SECTION 5

DESIGN OF COMMON EFFLUENT TREATMENT PLANTS FOR NONHAZARDOUS INDUSTRIAL WASTEWATER

This section addresses major considerations for design and selection of treatment processes for common effluent treatment plants (CETPs) using conventional wastewater treatment technologies. CETPs are designed only to treat nonhazardous industrial wastewater and should focus on simple technology that is cost-effective, requires low maintenance, and has minimal operator requirements. These plants should include processes such as pH adjustment, aerated lagoons, sedimentation/facultative basins, and polishing/infiltration ponds. All of these treatment processes are discussed below.

This section assumes that a piping network or some other collection system (e.g., tank trucks) is in place that carries wastewater from individual sources to the CETP. This section also assumes that industrial wastewaters have been pretreated to remove corrosive and toxic substances that would adversely affect the operation of conventional wastewater treatment and collection processes or that toxic discharges have been directed to treatment facilities designed specifically for hazardous wastes. Section 6 covers the design of centralized treatment facilities for hazardous wastes.

5.1 DESIGN BASIS

Design of an industrial CETP is highly site specific. Major general considerations are site characteristics (see Section 5.1.1) and wastewater characteristics (see Section 5.1.2). Pretreatment standards for waters entering the collection system serving the CETP, and treatment standards for effluent discharged from the CETP also are significant design considerations (see Section 5.1.3). Within the framework of site and wastewater characteristics and treatment standards (see Section 5.15), treatment process selection involves consideration of numerous factors, such as treatment efficiency, reliability, and cost (see Section 5.1.4). Major references that address preliminary and detailed engineering wastewater treatment design in more detail include Metcalf and Eddy (1979), Fresenius et al. (1989), Patterson (1978), Qasim (1985), Sundstrom and Klei (1979), WEF/ASCE (1992), and Martin and Martin (1991).

5.1.1 Site Characteristics

Site characteristics such as topography, soils, geology, hydrology, climate, and land use require some consideration when designing a sewer network and CETP. Topography and depth to bedrock strongly influence the cost of sewer installation, with elevation distributions that allow gravity flow and adequate depth for burial of pipe most desirable. Soil thickness and soil characteristics such as clay content, sand content, organic matter, and permeability are major considerations when certain treatment options are being considered for CETPs, including land treatment, pond/lagoon treatment, or granular media filtration. Unfavorable hydrologic site conditions include:

- Aquifer recharge zones
- Flood-prone areas
- Wetlands
- Seasonally high water table
- Proximity to water supply wells or reservoirs

Important climatic factors to consider include precipitation, especially when infiltration/inflow is a problem with sewers, and evapotranspiration when treatment processes being considered rely wholly or in part on evaporation of treated wastewater. Land use may affect the area of land that is available for a facility, which in turn may affect the selection of treatment process options. Land-intensive treatment options such as stabilization ponds may not be feasible if land is not available or is too expensive.

5.1.2 Wastewater Characteristics

Key characteristics of wastewater that must be considered in designing CETPs include flow, and physical, chemical, and biological characteristics of the wastewater. Wastewater flow, commonly expressed as m^3/day, determines the size of the CETP. Minimum and maximum flow rates should be estimated as precisely as possible because they affect hydraulic computations and sizing of channels and distribution pipes. Design flows also should incorporate anticipated future increases. Large temporal flow variations (e.g., diurnal fluctuations, inflow/infiltration response to rainfall) may require use of equalization ponds or tanks to allow a constant or nearly constant flow rate through the downstream treatment processes. Another benefit of equalization ponds is to reduce the effect of toxic shock on treatment processes caused by accidental releases of toxic substances. This reduction is accomplished by blending wastewater with lower concentrations in the equalization basin.

Significant physical characteristics include solids, temperature, color, and odor. Solids in the form of floating debris and grease and oil slicks indicate a highly polluted waste stream and indicate untreated or ineffectively treated wastes. Suspended solids contribute to turbidity and silt load and generally require sedimentation or filtration for removal. Wastewater temperature is an important parameter because it affects chemical and biological reactions and the solubility of gases such as oxygen. Generally, higher temperatures increase reaction rates and solubility up to the point where temperature becomes high enough to inhibit the activity of most microorganisms (around 35 C). Color and odor serve as indicators of the degree of pollution of a waste stream, and their presence in wastewater indicates inadequate pretreatment prior to discharge.

Significant chemical characteristics of wastewater include organics, inorganics in solution, and gases. Biological oxygen demand (BOD) provides an indicator of the amount of organic substances of biological origin (proteins, carbohydrates, fats, and oils) and biodegradable synthetic organic chemicals in wastewater. A comparison between the BOD of influent wastewater and treated effluent provides a measure of the efficiency of a CETP in stabilizing organic matter. Chemical oxygen demand (COD) measures nonbiodegradable as well as biodegradable organics.

The ratio between BOD_5 (oxygen demand using a 5-day test) and COD provides an indicator of the ease of biological treatment. Biological decomposition processes generally start quickly and proceed rapidly with BOD_5:COD ratios of 0.5 or greater. Ratios between 0.2 and 0.5 are amenable to biological treatment, but decomposition may proceed more slowly because degrading microorganisms need to become acclimated to the wastewater. A ratio of less than 0.2 indicates serious limitations for biological treatment. The BOD:COD ratio of industrial wastewaters is typically less than 0.5, except for wastewaters from the food and beverage industries, which are often significantly higher than 0.5 (Fresenius et al., 1989).

Common inorganic constituents in wastewater include chloride, hydrogen ions (influencing pH), alkalinity-causing compounds, nitrogen, phosphorus, and sulfur. Nitrogen and phosphorus are essential nutrients for plant growth, and if they are significantly higher in treated effluent that is discharged to surface water, they can cause excessive algae growth. Concentrations of heavy metals and other toxic compounds, such as cyanides, are a major consideration in the design of CETPs. The setting and enforcing of pretreatment standards to prevent toxic shock to treatment processes is an important element in the design of an industrial CETP (Section 5.1.3).

Microbial action associated with biological wastewater treatment methods produces a variety of gases, including nitrogen, carbon dioxide, hydrogen sulfide, ammonia, and methane. The type of gases in treated wastewater indicates whether aerobic or anaerobic degradation is taking place. Most biological treatment processes are aerobic, with the maintenance of dissolved oxygen being a critical element of design. Anaerobic degradation, indicated by presence of gases such as hydrogen sulfide and methane, tends to produce obnoxious end products and indicate improper system design unless a specific anaerobic treatment process is being used.

5.1.3 Pretreatment Standards

As noted above, wastewater from industrial processes requires some form of pretreatment prior to discharge to a sewer to (1) minimize corrosion and clogging of sewer lines, and (2) prevent reductions in biological treatment process efficiency by toxic effects from toxic concentration of organic and inorganic substances. Table 5-1 identifies industrial wastewater effluent limits for discharge to sewers served by conventional wastewater treatment plants in Germany, Thailand, the metals finishing industry in the United States of America, and the city of Dallas, Texas. In the United States, wastewater pretreatment standards have been developed for most major industrial categories based on characteristics of the wastewater and the effectiveness of available treatment technologies. Limits in Table 5-1 are generally similar for most substances but differ by an order of magnitude for several (cadmium, lead, mercury, selenium, and silver). Generally, these differences can probably be attributed to differences in regulatory judgment based on an assessment of the availability and cost of treatment technologies.

Pretreatment standards for sulfides, sulfates, and pH are primarily concerned with preventing corrosion of concrete parts in sewers. Limits to discharge of oil and grease, grit, and heavy sediments prevent clogging of sewers. Limits to heavy metals and toxic organics, however, primarily ensure proper performance of biological treatment processes and minimize accumulation of contaminants in residual sludges.

To a certain extent, design of an industrial CETP may provide an opportunity for selecting treatment processes that tolerate higher influent concentrations of toxic substances than would normally be allowable for conventional wastewater treatment plants. For example, greater emphasis on granular media filtration rather than biological treatment might allow higher concentrations of heavy metals than indicated in Table 5-1. The tradeoff in relaxing pretreatment standards at the industrial source is increased levels of toxic substances in the CETP residuals, especially in sludges. It is essential, however, for the successful operation of a CETP to prevent toxic shock to treatment processes. Table 5-2 indicates ranges of concentrations at which various inorganic constituents and phenols are likely to inhibit biological treatment.

Table 5-1. Wastewater quality limits for discharge to conventional wastewater treatment plants

General parameters	Germany	Thailand	U.S. Metal finishing	Dallas, Texas
General parameters				
Temperature	< 35 °C	--	--	--
PH	6.5 a 10	6.5-9	6.0-9.0	--
Total suspended solids	--	--	31 mg/L	--
Organics	mg/L	mg/L	mg/L	mg/L
Saponifiable oils and greases	250	--	--	--
Oil and grease	--	300	26	--
Halogenated hidrocarbons	10	--	--	--
Volatile phenols in steam	100	--	--	--
Dyestuffs	[b]	--	--	--
Inorganics (dissolved and suspended)				
Arsenic	1.0	0.25	--	0.05
Barium	-	1.0	--	1.0
Cadmium	0.3	0.03	0.26	0.1
Chromium (VI)	0.5	--	--	--
Chromium, total	3.0	0.5	1.71	3.0
Copper	2.0	1.0	2.07	--
Lead	2.0	0.2	0.43	3.0
Manganese	--	5.0	--	1.0
Mercury	0.05	0.005	--	0.005
Nickel	4.0	0.2	2.38	--
Selenium	1.0	0.02	--	--
Silver	--	0.02	0.24	--
Tin	5.0	--	--	--
5.0	5.0	1.48	--	
Inorganics (dissolved)				
Ammonium (NH_4)/ammonia (NH_3)	5	--	--	--
Cyanide, easily	1	--	--	--
Cyanide, total	20	1	0.65	--
Fluoride	60	--	--	--
Sulfate	600	500	--	--
Sulfide	2	5	--	--

[a] Best practical control technology currently available (BPT), monthly average.
[b] Only in such low concentrations that after treatment in a sewage treatment plant, the effluent does not visually color the receiving water.
Sources: Germany: Fresenius et al. (1989); Thailand: Thailand Institute of Scientific and Technological Research (1994): U.S. metal finishing: 40 CFR 433.13; Dallas, Texas: Saltzberg and Cushnie (1985)

Table 5-2. Threshold concentrations inhibiting biological treatment processes

Parameters	General (mg/L)	Activated Sludge: Carbonaceous Removal[a] (mg/L)	Activated Sludge: Nitrification [b] (mg/L)
Aluminium	-	15-26	-
Ammonia	-	480	-
Arsenic	-	0.1	-
Borate (boron)	-	0.05-100	-
Cadmium	3-10	10-100	-
Calcium	-	2500	-
$Chromium^{6+}$	3-10	1-10	0.25
$Chromium^{3+}$	10-20	50	-
Cobalt	2-15	-	-
Copper	1-3	1	0.005-0.5
Cyanide	0.3-2	0.1-5	0.34
Hydrogen sulfide	5-30	-	-
Iron	-	1000	-
Lead	-	0.1	0.5
Manganese	-	10	-
Magnesium	-	-	50
Mercury	-	0.1-5	
Nickel	2-10	1-2.5	0.25
Silver	-	5	-
Sulfate	-	-	500
Zinc	3-20	0.08-10	0.08-0.5
Phenols:			
Phenol	-	200	4-10
Cresol	-	-	4-16
2-4 Dinitrophenol	-	-	150

[a] Generally equivalent to BOD_5 (degradation of organic material in the absence of nitrification).
[b] Oxidation of ammonia to nitrate.
Sources: General: Fresenius et al. (1989); activated sludge: WPCF/ASCE (1977).

Fresenius et al. (1989) give an example of a municipal treatment plant that received a toxic shock of chromate from the illegal discharge of a galvanizing bath containing chromic acid. The activated sludge unit received chromate-contaminated wastewater with concentrations as high as 270 mg/L of chromate for 1 hour. The toxic shock in the activation unit was evident by strong foaming and a dramatic decrease in treatment efficiency. Before the shock, discharge treatment efficiency was about 65 percent. Several hours later, it dropped to 25 percent. Treatment efficiency gradually recovered but had not fully recovered 4 days later.

5.1.4 Collection System

Industrial wastewater can be transported from manufacturing facilities to a central treatment plant by tank truck or through a piping system (i.e., sewer system). Trucking wastewater to centralized treatment facilities is discussed in detail in Section 6.1.2. Piping wastes is only practical if participating firms are located close to the central facility. Consequently, piping wastes to a CETP is usually limited to industrial estates.

Designs of sewer collection systems for industrial CETPs are generally the same as for municipal wastewater treatment plants. The following references provide detailed guidance on collection system design: American Society of Civil Engineers/Water Pollution Control Federation (ASCE/WPCF) (1969, 1982), Fresenius et al. (1989), and Metcalf and Eddy (1981). Design of piping systems for industrial CETPs generally requires more attention to corrosion prevention and control than do designs for municipal wastewater collection systems. Pretreatment to neutralize corrosive wastewaters and reduce sulfide/sulfate content before discharge to the sewer is the primary method of corrosion control, but intentional or accidental releases of strongly acid or alkaline wastewaters cannot be completely eliminated. Major measures to control corrosion of pipe materials include:

- Designing system hydraulics to avoid sulfide generation.
- Providing oxygen to water to avoid sulfide generation.
- Providing chemical control of sulfide generation.
- Increasing concrete pipe thickness to allow for some corrosion.
- Increasing neutralizing capacity of concrete pipe by using calcareous aggregate or increasing cement content.
- Using vitrified clay pipe, which is virtually immune to acid attack (requires gasketed joints and special installation practice and care in handling and transport).
- Using corrosion-resistant pipe linings or protective coatings.

The U.S. Environmental Protection Agency (EPA) (1985) provides detailed guidance on methods for control of corrosion in sewage collection systems.

If a wastewater collection system already has been installed prior to design of a CETP (e.g., as part of the development of an industrial estate), it may be necessary to evaluate the condition of the system and perform any necessary rehabilitation prior to constructing the CETP. EPA (1991) provides detailed guidance on methods for sewer system analysis and rehabilitation.

5.1.5 Treated Effluent Discharge Standards

Wastewater treatment processes differ in their effectiveness in reducing concentration of parameters of concern (e.g., BOD, total suspended solids), and the standards for discharge of treated wastewater effluent determines whether a given combination of treatment processes provides an acceptable level of treatment. Before beginning design, the applicable effluent discharge standards should be identified. Table 5-3 provides examples of standards for discharge of treated industrial wastewater for India, Thailand, and the United States. Standards may vary depending on the point of discharge of treated wastewater. The standards in Table 5-3 for India are for discharge to marine coastal areas, and for Thailand are for discharge to public waterways. The secondary treatment standards for publicly owned wastewater treatment facilities in the United States of America may or may not be acceptable for surface discharge depending on stream use and water quality. In Thailand, the suspended solids standard is a range that depends on the ratio of the volume of the wastewater discharge to the volume of the receiving waterway.

Table 5-3. Wastewater treatment effluent standards

Parameters	India[a]	Thailand[b]	United States[c]
Chemical oxygen demand (COD)	250		--
Biological oxygen demand (BOD)	100	20-60[d]	30
Suspended solids	100	30-150	--
Dissolved solids	--	2000-5000	--
Ammonium nitrogen (NH_4-N)	50		
Total Kjeldahl nitrogen	100	--	--
Oil and grease	20	5	--
pH	5.5-9.0	5.0-9.0	6.0-9.0

[a] Industrial effluent discharge into marine and coastal areas.
[b] Industrial effluent discharge standards into public waterway.
[c] Secondary effluent criteria for publicly owned treatment facilities.
[d] Fishery canning, noodle industry, tanning industry, pulp industry and frozen food industry are allowed a maximum of 100 mg/L.
Sources: India: Chemcontrol (1991), Thailand: TISTR (1994)

5.1.6 Unit Treatment Processes

Wastewater treatment can be divided into four major steps or categories:

1. *Preliminary treatment* may involve a number of unit processes to eliminate undesirable characteristics of wastewater received from the collection system. Processes include use of screens and grates to remove large particles, comminutors for grinding of coarse solids, preaeration for odor control, and some removal of grease.

2. *Primary treatment*, also called *primary clarification*, involves removal of readily settleable solids prior to biological treatment. Settling basins or sedimentation chambers are the main unit involved, but various auxiliary processes, such as flotation, flocculation, and fine screening, may also be used.

3. *Secondary treatment* involves the purification of wastewater primarily by decomposition of suspended and dissolved organic matter by microbial action. Numerous biological unit treatment processes are available, but most can be classified as land treatment, pond/lagoon, activated sludge, or biological filtration methods, such as disc rotating biological filters.

4. *Auxiliary treatment* encompasses a large number of mostly physical and chemical unit processes that can be used before or after secondary biological treatment to meet specific treatment objectives. The term *secondary clarification* or *tertiary treatment* may be applied to unit processes that follow secondary treatment.

Design of the actual treatment system for a CETP involves selection of a process train or alternative process trains based on the ability of individual unit treatment processes to remove specific waste constituents. Table 5-4 provides an overview of the major unit treatment processes, including their function and type of treatment (physical, chemical, biological), and points out the treatment stage during which they may be used. Section 5.2 discusses physical and chemical unit treatment processes further, and Section 5.3 discusses biological treatment processes further. Section 5.4 identifies criteria and procedures for the selection of unit treatment processes. Unit treatment processes that are used mainly for pretreatment or centralized treatment of hazardous industrial wastewaters are covered in Section 6.

Table 5-4. Overview of wastewater unit treatment processes

Unit Process Name/Description	Type of Treatment	Treatment Stage			
		P	I	II	III
PRIMARILY PRELIMINARY TREATMENT					
Equalization basin mixes wastewater to reduce concentration variations and prevent "peaks"	Physical	x			
Grit chamber removes grit and dirt	Physical	x			
Coarse screens (bar, woven wire) remove large solids	Physical	x			
Comminutor grind solids to reduce their size	Physical	x			
Oil/grease separator removes oily materials	Physical	x			
MAINLY PRIMARY TREATMENT					
Sedimentation removes readily setteable inert and organics solids	Physical		x	x	x
Fine screens remove inert and organic solids	Physical		x		x
Air flotation removes grease and light solids	Physical		x		
Flocculation (air and mechanical) improves removal of suspended solids	Physical Chemical		x	x	x
Emulsion-breaking system remove dispersed oil and grease	Physical Chemical		x		
MAINLY SECONDARY TREATMENT					
Land treatment provides filtration and aerobic treatment of wastewaters. Methods include: (1) rapid infiltration, (2) spray irrigation, (3) overland flow, (4) subsurface soil absorption	Biological Physical-chemical			x	
Stabilization lagoons/ponds treat wastewaters using largely natural processes. Types include (1) aerobic/facultative ponds, (2) aerated aerobic/facultative ponds, (3) total containment, (4) hydrograph controlled release, and (5) polishing ponds	Biological Physical			x	x
Conventional activated sludge provides aerobic treatment by use of suspended microbial floc particles and aerators in a single or series of reactor basins	Biological			x	
Other activated sludge methods with varying designs include: (1) contact stabilization, (2) extended aeration, (3) oxidation ditches, and (4) sequencing batch reactors	Biological			x	
Biological filters use microbial growth on filter media to provide aerobic treatment of wastewater. Major types include: (1) fixed media filters (numerous types classified according to media type, flow rate, and dosing frequency), and (2) rotating biological contactors	Biological			x	
Dual/two-step treatment systems combine activated sludge and biological filter processes	Biological			x	
Anaerobic treatment processes rely on facultative and anaerobic bacteria to degrade dissolved and organic solids. Units also proved flotation and sedimentaiton functions. Major types include: (1) septic/Imhoff tanks, (2) biolytic tanks (suspended biomass), (3) submerged filters and discs (fixed biomass)	Biological Physical		x	x	
Treatment with wetlands uses the natural capacity of certain vegetal species and aquatic ecosystems to depurate pollutant agents	Biological			x	x

AUXILIARY/TERTIARY TREATMENT					
Granular media filtration removes suspended solids by straining, sorption and biological decomposition. Numerous types: (1) sand filters (slow, rapid, intermittent, recirculating), (2) mechanically cleaned high rate, pressure and upflow filters, (3) dual/multi-media filters)	Physical Chemical Biological			x	x
Chemical precipitation/coagulation is used primarily for dissolved solids and phosphorus removal in combination with flocculation and sedimentation. Common chemicals used to promote coagulation include: lime, ferric chloride, polymer, sodium carbonate, barium chloride, sodium hydroxide, alum	Chemical	x	x		x
Chemical oxidation is used primarily for disinfection and odor control. Major methods include (1) chlorination, (2) ozonation, and (3) radiation.	Chemical	x	x		x
Other chemical treatment methods that may be used for wastewater treatment include: (1) addition of nutrient to enhance biological treatment processes, (2) recarbonation to reduce pH, and (3) other neutralization methods.	Chemical			x	x
Activated carbon adsorption removes solids and organic material	Physical-chemical		x		x

Treatment stages: P = preliminary, I = primary, II = secondary, III = tertiary

5.2 PHYSICAL AND CHEMICAL TREATMENT PROCESSES

Physical wastewater treatment mainly separates solids from wastewater mechanically, as with screens, or uses density differences, as with sedimentation and flotation. Most *chemical* treatment of wastewater involves the use of chemicals to remove specific wastewater constituents. In some treatment processes, such as flocculation and sorption, physical and chemical processes are so intertwined that the term *physical-chemical* treatment is used. Table 5-4 indicates that physical and chemical treatment processes are used mainly in preliminary, primary, and tertiary treatment stages.

5.2.1 Preliminary Treatment

Preliminary treatment processes are mainly physical. The simplest *grit chambers* use gravity to remove grit and dirt, which consist largely of mineral particles that need to be removed before biological treatment. *Coarse screens*, typically bars or woven wire, strain out large solids. Where organic material enters as large particles, *comminutors* may be used to reduce particle size to enhance treatment in later stages. *Equalization basins* mix influent wastewater to reduce the variations in concentrations of wastewater constituents and are also used with potentially toxic wastewaters (see Figure 5-1) to: (1) discharge effluent to treatment processes at a uniform rate, leveling out the effect of peak and minimum flows, (2) mix smaller volumes of concentrated wastes with larger volumes at lower concentrations, and (3) control pH to prevent fluctuations that could upset the efficiency of treatment system units by mixing acid and alkaline wastes. *Preaeration* or *prechlorination* may be required to control odors if wastewater becomes oxygen-deficient while traveling through the sewer collection system or to facilitate grease removal during primary clarification. Major references for additional information on preliminary treatment include Kreissl and Gilbert (1987) and Water Pollution Control Federation/Water Environment Federation (WPCF/WEF) (1980).

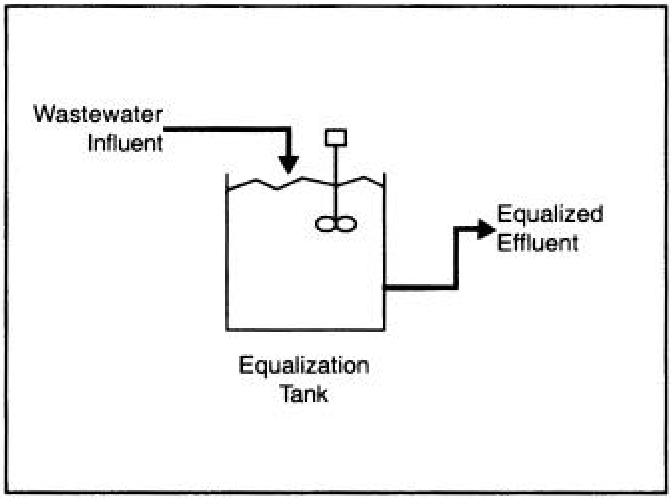

Figure 5-1. Equalization system design (U.S. EPA, 1995)

5.2.2 Primary Treatment

Primary treatment processes are also mainly physical. Removal of readily settleable inert and organic solids is usually accomplished using *sedimentation chambers*, but *fine screens* may also be used as an auxiliary step at various stages in the treatment process. Sedimentation chambers often are designed to remove grease and floatable solids using baffles and oil skimmers, and may include mechanical scrapers for removal of solids/sludge that settle at the bottom of the chamber. Figure 5-2a illustrates a gravity sedimentation unit that is specially designed for use with oil wastewaters. Separation of free and dispersed oil and grease and light solids can be facilitated by *air flotation*, a purely physical process (see Figure 5-2b), or *flocculation*, a physical-chemical process that encourages the aggregation of coagulated colloidal and finely divided suspended matter by physical mixing or chemical coagulant aids. There are three different types of flocculants: inorganic electrolytes, natural organic polymers, and synthetic polyelectrolytes. Air flotation and flocculation reduce the sedimentation times of suspended solids that have a specific gravity slightly greater than 1.0.

Emulsion-breaking systems involve the addition of chemicals and/or heat to cause dispersed oil droplets to coalesce and separate from the wastewater (see Figure 5-2c). Emulsion-breaking systems are not commonly used in conventional wastewater treatment facilities but are a common process for pretreatment of oily wastewaters (5 to 10 percent oil) before discharge to a sewer and in industrial common waste treatment facilities. Gravity separation (see Figure 5-2a) is often used as a pretreatment step to remove free oils prior to emulsion-breaking treatment, and air flotation is applied after emulsion breaking to improve treatment performance and shorten retention time. The term *clarification system* is usually applied to gravity separation units that remove particulates, flocculated impurities, and precipitates following wastewater treatment processes that generate suspended solids, such as chemical precipitation and biological treatment. A circular clarification system is illustrated in Figure 5-2d. WPCF/WEF (1985) provides more detailed information on clarifier design.

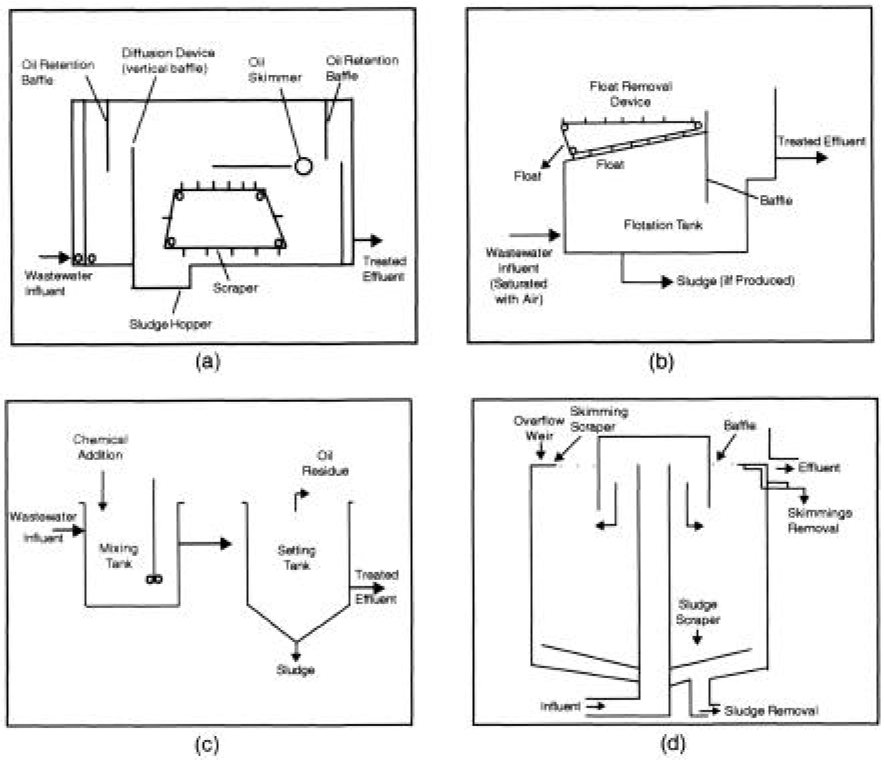

Figure 5-2. Gravity separation system designs: (a) API separator, (b) dissolved air flotation, (c) emulsion-breaking system, (d) clarification system (U.S. EPA, 1995)

5.2.3 Granular Media Filtration

Many specific unit treatment processes fall in the category of granular media filtration, the common element being the use of mineral particles as the filtration medium. Granular media filtration removes suspended solids by physical filtration, physical-chemical adsorption processes, and biological decomposition. Granular media filters are distinguished from biological filters (see Section 5.3.4) mainly by the smaller particle size (generally less than 2 mm, although a graded medium ranging from sand to gravel), which increase the significance of filtration and adsorption as part of the treatment process.

Sand filters using silica sand, a readily available material in many parts of the world, are the most common type of unit in this category. Design elements to define a specific type of sand filter include:

- Hydraulic loading rate (slow, rapid, high)
- Temporal loading (continuous, pulsed, intermittent)
- Method/direction of delivery (trickling/downflow, pressure/upflow)

Dual and *multimedia* filters consist or two or more media. A multimedia filter operates with the finer, denser media at the bottom and the coarser, less dense media at the top. A common arrangement is garnet at the bottom of the bed, sand in the middle, and anthracite coal at the top. The flow pattern of multimedia filters is usually top-to-bottom with gravity flow (see Figure 5-3). Upflow filters, horizontal filters, and biflow filters are also used.

Multimedia filters require periodic backwashing to maintain their efficiency. When clogging from trapped solids reduces the rate of movement of wastewater through the filter bed to a limiting value, the end of the filter run is reached and the filter must be backwashed to remove the suspended solids in the bed. During backwashing, the flow through the filter is reversed so that solids trapped in the media are dislodged and can exit the filter. The bed may also be agitated with air to aid in solids removal. The backwash water is then recycled back into the wastewater feed stream. Backwashing may also be used with sand filters.

Granular media filtration is most commonly used for tertiary treatment in municipal wastewater treatment plants and for supplemental removal of residual suspended solids from the effluent of chemical treatment processes. Land biological treatment systems (see Section 5.3.1) can be considered a form of natural granular media filtration, however, and in the United States of America, sand filters are being increasingly used for onsite treatment of residential wastewater and for secondary treatment in small community wastewater treatment systems.

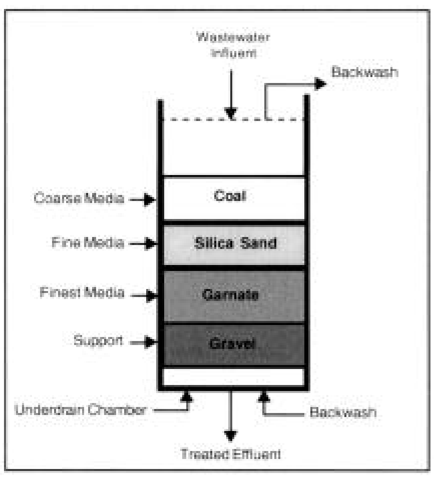

Figure 5–3. Multimedia filtration system diagram (U.S. EPA, 1995)

5.2.4 Chemical Treatment

Chemical treatment methods for conventional wastewater treatment may be used, as appropriate in any stage of the treatment process. The most commonly used methods include:

- *Neutralization* to maintain optimum pH for biological treatment processes.
- *Precipitation* reactions for removal of dissolved solids and phosphorus.
- *Oxidation* (chlorination, ozonation, ultraviolet radiation) for disinfection and odor control.

Chemical treatment methods for industrial corrosive and toxic-substance-containing wastewater are discussed in more detail in Section 6.2.

5.3 BIOLOGICAL TREATMENT PROCESSES

Biological treatment processes are used primarily for secondary treatment and use microbial action to decompose suspended and dissolved organic matter in wastewater. Most biological treatment processes are *aerobic*, in which carbon provides the energy source for aerobic respiration, with carbon dioxide and water being the main byproducts. *Nitrification*, the microbial conversion of ammonia to nitrate, may also be a significant process in wastewater treatment plants. *Anaerobic* decomposition of organic matter generally proceeds much more slowly than aerobic decomposition but may be a suitable option in some situations, especially for wastes with high BOD (see Section 5.3.6).

There are various ways that biological treatment processes can be classified, but most can be broadly categorized as (1) natural methods with large area requirements, or (2) engineered methods with small area requirements. Land treatment methods (see Section 5.3.1) and stabilization lagoons and ponds (see Section 5.3.2) fall in the first category. Compact, engineered methods can further be classified as:

- Activated sludge processes (see Section 5.3.3).
- Biological filters (see Section 5.3.4).
- Dual treatment systems that combine activated sludge and biological filters (see Section 5.3.5).
- Anaerobic treatment systems (see Section 5.3.6).

Major references for additional information on compact biological treatment methods for wastewater include Irvine (1985), U.S. EPA (1977b), and WPCF/WEF (1988b). Aeration, a critical component of mechanically assisted aerobic treatment processes, is covered in more detail in EPA (1989) and WPCF/WEF (1988a). In this biological treatment group, it is relevant to include references on wastewater through wetlands.

5.3.1 Land Treatment

Major types of wastewater land treatment systems include:

- *Slow rate*: Wastewater is applied using pipes or sprinklers to a vegetated land surface at such a rate as to avoid surface runoff. The wastewater is treated by the plant-soil matrix, with some transpired by vegetation and the rest entering the ground-water system.

- *Rapid infiltration*: Wastewater is applied to unvegetated flooding basins on soils with high percolation rates. The wastewater is treated by the soil matrix and enters the ground-water system.

- *Subsurface infiltration*: Wastewater is discharged to subsurface soil absorption drainfields. The wastewater is treated by the soil matrix and enters the ground-water system.

- *Overland flow*: Wastewater is applied to the upper reaches of grass-covered slopes using pipes or sprinklers and is allowed to flow over the vegetated surface to runoff collection ditches. The wastewater is treated by physical, chemical, and biological means as it flows in a thin film down the length of the slope.

Design and treatment performance comparisons for land application systems for domestic wastewater are shown in Table 5-5. EPA (1981a and 1981b) provides detailed guidance on design of land treatment systems for municipal wastewater. The information on treatment performance in Table 5-5 should only be applicable to industrial wastewaters with characteristics similar to domestic sewage. Generally, industrial wastewaters from manufacturing have lower BOD_5:COD ratios and higher levels of toxic substances (see Section 5.1.2), making wastewaters unsuitable for land treatment. On the other hand, wastewaters from many food processing industries may be suitable for land treatment, provided that suitable land is available nearby. Table 5-6 rates the suitability of wastewaters from various industries for agricultural use (slow rate treatment). Most industries that are suitable or provisionally suitable are from the food processing sector, whereas most industries that are rated unsuitable are in the manufacturing or energy production sectors.

Table 5-5. Design and treatment performance comparisons for land application systems for domestic wastewater

Feature	Slow Rate	Rapid Infiltration	Subsurface Infiltration	Overland Flow
Site Conditions				
Soil texture	Sand loams to clay loams	Sands, sandy loams	Sands to clay loams[a]	Silt loams, clay loams
Depth to ground water[b] (m)	1.0	1.0	1.0	Not critical[c]
Vegetation	Required	Optional	Not applicable	Required
Climatic restrictions	Growing season[d]	None	None	Growing season
Design Loadings				
Pretreatment[e]	Primary sedimentation[f]	Primary sedimentation[f]	Primary sedimentation	Primary sedimentation
Average daily loading (cm)	1.2 –1.5	1.5-10	0.2-4.0[g]	1.0-6.0
Application method	Sprinkler or flooding	Flooding	Flooding	Sprinkler or flooding
Disposition of wastewater	Evapotranspiration and percolation	Percolation	Percolation	Surface runoff and evapotranspiration
Treatment Performance				
BOD_5(mg/L)	5	10	5	15
SS (mg/L)	5	5	5	20
Total nitrogen as N (mg/L)	3-8[h]	10-20[i]	25-35[i]	5-19[i]
Total phosphorous as P (mg/L)	0,1-0,4	1-2	0,1-0,5	4-5
Toxic organics[j]	?	?	?	?
Fecal coliforms (per 100mL)	< 10	< 200	< 10	< 2000
Virus, log removal average	≈3 +	≈2	≈3	< 1
Metals (%)	High	Medium	High	Low

[a] Applies to single or small cluster household systems; larger systems limited to sands and sandy loams (where significant, depth to top of ground-water mound).
[b] Minimum separation distance from infiltration surface to highest ground-water mound elevation.
[c] Critical only if significant percolation occurs.
[d] Application during few weeks before and after growing season.
[e] Minimum pretreatment requirements.
[f] With restricted public access; crops not for direct human consumption.
[g] Loading based on trench bottom area, not total site area.
[h] Varies with applied concentration and crop.
[i] Varies with applied concentration.
[j] Data are limited, but good removals (> 90%) appear to occur at low application rates in aerobic soils for biodegradable organics, adsorbed species are removed effectively until the underlying soil column becomes saturated, whereupon removals cease; volatiles are removed effectively in the unsaturated soil zone if rates are sufficiently low.

Table 5-6. Suitability of industrial wastewaters for agricultural use

I	II	III
Generally suitable[a]	**Conditionally suitable**[b]	**Generally Unsuitable**[c]
Breweries Distilleries Malting plants Yeast production plants Retting pits Potato chip production Vegetable canneries Jam, marmalade, fruit syrup production plants Dairies Wood grinding plants Starch production plants	Sugar refineries Rice and corn starch production plants Leather glue production plants Bone glue production plants Knacker's yards Slaughterhouses and meat canneries Tanneries Margarine production plants Sauerkraut pickling plants Paper mills Cardboard and strawboard mills Sulfate pulp production plants Textile industry (bleaching plants, mercerizing plants, finishing works, fulling mills, dyeing shops and plants, printing plants, etc.) Wool washing shops Copper rayon industry Fish meal industry Fish canneries Wood saccharification industry Mining	Varnish and dyestuff production plants Soap production plants Industries producing inorganic heavy metals Pharmaceutical industry Metal industry Sulfite cellulose production plants Viscose rayon mills Low temperature carbonization plants Gas works Byproduct production from coking plants Generator gas facilities Wood carbonization industry Laundries Synthetic rubber production plants Explosives production plants Coal washing plants Mineral oil industry

[a] Requires suitable available land nearby. Care required in segregating minor waste streams containing toxic substances.
[b]Requires suitable available land nearby and limitation of use to nontoxic process wastewaters or pretreatment or toxic or putrescible wastewaters.
[c]Generally unsuitable due to toxic contaminants in wastewater.

Source: Adapted from Fresenius et al. (1989).

5.3.2 Stabilization Ponds and Lagoons

Stabilization ponds, also called *oxidation ponds*, treat raw wastewater by the interaction of sunlight, wind, and algae, with or without the assistance of mechanical aeration equipment. Usually, the terms *lagoon* and *pond* are used interchangeably, but in general, lagoons are smaller than ponds and have a second pond to remove suspended solids. General advantages of lagoons include:

- Simple design and function results in low operation and maintenance costs.
- Preliminary or primary treatment is generally not required.
- The control of discharge may eliminate the need for additional treatment.

These characteristics make lagoons good candidate treatment processes for CETPs in newly industrialized countries. Disadvantages include:

- The large land requirements (mechanical aeration can reduce land requirements by one-third to one-tenth).
- Lagoons may require low permeability liners to protect ground water.
- Odors may be a problem.

Stabilization ponds can be either *aerobic* (aerobically treated entirely by natural processes) or *aerated* (oxygen is added to enhance treatment). In *facultative* ponds, biodegradation occurs by a combination of aerobic microorganisms, anaerobic microorganisms at the bottom of the ponds, and a large number of facultative microorganisms that thrive under both aerobic and anaerobic conditions. Table 5-7 summarizes information on four types of stabilization ponds. Major references for additional information on stabilization ponds and lagoons include EPA (1977a, 1981b, 1983).

Other types of ponds include (1) *total containment ponds*, where all wastewater is evaporated (used only in dry climates), (2) *hydrograph controlled release ponds*, where wastewater is discharged only during periods of high streamflow, (3) *aquaculture ponds*, used for raising fish or plants (especially water hyacinth), and (4) *polishing ponds*, for providing tertiary treatment of wastewater treated using other biological methods. *Natural* and *constructed wetlands* can also be considered a type of stabilization pond.

Table 5-7. Major types of stabilization ponds

Type	**Aerated Aerobic** (h:0.4 a 7.5 m)	**Aerated Facultative**	**Aerobic Facultative** (h: 0.6 a 1.5 m)	**Aerobic**
Description	Aeration of pond accomplished by use of mechanical oxygen diffusers; sediment facilities required	Uses only surface aerators; some anaerobic decomposition takes place in sediments at the pond bottom	Oxygen supply provided at surface by algae and surface mixing by wind; some anaerobic activity in bottom sediments	Shallow ponds where algae provide oxygen to maintain aerobic conditions in pond
Advantages	- Relatively small volume/land area required - Odor-free - High degree of treatment	- Relatively small volume/land area required - Relatively odor-free - High degree of treatment	- Low O&M costs - High degree of treatment	- Low O&M costs
Disadvantages	- Highest O&M cost of any pond system	- Substantial O&M costs	- Large volume and land area required - Possible odors	- Large volume and land area required - Possible odors
Labor	Maintain aerators; sludge removal	Minimal	Minimal	Minimal
Energy	Moderate	Low (for aerators)	None	None
Degree of complexity	Moderate; limited amounts of skill for equipment maintenance	Simple; no skilled labor required	Simple; no skilled labor required	Simple; no skilled labor required
Residuals	Sludge	Sludge removal once every 10 to 20 years	Sludge removal once every 10 to 20 years	Algae cells

h: average depth

Source: Adapted from the National Association of Towns and Townships (1989)

5.3.3 Activated Sludge Processes

A variety of unit processes combine *activated sludge*, a suspension of microbial floc particles and *aerators* to create optimum conditions for aerobic decomposition of organic matter in wastewater. *Conventional* activated sludge systems involve a single reactor basin (complete mix activated sludge system [CMAS]) or a series of basins (plug and series flow systems). Figure 5-4a shows a schematic of a CMAS system. An advantage of CMAS systems over plug and series flow systems is that mixing may reduce the adverse effects of short-term high concentrations of undesirable wastewater constituents.

Other activated sludge systems have designs that differ to a greater or lesser degree from conventional systems. The configuration for *contact stabilization* is similar to Figure 5-4a, except that sludge from the secondary clarification basin goes into a sludge stabilization basin rather than being recycled directly to the aeration basin. The contact (aeration) basin has a relatively short residence time, while the sludge stabilization basin generally has twice the detention time used in the contact basin. This method is best suited for smaller flows where a long sludge residence time is desired and is less vulnerable to shock organic or toxic loadings than conventional activated sludge systems.

Extended aeration modifies conventional CMAS systems by increasing hydraulic and solids retention times, and often incorporates aerobic sludge digestion units (see Figure 5-4b). These systems are widely used where wastewater flows are less than 2 L/s (50,000 gpd). Major advantages include:

- Lowest sludge production of any activated sludge process
- Ability to achieve high-quality effluent
- Installation of preengineered package plants with minimal site preparation
- Reliability with sufficient operator attention
- Nitrification likely at wastewater temperatures greater than 15 C
- Relatively modest land requirements
- Relatively low initial cost
- Ability to handle moderate-shock hydraulic loadings with minimal problems

Major disadvantages include:

- High power consumption and energy cost compared with land-based or natural systems.
- Skilled operators and high operation and maintenance requirements.
- Ability of high flow variations to reduce effectiveness of suspended solids (SS) and BOD removal.
- Potential freezing problems in cold climates.
- Potential for rising sludge due to denitrification in final clarifier in warmer months.
- Potential for blower noise and sludge handling odor.
- Possibility that preengineered plants may require additional components or modifications to meet specified effluent limitations.

The *oxidation ditch* is a closed-loop variation of the extended-aeration process with similar hydraulic and solids retention times. Oxidation ditch loops are generally oval in shape, with aeration provided by horizontally mounted rotating brush, cage, or disc aerators (see Figure 5-4d). They are well suited for wastewater flows in excess of 0.4 L/s (10,000 gpd). Advantages and disadvantages are similar to extended aeration systems, with the aerators being the main high-maintenance part of the system. *Triple channels* are a type of oxidation ditch in which three ditches are constructed in series. Sedimentation of activated sludge and discharge of treated wastewater take place alternately from the two outermost ditches. The advantage of the system is that it eliminates the need for separate sedimentation tanks, making it relatively cheap to construct.

The *sequencing batch reactor* (SBR) is a form of the activated sludge process in which aeration, sedimentation, and decant functions are combined in a single reactor. SBRs usually consist of two or more parallel tanks that operate alternately or in sequence on a five-state cycle: fill, react, settle, draw, and idle (see Figure 5-4c). The batch operation of an SBR makes it a feasible biological option for treatment of industrial wastewater, where the wastewater volumes and characteristics are often highly variable. Major advantages of the SBR process include:

- Simple and reliable
- Well suited for small wastewater flows with wide flow variations
- Achieves high and consistent effluent quality due to quiescent batch settling
- Requires less operator attention than most other mechanical systems
- Capable of nutrient removal due to high operational flexibility

Disadvantages include:

- Some problems reported with decant systems
- Requires skilled operator and regulator inspection and maintenance

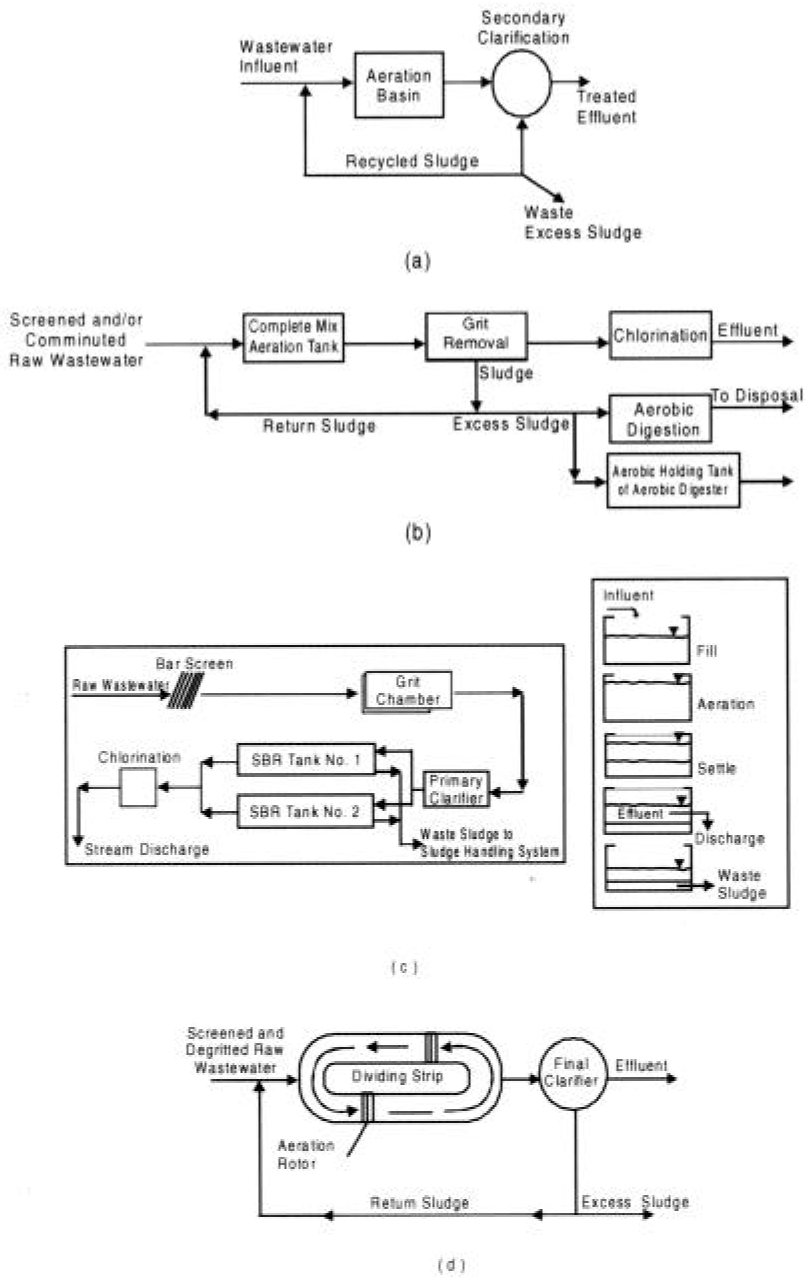

Figure 5-4. Activated sludge systems: (a) conventional complete mix activated sludge system (U.S. EPA, 1995), (b) extended-aeration process (U.S. EPA, 1992a), (c) oxidation ditch (U.S. EPA, 1992a), and (d) sequencing batch reactor (U.S. EPA, 1992a).

5.3.4 Biological Filters

Biological filters provide a surface that is repeatedly exposed to wastewater and air, and on which a microbial layer can grow. Treatment is provided by the fixed film of microorganisms that forms on the surface, which adsorbs organic particles and degrades them aerobically. Biological filters are classified as *fixed media* filters and *rotating biological reactors* (described below). Both rely on a fixed microbiological film on the media to provide treatment.

Trickling filters are the most commonly used type of fixed media filters for conventional wastewater treatment. Wastewater is distributed over a bed, usually made of rock or plastic, and flows over the media by gravity. Major advantages of trickling filters compared with activated sludge systems include:

- Greater simplicity
- Low operating and maintenance costs
- Reduced sludge production
- Increased shock resistance.

Disadvantages include:

- Somewhat lower BOD removal (less than 85 percent, compared with 90 percent for activated sludge)
- Higher initial cost
- Require more land area
- Possible need to be covered in cold climates
- Potential odor problems.

The *biotower* is a relatively new type of fixed-media filter that uses plastic honeycomb waffles for the biological film growth, an inoculum of commercially available bacteria culture and a separate nutrient solution consisting of ammonia and phosphorus to enhance bacterial growth. The inoculum, nutrient solution, and wastewater stream are fed into the bottom of the biotower, where they are mixed and passed up through the packing by air blowers, with the treated effluent exiting from the top of the biotower (see Figure 5-5).

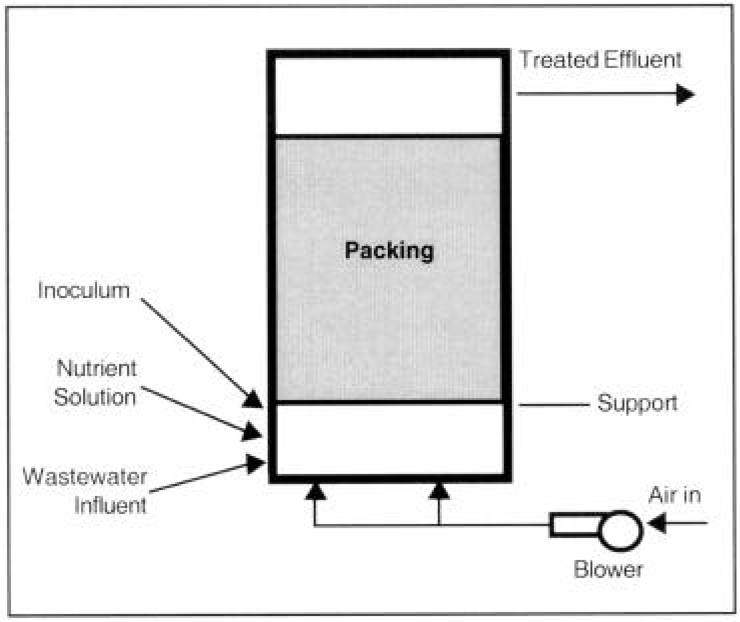

Figure 5-5. Biotower system diagram (U.S. EPA, 1995)

A *rotating biological contactor* (RBC) consists of a series of corrugated plastic discs mounted on a horizontal shaft (see Figure 5-6). The rotating discs, with approximately 40 percent of the surface area immersed in the wastewater and the remainder of the surface exposed to the atmosphere, provide a surface for a microbial slime layer. The alternating immersion and aeration of a given portion of the disc enhance growth of the attached microorganisms and facilitate oxidation of the dissolved organic and nitrogenous materials in the wastewater, and provide a high degree of waste treatment in a relatively short time. Covers are usually required to protect the plastic discs from degradation by ultraviolet light, to inhibit algae growth, and to control the release of volatiles. RBCs are a well-established technology for treating both municipal and industrial wastewater. Provided that wastewaters do not contain high concentrations of heavy metals, certain pesticides, herbicides, or high chlorinated organics that inhibit microbial activity, RBCs have the potential for treating industrial wastewaters that most other biological treatment processes could not handle.

5.3.5 Dual/Two-Step Treatment Systems

Dual or two-step treatment systems combine biological filters (fixed media or rotating contactors) for the first treatment step, followed by a solids contact or activated sludge system. Many configurations of units described in the previous two sections are possible. The *trickling filter solids contact* (TFSC) process is a relatively innovative approach to the trickling filter process in which discharge from the trickling filter flows through an aerated short-detention-time tank with secondary return sludge to encourage flocculation and agglomeration of the trickling filter fines, thus improving SS and associated BOD removal in the final clarifier. Figure 5-7 illustrates three possible configurations for the TFSC process.

5.3.6 Anaerobic Treatment Systems

Anaerobic treatment systems are rarely used in conventional wastewater treatment plants, except as a means for sludge stabilization. This is primarily because anaerobic degradation processes proceed more slowly than aerobic degradation, and when sulfur is present, noxious hydrogen sulfide gas is generated. Many toxic organic compounds, especially chlorinated hydrocarbons that are not amenable to aerobic biodegradation, can be anaerobically degraded, however.

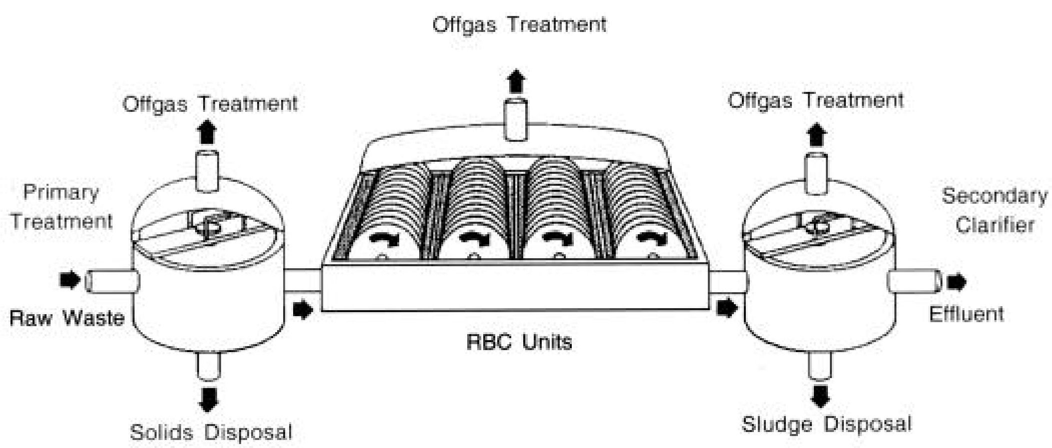

Figure 5-6. Typical rotating biological contactor plant schematic (U.S. EPA, 1992b)

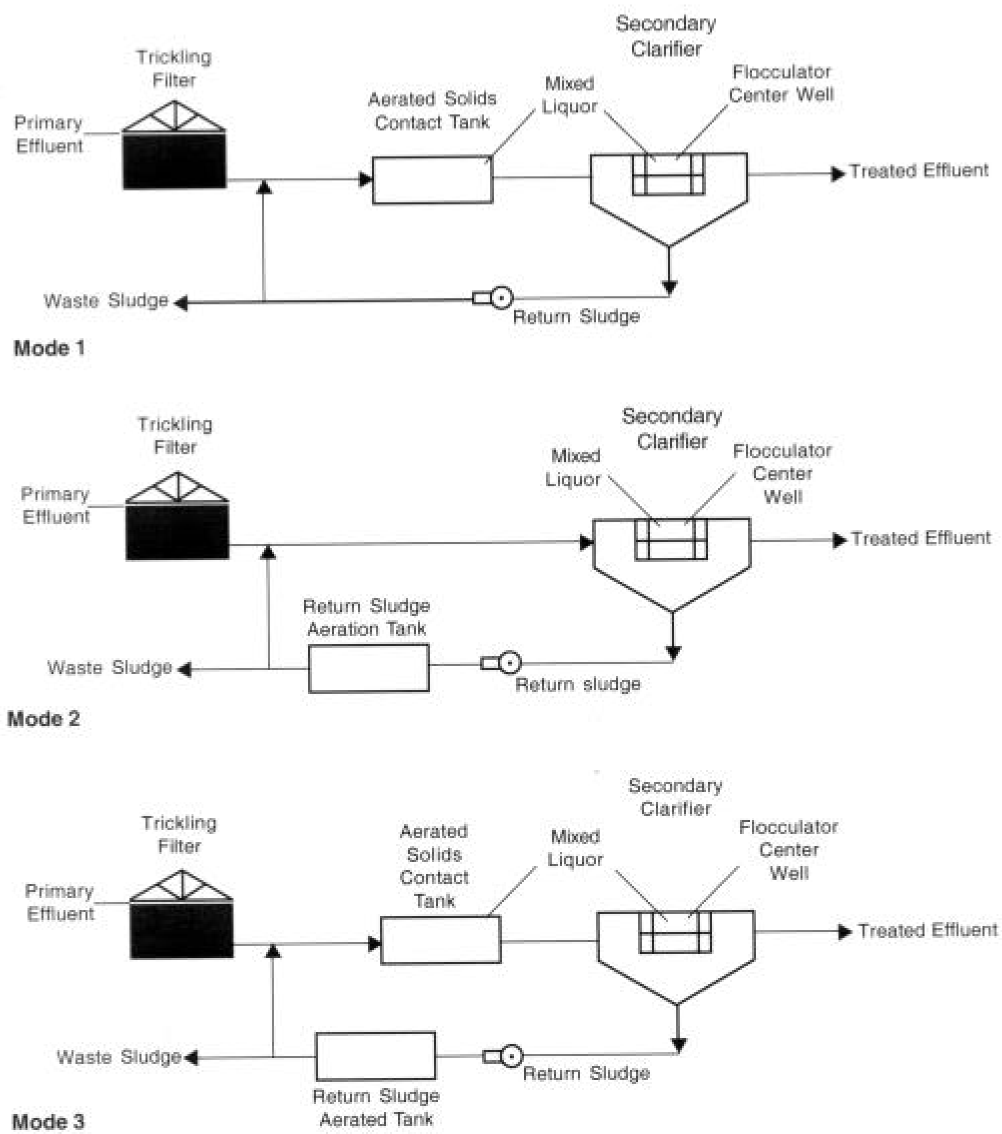

Figure 5-7. Schematics of trickling filter-solids contact processes (U.S. EPA, 1992a)

5.3.7 Treatment systems with artificial wetlands

Wetlands are areas that flood with water up to 0.6 m to enhance growing of plants with roots fixed to the soil, such as canes and ditch reeds. Other wetlands can contain floating vegetation, such as water hyacinths and water lentils, and have a variable water depth of 0.5 to 1.8 m.

Artificial wetlands offer all the same treatment capacities as natural wetlands. It is usually necessary to implement pre-treatment systems for the adequate operation of artificial wetlands. Treatment occurs with the slow passage of water through stems and roots of the aquatic vegetation which provides the surface required for bacteria layers that filtrate and adsorb elements in wastewater, transfer oxygen to the water column, control algae growth and thus hinder the passage of sunlight.

5.4 SELECTION OF UNIT TREATMENT PROCESSES

The selection of the combination of unit wastewater treatment processes that is best suited for the conditions at a particular location requires (1) defining selection criteria that allow quick screening out of obviously unsuitable processes, (2) preliminary engineering and cost evaluation of a number of candidate treatment systems that meet the selection criteria, and (3) detailed engineering design for the system that appears best, based on the preliminary engineering and cost evaluation.

5.4.1 Selection Criteria

Worksheet D in Volume II, provides information on nonhazardous wastewater treatment processes. Table D-1 identifies 21 criteria for conventional wastewater treatment technologies and provides qualitative ratings for more than 40 specific technologies. Each criterion is discussed briefly below and its significance for the design of CETPs for SMSEs in newly industrialized countries is identified. Obviously, not all the criteria can be optimized, so tradeoffs have to be made.

- **Life-cycle cost**. This includes installation costs and operation costs, which are usually capitalized over the life of the project to provide a common basis for comparing different options. This is a major consideration for CETPs specifically designed to treat SMSE wastewater.

- **Cost-effectiveness**. This is another important economic measure, often expressed as a unit cost to provide a basis for comparing different options (e.g., \$/gallon, \$/m^3). Care should be taken to ensure that unit cost comparisons are appropriate. For example, economies of scale often reduce the unit cost of treating wastewater but are not necessarily cost-effective if wastewater flows are not high enough to allow the technology to perform optimally.

- **Reliability**. This is a measure of how well a system performs in relation to expectations without breakdowns or failure to treat wastewater to meet water quality objectives. For CETPs designed for SMSEs, reliability also needs to be associated with simplicity of operation and ease of maintenance. Reliable systems that require highly skilled operators and careful maintenance would be less appropriate.

- **Simplicity of operation** This is highly desirable for CETPs designed for SMSEs.

- **Ease of maintenance**. This is also highly desirable for CETPs designed for SMSEs.

- **Performance**. This is usually measured in terms of percent removal (see Tables D-2 through D-4) or may be expressed as typical treated effluent concentrations. Influent concentrations and treated effluent concentrations required to meet water quality objectives determine whether performance of a particular treatment option or combination of options is acceptable.

- **Ability to meet water quality objectives.** This is a primary screening criterion. Any system that is not able to meet water quality objectives does not need to be considered any further.

- **Adaptability to change in influent quality.** This is a very important criterion for CETPs designed for SMSEs because wastewater quality tends to be more variable than for conventional municipal wastewater treatment.

- **Performance dependent on pretreatment.** This may or may not be a significant consideration. All other things being equal, however, options that can meet water quality objectives without pretreatment would be favored.

- **Adaptability to varying flow rate.** This may be an important criterion for CETPs designed for SMSEs if the industries involved have highly varying flow rates.

- **Ease of construction.** This is a desirable characteristic for CETPs designed for SMSEs.

- **Adaptability to upgrading.** This may or may not be a significant consideration for CETPs designed for SMSEs, depending on local conditions.

- **Availability of major equipment.** This is a primary consideration in the design of CETPs for SMSEs. Obviously, if the equipment is not available locally or regionally, or is not available at a price that is reasonable due to high transportation costs, the option can be excluded from further consideration.
- **Equipment/supplies available locally.** The comment on availability of major equipment applies here too.

- **Postinstallation service/chemical delivery.** Generally, systems that minimize postinstallation service for CETPs for SMSEs are desirable. If chemicals are used, it is critical that they be readily available.

- **Personnel skill level.** Generally, options that require low personnel skill levels are preferred for CETP in SMSE to options that require a high skill level. This generally goes along with simplicity of operation and ease of maintenance.

- **Energy utilization**. Generally, options that require no or low energy input are preferred for CETPs designed for SMSEs to those that use large amounts of energy.

- **Residue production.** This is a major consideration for CETPs designed for SMSEs if sludges are sufficiently contaminated that they are not suitable for land application. In this situation, options that minimize sludge production are desirable.

- **Cost of residual disposal.** This is closely related to the amount and quality of residues produced.

- **Potential for effluent use/reuse.** High potential for effluent use or reuse would be a favorable characteristic for CETPs designed for SMSEs.

- **Potential for air emissions** Some treatment processes have greater potential for creating noxious odors than others. These need some form of additional control to lessen odors.

5.4.2 Preliminary Evaluation of Treatment Alternatives

Preliminary evaluation of treatment alternatives usually involves selecting several candidate treatment trains capable of meeting the water quality objectives for the treated effluent. Typically, preliminary engineering and cost estimates are based on a specified wastewater flow and strength (BOD/COD) that is similar to expected design specifications for the actual CETP. The cost of a particular candidate treatment train is highly dependent on local conditions (e.g., land and labor costs, equipment availability and price), and consequently, it is important that an engineering firm or other individuals familiar with local conditions be involved in developing the preliminary cost comparisons.

A preliminary cost evaluation should separate out initial construction costs and operation and maintenance costs projected for the life of the project. A convenient way to compare costs of different options is to present costs relative to a "base" technology. Table 5-8 illustrates two ways in which this kind of cost comparison can be done. Chemcontrol (1991) developed estimates of installation costs, operation costs, and total capitalized costs for a 50,000-m^3/day industrial CETP in India for eight treatment alternatives. Activated sludge with primary sedimentation was defined as the base for comparison in each cost category (100 percent).

Table 5-8 shows that three options (trickling filters with plastic media, trickling filters with stone media, and aerated lagoons with polishing ponds) had total capitalized costs that were less than the activated sludge system. The aerobic pond option clearly illustrates the importance of differentiating installation and operating costs. Overall costs were equal to the activated sludge system, but the installation and operation cost was 25 percent lower.

The Thailand Rangsit preliminary design comparison presents cost comparisons in a slightly different way. All costs are reported relative to the initial investment cost for low-load extended aeration (100 percent). By comparison, initial costs for both conventional activated sludge and aerated lagoons are higher, but substantially lower operation and maintenance costs make aerated lagoons the lowest cost option overall (154 percent compared with 173 percent for low-load extended aeration).

Table 5-8. Example cost comparisons of CETP treatment alternatives

Process	Installation Costs	Operation Costs	Capitalized Costs
India Prefeasibility: 50,000 m3/day, 400 mg/L BOD			
Activated sludge with primary sedimentation	100%	100%	100%
Trickling filters with plastic media	115%	60%	75%
Trickling filters with stone media	105%	65%	75%
Aerated lagoons with polishing ponds	190%	55%	95%
Aerobic ponds	290%	25%	100%
Extend aeration with secondary sedimentation	105%	115%	110%
Oxidation ditches with secondary sedimentation	135%	105%	115%
Triple channels	155%	110%	125%
Thailand: Rangsit Preliminary Design	**Investment Costs**	**Capitalized O&M[a]**	**Total**
Conventional high rate activated sludge	112%	64%	176%
Low-load extended aeration	100%	73%	173%
Aerated lagoons	109%	45%	154%

[a] Operation and maintenance costs.
Sources: India: Chemcontrol (1991); Thailand: TISTR (1994).

5.4.3 Detailed Engineering Design

Final selection of treatment processes for a CETP depends on careful evaluations of both cost analyses, such as those summarized in Table 5-8 and other factors discussed in Section 5.4.3. The final choice need not have the lowest overall cost, but if the lowest cost option is not selected, the reasons should be well documented. Detailed engineering design is beyond the scope of this manual, but major references that may be useful for general and specific aspects of detailed engineering design are identified throughout this chapter.

5.5 SLUDGE TREATMENT, USE, AND DISPOSAL

The treatment processes described above concentrate solids from industrial wastewater into a sludge that must be treated (e.g., stabilized and dewatered) before being finally disposed. Because of the high quantities of heavy metals and toxic substances, the options for the proper use of sludge from industrial CETP are more limited than in the case of municipal wastewater treatment plants. Sludge treatment, use, and disposal should be an integral consideration when evaluating treatment alternatives and the engineering design of a CETP. Section 6.5 addresses sludge treatment processes and final disposal options relevant to both CETPs and hazardous waste treatment centers.

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