water.

For low-TDS wastewater, no pretreatment is necessary before a DI closed-loop that produces a high-purity-water final rinse. For high-TDS wastewater, pretreatment before the final rinse DI closed-loop is required. The dragout wastewater from a wash tank along with the rinse wastewater might be recycled through a single RO or double-pass RO. In other cases, a dragout reduction step prior to the RO may be a better choice to achieve the required water purity. If a dragout reduction step followed by a single-pass RO does not achieve the desired water purity, a double-pass RO might provide the additional removal of the dissolved solids. For high-purity-water requirements above about 1 M(-cm for the final rinse, a DI closed-loop may be necessary.

Wastewater Discharge Options

Federal, state, and local regulations determine a user's program of action for which of the contaminants and how much of the contaminants to treat. Each user must comply with the federal regulations at a minimum. After this requirement, the state regulations, which may be the same or even more stringent than the federal, must be followed. Finally, the local community regulations, which must be as restrictive as the state and federal regulations at a minimum, might be still more stringent. Local compliance issues can vary greatly throughout the United States. It is very important for any user planning to discharge any industrial wastewater to obtain a permit from the local regulatory agency, a POTW). Even though the wastewater is in compliance with the discharge regulations, discharges from small batch-type cleaners, like a household dishwasher, are considered industrial wastewater discharges subject to permitting before any discharge is allowed.

In the past, the testing point usually was the end of the sewer pipe from the building. However, in increasingly more states, the wastewater is tested in the building at the source of discharge as it comes from the equipment. This makes compliance more difficult.

The typical regulation requirements pertain to FOG, pH, BOD, and COD, and heavy metals. General treatment methods will be discussed for each of these conditions.

Fat, Oil, and Grease

Most POTWs regulate the amount of these three contaminants in wastewater. These contaminants come from petroleum and synthetic compounds from the parts being cleaned. The ability to remove them depends on numerous factors and conditions, including the condition of oil (free, dispersed, chemically or physically emulsified), temperature, amount removed per unit of time, types of petroleum and synthetic compounds, amount of TSS and TDS, available space, maintenance, and other operating conditions.

There are a number of removal methods selected on the basis of the specific application. *Membranes,* both MF and UF remove contaminants by preventing them from penetrating the membrane and allowing water to pass through. *Dissolved air flotation* (DAF) uses air that attaches to free or dispersed oil and facilitates its rise to the surface of the wastewater for easy removal. Chemicals are often used to enhance the process efficiency. *Chemical precipitation* causes separation of the contaminants by precipitation.

Centrifugation spins the wastewater at high velocities, forcing the heavier particles and high-molecular-weight compounds to separate from lighter molecules or particles. A *coalescer is* a device constructed of materials that allows the adherence of very small droplets of contaminants that grow in size and are released to the surface of the water. An *oil skimmer* includes a belt, disk, or other mechanical device or other methods such as a thinfilm technology to remove contaminants from the surface of the wastewater. *A decanter* (gravity separator) allows the separation to the surface of contaminants lighter than water, which then, under low turbulence conditions, spill over a weir into a waste container.

The following guideline shows an approximate order for the effectiveness of each process according to its ability to remove petroleum and synthetic compounds from wastewater.

- Membranes (most effective)
- -UF
- -MF
- Dissolved air flotation
- Chemical precipitation
- Centrifugation
- Coalescers
- Oil skimmers
- Decanters (least effective)

pH

Typically, the wash tank of a cleaning operation contains an alkaline cleaner with a pH higher than the local discharge limit. This condition can be corrected by using an acid pH chemical control system. When there are regulated hazardous metals, the user must comply with the federal, state, and local regulations when disposing of the waste. Treatment of hazardous metals is discussed below.

Biological Oxygen Demand and Chemical Oxygen Demand

BOD is a test method that uses microorganisms to determine the amount of oxygen required to oxidize organic contaminants in water. COD is a test that uses a chemical oxidant to determine indirectly the amount of oxygen required to oxidize both organic and inorganic contaminants in water.

Sometimes, state and local. regulatory agencies have limits for BOD and COD. The removal methods for petroleum and synthetic contaminants may achieve sufficient reduction of these two measurements to meet these discharge limits. However, BOD and COD not only measure these contaminants, but also other oxidizable compounds that the FOG test does not.

A packaged biological wastewater treatment system reduces the BOD levels to meet the discharge limits. It is a natural process that uses microorganisms to achieve the degradation of the organic contaminants and is used by essentially all POTWs in the United States. An equivalent industrial design is based on the amount of wastewater being processed and is usually much smaller than what a POTW would use. Since COD is composed of both inorganic and organic contaminants and microorganisms effectively oxidize only organic contaminants, an insufficient amount of the inorganic contaminants might be oxidized to meet the discharge limits.

To reduce the COD further, a chemical oxidant, carbon adsorption, ultraviolet oxidation, ozonation, or other means is required. A membrane process such as ultrafiltration, nanofiltration, and RO could be used, but they are more often used in a recycling process where the permeate would be reused. The reject stream for either of these two processes increases the concentration of the contamination from 10 to 100 times.

Hazardous Metals

The eight hazardous metals that are federally regulated are cadmium, lead, selenium, mercury, barium, chromium, silver, and arsenic. In addition, some states and local agencies might list others. Any of the four following methods might be used to reduce the metal concentration in the wastewater to meet discharge limits:

1. Mechanical filtration (particulate only)
2. Chemical precipitation (particulate and dissolved) 3. Ionic removal (dissolved only)
4. Membrane (particulate and dissolved)

The choice depends greatly upon the metal and its state (dissolved, particle, colloidal), flow rate, total flow per day, and other factors. For example, if a user is cleaning cadmium-plated parts and must comply with an FOG and cadmium metal regulation, a OF might achieve both so long as the dissolved cadmium metal is not beyond the regulatory limit. The membrane does not effectively remove dissolved low-molecular-weight contaminants. In some cases, the processed water could be reused instead of being disposed. The reject stream containing the concentrated metal and oils would be hauled as hazardous waste.

Determining the Wastewater Treatment for a New Process

This is one of the most difficult applications. To reduce the uncertainty of wastewater treatment decisions, the user should determine the local source water conditions, similar processes in the industry (competitors), availability of hauling, potential discharge waivers, and piloting the process, all of which can aid in limiting overdesigning costs. The less that is known about a process, the greater the margin of safety that is usually necessary to ensure a treatment system that meets the user's requirements. The user should try to maintain maximum flexibility before buying a permanent system. This section examines three possible decision-making areas.

Source Water Treatment

If a water sample is available, it is best to have it analyzed especially if high-purity water is necessary. It is best to wait for the results of the analysis before renting a long-term systemorbuying a permanent system unless the uncertainty of the treatment process is minimal.

No-Wastewater-Discharge Design

It is difficult to achieve an economical wastewater treatment system for a nowastewater-discharge design because of the unknowns: type of wash chemical, specific contamination generated by the process, surface quality of the parts, and other conditions. For small-volume applications, the entire wash tank and rinse water could be hauled. For large volumes of wastewater, where hauling might be a problem and the user is on a municipal sewer, it may be possible to discharge it with minimal treatment on a waiver. If on a septic system, river, or other body of water, hauling maybe the only practical way. Another alternative for any of the above could be a temporary treatment system alone or along with hauling until enough data are gathered to define the final permanent treatment system.

Wastewater-Discharge Design

If the user has decided to discharge to a POTW, it is necessary to obtain the discharge regulations to determine the wastewater conditions that must be met and to obtain a permit. It is easier to prepare for this application than for a zero-discharge design because there are far fewer conditions affecting the final design. For example, for most alkaline cleaning applications, pH and oil are the two key concerns. For the pH adjustment, equipment is usually easily obtainable on relatively short notice. The amount of oil in the wastewater is more difficult to assess and could lead to a large, unnecessary initial expenditure if a large margin of safety is required, such as considering a OF membrane or chemical treatment system. In such cases, a discharge waiver from a POTW would be of great value until the final effluent is tested.

Overcapacity of Current Wastewater Treatment System

In such applications, usually recycling at the source of the discharge can become a primary solution. The reason is that the cost of expanding the entire wastewater treatment system is usually much more than trying to reduce the amount of wastewater going to the treatment system by using a point-source treatment system. A careful evaluation of all discharge sources is made to determine which are the most viable from a cost standpoint. It is unusual for the expansion of the central wastewater treatment to be the most economical choice. For temporary overcapacity applications, hauling may be most economical.

CASE HISTORIES

Case 1-Manufacturer Unable to Reduce the High Failure Rate of Plated Parts

Situation

"We are replacing our wash chemical weekly, but part spotting is still a substantial problem that causes post-cleaning plating part failures."

Discussion

The user was replacing the 600 gal of wash chemical weekly because neither coalescing nor skimming was capable of removing the emulsified oil, causing part spotting. To consider a wash chemical membrane recycling system, the user had to try another type of wash chemistry. After a successful match of a new wash chemistry with a recycling system, the incidence of spotting was essentially eliminated. After the new equipment was installed, the user's costs from product defects, chemical purchases, haulage of spent chemicals, and labor totaling about $120,000/year were eliminated. With the new system the concentration and cleanliness of the wash chemical are maintained at a relatively constant level where, previously, the emulsified oil would build up toward the end of the weekly cycle of replacement of wash chemical.

Lesson

New technologies can sometimes help solve problems that existing methods cannot and, in addition, can yield additional unforeseen benefits.

Case 2-Large Computer Manufacturer Buys a System from Local Supplier

Situation

"I have a local wastewater treatment company that said it could do it."

Discussion

The manufacturing engineer was not familiar with wastewater treatment and believed the local company. The installed system cost in excess of $50,000 and required essentially a full-time operator trained in chemical wastewater treatment practices and a 20 X 20 ft floor space. This type of system is very typical in a printed circuit board fabrication facility. High operating costs, floods, and high volumes of water discharged to drain characterized the first year's operation before a major design change eliminated one of the three major problems (floods). Another vendor with extensive experience with these systems had informed the engineer that it was not economically feasible to operate a closed-loop system without major changes in the way the cleaner had to operate. Several months later, the engineer left the company under unknown circumstances, and a supervisory engineer involved in the decision making was reassigned. Several months later, the company purchased another closed-loop wastewater recycling system for about $35,000 with a specially designed cleaner specified by the recycling vendor. The system only required an operator once every 3 to 4 weeks for 2 h for normal maintenance.

Lessons

1. The engineer lacked the fundamental knowledge necessary to judge the technical merits of the two competing companies.
2. The local vendor had no operating systems experience or knowledge of these systems, despite its other wastewater treatment experience.

Case 3-Large New England Military Contractor Decides to Build Its Own System and Makes a Large Investment

"I can do it myself for less money."

Case 4-Small Contractor

Situation

"If we did it over again, we would have spent less money, and saved 160 hours of engineering time and liability concerns with a local water purification company servicing a waste treatment application."

Discussion

Upper management decided that a local water purification company, not experienced in waste treatment, could perform the service less expensively. The user purchased a water treatment system at a substantial cost without the necessary functional features. In addition, the user was not aware of the liability issues concerning the possible misuse of lead contaminated ion-exchange resin by vendors servicing both waste treatment systems and high-purity systems such as medical facilities, laboratories, and other sensitive customers. If these other customers knew that their vendor was supplying them with resins that had been exposed to wastewater containing lead and other contaminants, they would immediately discontinue their business relationship.

Lesson

The engineering and design of closed-loop wastewater recycling systems were seriously underestimated and liability issues were completely overlooked.

CONCLUSION

The current general trend is increasing stringency of discharge regulations. This requires continual vigilance by users in maintaining their knowledge of current water and wastewater practices.

Selecting the best source water and wastewater treatment processes for a cleaning application requires a methodical approach. In the case of solving an immediate cleaning problem, it is usually best to take a systems approach by evaluating the entire cleaning process each time because of the interdependency of each part of the cleaning process. Sometimes a simple change in the cleaning or water/wastewater process can alter the entire economic equation, transforming a previously uneconomical solution into an economical or, perhaps, even the best choice.

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