CHAPTER 1

Theories and Practices

Volume Reduction

In general, the first step in minimizing the effects of industrial wastes on receiving streams and treatment plants is to reduce the volume of such wastes. This may be accomplished by: (1) classifying wastes; (2) conserving wastewater; (3) changing production to decrease wastes; (4) reusing both industrial and municipal effluents as raw water supplies; or (5) eliminating batch or slug discharges of process wastes.

Classification of Wastes

If wastes are classified so that manufacturing-process waters are separated from cooling waters, the volume of water requiring intensive treatment may be reduced considerably. Sometimes it is possible to classify and separate the process waters themselves so that only the most polluted ones are treated and the relatively uncontaminated ones are discharged without treatment. The three main classes of wastes are as follows:

1. Wastes from manufacturing processes: These include waters used in forming paper on traveling wire machines, those expended from plating solutions in metal fabrication, and those discharged from washing of milk cans in dairy plants, dyeing and washing of textile fabrics, and washing of picked fruits from canneries.
2. Waters used as cooling agents in industrial processes: The volume of these wastes varies from one industry to another, depending on the total Btu's to be removed from the process waters. A single large refinery discharges 150 million gallons per day (mgd), of which only 5 mgd is process waste; the remainder is only slightly contaminated cooling-water waste. Cooling waters have been found to be contaminated by small leaks, corrosion products, or the effect of heat; however, these wastes usually contain little, if any, process matter and are generally considered nonpollutional. Power plants, however, represent an industry in which cooling waters are segregated and account for a high percentage of total volume of plant wastes, and may contain hazardous contaminants under infrequent malfunctioning conditions.

3. Wastes from sanitary uses: These will normally range from 25 to 50 gallons per employee per day. The volume depends on many factors, including size of the plant, amount of waste-product materials washed from floors, and the degree of cleanliness required of workers in the process operation.

Unfortunately, in most older plants, process, cooling, and sanitary wastewaters are mixed in a single pipeline; before 1930, industry paid little attention to segregating wastes to avoid stream pollution. Awareness of the problems and the differences in these three wastes led industry to practice separation when constructing new plants during World War II and thereafter.

Conservation of Wastewater

Water conservation is waste saved. Conservation begins when an industry changes from an "open" to a "closed" system. For example, a paper mill that recycles white water (i.e., water passing through a wire screen upon which paper is formed) and thus reduces the volume of wash waters it uses is practicing water conservation. Concentrated recycled wastewaters are often treated at the end of their period of usefulness, because usually it is impractical and uneconomical to treat the wastewaters as they complete each cycle. The savings are twofold: Water costs and waste-treatment costs are lower. However, many changes to effect conservation are quite costly and their benefits must be balanced against the costs. If the net result is deemed economical, then new conservation practices can be installed with assurance.

A paperboard mill may discharge 10,000 gallons of wastewater per ton of product, although there are many variations from one mill to the next. Paper mills may release as much as 100,000 gallons or as little as 1,000 gallons of wastewater per ton of product. The latter figure is usually the result of a scarcity of water and/or an awareness of the stream-pollution problem, and demonstrates what can be accomplished by effective waste elimination and conservation of water. One large textile mill reduced its water consumption by 50% during a municipal water shortage, without any decrease in production. The author observed that despite the savings to the mill, water usage returned to its original level once the shortage was over. This incident further illustrates the relative "cheapness" of water to the typical industrial plant manager of the mid-twentieth century.

Steel mills reuse cooling waters to quench ingots, and coal processors reuse water to remove dirt and other noncombustible materials from coal. Many industries installed countercurrent washing to reduce water consumption. By the use of multiple vats, the plating industry utilized makeup water so that only the most exhausted waters were released as waste. Automation, in such forms as water-regulating devices, also aided conservation of water. The introduction of conservation practices requires a complete engineering survey of existing water use and an inventory of all plant operations using water and producing wastes, to develop an accurate balance for peak and average operating conditions. For example, in 1950 Rudolfs and Nemerow found that recirculation of paperboard white water was objectionable because of slime formation that subsequently fouled fibers or even slowed down paper machines. Low pH and high temperature of these recirculated waters were found to abate the situation.

Changing Production to Decrease Wastes

Changing production to decrease wastes is an effective method of controlling the volume of wastes but is difficult to put into practice. It is hard to persuade plant managers to change their operations just to eliminate wastes. Normally, the operational phase of engineering is planned by the chemical, mechanical, or industrial engineer whose primary objective is cost savings. The main considerations of the environmental engineer, on the other hand, include the protection of public health and the conservation of a natural resource. Yet, there is no reason that both objectives cannot be achieved.

Waste treatment at the source should be considered an integral part of production. If the chemical engineer argues that it would cost the company money to change its methods of manufacturing to reduce pollution at the source, the environmental engineer can do more than simply enter a plea for the improvement of the environment. The environmental engineer can point out, for instance, that reduction in the amount of sodium sulfite used in dyeing, that of sodium cyanide used in plating, and that of other chemicals used directly in production has resulted in both reducing wastes and saving money. The engineer can also mention that balancing the quantities of acids and alkalis used in a plant often results in a neutral waste, along with saving chemicals, money, and time spent in waste treatment. Rocheleau and Taylor (1964) point out several measures that can be used to reduce wastes: improved process control, improved equipment design, use of different or higher quality raw materials, good housekeeping, and preventative maintenance.

Reusing Both Industrial and Municipal Effluents for Raw Water Supplies

Practiced mainly in areas where water is scarce or expensive, reusing industrial and municipal effluents for raw water supplies is proving a popular and economical method of conservation; of all sources of water available to industry, sewage plant effluent is the most reliable at all seasons of the year and the only one that is actually increasing in quantity and improving in quality. Although there are many problems involved in reusing effluents for raw water supply, it must be remembered that *any* water supply poses problems to cities and industries. Because the problems of reusing sewage effluents are similar to those of reusing industrial effluents, they are discussed here jointly.

Many industries and cities hesitate to reuse effluents for raw water supply. The reasons given (Keating and Calise 1954) include lack of adequate information on the part of industrial managers, difficulty negotiating contracts satisfactorily for both municipalities and industrial users, certain technical problems such as hardness, color, and so forth, and an aesthetic reluctance to accept effluents as a potential source of water for any purpose. Also, treatment plants are subject to shutdown and slug (sudden) discharges, both of which may make the supply undependable or of variable quality. In either case, industry may need an alternate source of water for these emergency situations. In addition, the "resistance to change in practice" factor cannot be overlooked as a major obstacle. However, as the cost of importing raw water supply increases, it would seem logical to reuse waste-treatment plant effluents to increase the present water supply by replenishing the groundwater. It cannot be denied that the ever-available treatment-plant effluent can produce a low-cost, steady water source through groundwater recharge. If any portion of a final industrial effluent can be reused, there will be less waste to treat and dispose. Similarly, reuse of sewage effluent will reduce the quantity of pollution discharged by the municipality. Still, in 1966 one of the deterrents to reusing treated municipal (or industrial) wastewater was the competition with lower-priced freshwater. For example, in San Diego, California, although supporters for using reclaimed waters from treated sewage have proclaimed that "it doesn't make sense to use water only once" and that "pushing for expensive reclaimed water doesn't make economic sense" when the county can buy a large supply of less costly water from Imperial County (Applebaum 1966).

The greatest manufacturing use of water is for cooling purposes. Because the volume of this water requirement is usually great, industries located in areas where water is expensive should consider reusing effluents. Even if the industry is fortunate enough to have a treated municipal water supply, the cost will usually be excessive in comparison, which may have a generally beneficial effect.

As far back as 1955, Smallwood and Nemerow presented a few examples of the water required to produce typical products we purchase:

0.25 gallons for every pound of rayon
0.11–0.25 gallons for every pound of butter
15–30 gallons for every pound of paper produced
5 gallons for every pound of paperboard produced
2.5–45.0 gallons for every pound of paper pulp (newspaper) produced
7.5–250 gallons for every can of food
3 gallons for every 3 pounds of chicken slaughtered
127 gallons for every hog slaughtered
0.75 gallons for every quart of milk that is bottled
8 gallons for every pound of hides tanned into leather
90 gallons for every pound of wool scoured
400 gallons for every guest room per day for hotels

Reusing municipal and industrial effluents saves water and brings revenue into the city. The design of wastewater-treatment plants will be greatly influenced because the effluent must satisfy not only conventional stream requirements but also those of industry.

Many cases are cited in the literature of industrial reuse of intermediate untreated effluents, such as white waters from paper machines as spray and wash waters. The practice of reusing treated industrial effluents, however, was still in its infancy; there are more instances of industrial reuse of municipal effluents. For example, Wolman (1948) described the design and performance of a sewage-effluent treatment plant producing treated water at a rate of about 65 mgd for use in steel-mill processing operations. The plant employed a conventional coagulation treatment, using alum combined with chlorination; final water averaged 5–10 ppm turbidity, with little or no coliform bacterial contamination. The most serious problem encountered was the presence of a high concentration of chlorides. Operating costs, exclusive of interest and amortization but including pumping costs, were $1.75 per million gallons (although this figure does not include the cost of raw-sewage treatment). It is interesting to compare this with the usual municipal cost of collecting, treating, and distributing raw water of $50–250 per million gallons, excluding fixed charges. Even when one adds $15–50 per million gallons for treating the raw sewage, the reusable effluent is much more economical than water obtained by developing a separate source of raw water. Treatment-plant reuse facilities at the Sun Oil Toledo refinery were evaluated (Mohler et al. 1964) for use as makeup water in the cooling towers. The cost savings resulting from elimination of municipal freshwater makeup were found to be $100,000 per year.

Keating and Calise (1954) list five main differences between most sewage-plant effluents and typical surface- or well-water supplies: (1) higher color, (2) higher nitrogenous content, (3) higher biochemical oxygen demand (BOD) content, (4) higher total dissolved solids, and (5) the presence of phosphates due to detergents. Industrial effluents may also possess these characteristic differences, as well as others such as higher temperature. Despite these contaminants, in many parts of the United States the effluent from properly operated secondary sewage plants is actually superior to available surface- or well-water supplies.

Dan Okun, a renowned twentieth-century environmentalist, was—and still is—recommending and strongly urging the reuse of treated sewage effluents for use as "secondary" water supplies for municipalities. The reader can refer to his many published papers on the subject. The debate goes on even in the twenty-first century on the acceptability of such a dual water-supply system.

The number and variety of return-flow and on-site reuse systems have increased. The overall reuse rate increased from 106% (of water reused) to 136% between 1954 and 1959 alone. Reuse in all industries other than steam-electric generation increased from 82% to 139% during the same period. In 1959, the primary metal, chemical, paper, oil, and food industries were particularly large reusers of water.

In 1957, El Paso Products Company founded a petrochemical complex near Odessa, Texas, designed to use sewage-plant effluent for cooling and boiler water. After pretreatment, the only problem encountered was foaming (largely eliminated by the switch to "soft" detergents in domestic use). Reusing sewage effluents often frees municipal or surface water for other valuable purposes. For example, reutilization of sewage for agricultural purposes in Israel could add 10% to its total water supply. It was found that the soil structure is improved by the organics in sewage, but where industrial wastes (particularly heavy metals) are present, treatment beyond oxidation ponds is needed.

"Dry" cleaning of processing equipment, instead of washing with water, can greatly reduce the volume of wastewater. However, this will still leave a solid waste for disposal rather than a liquid one. Hoak (1964) presents a set of conservation techniques largely adapted from his experience in steel mills:

1. Install meters in each department to make operators cost and quantity conscious
2. Regulate pressure to prevent needless waste
3. Use thermostatic controls to save water and increase efficiency
4. Install automatic valves to prevent loss through failure to close valves when water is no longer needed
5. Use spring-closing sanitary fixtures to prevent constant or intermittent flow of unused water

6. De-scale heat exchangers to prevent loss of heat transfer and subsequent inefficient and excessive use of cooling water
7. Insulate pipes so that water is not left running to get it either cold or hot
8. Instigate leak surveys as a routine measure
9. Use centralized control to prevent wastages from improper connections
10. Recirculate cooling water, thereby saving up to 95% of the water used in this process
11. Reuse, for example, blast-furnace cooling water for gas washing and clarified scale-pit water on blooming mills
12. Use high-pressure, low-volume rinse sprays for more efficiency and use a small amount of detergent, wetting agent, or acid to improve the rinsing operation
13. Recondition wastewater (often some minor in-plant treatment will provide water suitable for process use)

Eden and Truesdale (1968) give typical analyses of effluents from three towns in the south of England (Table 1.1). They found that the total solids content appeared to increase by about 340 mg/liter between the water supply and the sewage effluent derived from it. The total solids concentration is one of the chief limiting factors in reusing any wastewater; the number of times sewage can be reused for industrial water supply is controlled by the pickup of dissolved solids that can be removed only by expensive treatment methods. Some discussion of the contaminants listed in Table 1.2 is relevant to potential reuse of sewage effluents for industrial water. Many industrial purposes demand concentrations of suspended solids of less than 2 mg/liter, but sewage effluents contain considerably more than this and, even after tertiary treatment, often contain at least 7 mg/liter. The organic constituents of sewage effluents are still largely unknown. Absorption has been suggested as a method for reducing most of the organic matter. At Lake Tahoe, for example, it has been possible to reduce the organic matter (as measured by chemical oxygen demand [COD]) to less than 16 mg/liter by a combination of coagulation, filtration, and absorption. Detergents can also be removed in this manner to a theoretical minimum level of about 0.2 mg/liter. Additional removal of ammonia, nitrite, and nitrate is relatively expensive and difficult. Ammonia, which can be air-stripped at high pH values, is objectionable in concentrations of more than 0.1 mg/liter for drinking-water supplies that are to be chlorinated. Removal of phosphates is important whenever the water used by industry will be subjected to algae growth conditions. The Tahoe method will reduce the level of phosphate to less than 1.0 mg/liter; controlled activated-sludge and lime-precipitation methods are also effective. At high chlorine levels, it is possible to even remove many viruses. Because sewage effluents contain many types of microorganisms, they should be sterilized even for industrial-process use. In addition, color and hardness in sewage effluents may be harmful to certain industries.

Dowdy et al. (1976) derived a "typical" chemical composition of treated wastewater effluent from a selected number of cities. This composition was compared to that of water from the Colorado River—a source for crop production in several western states—for many of the water quality criteria important in irrigation.

TABLE 1.1
Typical Analyses of Sewage Effluents After Conventional Primary and Secondary Treatment

Constituent[a]	***Source***		
	Stevenage	*Letchworth*	*Redbridge*
Total solids	728	640	931
Suspended solids	15		51
Permanganate value	13	8.6	16
BOD	9	2	21
COD (chemical oxygen demand)	63	31	78
Organic carbon	20	13	
Surface-active matter			
Anionic (as Manoxol OT)	2.5	0.75	1.4
Nonionic (as Lissapol NX)			0.4
Ammonia (as N)	4.1	1.9	7.1
Nitrate (as N)	38	21	26
Nitrite (as N)	1.8	0.2	0.4
Chloride	69	69	98
Sulfate	85	61	212
Total phosphate (as P)	9.6	6.2	8.2
Total phenol			3.4
Sodium	144	124	
Potassium	26	21	
Total hardness	249	295	468
pH value	7.6	7.2	7.4
Turbidity (A.T.U.)[b]			66
Color (Hazen units)	50	43	36
Coliform bacteria (#/ml)	1,300		3,500

[a] Results are given in milligrams per liter, unless otherwise indicated.
[b] Absorptiometric turbidity units.
Adapted from Eden and Truesdale (1968).

Examination of Batch or Slug Discharges of Process Wastes

In "wet" manufacturing of a product, one or more steps are sometimes repeated, which results in production of a significantly higher volume and strength of waste during that period. If this waste is discharged in a short period, it is usually referred to as a *slug discharge*. This type of waste, because of its concentrated contaminants and/or surge in volume, can be troublesome to both treatment plants and receiving streams. There are at least two methods of reducing the effects of these discharges: (1) the manufacturing firm can alter its practice to increase the frequency and lessen the magnitude of batch dischargers; and (2) slug waste can be retained in holding basins from which they are allowed to flow continuously and uniformly over an extended (usually 24-hour) period. These are called *proportioning* and *equalization* (of slug wastes) and are described more fully in Chapter 4 of this book.

TABLE 1.2
Composition of Secondary Treated Municipal Wastewater Effluents and Irrigation Water

Parameter	***Secondary Effluent***[a] *Range*	***Secondary Effluent***[a] *Typical*	*Colorado River*[b]	*Irrigation Water Quality Criteria*[c]
Total solids	U	425	U	NA
Total dissolved solids	200–1, 300	400	668.0	<2,000
pH	6.8–7.7	7.0	7.9	6.5–8.4
Biochemical oxygen demand	2–50	25	U	NA
Chemical oxygen demand	25–100	70	U	NA
Total nitrogen	10–30	20	U	<30
Ammonia nitrogen	0.1–25.0	10	U	NA
Nitrate nitrogen	1–20	8	0.1–1.2	NA
Total phosphorus	5–40	10	<0.02	NA
Chloride	50–500	75	55–77	<350
Sodium	50–400	100	71–97	<70
Potassium	10–30	15	4–6	NA
Calcium	25–100	50	66–163	NA
Magnesium	10–50	20	23–28	NA
Boron	0.3–2.5	0.5	0.10–0.54	<3.0
Cadmium (μg/liter)	<5–220	<5	<1–69	10
Copper (μg/liter)	5–50	20	<10–10	200
Nickel (μg/liter)	5–500	10	<1–4	200
Lead (μg/liter)	1–200	5	<5	5,000
Zinc (μg/liter)	10–400	40	<3–12	2,000
Chromium (μg/liter)	<1–100	1	<1	100
Mercury (μg/liter)	<2–10	2	<0.1–0.1	NA
Molybdenum (μg/liter)	1–20	5	2–8	10
Arsenic (μg/liter)	<5–20	<5	4–16	100

Note: All units in milligrams per liter unless otherwise noted as micrograms per liter (μg/liter). U, unavailable; NA, not applicable.

[a] Adapted from Asano et al. (1984) and Treweek (1985).

[b] Radtke et al (1988).

[c] From Westcot and Ayers (1985) and National Academy of Sciences (1973).

Example of Twentieth-Century Practice of Volume Reduction

An unusual example of reducing the volume of wastewater was described by Zimmerman et al. (1995). They determined the optimal liquid storage volume at minimum cost of a biosolid settling tank. The liquid volume arriving at different settling rates determined the amount of liquid to be discharged to waste. They concluded that obviously the thickening rate was the most significant factor affecting the required tank volume (and, hence, the liquid amount to be decanted and wasted). Although these authors were primarily interested in designing the proper-sized tank, they also revealed a connection between the thickening rate and the increase or decrease in liquid volume to be wasted. Therefore, they showed that this volume could be reduced by controlling the settling rate of biosolids.

Review Questions

1. What are the three major classifications of industrial wastes at an industrial plant?
2. What are the implications of these three types of wastes?
3. What do we mean by "industrial water conservation?"
4. What is another method of reducing volume? Give examples.
5. What advantage do we get by reducing waste volume?
6. What is another method of reducing volume?
7. What is the greatest factor influencing an industry to reuse its wastewater?
8. What is usually the greatest deterrent to industrial reuse of wastewaters?
9. How can we encourage water conservation in an industrial plant?
10. What is yet another method of reducing the volume of wastewaters?

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