CHAPTER 4

TREATMENT TECHNOLOGIES

4-1. Applicability. This chapter provides descriptive information on state-of-the-art design methodology for the treatment of industrial and hazardous waste. The information presented is applicable for the planning level design of remedial action treatment systems. The process designs described must be adjusted for site-specific conditions to ensure appropriate technology application.

4-2. Techniques. Because hazardous waste treatment must consider so many materials and conditions, good reliable treatability data are essential. Considerable information is available in the literature that can be used in planning level designs and should be extracted and compiled under one cover. However, final designs must be based upon field data ascertained from bench and/or pilot plant scale testing of specific waste streams. EPA Guidance Manual Guide for Conducting Treatability Studies under CERCLA gives an excellent coverage of this area.

Section I. Treatment of Liquid Waste Streams

4-3. Definitions. Liquid waste streams include leachates, ground water, surface water, concentrated hazardous wastes, and effluents resulting from other treatment technologies such as incineration or soil washing. The technologies presented in this section are commonly used for the treatment of liquid waste streams.

4-4. Air Stripping. Air stripping removes volatile contaminants from an aqueous waste stream by passing air through the wastes. This process can be accomplished either in a stripping lagoon or in a packed column. When air is passed through the waste the volatile dissolved gases are transferred to the air streams for possible collection and treatment in the case of a packed column, if the air stream is considered hazardous. Figures 4-1 and 4-2 illustrate both processes. The major factors affecting performance and design include pH, temperature, Henry*s law constant of the chemicals to be stripped, airflow, hydraulic loading, and column packing depth and spacing. The process requires a high pH, 10.8 to 11.5 for ammonia stripping, and increased airflow as the temperature of the influent stream decreases.

a. Applications. Air and steam stripping have been used to remove volatile organic compounds (phenol, vinyl chloride, etc.) and compounds with relatively high vapor pressure and low solubility such as chlorinated hydrocarbons from waste streams. Air stripping has been directly applied to ground-water treatment in removing trichloroethylene (TCE), trihalomethane (THM), and hydrogen sulfide. Removal rates as high as 99 percent for TCE from ground water have been seen. Air stripping has been widely used to remove ammonia from wastewaters with removal efficiencies exceeding 90 percent.

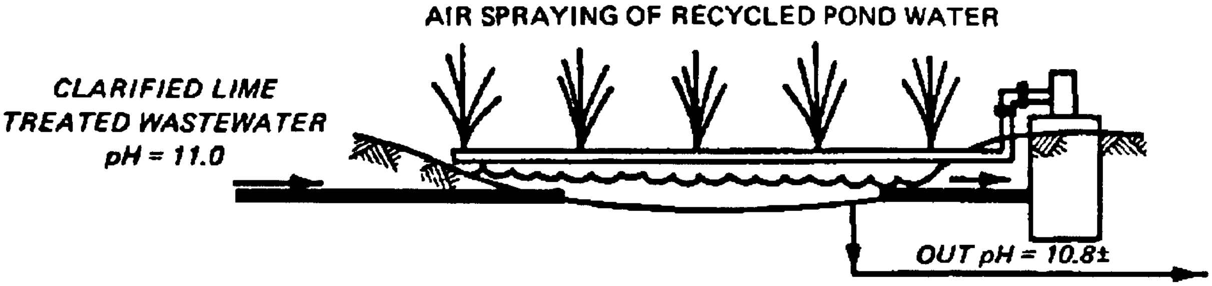


Figure 4-1. Ammonia Stripping Lagoon (Source: EPA 1978)

b. Advantages/Disadvantages. The advantages and disadvantages of air stripping are summarized below.

Advantages	Disadvantages
Can reduce levels of volatiles by over 90 percent	Cost prohibitive to operate at temperatures below freezing
Process is relatively independent of volatile concentration	Sensitive to pH, temperature, and fluxes in hydraulic load
Can reduce TCE concentrations by 99 percent	May pose potential air pollution problems requiring permitting, recovery, and treatment if hazardous volatile organic compounds are present in waste stream

c. Data Requirements. An air stripping system requires the following data.

(1) Feed stream characteristics.

(a) Average water flow, Q, m^3d (mgd).

(b) Peak water flow, m^3d (mgd).

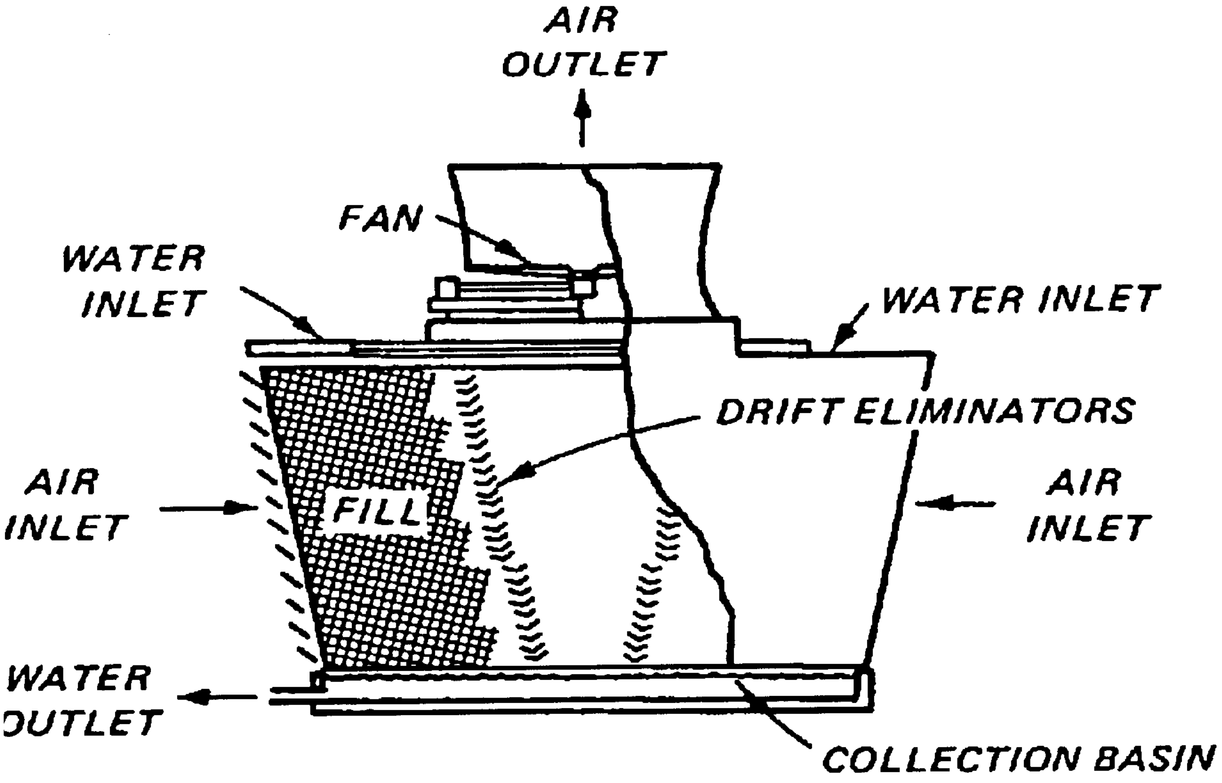
(c) Water temperature, T, °C (°F).

(d) Contaminant concentration in water, Xo, mg/ℓ

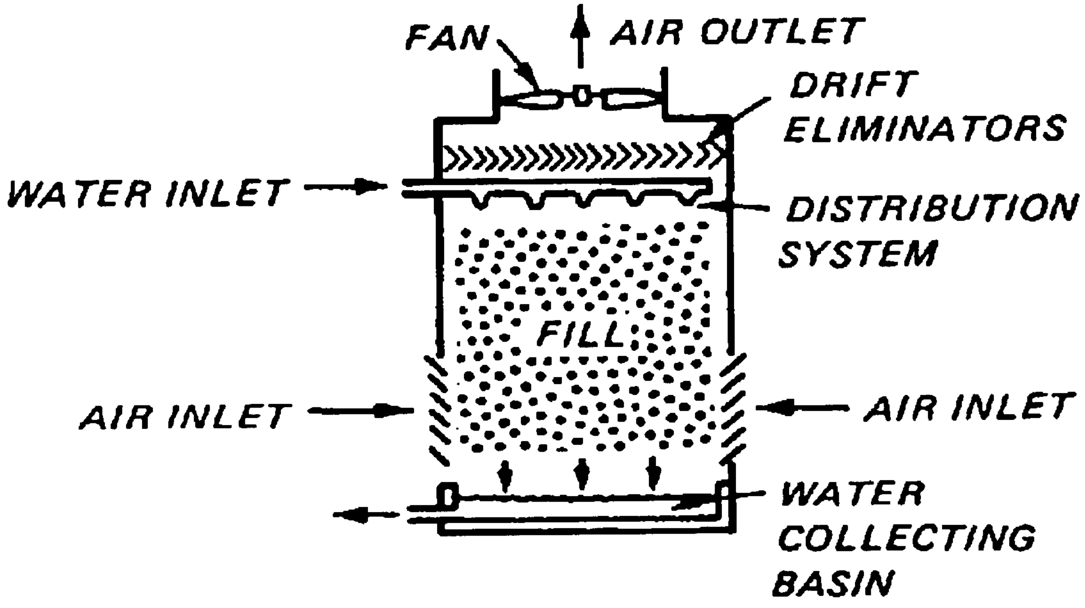
(e) pH of water.

(2) Effluent stream characteristics (contaminant concentration, X, mg/ℓ).

(3) Design decisions.



CROSS-FLOW TOWER



COUNTERCURRENT TOWER

Figure 4-2. Ammonia Stripping Tower

(a) Liquid loading rate, L, lb H_2O/hr/sq ft (Kg H^2O/hr/m^2).

(b) Gas loading rate, G, lb air/hr/sq ft (Kg/hr/m^2).

(c) Tower width, W, or diameter, D, ft (m).

(d) Excess capacity factor.

(4) Packing characteristics (from manufacturer).

(a) Packing height of a transfer unit versus gas/liquid ratio (G/L), ft (m).

(b) Height of a transfer unit for cooling versus gas and liquid loading rates, ft (m).

(c) Pressure drop characteristics as function of gas loading.

(5) Henry*s law. Constants for chemicals to be stripped, H, atm.

d. <u>Design Criteria</u>.

(1) Air stripping can be carried out either in a stripping lagoon or in a packed column. The major factors affecting performance and design include pH, temperature, airflow, hydraulic loading, and tower packing depth and spacing. Cost and performance are relatively independent of influent ammonia concentrations. For materials like ammonia, the pH must be raised to a point where all or nearly all ammonia is converted from ammonium ion NH^+_4 to NH_3 gas. The pH for efficient operations varies from about 10.8 to 11.5. Where lime precipitation is part of a treatment scheme, it is advantageous to locate the ammonia stripping unit after lime precipitation to take advantage of the high pH in the clarifier effluent.

(2) As water temperature decreases, it becomes more difficult to remove volatiles by stripping. The amount of air per gallon (m^3) must be increased to maintain removal as temperature decreases. It is impractical to heat stripping units when the temperature reaches freezing.

(3) The hydraulic loading rate in a packed tower is a critical factor in determining performance. If hydraulic loading becomes too high, good droplet formation needed for efficient stripping is disrupted. If the rate is too low, packing may not be properly wetted, resulting in poor performance and formation of scale. To determine the packing height required in an air stripping column use equation 4-1.

$$Z_T = \frac{L}{K_{La}} * \frac{r}{(R-1} * \ln \frac{X_T/X_B * (R-1) + 1}{R} \qquad (4\text{-}1)$$

where

Z_T = packing height, m (ft)

L = liquid loading rate, kg/hr/m^2 (lb H_2O/hr/sq ft)

X_T = contaminant influent concentration, mg/ℓ

X_B = contaminant effluent concentration, mg/ℓ

K_{La} = mass transfer coefficient

$$\frac{K_{La}}{D} = \alpha \left(\frac{L}{\mu_L}\right)^{1-n} \left(\frac{\mu_L}{\rho_L^{D}}\right)^{0.5}$$

where

μ_L = liquid viscosity, kg/m/hr (lb/ft/hr)

D_L = density of liquid, kg/m^3 (lb/ft^3)

D = diameter of column, m (ft), determined experimentally

R = stripping factor

$$R = \frac{G * P_a/M_a}{L * P_w/M_w} * \frac{H}{P_T}$$

where

G = air loading rate, kg/hr/m^2 (lb/hr/sq ft)

P_a= air density, 1.205 g/m^3 @ 20 °C (0.075 lb/ft^3 @ 70°F)

M_a = molecular weight of air, 28.84, gmw

P_w = liquid density, 998.2 kg/m^3 @ 20 °C (62.3 lb/ft^3 @ 70 °F)

M_w = molecular weight of water, 18, gmw

H = Henry*s law constant, atm

P_T = operating pressure, atm, 1.0 at sea level

(4) Where ammonia concentrations are high (in excess of 100 mg/l), it may be attractive both economically and environmentally to recover the ammonia in an adsorption tower. With good countercurrent contact, 90 to 95 percent of

the ammonia can be transferred to the adsorption solution. Figure 4-3 illustrates the ammonia removal and recovery process.

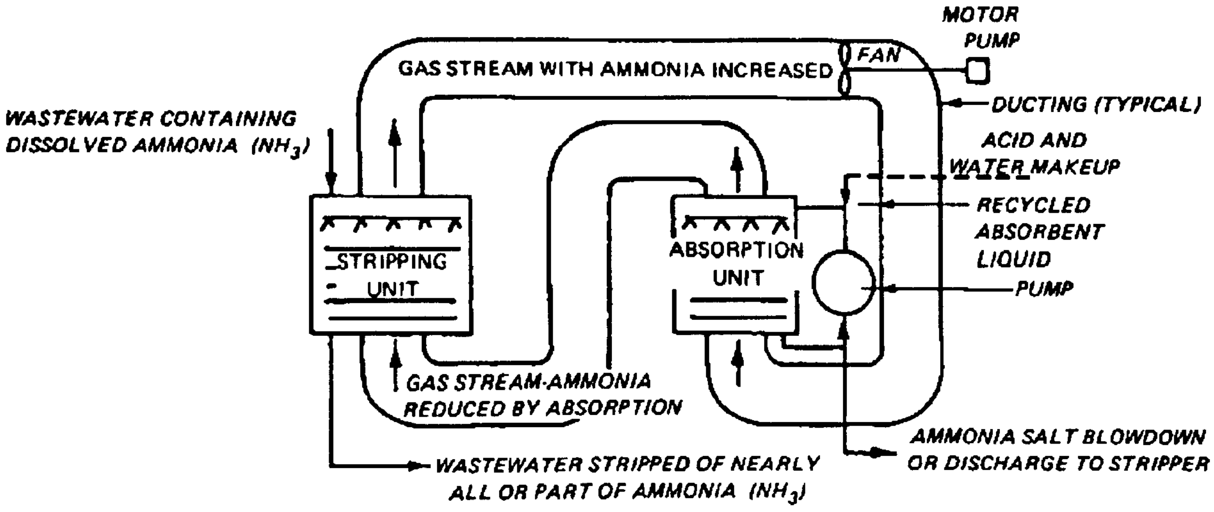


Figure 4-3. Ammonia Stripper and Recovery System

(5) When used for treatment of waters containing volatile organics, air stripping results in off gasses that may exceed regulatory criteria. Off gas treatment systems such as activated carbon or thermal destruction using incineration or catalytic oxidation may be required.

4-5. Biological Treatment.

a. Background.

(1) The major objectives of biological treatment of leachate and contaminated ground water are to reduce the dissolved organic content, to remove heavy metals and nutrients such as nitrogen and phosphorus, and to coagulate and remove colloidal solids. The major treatment effects are caused by incorporation of these materials into microorganisms* tissues. The microorganisms can either be attached to media (trickling filters, rotating biological contactors, or anaerobic filters), or settled out and discarded (lagoons and stabilization ponds), or recycled (activated sludge systems). The biological unit processes are listed in Table 4-1.

(2) Most organic chemicals are biodegradable, although the relative ease of biodegradation varies widely. With properly acclimated microbial populations, adequate detention time, and equalization to ensure uniform flow, biological treatment can be used to treat many organics. There is considerable flexibility in biological treatment because there are several available processes, and microorganisms are remarkably flexible. Several generalizations can be made about the biological treatment of organics:

Table 4-1. Summary of Biological Treatment Processes

Treatment method	Feed stream requirements and limitations	Major design and performance criteria	Environmental impact	Technology status	Reliability
Activated sludge	Can handle BODs of 10,000 mg/ℓ (10,000 ppm) Required low level of suspended solids--usually 1 percent Oil and grease should be less than 50 mg/ℓ Effective for readily degradable organics or organics to which it can be acclimated Sensitive to heavy metals	Detention time Organic load Food-to-microorganism ratio Aeration	Generates excess sludge containing refractory organics and metals that have been sorbed	Highly developed; widely used	Process reliability is very good in absence of shock loads
Pure oxygen-activated sludge	Requires suspended solid levels of about 1 percent or less Can handle higher organic loads than conventional activated sludge and is more tolerant of shock loads Sensitive to heavy metals and oil and grease	Detention time Organic load Food-to-microorganism ratio Oxygen requirements	Generates sludge containing refractory organics and sorbed metals	Relatively new technology but demonstrated for some industrial wastewaters	Reliability fully established; complex and requires high level of maintenance

(Continued)

Table 4-1. (Continued)

Treatment method	Feed stream requirements and limitations	Major design and performance criteria	Environmental impact	Technology status	Reliability
Aerobic, anaerobic, aerated, or facultative	Requires very low suspended solids (0.1 percent) Requires low strength organic wastes (except anaerobic) Sensitive to heavy metals and oil and grease	Detention time Depth Organic load Ph Oxygen levels	May create odors; may release volatiles, H_2S, and methane if anaerobic; must be lined to prevent seepage into ground water	Well demonstrated for stabilization of organics but not widely used	High if proper Ph maintained and organic load is low; sensitive to shock loads since no sludge recycled
Rotating biological contactor	Suitable for treatment of readily degradable organics; can handle higher organic loads than trickling filter but lower than activated sludge Better suited to treatment of suspended or colloidal organics rather than soluble Sensitive to oil and grease and metals	Detention time Hydraulic load Organic load Temperature Number of stages and trains	Generated sludge containing refractory organics and sorbed metals; may cause odors	Process is relatively new, not widely used but gaining in popularity	Moderate in the absence of high organic loads and temperatures below 12.8 °C (55 °F)

(Continued)

Table 4-1. (Concluded)

Treatment method	Feed stream requirements and limitations	Major design and performance criteria	Environmental impact	Technology status	Reliability
Trickling filter	Can handle only very low organic loads as compared to activated sludge	Media type Hydraulic load	Generates sludge that contains refractory organics and sorbed metals; causes odors	Widely used as a roughing filter for industrial wastes	Fair for secondary treatment; moderate as a roughing filter
	Better suited to treating suspended and colloidal organics rather than soluble ones	Organic load Bed depth Temperature			
	Sensitive to metals and oil and grease	Recirculation			

(a) nonaromatic (noncyclic) hydrocarbons are more easily treated than aromatics;

(b) materials with unsaturated bonds, such as alkenes, are more easily treated than materials with saturated bonds;

(c) stereochemistry affects the susceptibility of certain compounds to attack

(d) soluble organics are usually more readily degraded than insoluble materials; dissolved or colloidal materials are generally more readily degraded than insoluble materials. Dissolved or colloidal materials are more readily attacked by enzymes; and

(e) the presence of key functional groups at certain locations can affect the degradation rate of compounds; alcohols, for example, are more easily degraded than their alkane or alkene homologues. On the other hand, addition of a Cl group or an NO_2 group increases resistance to biodegradation.

(3) Although many compounds in leachate and contaminated ground water may be resistant at first to biological treatment, microorganisms can be acclimated to degrade many of these. Similarly, while heavy metals hinder biological treatment, the biomass can also be adjusted, within limits, to tolerate higher concentrations of metals. Concentrations of metals above which the treatment efficiency of biological processes may lessen are as follows:

Material	Inhibitory threshold (mg/ℓ)
Ammonia	480
Arsenic	0.1
Cadmium	1 to 5
Calcium	2500
Chromium (+3)	10
Chromium (+6)	1 to 10
Copper	1 to 10
Iron (+3)	15
Lead	10
Manganese	10
Mercury	0.1 to 5
Nickel	1 to 2.5
Silver	0.03
Vanadium	10
Zinc	1 to 10

b. Suspended Growth (Activated Sludge). Activated sludge is a heterogeneous suspended growth microbial culture composed largely of bacteria, protozoa, rotifers, and fungi. The bacteria are responsible primarily for assimilating most of the organic material from the waste; the protozoa and rotifers complete the process by removing the dispersed bacteria that otherwise would escape in the plant effluent, giving high COD and suspended solids. Aeration can be by air or by pure oxygen. Activated sludge systems are usually made up of several unit processes, including primary sedimentation, an aerated reactor with sludge recycle, and clarification in a settling tank. A diagram of a typical activated sludge system is presented in Figure 4-4.

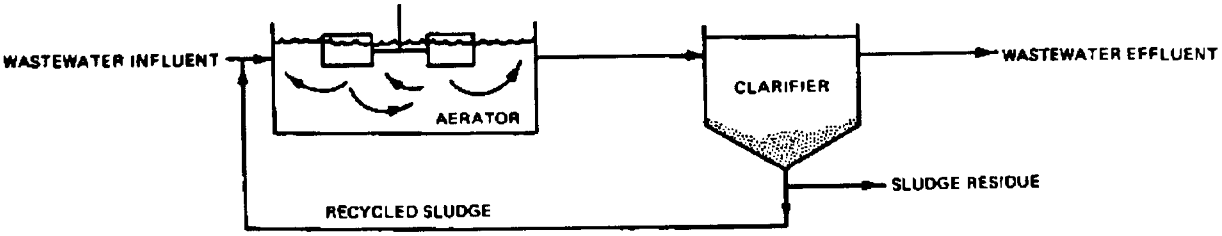


Figure 4-4. Typical Activated Sludge System (Source: Arthur D. Little, Inc. 1976).

(1) Applications.

(a) The air-activated sludge process has proven effective in the treatment of industrial wastewaters from refineries and coke plants, or pharmaceutical wastes, PVC wastes, and food processing wastes. Conventional activated sludge has treated petroleum wastes with a BOD_5 as high as 10,000 ppm.

(b) The process has also been reasonably well demonstrated for the treatment of leachate from municipal landfills. At the GROWS landfill in Bucks County, Pennsylvania, BOD removal of over 98 percent was achieved for an influent concentration of almost 5,000 milligrams per liter. Treatment included physical/chemical as well as biological treatment. Experiments have shown that activated sludge is generally well suited to treatment of high strength leachates containing high concentrations of fatty acids. As the landfill stabilizes, the ratio of BOD/COD decreases and the wastes become less amenable to biological treatment.

(c) The activated sludge process is sensitive to suspended solids and oil and grease. It is recommended that suspended solids be less than one percent. Oil and grease must be less than 75 milligrams per liter, and preferably less than 50 milligrams per liter, for effective treatment.

(2) Advantages/disadvantages. The advantages and disadvantages of both air- and pure-oxygen-activated sludge treatment are summarized below:

Advantages	Disadvantages
Activated sludge has been widely used in industrial waste water treatment	Capital costs are high Process is sensitive to suspended solids, fats and oils, and metals
Numerous process variations which allow for high degree of flexibility	Generates sludge which can be high in metals and refractory organics
Process reliability is good (although not well known for pure-oxygen-activated sludge)	Subject to upsets from shock loads Fairly energy intensive
Can tolerate higher organic loads than most biological treatment processes	O&M intensive

(3) Data requirements. Principal data requirements for the design of a activated sludge system include:

(a) Specific BOD reaction rate coefficient (for retention time).

(b) Oxygen coefficients (for oxygen requirements).

(c) Sludge coefficients (biodegradable fraction).

(d) Biodegradable sludge fraction.

(e) Oxygen transfer coefficient.

(f) Standard oxygen transfer efficiency.

(g) Oxygen saturation coefficient.

(h) Temperature correction coefficient.

(i) Average and maximum influent flow.

(j) Influent temperature.

(k) Extreme ambient temperature, summer and winter.

(l) Average and maximum influent BOD.

(m) Influent suspended solids.

(4) Design criteria.

(a) Key design parameters for activated sludge include aeration period of detention time; BOD loading per unit volume, usually expressed in terms of pounds BOD applied per day per g BOD/m^2 (1,000 cubic feet) of aeration basin;

and the food-to-microorganism ratio (F/M), which expresses BOD loading with regards to microbial mass (MLVSS). There are several modifications of the activated sludge process that may be used depending upon the BOD loading and the required treatment efficiency. Table 4-2 summarizes the loading and operational parameters for aeration processes that may be applicable to treatment of hazardous leachate.

(b) Even though conventional treatment has limitations such as poor tolerance for shock loads, a tendency toward producing bulking sludge that results in high suspended solids in the effluent, and low acceptable BOD loadings, these problems can be alleviated to varying extents with variations in process design. The completely mixed activated sludge (CMAS) modification of the process (Table 4-2) is the most widely used for treatment of waste-waters with relatively high organic loads. The advantages of this system are:

♡ Less variation in organic loading, resulting in more uniform oxygen demand and effluent quality.

♡ Dilution of the incoming wastewater into the entire basin, resulting in reduced shock loads.

♡ Uses the entire contactor contents at all times because of complete mixing.

(c) The extended aeration process involves long detention times and a low F/M ratio (0.1). Process design at this low F/H ratio results in a high degree of oxidation and a minimum of excess sludge. The contact stabilization process--in which biological solids are contacted with the wastewater for short periods of time, separated, and finally aerated to degrade absorbed organics--has shown some success for industrial wastes with a high content of suspended and colloidal organics. Pure oxygen systems have resolved several major drawbacks of conventional treatment. Pure oxygen systems show increased bacterial activity, decreased sludge volume, reduced aeration tank volume, and improved sludge settling. The pure oxygen process has been demonstrated to be applicable to a wide range of wastes at high F/M ratios. Such wastes streams include: petrochemical, dye, pharmaceutical, and pesticide wastes.

(d) In addition to process variations, there are several measures available for minimizing process upsets and maximizing stability:

♡ The deleterious effects of hydraulic and organic load variations can be minimized by equalization preceding biological treatment.

♡ A commonly used method for providing increased biodegradation is to increase the inventory of biological solids in the aeration basin by increasing the sludge-recycle ratio or reducing sludge wastage. However there is usually a tradeoff to such an approach. Higher sludge quantities lead to increased need for food and air. Also, old heavy sludge tends to become mineralized and devoid of oxygen, creating a less active floc. The rate of return sludge may vary from 35 to 50 percent in systems carrying a low MLSS concentration (approximately 2,000 milligrams per liter) and from 75 to 100 percent in systems carrying higher MLSS.

Table 4-2. Summary of Operating Parameters for Air-Activated Sludge and Pure-Oxygen-Activated Sludge

Process mobilization	Aeration system	BOD loading g BOD/m^3 (lb BOD/ 1,000 ft^3)	FM ratio g BOD/day g MLVSS (lb BOD/day lb MLVSS)	Mixed liquor suspended solids (mg/ℓ)	Applications and limitations
Conventional	Diffused air, mechanical aerators	320-640 (20-40)	0.2-0.4 (no conversion required)	1,500-3,000	Low strength wastes; subject to shock load
Step aeration	Diffused air	640-960 (40-60)	0.2-0.4	2,000-3,500	Flexible and generally applicable to a wider range of wastes than conventional treatment. Uses lower volumes of air and shorter detention times than conventional processes, but can handle higher BOD loads
Complex-mix	Diffused air, mechanical aerators	800-1920 (50-120)	0.2-0.6	3,000-6,000	Resistant to shock loads, generally applicable
Extended aeration	Diffused air, mechanical aerators	160-400 (10-25)	0.05-2.0	3,000-6,000	Requires long detention times and low organic load; produces low volume of sludge; available as package plant
Contact stabilization	Diffused air, mechanical	960-1200 (60-75)	0.2-0.6	1,000-3,000[1] 4,000-10,000[2]	Low aeration requirements; not suitable for soluble BOD

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[1] Contact unit.

[2] Solids stabilization unit.

(Source: Hammer 1975, Metcalf and Eddy, Inc. 1972, Nemerow 1978).

Table 4-2. (Concluded)

Process mobilization	Aeration system	BOD loading $g\ BOD/m^3$ (lb BOD/ 1,000 ft^3)	FM ratio g BOD/day g MLVSS (lb BOD/day lb MLVSS)	Mixed liquor suspended solids (mg/ℓ)	Applications and limitations
High rate	Mechanical aerators	1280+ (80+)	0.5-1.0 (no conversion required)	4,000-10,000	Well suited to shock loads; requires little supervision. However, requires long detention times, requiring three times as much air as conventional treatment
Pure-oxygen	Mechanical aerators	1920+ (120+)	0.6-1.5	6,000-8,000	High efficiency possible at increased BOD loads and reduced aeration

- Suspended solids should be reduced as much as possible by sedimentation or filtration.

- Since kinetics of biological degradation are concentration-dependent, dilution can minimize process upsets under some conditions.

- Sludge bulking, which leads to poor effluent quality, can be controlled by pH adjustment, sufficient aeration, and adequate nutrient supply. An important consideration for leachate treatment is that microbial growth is a function of the limiting nutrient. Some leachates may be phosphorus or nitrogen limited. Requirements for nitrogen and phosphorus are generally

N = 5 kg/100 kg BOD_5 (5 lb/100 lb BOD_5) removed

P = 1 kg/100 kg BOD_5 (1 lb/100 BOD_5) removed

(e) Equipment used for activated sludge treatment varies considerably, but the major types of aerators are mechanical surface, diffuse air, and sparged turbine aerators.

- Mechanical surface aerators are most economical but have the lowest transfer rates.

- Compressed air diffusers: Coarse air diffusers have lower energy requirement and lower gas transfer efficiency. Fine air diffusers have higher energy requirement and higher gas transfer efficiencies.

- Sparged turbine aerators use most energy but have best gas transfer efficiency. This form of diffused air is very fine and benefits from improved gas transfer kinetics.

(f) Secondary clarifiers are used to separate activated sludge solids from the mixed liquor and to produce concentrated solids for the return flow required to sustain biological treatment. Average hydraulic loading varies from 1.6 to 3.3 $m^3/day/m^2$ (400 to 800 gallons per day per square foot) and peak loadings range from 2.9 to 4.9 $m^3/day/m^2$ (700 to 1,200 gallons per day per square foot), depending on MLSS concentration and percent sludge recycle. Average solids loading of 2.9 to 5.9 $kg/hr/m^2$ (0.6 to 1.2 pounds per hour per square foot) and peak loadings of 6.1 to 9.8 $kg/hr/m^2$ (1.25 to 2.0 pounds per hour per square foot) are typical for activated sludge plants. Depths are normally 3.7 to 4.6 m (12 to 15 feet).

c. Fixed Film (Trickling Filter). Trickling filters are a form of biological treatment in which a liquid waste of less than 10,000 mg/ℓ suspended solids is trickled over a bed of rocks or synthetic media upon which a slime of microbial organisms is grown. The microbes decompose organic matter aerobically; these conditions are maintained at the outer slime surface by updrafts of air. Some anaerobic decomposition may occur at the interior surface adjacent to the trickling bed media. Periodically, the slime layer sloughs off due to the weight of the microbial growth or the hydraulic flow rate of the effluent. A schematic diagram of a typical trickling filter treatment system appears in Figure 4-5.

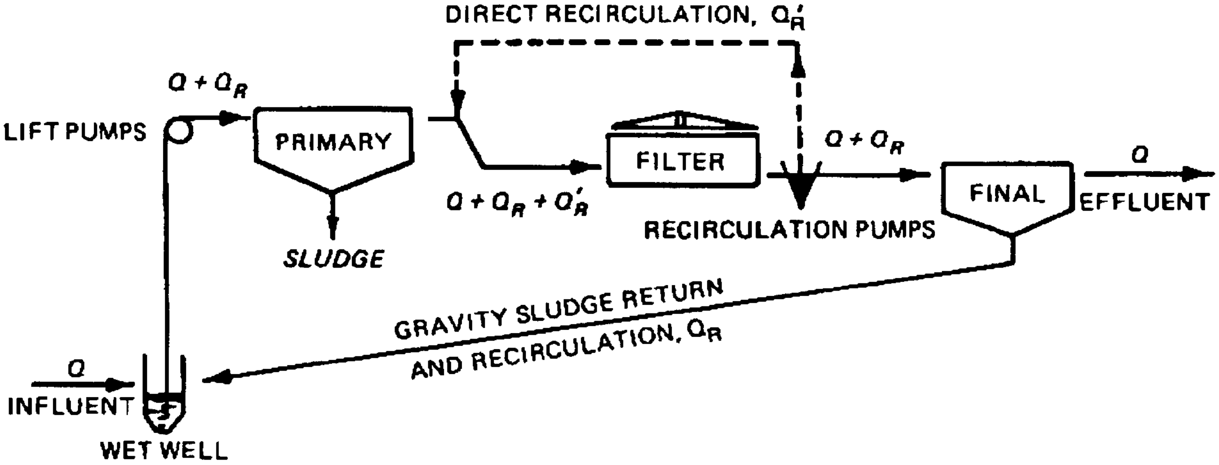

Figure 4-5. Trickling Filter Recirculation (Source: Hammer 1975, EPA 1982)

(1) Applications.

(a) Trickling filters are well suited to treatment of low flow waste streams and are often used as roughing filters to reduce organic loads to a level suitable for activated sludge treatment. Trickling filters are currently used in conjunction with other treatment methods to treat wastewaters from refineries, pharmaceuticals, pulp and paper mills, etc. Efficiency of trickling filters in the treatment of refinery and petrochemical wastes ranges from 10 to 20 percent when used as a roughing filter to 50 to 90 percent when used for secondary treatment. The process is more effective for removal of colloidal and suspended materials than it is for removal of soluble matter.

(b) Because of the short hydraulic residence time on the filter material, biodegradation along the filter media is generally insufficient as the sole means of biological treatment. For concentratrated wastes, a high rate of recirculation would be required for significant reduction of organics. The short residence time, however, has the advantage of allowing greater variations in influent waste composition as compared with activated sludge or anaerobic digestion. By placing a trickling filter in sequence with activated sludge treatment, the filters could be used to equalize loading variations while the activated sludge would achieve the high removal efficiencies needed.

(2) Advantages/disadvantages. Advantages and disadvantages of trickling filters as compared to other biological treatment methods and nonbiological methods for removal of organics are as follows:

Advantages	Disadvantages
Because of short hydraulic residence times, process is not highly sensitive to shock loads	Vulnerable to below-freezing temperatures
Suitable for removal of suspended or colloidal matter	Limited treatment capability in a single-stage operation
	Potential for odor problem
Has good applicability as a roughing filter to equalize organic loads	Has limited flexibility and control
	Requires long recovery time if disrupted
	Requires large surface area compared with other biological treatment systems

(3) Data requirements. The data required for trickling filter design are generally the same as for activated sludge with the exception of no requirements for biodegradable sludge fraction, average MLVSS, and nonbiodegradable fraction. Summer and winter ambient conditions are required, these include:

(a) Temperature.

(b) Wind velocity.

(c) Insolation-solar radiation.

(d) Relative humidity.

(4) Design citeria.

(a) The variables that influence design and performance of the trickling filter include: organic and hydraulic load, media type, nature of the waste, pH, and temperature. Trickling filters are classified according to their ability to handle hydraulic and organic loads. Typical design criteria for low and high rate filters are shown in Table 4-3. Use of plastic media filters with low bulk density has resulted in increased organic and hydraulic loading rates over those achieved with rock media filters. Plastic media filters have generally shown good performance under high BOD loading conditions that would not be tolerated by a conventional-type system because of clogging problems.

Table 4-3. Design Criteria for Trickling Filters

Design Parameter	Plastic media filter	High rate, rock media	Low rate, rock media
Hydraulic loading, $m^3/day/m^2$ ($gal/day/ft^2$)	2.9-5.7 (700-1,400) (secondary) 9.4-18.9 (2,3000-4,600) (roughing filter)	.94-3.7 (230-900)	0.1-.37 (25-90)
Organic loading lb BOD/day/ 1,000 ft	10-50 (secondary) 100-500 (roughing filter)	20-60	5-20
Bed depth, ft	20-30	3-6	5-10
Media type	Plastic	1- to 5-in. rock	1- to 5-in. rock

(Source: EPA 1982).

(b) Recirculation is generally required to provide uniform hydraulic loading as well as to dilute high-strength waste waters. However, there is a limit to the advantage achievable with recirculation. Generally, recirculation rates greater than four times the influent rate do not increase treatment efficiency. Several recirculation patterns are available. One of the most popular is gravity return of the underflow from the final clarifier to a wet well during periods of low flow and direct recirculation by pumping filter discharge back to the influent as shown in Figure 4-5.

(c) Several formulas have been proposed which predict BOD removal efficiency based on waste type, influent BOD, hydraulic load, and other factors related to performance. Problems with these models include the need to determine treatability on a case-by-case basis and the fact that the models are usually applicable for only very specific conditions.

(d) The National Research Council (NRC) formulation to predict BOD removal efficiency was the result of an extensive analysis of operational records from stone-media trickling filter plants at military installations. The NRC data analysis is based on the fact that the amount of contact between the filter media and organic matter depends on the filter dimensions and the number of passes, and that the greater the effective contact, the greater will be the efficiency. However, the greater the applied load, the lower will be the efficiency. Therefore, the quantity that primarily determines efficiency in a trickling filter is a combination of effective contact and applied load. The efficiency through the first or single stage (E_1) and through the second stage (E_2) can be predicted from equations 4-2 and 4-3.

$$E_1 = \frac{100}{1 + 0.0085\left(\frac{W_1}{VF}\right)^{\frac{1}{2}}} \tag{4-2}$$

$$E_2 = \frac{100}{1 + \frac{0.0085}{1-E_1}\left(\frac{W_2}{VF}\right)^{\frac{1}{2}}} \tag{4-3}$$

where

E_1 = percent ROD removal efficiency through the first-stage filter and settling tank

W_1 = BOD loading (lb/day; 1 lb/day = 0.45 Kg/day) to the first- or second-stage filter, not including recycle

V = volume (acre-ft; 1 acre ft = 1,233.5 m^3) of the particular filter stage (surface area times depth of media)

F = number of passes of the organic material, equal to

$$(1 + R/I)/[1 + (1 - P)R/I]$$

where R/I equals the recirculation ratio (recirculated flow/plant influent flow), and P is a weighting factor which, for military trickling filter plants, was found to be approximately 0.9

E_2 = percent BOD removal efficiency through the second-stage filter and settling tank

W_2 = BOD loading (lb/day) to the second-stage filter, not including recycle

(Note: Empirical equations, can only be used with English units - to use with metric, must convert to English before putting in Equation.)

(e) If recirculation is not being used, F will equal 1. It should be remembered that the NRC formulation was based on military waste water which is characteristically more concentrated than average domestic waste water. This could make the NRC formula more applicable to hazardous waste treatment. The effect of temperature on performance was not considered since most of the plants studied were in the middle latitudes of the United States.

d. Rotating Biological Disks. A rotating biological disk (RBD) is a fixed film biological method for treating effluent containing organic waste, similar in operating principle to trickling filters. A series of disks (1.8 to 3.0 in (6 to 10 feet) in diameter), or drums in some configurations, coated with a microbial film, rotate at 0.5-15 revolutions per minute through troughs containing the effluent; 40-50 percent of the disk surface area is immersed in the effluent while the uncovered portion of the disk exposes the microbial film to the atmosphere during each rotation. Supplemental aeration is sometimes beneficial. The shearing motion of the disk through the effluent keeps the biological floc from becoming too dense. Periodic reversing of drum rotation is often used to control biological growth. The disks are usually arranged in series in groups of four. A schematic of a RBD is shown in Figure 4-6.

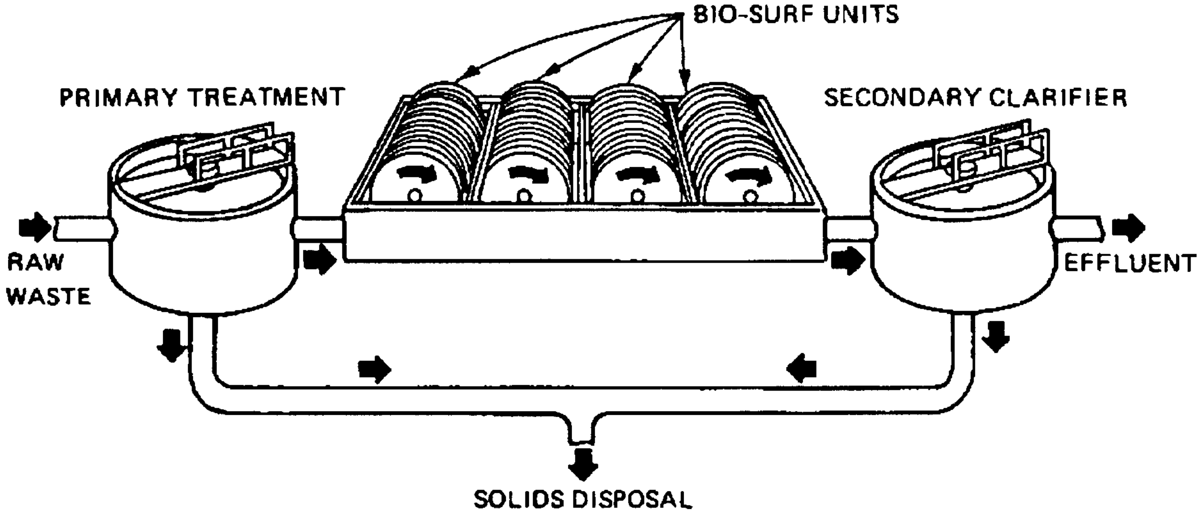

Figure 4-6. Rotating Biological Disk Treatment Schematic

(1) Applications. Rotating biological disks are currently being used at full scale to treat waste waters from the manufacture of herbicides, pharmaceuticals, petroleum, pulp and paper, and pigments and may have application for ground-water or leachate treatment at hazardous waste sites. They also have found use for domestic waste-water treatment. The process has only been used in the United States since 1969. Its modular construction, low hydraulic head loss, and adaptability to existing plants have resulted in growing use. The process can be used for roughing, nitrification, or secondary treatment.

(2) Advantages and disadvantages. Avantages and disadvantages of rotating biological disks as compared to trickling filters and activated sludge are summarized below:

Advantages	Disadvantages
Process has considerably more flexibility than trickling filters; both the intensity of contact between biomass and waste water and the aeration rate can be easily controlled by the rotational speed of the disks	Vulnerable to climate changes if not covered
	High organic loads may result in first-stage septicity and supplemental aeration may be required

(Continued)

Advantages	Disadvantages
Waste-water retention time can be controlled by selecting appropriate tank size; thus higher degrees of treatment can be obtained than with trickling filters	Odor may be a problem if septic conditions develop
In contrast to the trickling filter, biological disks rarely clog since shearing forces continuously and uniformly strip excess growth	As with trickling filters, biomass will be slow to recover if disrupted
As compared with activated sludge, rotating biological disks can handle large flow variations and high organic shock loads	Can handle only relatively low-strength wastes as compared with activated sludge
Modular construction provides flexibility to meet increased or decreased treatment needs	
Low O&M and energy requirements	
Requires small surface area when compared with other biological systems	

(3) Data requirements. The data required for the design of rotating biological disks are generally the same as for trickling filter design.

(4) Design criteria. For adequate treatment it is recommended that the process include four stages (disks) per train and the use of at least two parallel trains. Based on the design criteria, rotating biological disks can handle organic loads similar to a high-rate trickling filter. Typical design criteria include:

	(Without nitrification)	(With nitrification)
Organic Loading:	480-960 g BOD/m^3 (30-60 lb BOD/1,000 ft^3 media)	240-320 g BOD/m^3 (15-20 lb BOD/1,000 ft^3 media
Hydraulic Loading:	3×10^{-3} to 6.1×10^{-3} m^3/day/m^2 (0.75 to 1.5 gal/day/ft^2)	1.2×10^{-3} - 2.5×10^{3} m^3/day/m^2 (0.3-0.6 gal/day/ft^2)
Detention Time:	40-90 min	90-230 min

e. Lagoon Treatment. Lagoons or waste stabilization ponds are systems in which the processes of microbial oxidation, photosynthesis, and sometimes anaerobic digestion combine to break down hazardous organic compounds. They are similar to activated sludge units without sludge recycling. Aeration may be supplied passively by wind and algae or, in aerated lagoons, by mechanical aerators or diffused air. The ecology of lagoons closely resembles a natural eutrophic lake, a more complex system than other biological treatment systems. A secondary benefit of lagoons is clarification. Physical and chemical treatment processes may also be carried out in lagoons. Figure 4-7 shows a flow diagram of an aerated lagoon, with a secondary clarifier. A separate clarifier may not be required with other lagoon designs, e.g., facultative lagoons, if the design includes a separate baffled settling compartment, two or more lagoons in series, or other special features.

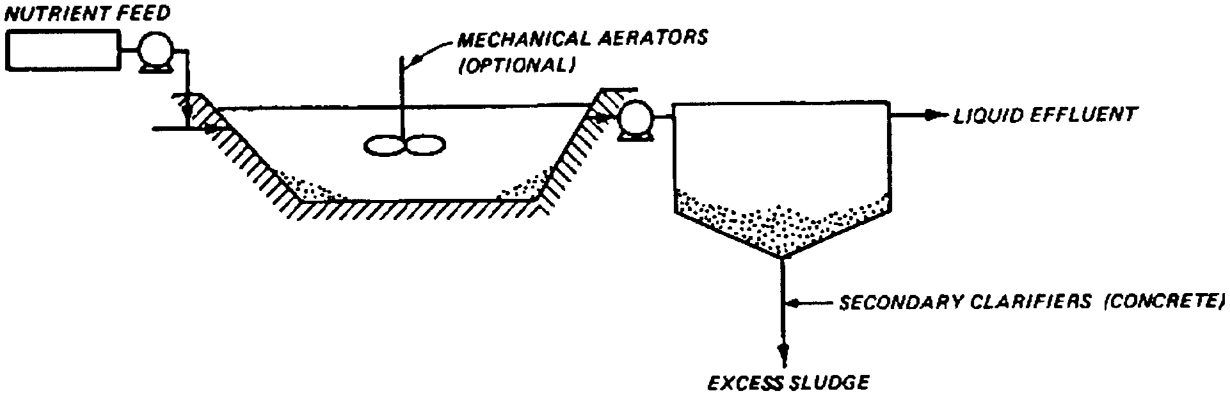

Figure 4-7. Aerated Lagoon (Polymeric-Lined Earth Construction)

(1) Applications. Waste stabilization ponds have been used to treat low-strength industrial wastes, landfill leachate, and as a polishing step for certain waste types. This treatment module is employed in food processing industries, paper and pulp mills, textile mills, refineries, and petrochemical plants.

(2) Advantages/disadvantages. The advantages and disadvantages of stabilization ponds and aerated lagoons are as follows:

Advantages	Disadvantages
Operating costs are low compared with other biological treatment methods	Tolerate low-strength wastes only Intolerant of suspended solids and metals
Cost-effective treatment for polishing effluent	Require large land areas
Waste stabilization ponds require minimal energy	Performance markedly affected by temperature, and treatment method is not suitable for freezing temperatures

(Continued)

Advantages	Disadvantages
	System has limited flexibility
	Volatile gases may be emitted from processes

(3) Data requirements. The data requirements are generally the same as those for activated sludge systems. The nonbiodegradable fraction and average MLVSS are not required; however, the summer and winter ambient conditions will affect performance.

(4) Design criteria.

(a) Each subtype of waste stabilization pond utilizes a different type of bacteria but is of similar construction, with an earthen pit and earthen side levees. Treatment of leachates requires that the pond be lined. The designs of various waste stabilization ponds and anaerobic lagoons differ significantly. Table 4-4 summarizes the major design criteria. The criteria indicate that, in general, lagoons can treat only low-strength waste and therefore will be best suited as a polishing step used in conjunction with other treatment methods.

(b) As Table 4-4 indicates, the aerobic lagoon requires the greatest surface area to treat an equivalent waste load. Oxygen transfer depends on the ratio of lagoon surface area to volume (length-to-width ratio should be less than 3:1), temperature, turbulence, and bacterial oxygen uptake. The system has the least tolerance for high organic loads but benefits from a short detention time. Anaerobic stabilization ponds require significantly less surface area and can handle substantially higher organic loads. Deep lagoons benefit from better heat retention, and an effluent length-to-width ratio of 2:1 is recommended.

(c) Sludge buildup is much less for the anaerobic pond than that for the aerobic; for every Kg (pound) of BOD destroyed by the anaerobic process, about 0.1 Kg (pound) of solids is formed, as compared to 0.5 Kg (pound) for the aerobic lagoon. The major disadvantage of the anaerobic lagoon is that it produces strong odors unless the sulfate concentration is maintained below 100 milligrams per liter.

(d) The facultative lagoon benefits from having an aerobic layer that oxidizes hydrogen sulfide gas to eliminate odors. It can handle BOD loads intermittently between the anaerobic and aerobic lagoon.

(e) Artificial aeration with mechanical or diffused aerators allows for deeper basins and higher organic loads than those obtained in aerobic lagoons. The basins are designed for partial mixing only, and anaerobic decomposition occurs on the bottom. Operating costs are significantly less than those for activated sludge, but the system cannot withstand the organic loads tolerated by activated sludge. In general, the use of several lagoons in series is more

Table 4-4. Design Criteria for Waste Stabilization Ponds[1]

Design parameter	Aerobic	Facultative	Anaerobic	Aerated
Depth, m (ft)	0.27 to 0.55 (0.9 to 1.8)	0.55 to 1.4 (1.8 to 4.5)	2.3 to 5.5 (7.5 to 18)	9.1 to 5.5 (3 to 18)
Organic load, kg/ha/day (lb BOD/acre/day)	100 to 200 (89.3 to 178.6)	10-to 100 (8.93 to 89.3)	200 to 2000 (178.6 to 1786)	10 to 31 (8.93 to 267.9)
Detention time typical, days	2 to 6	7 to 30	30 to 50	3 to 10
Influent BOD, mg/ℓ	200	200 to 500	500 and up	200 to 500
Flow regime	Intermittently mixed	Mixed surface layer	Not mixed	Completely mixed
Principal conversion product	Algae, CO_2, bacteria	Algae, CO_2, CH_4, bacteria	CO_2, CH_4, bacteria	CO_2, bacteria
Algal concentration, mg/ℓ	40 to 100	10 to 80	0 to 5	--
Operating pH	6.5 to 10.5	6.5 to 9.0	6.8 to 7.2	6.5 to 8.0
Effluent suspended solids, mg/ℓ	10 to 140	40 to 100	80 to 160	80 to 250

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[1] Adapted from EPA (1979), Liptak (1974), and Metcalf and Eddy, Inc. (1979).

efficient than one lagoon since it can reduce short-circuiting and lead to increased organic removal efficiency.

4-6. Carbon Adsorption.

a. Process Description.

(1) Activated carbon, granular or powdered, when contacted with water containing organic material, will remove these compounds selectively by a combination of adsorption of the less polar molecules, filtration of the larger particles, and partial deposition of colloidal material on the exterior surface of the activated carbon. Adsorption results from the forces of attraction between the surface of a particle and the soluble organic materials that contact the particle. As a result of the activation process, activated carbon has a large surface area per unit weight, making it a very efficient adsorptive material. It has long been used to remove taste and odor-causing impurities from public water supplies. More recently, activated carbon adsorption has been used in waste-water treatment as a tertiary process following conventional secondary treatment or as one of several unit processes comprising physical-chemical treatment. Pesticides and other long-chain organics have excellent adsorption characteristics on activated carbon.

(2) The most efficient and practical use of activated carbon in wastewater treatment has been in fixed beds of granular activated carbon. A typical adsorption system consists of several adsorption trains operated in parallel. Each train contains two adsorbers arranged for series flow. The waste water is applied to the adsorbers at a flow rate ranging from 1.6×10^{-2} to 3.3×10^{-2} $m^3/min/m^2$ (4 to 8 gallons per minute per square foot). Contact time (empty bed residence time) ranges from 15 to 35 minutes depending on the desired effluent quality. Countercurrent flow systems allow systems to approach activated carbon isotherm capacity and are recommended.

(3) To minimize suspended solids collection which can clog the pores and reduce adsorber capacity, the carbon adsorption system should be preceded by media filtration. Provisions must be made to regularly backwash the adsorption system to flush out accumulated suspended solids and biological growth. A good design practice is to allow for a bed expansion of up to 50 percent. Flow rates during backwash should range from 6.2×10^{-2} to 8.2×10^{-2} $m^3/min/m^2$ (15 to 20 gallons per minute per square foot). Biological growth can be controlled effectively by chlorination of the influent to the adsorber or by chlorination during the backwash operation.

(4) When the active sites on the carbon particles have been filled, the effluent quality deteriorates and the carbon must be regenerated or replaced. It is not economical to have onsite regeneration for systems requiring regeneration of less than about 91 kg (200 pounds) of carbon per day. For larger systems, a regeneration system should be provided. A typical regeneration system includes: (a) hydraulic transport of the carbon to the regeneration unit, (b) dewatering of spent carbon, (c) heating of carbon to oxidize or volatilize the adsorbed impurities, (d) water cooling of the carbon, (e) water washing and hydraulic transport back to the adsorbers, and (f) scrubbing of