Treatment of Industrial Waste

CEU 260

Continuing Education from the American Society of Plumbing Engineers

June 2018

ASPE.ORG/ReadLearnEarn

Note: In determining your answers to the CE questions, use only the material presented in the corresponding continuing education article. Using information from other materials may result in a wrong answer.

Industrial wastewater is a generic term used to describe non-sanitary (plumbing) effluent, such as that typically discharged from chemical, pharmaceutical, and other manufacturing facilities. It also may be applied to wastewater from commercial facilities such as self-service laundries or large restaurants. The definition also includes stormwater runoff containing anything considered harmful by the U.S. Environmental Protection Agency (EPA) that is discharged from sites involving any industrial activity or construction.

Whether discharged to municipal sewers, surface waters, deep wells, or land, industrial wastewater and some stormwater runoff are subject to government permitting requirements. In most cases, these wastes must be treated before discharge to abate pollution. Permits specify the maximum allowable concentrations of pollutants in the discharge and the frequency and type of monitoring required to show compliance. Pollution abatement by dilution is no longer allowed. The segregation of incidental water streams, such as non-contact cooling water or stormwater runoff, from process wastewater is almost universally required. Even clean, incidental wastewater streams require a permit.

Most nonaqueous liquids (including solvents, oils, and sludge) and some solids and gases are regulated as hazardous substances or hazardous wastes during their generation, use, collection, storage, transportation, treatment, and disposal. Some aqueous wastes that are not regulated under a wastewater permit are regulated as either hazardous substances or hazardous wastes.

As a result of these regulations, plumbing designers must either consult with an experienced environmental engineer or become familiar with the various environmental requirements to ensure an acceptable installation. New facilities must meet both environmental and plumbing code requirements. For novel manufacturing processes, the designer, environmental engineer, and owner may be required to work with regulatory authorities during the design stage to ensure compliance with the intent of the various codes and regulations. The designer is responsible for producing an installation with a low probability of failure. For plumbing design, this means minimizing the possibility of leaks and providing a means to limit the impact of spills on the public's safety and the environment.

This chapter describes the regulatory framework governing industrial wastewater, hazardous substances, and hazardous wastes and the impact of these regulations on industrial process plumbing design. It also contains design considerations and describes a few of the more common treatment technologies.

TERMINOLOGY

Hazardous substance Under Section 311 of the Clean Water Act (CWA), the EPA has compiled a list of hazardous substances (40 CFR 116). If a substance on this list is spilled or discharged, it must be reported to the EPA.

Priority pollutant The Natural Resources Defense Council and the EPA determine priority toxic pollutants. These pollutants have been incorporated into several regulatory programs, including National Pollutant Discharge Elimination System (NPDES) permits, pretreatment standards (40 CFR 403), hazardous wastes (40 CFR 261), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (42 USC 103).

Hazardous waste The EPA has adopted regulations to control hazardous wastes under the Resource Conservation and Recovery Act (RCRA). These regulations (40 CFR 261) list hazardous wastes, including specific chemicals and mixtures defined by their characteristics. It should be noted that controls under RCRA apply to waste only and not to hazardous substances that are being stored prior to use in product manufacturing or that are to be reclaimed, recycled, or reused. RCRA regulates the generation, transportation, storage, treatment, and disposal of hazardous wastes.

Hazardous material This term means substances or materials that have been determined by the U.S. Secretary of Transportation, under 49 CFR 172, to be capable of posing an unreasonable risk to health, safety, and property when transported in commerce. Chemicals included in this definition are hazardous substances, hazardous wastes, most of the priority pollutants, and many other chemicals in commerce that are too numerous to mention here. In this chapter, the term *hazardous material* is used to describe all of the previously defined materials and substances.

For detailed listings of these and other regulated chemicals and wastes, refer to the regulations cited in the above definitions.

REGULATORY FRAMEWORK

The most important pieces of environmental legislation affecting the design of plumbing systems for hazardous material and waste facilities serving industrial plants are the Clean Water Act, Resource Conservation and Recovery Act, and Comprehensive Environmental Response, Compensation, and Liability Act (also known as Superfund). The National Pollutant Discharge Elimination System permitting program also includes the discharge of stormwater from selected industrial sites. These regulations, promulgated by the EPA and enforced by either the EPA or counterpart state agencies, provide a comprehensive framework of pollution control.

Current EPA regulations can be found in the Code of Federal Regulations (CFR), which is an annually updated compendium of all federal regulations. Any updates or regulation changes after the last publication date of the CFR can be found in the *Federal Register,* a daily government publication in which all U.S. agencies and departments publish their notices, proposals, and final regulations. Most states with counterpart regulations have similar publications.

The great body of codes and regulations can easily be a labyrinth, even for those persons with a good understanding of the overall outline and purpose of the statutes. Plumbing engineers should not hesitate to seek advice from trade groups, regulatory officials, environmental engineers, lawyers, and other specialists as needed. Numerous current event reporting services digest federal and state regulatory actions and publish readable evaluations as well as reprints of important regulations, policies, and case notes.

Clean Water Act

The CWA sets uniform national standards for discharges to surface waters and sewers. The EPA has established categorical effluent standards, usually prorated to production volume, for approximately 58 industrial classifications under the Effluent Guidelines Program Plan. Current information on these classifications can be found at www2.epa.gov/eg. The EPA has also promulgated general standards for discharges to public sewer systems. These standards restrict pollutants that interfere with sewage treatment, pass through the system untreated, damage sewer lines or treatment facilities, or overload treatment processes.

State laws and regulations follow the federal format, with a few important differences. All states are allowed to make their regulations more stringent than the federal standards. Additionally, some states regulate discharges to the land (and hence to the groundwater). States also set goals for water quality levels in streams, lakes, and coastal waters. They then determine the allowable loading of each pollutant and allocate portions of that loading based on low-flow conditions where dilution is minimal. Water quality-based discharge permit limits are almost always more stringent than the industry-wide limits of the categorical effluent standards.

Two types of water discharge permits may require treatment processes. Permits for a direct discharge into a surface water (stream, lake, ocean) are called National Pollutant Discharge Elimination System permits. These permits may be issued by the EPA or a state or jointly, depending on the location. Application is required well in advance of initiating a discharge.

The other type of industrial discharge permit is obtained from a publicly owned treatment works (POTW). Industrial discharges to a POTW are called indirect discharges and are regulated by pretreatment ordinances to ensure that the POTW meets the conditions of its NPDES permit. The ordinances are usually administered by the POTW, except when the industrial discharge is large, the POTW fails to meet its permit requirements, or the discharge is from an industry regulated under the Effluent Guidelines Program Plan.

RCRA and CERCLA

The Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation, and Liability Act, together with the federal and state regulations derived from them, have a major impact on the industrial management of hazardous substances and hazardous wastes. Almost all nonaqueous liquids, many aqueous mixtures, and many solids and gases are regulated when they become wastes or are spilled.

The purpose of CERCLA is to limit the uncontrolled release or threat of release of hazardous substances into the environment and to provide for a coordinated and effective response to mitigate actual releases. CERCLA requires industrial risk evaluations, in the form of contingency plans, and establishes a mechanism for governmental response to environmental and health hazards. CERCLA does not require any permits and does not force changes in current hazardous substance handling methods. Nevertheless, a great deal of negative publicity can result when the mishandling of hazardous substances leads to an environmental incident. It also can be very costly to dispose of the hazardous wastes generated during a spill. These are strong inducements to chemical manufacturers and users to install process systems that minimize risk.

RCRA's purpose is similar to CERCLA's, except that RCRA regulates hazardous wastes from ongoing manufacturing activities. The goals of RCRA are accomplished through strict licensing and operational standards for every aspect of hazardous waste management.

RCRA requires identification numbers and/or permits for every hazardous waste activity. The permit application requirements are lengthy and technical for some of the regulated activities. In some cases, the regulations give performance standards that the designer must meet to obtain a permit for the facility. In other cases, the compliance method is almost completely specified. Obtaining RCRA permits for a facility may take many months and may require public hearings and the disclosure of detailed process and waste information, including chemical material safety data sheets (MSDS).

When evaluating waste streams to determine if they are regulated as hazardous wastes, it is important to check both federal and state regulations. This is because states are allowed to be more stringent than the EPA. States may define certain wastes as hazardous when the EPA doesn't consider them so. For example, waste oil is considered hazardous by many states, but not by the EPA.

The relationship between RCRA and CERCLA is shown by this example: A tank containing a hazardous substance begins to leak onto the ground. Under CERCLA, the owner must notify the EPA and the state, stop the leak, and clean up the spilled material. If the owner fails to take action, the regulatory agency may act under CERCLA and then seek reimbursement up to triple the cost of its expenses. Under RCRA, the spilled hazardous substance and any contaminated soil become hazardous waste. The hazardous waste must be removed, stored, transported, and disposed of in accordance with RCRA requirements.

DESIGN CONSIDERATIONS

For plumbing designers, the challenge is to design systems that minimize the chance of leaks, contain any spills that might occur, and segregate hazardous substances from both nonhazardous process streams and incompatible hazardous process streams. The design of a system that anticipates the potential for leaks and spills must include suitable materials, reliable joining, good fabrication, and a provision for the secondary containment of liquids in areas and systems that pose a high spill risk.

Many leaks occur as a result of material incompatibility between equipment and either the hazardous substances handled or the atmosphere in which the equipment is utilized. The incompatibility can be physical, such as polyvinyl chloride (PVC) pipes melting at high temperatures or plastic pipes dissolving in solvents they were not designed to contain. Table 3-1 lists the general properties of the most common tank and pipe materials. Specific applications should be checked with the appropriate chemical compatibility references from the manufacturer.

Table 3-1 General Properties of Materials Used for Storage Tanks and Piping

Material	Advantages	Disadvantages
Carbon steel	Compatible with petroleum products and dry organics and incompatible with many aqueous solutions.	Subject to attack by corrosive soils and chemicals.
Stainless steel	Better corrosion resistance than carbon steel and higher structural strength. More than 70 standard types of stainless steel and many special alloys are available.	Corroded by chloride and exposure to reducing environments.
Fiberglass-reinforced plastic	Compatible with a wide range of petroleum and chemical products if the proper resin is selected.	Lacks the structural strength and impact resistance of steel tanks.
Polyvinyl chloride	Excellent chemical resistance to acids, alkalis, and gasoline.	Lower structural strength than steels and generally not suited for the storage or handling of organic solvents such as benzene, carbon tetrachloride, and acetone or use at temperatures above 140°F (60°C).
Concrete	Generally good resistance to alkaline chemicals. Epoxy coatings are often applied to increase chemical resistance.	Subject to cracking and spalling with changes in temperature such as during freeze/thaw cycles. Uncoated concrete absorbs solvents.
Polypropylene	Resistance to all aqueous solutions except strong oxidizers.	Low structural strength and a temperature limit of 248°F (120°C).
Lined steel	Chemical resistance of plastic and the structural strength of steel.	Relatively high cost for material and installation.

Even the best designed liquid-handling systems are subject to occasional failure, particularly during liquid transfer operations. Secondary containment is an important aspect of any hazardous material system design to protect employees and the environment. Secondary containment may include a dike around a tank or tank farm or pipes within pipes for systems handling extremely hazardous liquids.

Common secondary containment systems typically have the following features:

- Containment floors, pads, ponds, and dikes constructed of materials impervious to the substance stored
- Perimeter diking and storage reservoirs sized to contain 110 percent of the largest tank plus the maximum rainfall predicted to occur over 24 hours once in 10 years for exterior areas or 20 minutes of sprinkler water flow for interior areas
- Pumps, drain valves, or siphons to empty the secondary containment area to either a storage tank or a treatment facility
- Controls and procedures to prevent the accidental release of contained spills and an alarm system to notify operations personnel if a spill occurs

Minimal equipment and practices to prevent transfer spills should include overfill prevention with level sensors, gauges, and a high level alarm; automatic valve and pump shutdown; established transfer procedures including an operator on duty; proper curbing and containment; redundant valves and controls; vapor recovery; alarms; regular inspections; and a maintenance program. The equipment used in water treatment is operated to achieve the following: mixing and flocculation, sedimentation, clarification, filtering, turbidity removal, metals removal, and disinfection.

Historically, underground tanks up to 10,000 gallons (37,854 L) in capacity and occasionally larger have been preferred for hazardous materials, primarily to minimize fire risks. Unfortunately, many of these tanks were kept in service too long and, because of corrosion, have leaked and contaminated drinking water supplies. As a result, designers now must compare the environmental and fire risks of aboveground tanks. In either case, more attention must be given in the design to ensure that an installation is resistant to leaks and capable of containing spills. Soil conditions and groundwater levels, which affect the design, must be evaluated for each installation. Secondary containment of these tanks is the primary method of ensuring against leakage.

ELEMENTS OF AN INDUSTRIAL WASTEWATER HANDLING SYSTEM

pH Control

Neutralization for pH control involves the chemical reaction of an acid with an alkaline substance (a base), resulting in the formation of a salt and water. In an aqueous solution, the acid or base molecules dissociate and form ions. Sulfuric acid is presented in the solution as H^+ (hydrogen) and SO_4 (sulfate) ions and caustic soda as Na^+ (sodium) and OH^- (hydroxide) ions. The H^+ ions of the sulfuric acid and the OH^- ions of the caustic soda have a strong attraction to each other and combine to form H_2O (water). For example, in the neutralization reaction of H_2SO_4 (sulfuric acid) and NaOH (sodium hydroxide), the following process occurs:

$$H^+{}_2SO_4 + 2Na^+OH^-$$

$$Na^+{}_2SO_4 + 2H_2O$$

If excess hydrogen ions remain, the liquid will be acidic, and with a surplus of hydroxide ions, the liquid will be alkaline.

The acidity or alkalinity of a solution is expressed on the pH scale, with neutral water at a pH of 7, in the middle of the range between extremely acid (pH = 0) and extremely alkaline (pH = 14). The scale is logarithmic, so a pH of 3 is 10 times more acidic than a pH of 4. Buffers, such as bicarbonate/carbonate, undergo a chemical change when strong acids or bases are added to a solution and thereby act as capacitors that must be filled before the pH will change.

A typical two-stage, continuous-flow pH neutralization process is shown in Figure 3-1. For flows less than 10 gallons per minute (gpm) (37.85 L/min), neutralizing in a batch basis, with two tanks alternating between collection and treatment, is sometimes preferred.

The most critical feature of the pH adjustment system is the controller that activates the chemical feed pumps. The controller must have the ability to prevent overfeeding of either acid or base, which would cause wide pH swings and subsequent repetitive chemical additions. Overfeeding is most probable in wastewater with no buffering capacity near the pH setpoint (e.g., deionized and soft water). Controllers with multi-rate response adjustment should be specified for each application.

Sulfuric acid is the most common acid used for pH adjustment purposes, although in some cases the commercial 93 percent acid must be diluted prior to use. The manufacturer's recommendations regarding materials of construction, control of the heat of dilution, and safety precautions should be carefully followed. Carbon steel pipe and tanks are commonly used for 93 percent sulfuric acid, with stainless alloy 20 (a high nickel alloy) valves, as well as PVC and chlorinated polyvinyl chloride (CPVC) plastics. For sulfuric acid at concentrations below 93 percent, polypropylene (PP), fiberglass-reinforced plastic (FRP), PVC, CPVC, and lined steel are preferred.

Sodium hydroxide (caustic or caustic soda) in 50 percent solution is the most convenient commercial alkaline material for pH adjustment. Unfortunately, 50 percent caustic freezes at 54°F (12.2°C), so indoor storage or heated tanks are necessary. (Note that 20 percent caustic freezes at -18°F [-27.7°C].) Caustic solutions may be handled in carbon steel, stainless steel, and PVC tanks and pipe. Lime and hydrated lime are considerably less expensive than caustic but must be fed with dry feeders and/or slurry tanks, which require considerable maintenance. Consequently, lime is favored in applications where the cost outweighs the convenience of caustic.

Removal of Dissolved and Suspended Metals

Another common industrial wastewater treatment requirement is the removal of dissolved and suspended metals. The most popular method is to separate cyanide and chromium VI wastewater sources from each other and all other metal-bearing wastewater. The cyanide is destroyed by oxidation with chlorine (or a sodium hypochlorite solution) at a pH of 9 to 11, and the chromium VI is reduced to chromium III with sulfur dioxide or sodium bisulfate at a pH of 2. Various treatment methods are shown in Figures 3-2, 3-3, and 3-4.

For trace metals up to 1,000 parts per million (ppm), the use of ion-exchange vessels containing resin beads tailored to the application may be considered. Ion exchange is a reversible chemical reaction wherein an ion (an atom or molecule that has lost or gained an

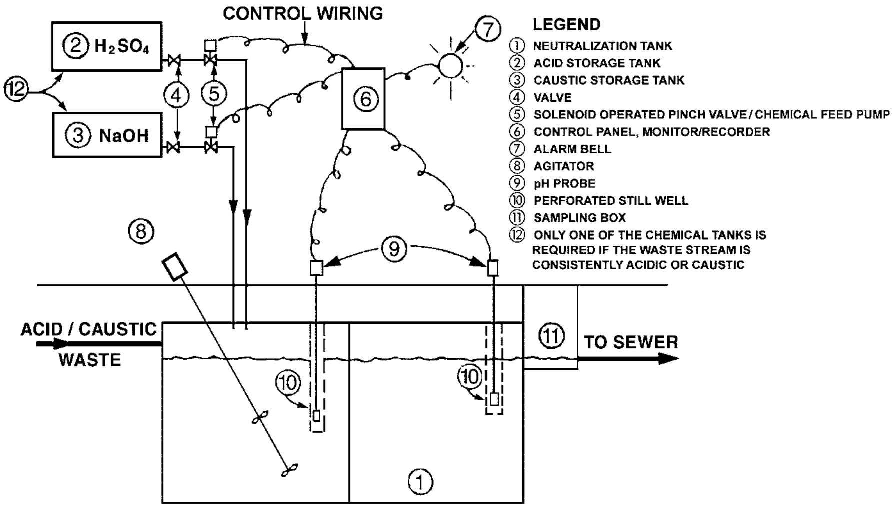

Figure 3-1 Acid/Caustic Neutralization Diagram
Note: Not to scale.

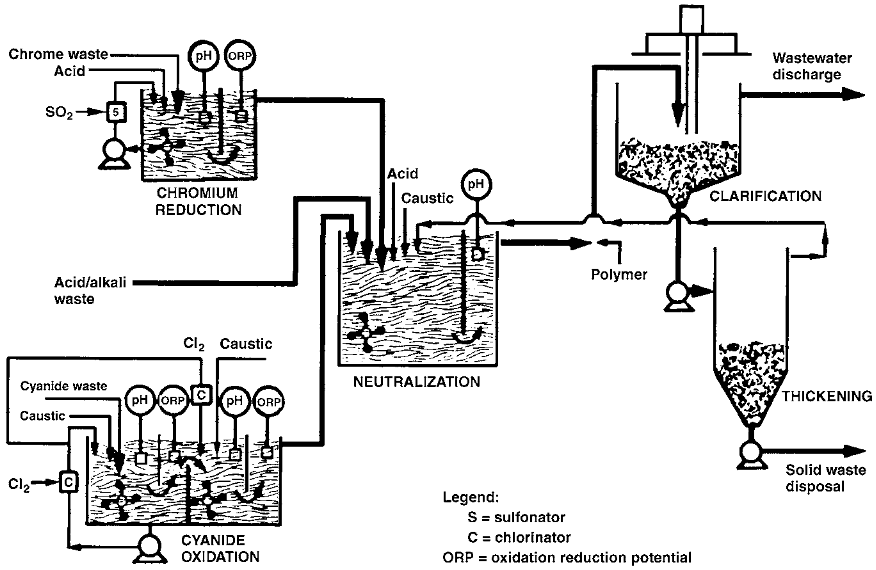

Figure 3-2 Conventional Electroplating Industry Wastewater Treatment
Note: Not to scale.

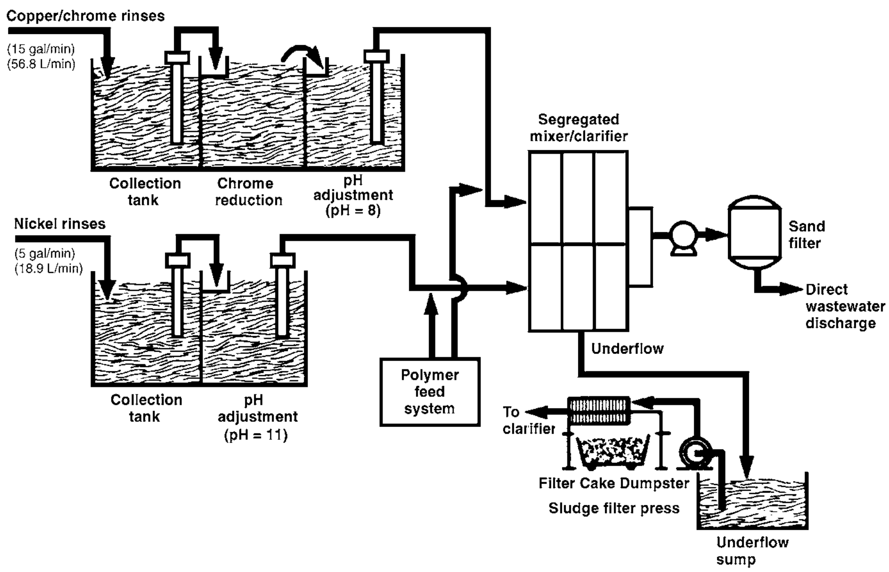

Figure 3-3 Treatment System with Wastewater Stream Segregation
Note: Not to scale.

electron and thus acquired an electrical charge) from a wastewater solution is exchanged for a similarly charged ion attached to an immobile solid particle. These solid ion particles are either naturally occurring inorganic zeolites or synthetically produced organic resins, which are the predominant type used today because their characteristics can be tailored to specific applications. This process is similar to the process for purifying water for laboratory or process applications. The exact ion combinations are based on the metals to be removed.

The exchange vessels can be sized for the wastewater flow, or multiple vessels can be manifolded together to handle higher wastewater flows or to allow standby capacity. Automated controls and accessories can be furnished to back-flush or regenerate the vessels. The removed metals can then be reclaimed or safely disposed. This technology should be evaluated against other technologies for overall operating costs based on size and the type of application.

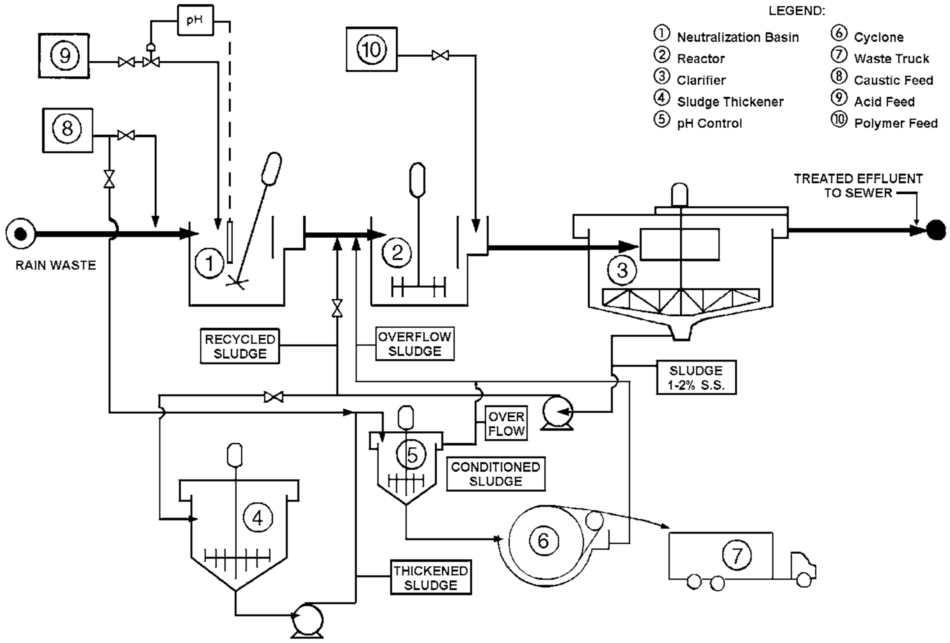

Figure 3-4 Typical Continuous Treatment of Wastewater and Solids-Handling System for Heavy Metals
Note: Not to scale.

Oil/Water Separation

Oil/water separation may involve free-floating oils, mechanical emulsions or diversions, and chemical emulsions. The size of the oil droplets in emulsions may range from less than 20 microns (µ) to more than 150 µ. In selecting the separation equipment, the designer must consider the oil quantity, droplet size, the presence of emulsifiers, the temperatures of the water and oil, the difference in the specific gravities of the fluids, fluid viscosity, pH, and other wastewater constituents.

Separators are on the market to suit every situation, including simple settling tanks (e.g., American Petroleum Institute separators), tanks with coalescing media to promote the agglomeration of dispersed oils, and tanks with chemical pretreatment to promote the separation of chemically emulsified oils. Equipment options include sludge removal and automatic oil skimming. In special conditions, such as where oil is mixed with and adheres to suspended solids, dissolved-air flotation separators may be necessary. Figure 3-5 shows a unit designed to remove free and mechanically emulsified oil.

Biological Treatment

Wastewater discharging directly to surface water or groundwater must be treated to remove organic compounds that would deplete the dissolved oxygen in the receiving water. Typically, permits allow an average of 30 milligrams per liter of five-day biological oxygen demand (BOD5). Treatment is accomplished by processes that convert soluble organic compounds to biological cell mass, which can be separated from the effluent by gravity in a clarifier. Colloidal materials and some nondegradable compounds are normally absorbed in the settled solids.

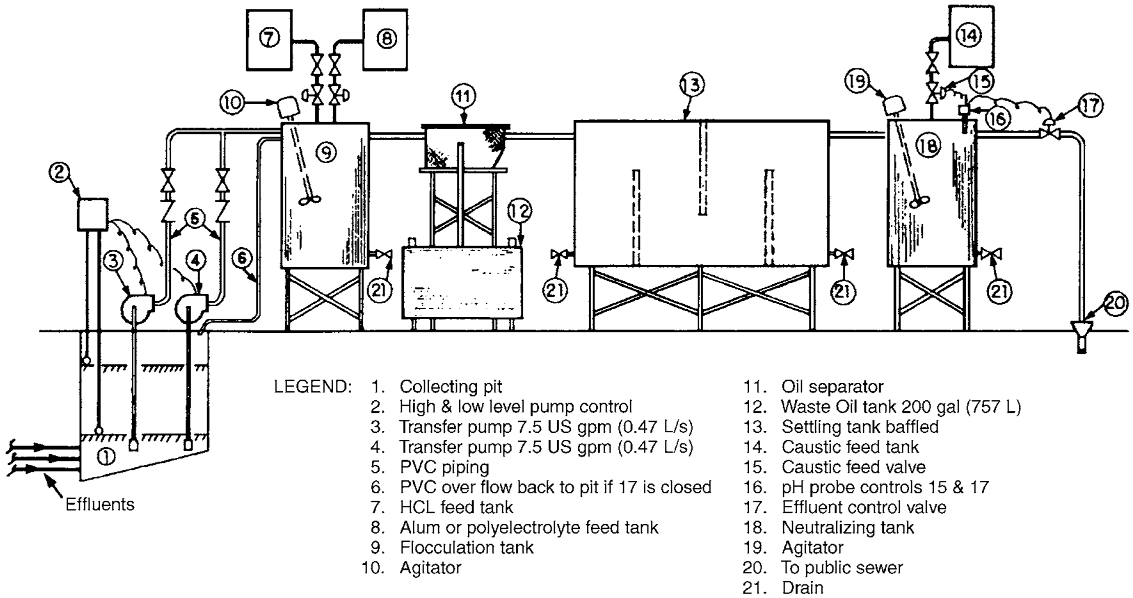

Figure 3-5 Emulsified Oil Removal Flow Sheet
Note: Not to scale.

Biological wastewater treatment plants are expensive to build and operate, and specialized experience is necessary to produce a successful design. Consequently, a company faced with biological treatment requirements should first compare the feasibility and economics of discharging to a municipal treatment system to building its own facility. If the build alternative is indicated, a choice must be made among the available application methods, including activated sludge, aerated lagoons, trickling filters and rotating filters, and the anaerobic process. Expert advice is warranted.

RESOURCES

- ASME B31.3: *Process Piping*
- API Spec 12D: *Specification for Field Welded Tanks for Storage of Production Liquids*
- API Spec 12F: *Specification for Shop Welded Tanks for Storage of Production Liquids*
- API Standard 650: *Welded Tanks for Oil Storage*
- *ASME Boiler and Pressure Vessel Code*
- FM Global Data Sheet 7-83: *Drainage Systems for Ignitable Liquids*
- NFPA 30: *Flammable and Combustible Liquids Code*
- UL 142: *Standard for Steel Aboveground Tanks for Flammable and Combustible Liquids*
- CFR 40: *Protection of Environment,* U.S. Environmental Protection Agency
- *Corrosion Resistant Materials Handbook,* D.J. DeRenzo
- *Kirk-Othmer Encyclopedia of Chemical Technology,* John Wiley and Sons Inc.
- *Perry's Chemical Engineers' Handbook,* Don Green and Robert Perry
- *Handbook of Corrosion Resistant Piping*, Philip A. Schweitzer
- American National Standards Institute: ansi.org
- American Petroleum Institute: api.org
- ASME International: asme.org
- FM Global: fmglobal.com
- National Fire Protection Association: nfpa.org
- National Technical Information Service: ntis.gov
- Underwriters Laboratories: ul.com

ASPE Read, Learn, Earn Continuing Education

You may submit your answers to the following questions online at **aspe.org/readlearnearn**. If you score 90 percent or higher on the test, you will be notified that you have earned 0.1 CEU, which can be applied toward CPD renewal or numerous regulatory-agency CE programs. (Please note that it is your responsibility to determine the acceptance policy of a particular agency.) CEU information will be kept on file at the ASPE office for three years.

Notice for North Carolina Professional Engineers: State regulations for registered PEs in North Carolina now require you to complete ASPE's online CEU validation form to be eligible for continuing education credits. After successfully completing this quiz, just visit ASPE's CEU Validation Center at aspe.org/CEUValidationCenter.

Expiration date: Continuing education credit will be given for this examination through **June 30, 2019**.

CE Questions — "Treatment of Industrial Waste" (CEU 260)
Test written by David Becker, CPD

1. A disadvantage of a lined steel storage tank is ________.
   a. low structural strength and a temperature limit of 248°F
   b. subject to attack by corrosive soils and chemicals
   c. corroded by chlorine and exposure to reducing environments
   d. relatively high cost for material and installation

2. In addition to the EPA, which of the following also sets goals for water quality levels in streams, lakes, and coastal waters?
   a. ICC
   b. states
   c. ASPE
   d. local AHJ

3. Cyanide is destroyed by oxidation with ________ at a pH of 9 to 11, and chromium VI is reduced to chromium III with sulfur dioxide or sodium bisulfate at a pH of 2.
   a. sulfur dioxide
   b. chlorine
   c. sodium bisulfate
   d. lime

4. Which of the following is not one of the most important pieces of environmental legislation affecting the design of plumbing systems for hazardous material and waste facilities serving industrial plants?
   a. MSDS
   b. RCRA
   c. CWA
   d. CERCLA

5. What term means substances or materials that have been determined by the U.S. Secretary of Transportation, under 49 CFR 172, to be capable of posing an unreasonable risk to health, safety, and property when transported in commerce?
   a. hazardous waste
   b. hazardous substance
   c. hazardous material
   d. priority pollutant

6. Typically, permits allow an average of 30 milligrams per liter of ________ biological oxygen demand.
   a. two-day
   b. three-day
   c. four-day
   d. five-day

7. Common secondary containment systems typically have what features?
   a. controls and procedure to prevent the accidental release of contained spills and an alarm system to notify operations personnel if a spill occurs
   b. pumps, drain valves, or siphons to empty the secondary containment area to either a storage tank or a treatment facility
   c. containment floors, pads, ponds, and dikes constructed of materials impervious to substance stored
   d. all of the above

8. Which regulation lists hazardous wastes, including specific chemicals and mixtures defined by their characteristics?
   a. 49 CFR 172
   b. 40 CFR 261
   c. 40 CFR 116
   d. 40 CFR 403

9. Which type of acid is the most common acid used for pH adjustment purposes?
   a. muriatic
   b. nitric
   c. sulfuric
   d. phosphoric

10. In aqueous solution, the acid or base molecules dissociate and form ________.
   a. concentrations
   b. buffers
   c. capacitors
   d. ions

11. Permits specify the maximum allowable ________ of pollutants in the discharge and the frequency and type of monitoring required to show compliance.
   a. volume
   b. discharge
   c. dilution
   d. concentrations

12. The size of the oil droplets in emulsions may range from less than ________.
   a. 20 μ to more than 120 μ
   b. 30 μ to more than 150 μ
   c. 20 μ to more than 130 μ
   d. 20 μ to more than 150 μ