

CHAPTER 7

Removal of Inorganic Dissolved Solids

Minerals are as significant in industrial wastewaters as they are in water and foods for human consumption. Trace concentrations in waste enhance the growth of flora in any receiving waters just as they enhance the growth and health of humans digesting the foods and water. At the same time, an excess of minerals stresses all receiving waters and the people who drink and eat them. Therefore, it is important for environmentalists to be able to differentiate between excessive and acceptable mineral content in all of our environments, and then we must be able to recommend removal techniques to keep these minerals at the proper concentration.

The removal of dissolved minerals from wastewaters has been given relatively little attention by waste treatment engineers, because minerals have been considered less polluttional than other constituents, such as organic matter and suspended solids. However, as we learn more about the causes and effects of pollution, the importance of reducing the quantity of certain types of inorganic matter, which wastewater treatment plants and many other industries permit to enter streams, is apparent. Chlorides, phosphates, nitrates, and certain metals are examples of the more common and significant inorganic dissolved solids. Among the methods employed mainly for removing inorganic matter from wastes are: (1) evaporation; (2) dialysis; (3) ion exchange; (4) algae; (5) reverse osmosis; and (6) miscellaneous methods. Other treatment methods that remove minerals incidentally but are aimed primarily at other contaminants are discussed in Chapters 6 and 8. One should not overlook the minerals contributed by natural runoff from overland flow. The amount of dissolved solids that these natural flows contain often exceeds that contributed by wastewaters from industry.

Evaporation

“Evaporation” is a process of bringing wastewater to its boiling point and vaporizing pure water. The vapor is either used for power production, condensed and used for heating, or simply wasted to the surrounding atmosphere. The mineral solids concentrate in

the residue may be sufficiently concentrated for the solids either to be reusable in the production cycle or to be disposed easily. This method of disposal is used for radioactive wastes, and paper mills have for a long time been evaporating their sulfate cooking liquors to a degree where they may be returned to the cookers for reuse.

Major factors in selection of the evaporation method include the following: (1) Economics: Does the value of the reusable residue outweigh the cost of fuel for evaporation? (2) Initial dissolved solids: Are there enough solids in the waste of a variable nature to warrant evaporation? Generally, 10,000 ppm are required. (3) Foreign matter: Is there foreign matter present that could cause scale formation or corrosion or interfere with heat transfer in evaporation? (4) Pollution situation: What effect will the minerals have on the receiving stream? For example, caustic soda kills fish, ammonium salts initiate troublesome algal growths and in some cases stimulate bacterial growth upon organic matter already present (Amberg 1955), salt interferes with water use by industries and municipalities, and so forth.

Today, many evaporators are heated by steam condensing on metallic tubes, through which flows the waste to be concentrated or evaporated. The steam is at a low pressure, usually less than 50 pounds per square inch (psi) (absolute). Most evaporators operate with a light vacuum on the vapor side, to lower the boiling point and to increase the rate of vapor removal from the evaporator. Vacuum systems are especially preferable to atmospheric evaporators when the decomposition of organic matter is involved. Care must be exercised, however, that the vacuum is not great enough to permit priming of the wastewater into the vapor.

Evaporating a waste presents many problems, which include concentration changes during evaporation, foaming, temperature sensitivity, scale formation, and the materials used in evaporator construction. In industrial-waste concentration, scale formation usually presents the major overall heat-transfer coefficient decreases, causing the efficiency to drop until it is necessary to shut down and clean the tubes—a complicated process when the scale is hard and tenacious.

Chrome, nickel, and copper acid-type plating wastes may be reclaimed from the rinse tank by evaporation in glass-lined equipment, or other suitable evaporators, and the concentrated solution returned to the plating system (Merril et al. 1949). Initial cost of equipment is high, so the quantity and value of chemicals to be recovered, plus the estimated cost of operating the treatment system if evaporative recovery were not practiced, are criteria one must use to justify purchasing such equipment.

Efficiency of evaporation is directly related to heat-transfer rate—expressed in British thermal units per hour (Btu/hr)—through the heating surface (tube wall). This rate is equal to the product of three factors: the overall heat-transfer coefficient, the heating surface area, and the overall change in temperature between the waste and the steam. It is expressed mathematically as

$$q = UA (t_s - t_w) = UA \Delta t,$$

where q is the rate of heat transfer (Btu/hr), U is the overall coefficient (Btu/ft²/hr/°F), A is the heating-surface area (ft²), t_s is the temperature of steam condensate (°F), t_w is

TABLE 7.1
Typical Overall Coefficients in Evaporators

<i>Type of Evaporator</i>	<i>Overall Coefficient, Btu/ft²/hr/°F</i>
Long-tube vertical	
Natural recirculation	200–600
Forced circulation	400–2, 000
Short-tube	
Horizontal tube	200–400
Calandria type	150–500
Coil	200–400
Agitated film	
Newtonian liquid viscosity	
1 centipoise	400
100 centipoises	300
10,000 centipoises	120

Adapted from Brown et al. (1950).

the boiling temperature of waste (°F), and $\Delta t = t_s - t_w$ is the overall temperature change between steam and waste. Typical values of U for various types of evaporators are given in Table 7.1. These figures are estimated within broad ranges, by considering the viscosity of the waste, scale formation, and operating temperatures (greater temperature differentials yield higher coefficients). Tube wall thickness also influences U : the greater the thickness, the lower the value of U .

Dialysis

“Dialysis” is the separation of solutes by means of their unequal diffusion through membranes (Eynon 1933; Lee 1935; Bassett 1938; Lovett 1938; Roetman 1944a,b; Kirk and Othmer 1950; Powell 1954; U.S. Department of Health, Education and Welfare 1963; Smith and Eismann 1964; “Reverse Osmosis” 1967). It is most useful in recovering pure solutions for reuse in manufacturing processes, for example, caustic soda in the textile industry (Michalson and Burhans 1962). Recovery involves separation of a crystalloid (NaOH) from a solution in which about 96% of the impurities is in the form of hemicellulose and the rest includes pectins, waxes, and dyes.

There are some 8–10 commercial dialyzers on the market. In our example, they all operate on the simple principle of passing a concentrated impure caustic solution upward, counter-current to a downstream water supply, from which it is separated by a semipermeable membrane (Figure 7.1). The caustic soda permeates the membrane and goes into the water more rapidly than the other impurities contained in the waste. The concentration of caustic soda is always greater in the impure solution than in the water,

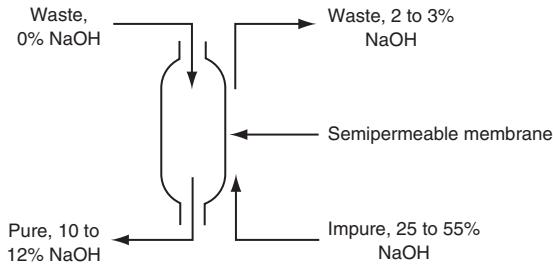


FIGURE 7.1. Typical dialysis flow diagram.

and the water that flows through the membrane into the impure caustic solution tends to dilute it. The quantity of sodium hydroxide diffusing through the diaphragm depends on the time, the area of the dialyzing surface, the mean concentration difference, and the temperature. These factors are expressed in the equation

$$Q = Kat (\Delta c),$$

where K is the overall diffusion coefficient, t is the time in minutes, A is area of dialyzing surface, and

$$\Delta c = \Delta c_{av} = (\Delta c_1 - \Delta c_2) / (2.3 \log_{10} \Delta c_1 / \Delta c_2),$$

where Δc_1 and Δc_2 are the differences in concentration between the two solutions at the top and bottom of the diagram, respectively.

When one actually computes the weight of NaOH recovered, it becomes apparent that the quality and type of diagram are important, which is evident from the following equation:

$$W = UA \Delta c_{\log \text{ mean}}$$

where W is the weight of material passing through the membrane in a unit of time (g/min), U is the overall dialysis coefficient, and $\Delta c_{\log \text{ mean}}$ is the logarithmic mean concentration gradient across the membrane ($= \Delta c_{av}$). Also,

$$1/U = 1/U_1 + 1/U_2$$

where U_1 is the combined film resistance (cm/min) and U_2 is the membrane resistance (cm/min). Each diaphragm shows a different membrane resistance (U_2). The restrictive characteristics of porous membranes are due to both a mechanical sieve action and a physicochemical interaction between solute, solvent, and membrane. Cellulose nitrate, parchment, and cellophane are the principal membranes used.

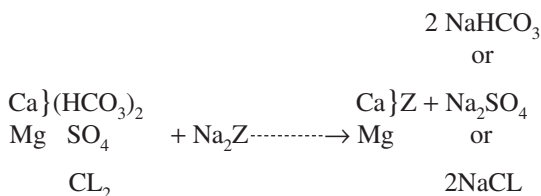
Smith and Eisemann (1964) present an excellent evaluation of electro dialysis. Dialysis is an operation requiring very little operator attention, and although its main

role is to conserve raw materials and to reduce plant waste, it also aids in waste treatment. With the introduction of acid-resistant membranes, dialysis has been used successfully in the recovery of sulfuric acid in the copper, stainless-steel, and other industries. Some operations can recover as much as 70–75% of the acid, but a recovery of as little as 20% may justify the process. In dialysis, the driving force of separation is natural diffusion because of concentration gradient; in electrodialysis this natural force is enhanced by the application of electrical energy. McRae (1965) found that, for a secondary effluent containing 900 ppm of dissolved solids, electrodialysis could achieve a 44% reduction, with costs ranging from 10 to 15 cents per 1,000 gallons. He found this process useful for treating the wastes from dairies.

Because of the resulting improvements in mechanical and thermal properties, ceramic-membrane filters now generally outperform polymer membranes, their established competitor (High Technology, August 1987). Ceramic membranes are made by blending dry mineral powders, such as alumina, spinel, cordierite, and zirconia, in various proportions with a solvent to form either a slurry, which is poured into a mold, or a dough, which is extruded. The resulting configurations, either hollow fibers, flat plates, or honeycombs, are then dried and fused together. Layers of supporting material are added to complete the filter. Because ceramic membranes tolerate acids and bases, they can be more thoroughly cleaned than other designs. Also, these membranes can be cleaned with steam up to 140 °C, whereas polymeric membranes cannot be steam-cleaned. Ceramic membranes can also be heated up to 500 °C to burn out impurities trapped during filtration. In addition to their relatively high cost, a major drawback is their brittleness.

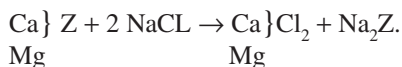
Ion Exchange

Ion exchange is basically a process of exchanging certain undesirable cations and anions of the wastewater for sodium, hydrogen, or other ions in a resinous material. The resins, both natural and artificial, are commonly referred to as *zeolites*. The ion-exchange process was originally developed to reduce hardness in domestic-water supplies but has been used to treat industrial wastewaters, such as metal-plating wastes. The softening reactions may be illustrated as follows (Nordell 1951):



where Z is the symbol for the zeolite radical. When the ability of the zeolite bed to produce soft water is exhausted, the softener is temporarily cut out of service. It is then backwashed to cleanse and hydraulically regrade the bed, regenerated with a solution of common salt that removes the calcium and magnesium in the form of their soluble

chlorides while restoring the zeolite to its original condition, rinsed free of these and the excess salt, and finally returned to service. The reaction may be indicated as follows:



Ion exchange as a means of waste treatment is only a new application of a traditional method of water softening. If the proper approach is used, it offers great potential for material and water conservation. For instance, in the treatment of metal-plating wastes (Merrill et al. 1949), rinse water is passed through beds of cationic and anionic resins selected for the particular application and the deionized water is then recycled through the rinse tank. This method may be applied on a continuous basis to the removal of contaminating metals (Merrill et al. 1949) from chromic acid solutions, permitting the return of pure chromic acid solution to the process tank. In the case of nickel- and copper-plating solutions, both the contaminating metals and the metal to be plated are cationic, so all will be extracted. Cation-exchange resins are suggested ("New Process Developed" 1965) for use in the steel industry to remove the iron from spent liquor and to recover sulfuric acid and iron oxide for further use. Unless the aim of the procedure is recovery of metals, ion exchange becomes simply a concentration method, and some treatment for the regenerated solution must be devised.

Walther (1965) reports the use of a continuous ion-exchange unit, consisting of a stainless-steel loop divided into sections by butterfly valves that successfully removed more than 700 mg/liter of dissolved inorganic solids. The unit contains about 15 ft³ of ion-exchange resin, which moves around the loop in about 3 minutes. When the resin becomes saturated with hardness, it is removed from the loop and regenerated resin is exchanged. The spent resin is then regenerated and returned to the loop on the next cycle.

Organic matter and pH have a pronounced effect on the operation and efficiency of resin beds; the leaching of organic matter from certain resins may have a detrimental effect on the metals plated. Chemicals used for regenerating resin beds may also require special treatment before disposal.

Deminceralization (ion exchange) is most useful when water of the highest quality is required, but it involves complex chemical reactions and, therefore, requires careful operation and supervision at all times. Furthermore, ion-exchange processes sometimes use chemicals that are hazardous to personnel and equipment. These are matters to think about before selecting an ion-exchanger system over an evaporator, although evaporators, too, are uneconomical in certain instances such as when the flow is light. Dialysis is normally economical and can compete in efficiency with both evaporation and ion exchange when the recovery of a pure compound is considered essential. The decision whether to use evaporation or deminceralization can be intelligently made only after a thorough evaluation of the heat balance of the plant and expected operating conditions (Paulson 1952). These factors, as well as operating costs, must be considered in relation to the capital investment needed for either system.

Algae

Algae require nine minor essential elements (Fe, Mn, Si, Zn, Cu, Co, Mo, B, and Va) and seven major essential elements (C, N, P, S, K, Mg, and Ca) for their optimum growth. The use of algae for removing minerals from wastewaters has been investigated; most investigations have been carried out on sewage effluents. One such study (Golueke and Oswald 1965) involved a suburban housing-development treatment plant and used primary sedimentation, trickling filtration, and stabilization ponds. Although the sedimentation and filtration did not remove any phosphorus, the algae actively growing in the ponds caused a reduction of about 42% of the phosphate content. Other mineral concentrations were not measured.

If this method is used to remove minerals such as phosphate over a period, algae must also be removed from the effluent before this is released into a stream used for water supplies and recreation. Golueke and Oswald (1965) observed three steps in harvesting oxidation-pond algae: (1) collection and initial concentration, (2) de-watering or secondary concentration, and (3) final drying. They found chemical precipitation and centrifugation to be most economical. The harvested algae can be sold as animal feed supplements. Oswald (1960) describes *Chlorella* and *Scenedesmus* as the most active algae in stabilization ponds, because they are extremely hardy. Krauss (1956) presented the elemental composition of these two algal types to validate their fixation of minerals (Table 7.2).

As we progressed towards the end of the twentieth century, the demineralization of seawater as well as tertiary treated domestic wastewater became more general

TABLE 7.2
Elemental Composition of Green Algae

<i>Element</i>	<i>Range of Dry Weight, %</i>
<i>Chlorella</i>	
Carbon	51.4–72.6
Hydrogen	7.0–10.9
Oxygen	11.6–28.5
<i>Scenedesmus</i>	
Nitrogen	2.2–7.7
Phosphorus	1.1–2.0
Sulfur	0.28–0.39
Magnesium	0.36–0.80
Potassium	0.85–1.62
Calcium	0.005–0.08
Iron	0.04–0.55
Zinc	0.0006–0.005
Copper	0.001–0.004
Cobalt	0.000003–0.0003
Manganese	0.002–0.01

Adapted from Krauss (1956).

practice. In these cases, it is necessary to remove most, if not all, of the residual minerals. The most promising methods of mineral removal—especially for salts—are membrane filters and reverse osmosis. Costs for these treatments are gradually becoming comparable to those of conventional complete water treatment systems.

Table 7.2 shows the extent to which algae take up minerals from any solution in which they grow. In fact, the continued photosynthesis of algae depends directly on the ability of the culture medium (wastewater) to supply these inorganic compounds over a long period, at a rate sufficient to support the growth potential of the algae. There is some evidence that the uptake (and the algal growth) depends on the availability and the presence of inorganic nutrients. Thus, insolubility and colloidal characteristics of the nutrients may hamper algal growth, but hardness in wastewaters can contribute to it. A statistical study of Massachusetts lakes and reservoirs carried out in 1900 showed that the hard-water supplies yielded more algae than the soft (Table 7.3). Bogan (1959)

TABLE 7.3
Occurrence of *Cyanophyceae* and *Chlorophyceae* in Massachusetts Lakes and Reservoirs

<i>Characteristic</i>	<i>Chemical Analysis, ppm</i>	<i>Often Above 1,000/cm³</i>		<i>Below 100/cm³</i>	
		<i>Cyano-phyceae</i>	<i>Chloro-phyceae</i>	<i>Cyano-phyceae</i>	<i>Chloro-phyceae</i>
Color	0–30	2	2	11	0
	30–60	2	2	3	1
	60–100	3	1	7	2
	>100	0	0	1	1
Chlorides (excess above normal)	0	2	1	3	1
	0.1–0.3	1	1	10	5
	0.4–2.5	1	0	9	6
	>2.5	3	3	0	0
Hardness	0–5	0	0	6	4
	5–10	2	1	10	5
	10–20	2	1	5	2
	>20	3	3	1	1
Albuminoid ammonia (dissolved)	0–0.10	0	0	4	3
	0.1–0.15	0	0	6	4
	0.15–0.20	2	2	7	3
	>0.20	5	3	5	2
Free ammonia	0–0.01	0	0	10	4
	0.01–0.03	0	0	8	5
	0.03–0.10	3	2	4	3
	>0.1	4	3	0	0
Nitrates	0–0.05	1	0	12	6
	0.05–0.10	3	2	10	6
	0.10–0.20	1	0	0	0
	>0.20	2	3	0	0

Adapted from Walther (1965).

capitalized on the ability of algae to use phosphorus in providing tertiary treatment of the sewage from Seattle, Washington, which utilized both algal activity and lime and removed more than 90% of the phosphorus in the secondary sewage-plant effluent. Oxidation-pond usage has been increasing since the advent of lower-cost mechanical aeration.

Reverse Osmosis

“Reverse osmosis” is a membrane permeation process for separating relatively pure water or some other solvent from a less pure solution. The solution is passed over the surface of a specific semipermeable membrane at a pressure in excess of the effective osmotic pressure of the feed solution. The permeating liquid is collected as the product and the concentrated feed solution is generally discarded. The membrane must be: (1) highly permeable to water, (2) highly impermeable to solutes, (3) capable of withstanding the applied pressure without failure, (4) as thin as possible consistent with the strength requirement, (5) chemically inert, mechanically strong, and creep resistant; and (6) capable of being fabricated into configurations of high surface-to-volume ratios. A number of commercial units in practice treat brackish waters of less than 2,000–3,000 ppm of total dissolved solids.

Although several types of membranes have been developed, two types of membranes are generally used in commercial equipment. The first is a symmetric of “skinned” cellulose acetate membranes made in flat or tubular forms. Generally, the membranes are approximately 100 μm thick, with a surface skin of about 0.2 μm that acts as the rejecting surface. Typically, they operate at 40–50 atmospheres pressure and produce a water flux of 10–20 gallons of water per square foot per day with a salt rejection of about 95%. These membranes have generally exhibited a decrease in flux rate with time because of both compaction (creep) and fouling of the membrane. Therefore, operating pressures are kept low to avoid creep, and the amount of suspended solids in the feed solution is kept as low as possible to prevent fouling.

The second type of membrane is an aromatic polyamide or polyamide hydrazide. The membrane in commercial units is in the form of hollow fine fibers. The patented membrane is claimed to operate at 27 atmospheres pressure and in a water flux of 1–2 gallons/ft²/day with a salt (NaCl) rejection of about 95%.

Some limitations of existing membranes other than the total dissolved solids concentrated are described by Lonsdale and Podall (1972) in the following manner: (1) The relatively high cost of operation could be reduced if the water flux could be substantially increased without loss in salt rejection or other properties. (2) Flux decline is serious with high-flux membranes. (3) Certain species are inadequately rejected—for example, boric acid, phenol, and nitrates. (4) For certain applications, existing membranes are not sufficiently resistant to chemical or microbiological attack, or their mechanical or thermal stability is inadequate. (5) Feed-water pH should generally be on the acidic side (pH 5–7) for best operation and to minimize membrane hydrolysis. For industrial waste treatment, some preliminary promising results have been reported with sulfite, kraft pulping, and textile dyeing wastes.

Substantial energy needed to constantly pressurize the incoming salty water is one of the drawbacks of the reverse-osmosis system. The Reliable Water Company (Figure 7.2) system uses an energy recovery mechanism that reclaims most of the fluid pressure from the brine waste as it leaves the system. Using hydraulic oil pumps, transfer barriers, and special valves, the system extracts the pressure in the brine and transfers it to the incoming waste saltwater, substantially reducing the energy requirements.

Osantowski and Ceinopoloc (1979) obtained excellent rejections of dissolved solids for desalting processes after pretreating de-inking paper-mill and slaughterhouse and meatpacking wastes. They used reverse osmosis, ion exchange, and electro dialysis. They found reverse osmosis was the most economical process for providing reusable quality water in both paper-mill and food products plants. Reuse quality requirements could be met in most cases by blending the reverse-osmosis product water with un-desalted wastewater. On the other hand, electro dialysis provided the optimal performance of the three desalting technologies investigated at an organic chemicals plant.

Ultrafiltration and Microfiltration

During the 1990s, ultrafiltration (UF) and microfiltration (MF) treatment systems began to be used in conjunction with and usually prior to reverse-osmotic systems. Ultrafilters and microfilters are membrane filters that remove larger-sized contaminants (0.001 microns and 0.01 microns, respectively) primarily by a sieving mechanism. Reverse-osmotic (RO) systems, on the other hand, remove contaminants as small as 0.00001 microns and, therefore are more useful in water-producing rather than waste-treating plants. When used in

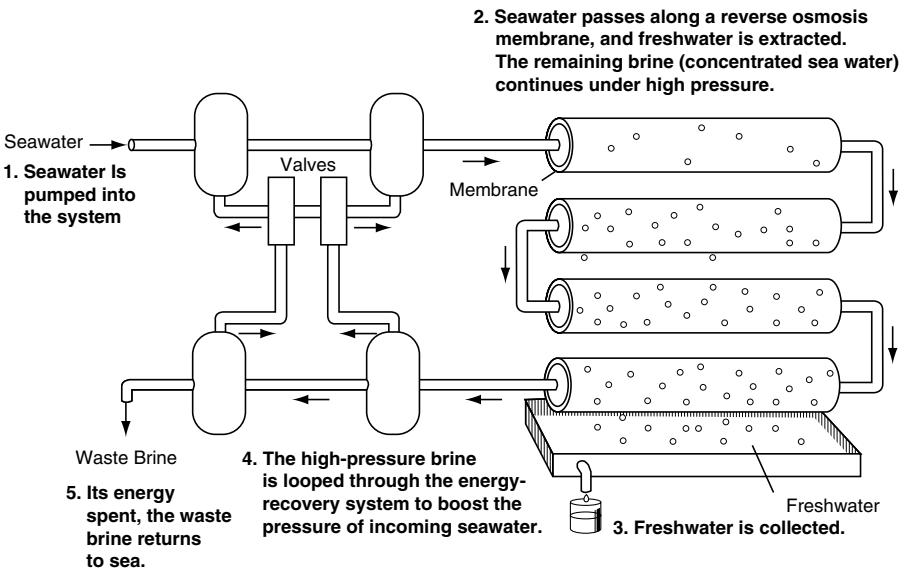


FIGURE 7.2. The desalination process using energy recovery and artificial intelligence control.

conjunction with and prior to reverse osmosis, less clogging and “plugging up” of the RO treatment units occur. This ensures longer life and a higher flux rate for the RO units.

When using any of the types of membrane filtration, one must not expect industrial operation to be comparable to municipal-water plants. Industries often treat smaller flow rates and higher solids concentrations, and they usually have less-stringent effluent requirements. The appropriateness of membranes for industry may depend on space needs, economics of plant operation, effluent discharge requirements, and any existing treatment system.

Miscellaneous Methods

Chemical precipitation or coagulation has been used to remove some inorganic matter from wastewaters. For example, elevated pH values aid in the removal of heavy metals by precipitation of the hydroxide or carbonate, and under some conditions, treatment of wastewaters with calcium hydroxide is reasonably effective in the removal of nitrogen and phosphorus.

In laboratory studies during the 1960s, we found that lime precipitation of raw sewage repressed algal growth, especially of the blue-green type. Soil percolation of sewage effluents through certain soils has also given some indication of being an effective method reducing blooms. Presumptions were that removal of either or both organic matter and limiting minerals such as phosphorus could be the critical elements in preventing excessive algal blooms (Jackson 1967).

Oxidation-reduction chemical reactions are used in certain cases to alter inorganic matter and, thus, enhance its removal. For example, chromate must be reduced, usually with ferrous sulfate or sulfur dioxide under acid conditions, to the trivalent form as a preliminary to precipitation with lime and subsequent removal as a chromic-hydroxide sludge (see reactions in Chapter 6). Likewise, cyanides must be completely oxidized, usually with chlorine under alkaline conditions, to split them up into harmless and volatile nitrogen gas and carbonate ions (see Chapter 6).

The ultimate disposal of salts has always been and still remains a major problem to the environmental engineer. One novel suggestion for the use of concentrated salt waste was proposed in 1981 (*New York Times*, p. A9, August 3, 1981). Salt solutions with at least 10% salt content can be added to the warm surface waters of lakes. The increased density of these warm surface waters tends to cause the salt solutions to sink to the bottom, where they stay and serve as a reservoir for hot-water energy. The hot-water energy is pumped out periodically to drive turbines to produce electrical energy. The hot water can also be used for space heating or for agricultural or industrial processes.

Refractories

“Refractories” can be defined for our purpose as solids in wastewater—generally in the dissolved stage—that are not susceptible to removal by the usual “primary” or “secondary” treatment techniques, including those of chemical coagulation. They may have

to be removed because the increased water reuse results in a gradual buildup in water supplies downstream and deterioration of the water for its best usage, and we are learning more about the potential hazardous effects of refractories in water, including the following:

1. Fluorides causing mottled teeth
2. Nitrates causing methemoglobinemia
3. ABS interfering with surface re-aeration and adding tastes to water
4. Metals causing blood poisoning
5. Certain insecticides and benzene-structured organics causing potential nerve damage and/or carcinogenic reactions

Presently, it is feasible to remove these refractory materials by (1) membrane filtration, (2) evaporation, or (3) adsorption. The theories of these methods are described in Chapters 5 and 6. Some of the major limitations and potentials for use are given in Table 7.4.

TABLE 7.4
Refractory Containment Removal Techniques

<i>Membrane filtration</i>	<i>Evaporation</i>	<i>Absorption</i>
<i>Limitations</i>		
(a) Life of Membrane	Requires source of relatively inexpensive energy input	Cost of new carbon is relatively high
(b) Loss in flux rate	Wastewater should be very high in solids content	Can clog quite easily with finely-divided suspended solids
(c) Relatively small amount of effluent which can be removed	Wastewater could cause scaling of pipes in evaporator thus interfering with heat transfer	Cost of regenerating equipment is high, but carbon costs are reduced to $\frac{1}{10}$ of above costs by regeneration of carbon
(d) Relatively limited type of materials which can be removed		
<i>When to use</i>		
With a relatively small volume of primarily two component is quite valuable; when recovered in relatively pure form. Each component should be as different as possible in molecular size and noncorrosive to membranes	With a high solids, noncorrosive, nonscale-forming waste; when an inexpensive source of heating is available	With a highly soluble, single-state waste, which however, has a high enough molecular weight to be easily removed by adsorption. Preferably, the contaminant should be organic and can either be recovered by solvent extraction if valuable, or destroyed by burning if not valuable

Example of Twentieth-Century Practice of Removal of Inorganic Dissolved Solids

Knoche et al. (1986) attempted to find acceptable treatment processes to remove inorganics so that the level of quality would be acceptable for recycle and reuse. They found that the most acceptable treatment involved the addition of powdered activated carbon in conjunction with metal ion coagulants to lower residual color levels to below 10 Pt-Co standards. However, required dosages were high. They recommended that further research be undertaken to increase the efficiency of inorganic dissolved solids removal beyond that which they obtained.

Review Questions

1. What percentage of industrial plants practice removal of minerals?
2. What are the significant minerals present in industrial wastes?
3. Name six major methods whereby inorganic ions can be removed?
4. Describe the principles and problems in using evaporation and its major use.
5. Describe the principles and problems in using dialysis and its major use.
6. Describe the principles and problems in using ion exchange and its major use.
7. What are algae used for and when are they most useful in waste treatment?
8. What miscellaneous methods are also available for removing minerals?

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