Wastewater Treatment

by

Dr. Monthon Thanuttamavong

Contents

Wastewater Quantities

- Sources
  - municipal (domestic, commercial, industrial)
- Flows
  - not vary as much as the water demand
- Design flows
  - for the collecting pipes, require the minimum flow-rate of 0.3 m/s
  - for the treatment plant, design the average daily flow

Sanitary Sewer System

- The purpose of the **sanitary sewer system** is to receive liquid wastes from dwelling, buildings, institutions, and other entities and transport them to the wastewater treatment plant without creating offensive conditions or health hazards.
- The system consists of the collection pipes or conduits and appurtenances, such as oil and grease traps, manholes, inverted siphons, and pump stations, where necessary.

- **Sewage** or **wastewater** is the liquid transported by a sewer. The term *sewage* is an older term; the most common modern term is *wastewater*.
- **Sanitary sewage** or **domestic wastewater** is the liquid wastewater from sanitary facilities within a building.
- **Industrial wastewater** is the liquid wastewater from an industry, such as a paper-making plant or a brewery.
- **Storm sewage** or **stormwater** is the storm runoff that occurs from rainfall.
- **Infiltration** is the groundwater or rainfall seepage that enters sanitary sewers through cracks in pipe joints and manholes, service connections, and defective pipes.

- Infiltration is maximum during storm events and may be termed **peak infiltration** or **storm infiltration** to differentiate it from **dry-weather flow infiltration**, which occurs during dry weather.
- **Inflow** is relatively unpolluted water that enters the sewer through such sources as manhole covers, roof downspouts, yard drains, foundation drains, and cooling-water discharge from air conditioners and industries.
- Inflow through manhole covers is almost unavoidable; however, these other sources can be avoided. Most cities have ordinances that prohibit connections that allow these sources of inflow to occur. Such sources should discharge into sewers that carry stormwater.

- A **combined sewer** carries sanitary sewage and rainfall runoff or stormwater and, in some cases, industrial wastewater from the area is serves.
- A separate sewer system has both sanitary and storm sewers and is considered good, modern engineering practice.
- When domestic wastewater temperature is very warm, travel times in the sewers are long, and sulfates are present in significant amounts, **corrosion** of the crowns or inside tops of concrete sewers has occurred.
- Sulfates, in anaerobic action, are converted to hydrogen sulfide, as shown in Figure 5.1.

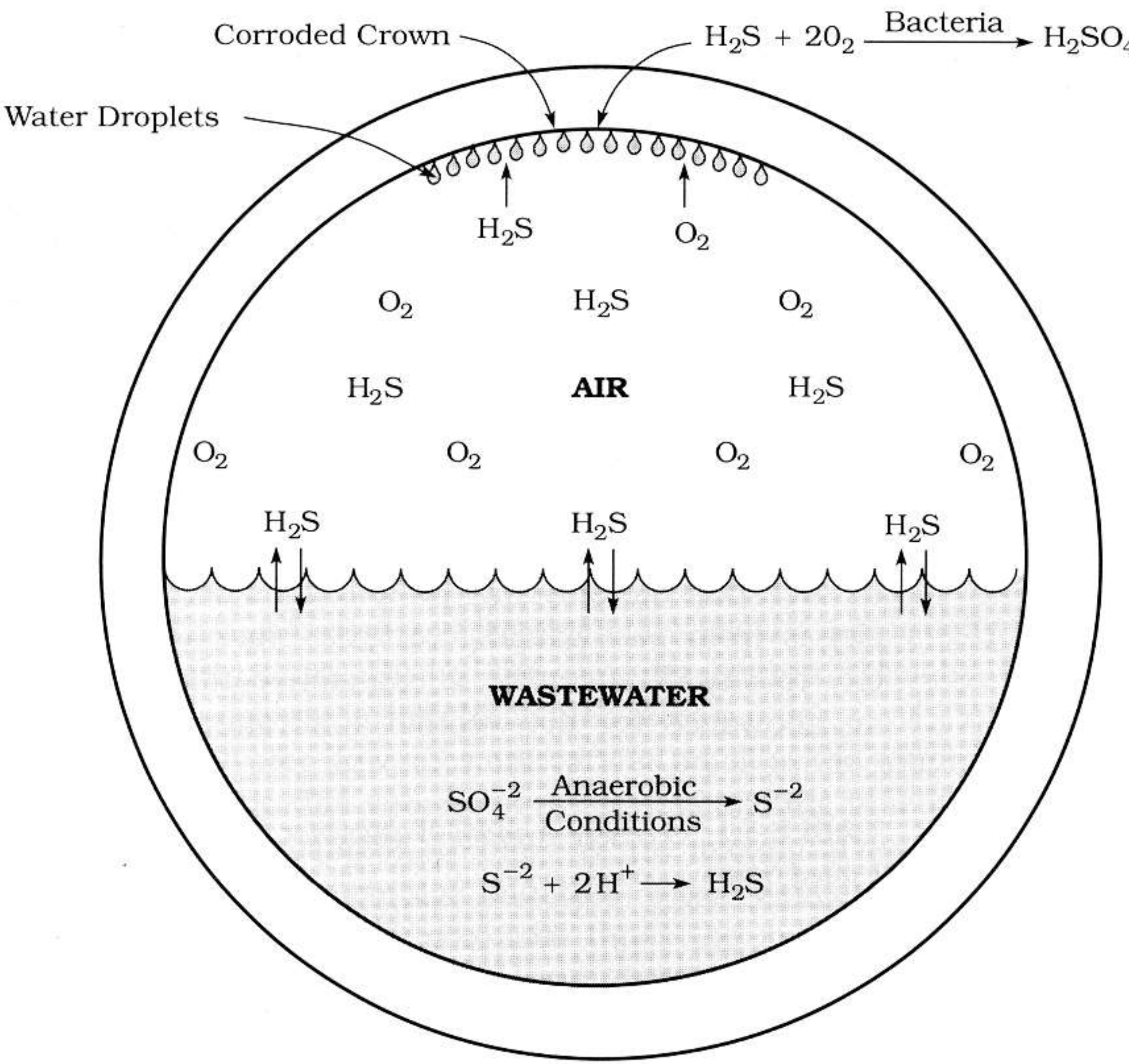

FIGURE 5.1 *Anaerobic Conditions in a Sanitary Sewer*

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Sewer conditions that cause H_2S generation are

(1) flat grades creating low velocities and long travel times,

(2) warm wastewater temperature,

(3) high sulfate ion concentration in the wastewater, and

(4) high organic content in the wastewater or high BOD_5.

- Corrosion by bacteria-generated sulfuric acid occurs also in cast iron and steel pipes, as well as in other acid-soluble materials.
- For these pipes, an inside protective coating is required.
- The main reason why clay pipe is such a good sewer conduit for sanitary sewers is that it is inert and resistive to acid attack.

TABLE 5.1 *Average Annual Wastewater Flows of Selected Cities and Districts in the United States*

CITY OR DISTRICT	AVERAGE ANNUAL WASTEWATER FLOW		PERCENTAGE OF THE WATER DEMAND
	gal/cap-d	ℓ/cap-d	
Baltimore, Md.	100	379	63
Berkeley, Calif.	68	257	89
Boston, Mass.	140	530	97
Grand Rapids, Mich.	190	719	84
Greenville, S.C.	150	568	73
Hagerstown, Md.	100	379	100
Jefferson County, Ala.	100	379	98
Johnson County, Kan.	60	227	86
Lancaster County, Neb.	92	348	55
Las Vegas, Nev.	209	791	51
Little Rock, Ark.	50	189	100
Los Angeles, Calif.	85	322	46
Peoria, Ill.	75	284	83
Memphis, Tenn.	100	378	80
Orlando, Fla.	70	265	47
Rapid City, S.D.	121	458	99
Santa Monica, Calif.	92	348	67
Wyoming, Mich.	82	310	56
Averages	100	396	76

Adapted from *Design and Construction of Sanitary and Storm Sewers*, Water Pollution Control Federation Manual of Practice No. 9.

The wastewater flow does not vary as much as the water demand. This is because of the storage volume in the sewers and the time it takes the flow to reach the point of gauging.

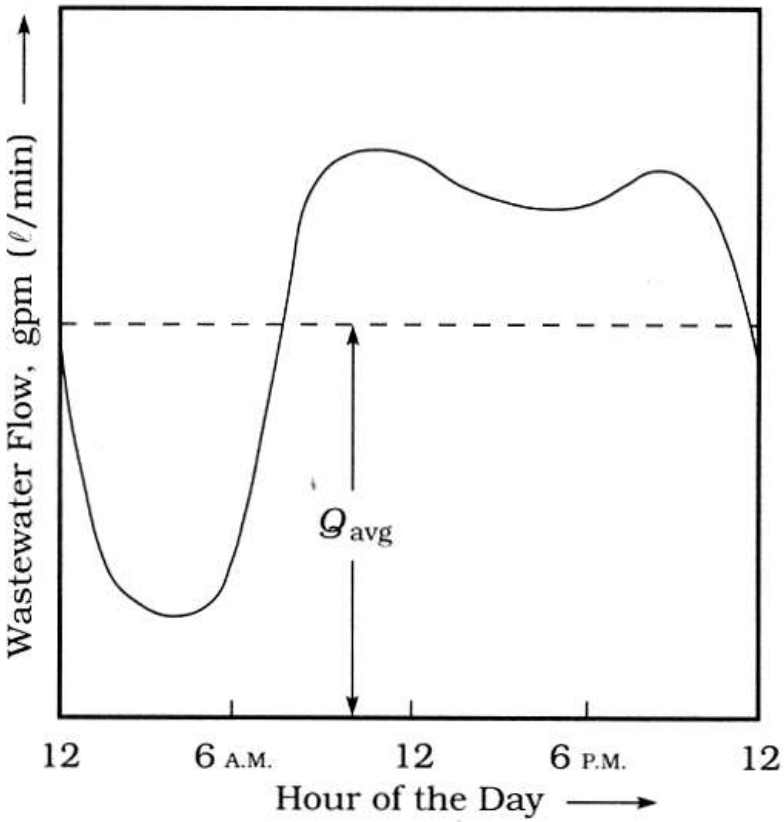

FIGURE 5.2 ***The Daily Variation in Wastewater Flow for a Typical City***

$$\frac{Q_P}{Q_A} = \frac{5}{P^{0.2}} \qquad (5.1)$$

where

Q_P = peak hourly flow

Q_A = average hourly flow

P = tributary population, thousands

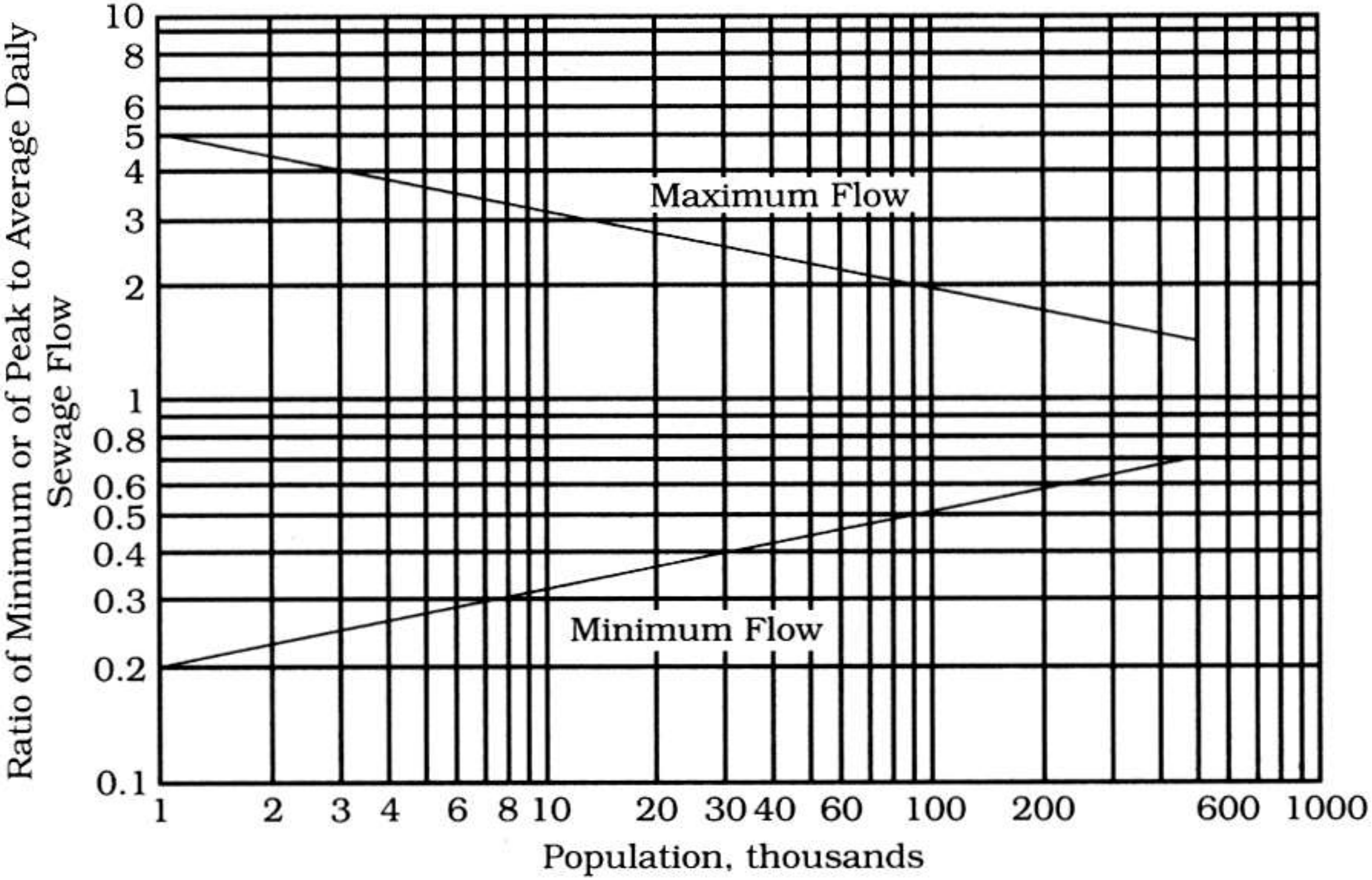

FIGURE 5.3 ***Ratio of Extreme Flows to Average Daily Flow for Municipal Wastewaters in Various Areas of the United States***

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Infiltration and Inflow

- The amount of infiltration to be expected will depend upon the care with which the system is constructed, the height of the groundwater table, and the type of soil.
- It is common to design for the peak hourly wastewater flow plus 71 m^3/km-d of sewer and house connections. This is where most of the system is above the permanent groundwater table.
- If most of the system is below the permanent groundwater table, 142 m^3/km-d is usually used for the design infiltration.

The peak infiltration in m^3/ha-d decreases as the tributary area increases. Since rainfall intensity decreases as the drainage area increases, it follows that peak infiltration should decrease as the tributary area increases.

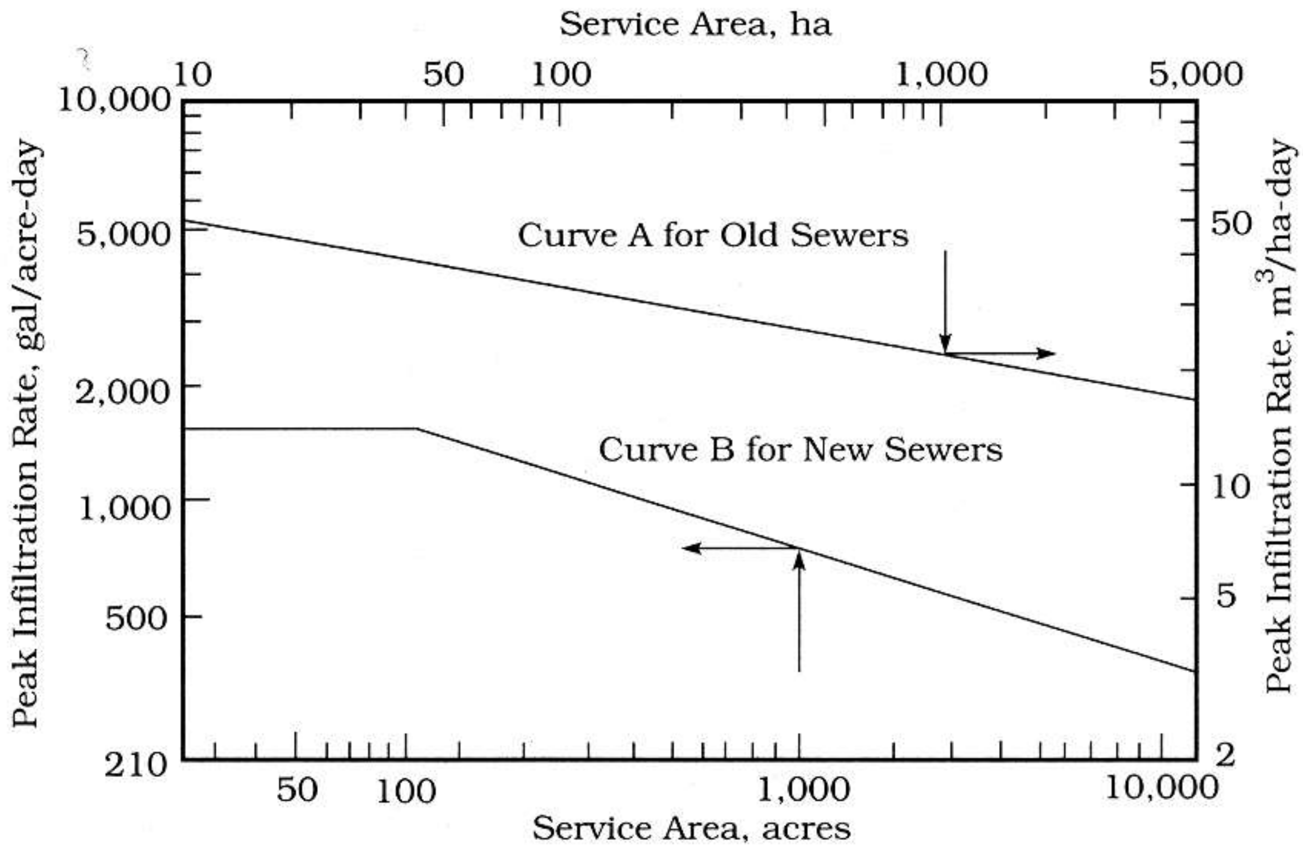


FIGURE 5.4 ***Peak Infiltration Allowances for Sanitary Sewers***

Adapted from *Wastewater Engineering: Collection and Pumping of Wastewater* by Metcalf and Eddy, Inc. Copyright © 1981 by McGraw-Hill, Inc. Reprinted by permission.

Design Flows

- The **minimum flowrate** is important in designing pipes and channels in a wastewater treatment plant that carry wastewater with suspended solids. The minimum velocity required to keep organic solids in suspension is about 0.3 m/s and to keep silt and fine sand in suspension is about 0.6 m/s.
- The **design flowrate** is usually assumed to be the average daily flow at the end of the design period. Usually the average daily flow is considered to be the average daily flow for a continuous 12-month period. The design flowrate is used for determining the organic loading to the treatment plant and for sizing the primary, secondary and sludge treatment facilities.
- The **maximum wet-weather flowrate** is the peak hourly flow plus flow due to the maximum storm infiltration and inflow. The maximum wet-weather flow determines the hydraulic capacity of the treatment plant and the collection system.

Wastewater Quality Characteristics

water-supply impurities + additional impurities after use

Physical

- turbidity
- color
- odor
- total solids
  - dissolved solids
    + *fixed solids*
    + *volatile solids*
  - suspended solids
    + *fixed solids*
    + *volatile solids*
  - settleable solids
- temperature

Chemical

- COD
- TOC
- N & P
- Cl^{-}, SO_4^{-2}
- pH
- alkalinity
- grease
- heavy metal ions
- trace elements

Biological

- BOD_5 / TOD
- Nitrogenous oxygen demand
- Microbial life
  - bacteria
  - protozoa
  - fungi
  - viruses
  - algae
  - rotifers
  - nematodes

TABLE 5.2 *Typical Characteristics of Untreated Municipal Wastewater in the United States*

CONSTITUENT	CONCENTRATION		
	Strong	Medium	Weak
Solids, total:	1250	800	450
Dissolved, total:	890	560	350
Fixed	295	295	185
Volatile	595	265	165
Suspended, total:	360	240	100
Fixed	145	75	25
Volatile	215	165	75
Settleable solids, mℓ/ℓ	7	5	3
Biochemical oxygen demand, 5-day, 20°C (BOD_5, 20°C)	400	200	100
Total organic carbon (TOC)	290	145	75
Chemical oxygen demand (COD)	910	455	230
Nitrogen (total as N):	75	40	16
Organic	40	20	8
Free ammonia	35	20	8
Nitrites	0	0	0
Nitrates	0	0	0
Phosphorus (total as P):	15	8	4
Organic	5	3	1
Inorganic	10	5	3
Chlorides[a]	83	42	21
Alkalinity (as $CaCO_3$)[a]	200	100	50
Grease	40	20	5

All values except settleable solids are expressed in mg/ℓ.
1 mg/ℓ = 1 g/m^3
[a] Values should be increased by the amount in the domestic water supply.

Biochemical Oxygen Demand

Up to about 10 to 12 days, the demand will be the oxygen required for oxidation of carbonaceous materials as shown by

$$\text{Organic matter} + O_2 \xrightarrow[\text{microbes}]{\text{Aerobic}} CO_2 + H_2O + \text{new cells} \\ + \text{energy} + \text{other end products} \qquad (5.2)$$

After about 10 to 12 days, the NH_3 will be oxidized to nitrites, and then to nitrates, by the reactions

$$NH_3 + 3O_2 \xrightarrow[\text{bateria } (\textit{Nitrosomonas})]{\text{Nitrite}} 2NO_2^- + 2H^+ + 2H_2O + \text{new cells} \\ + \text{energy} + \text{other end products} \qquad (5.3)$$

$$2NO_2^- + O_2 + 2H^+ \xrightarrow[\text{bateria } (\textit{Nitrobacter})]{\text{Nitrate}} 2NO_3^- + 2H^+ + \text{new cells} \\ + \text{energy} + \text{other end products} \qquad (5.4)$$

There are two distinct curves or stages – one for the breakdown of carbonaceous material and one for the nitrification of ammonia. In order to provide a standard test, a time of five days at 20°C was selected and is referred to as the **BOD_5**.

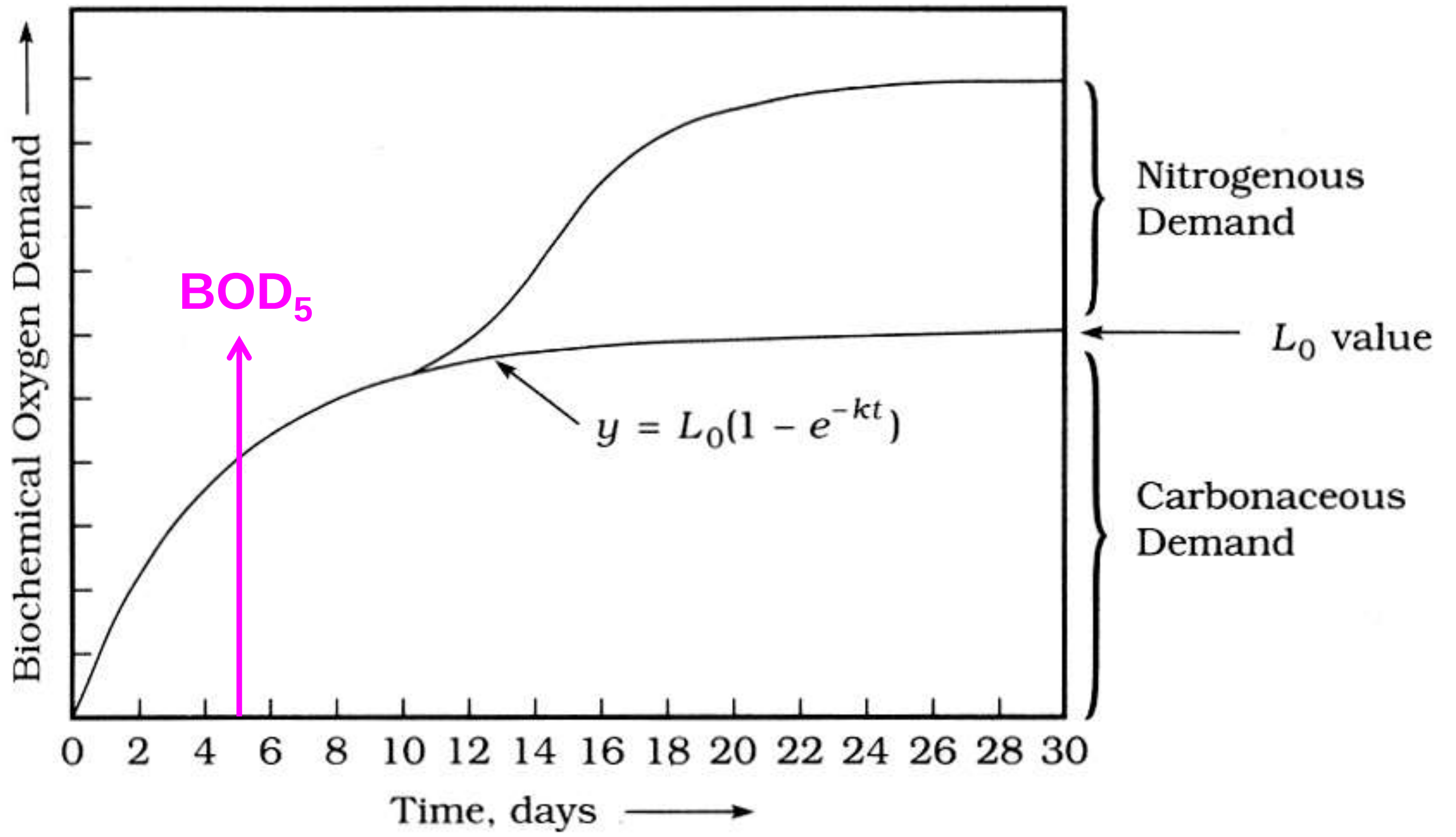


FIGURE 5.6 *The BOD Curves Showing Carbonaceous and Nitrogenous Demand*

$$-\frac{dC}{dt} = kC \xrightarrow{\text{Integration gives}} \boxed{\frac{C}{C_0} = e^{-kt}} \qquad (5.8)$$

where

dC/dt = rate of removal of organic material

k = rate constant to the base e

C = oxidizable organic material remaining at time t

C_0 = total oxidizable organic material originally present

t = test duration

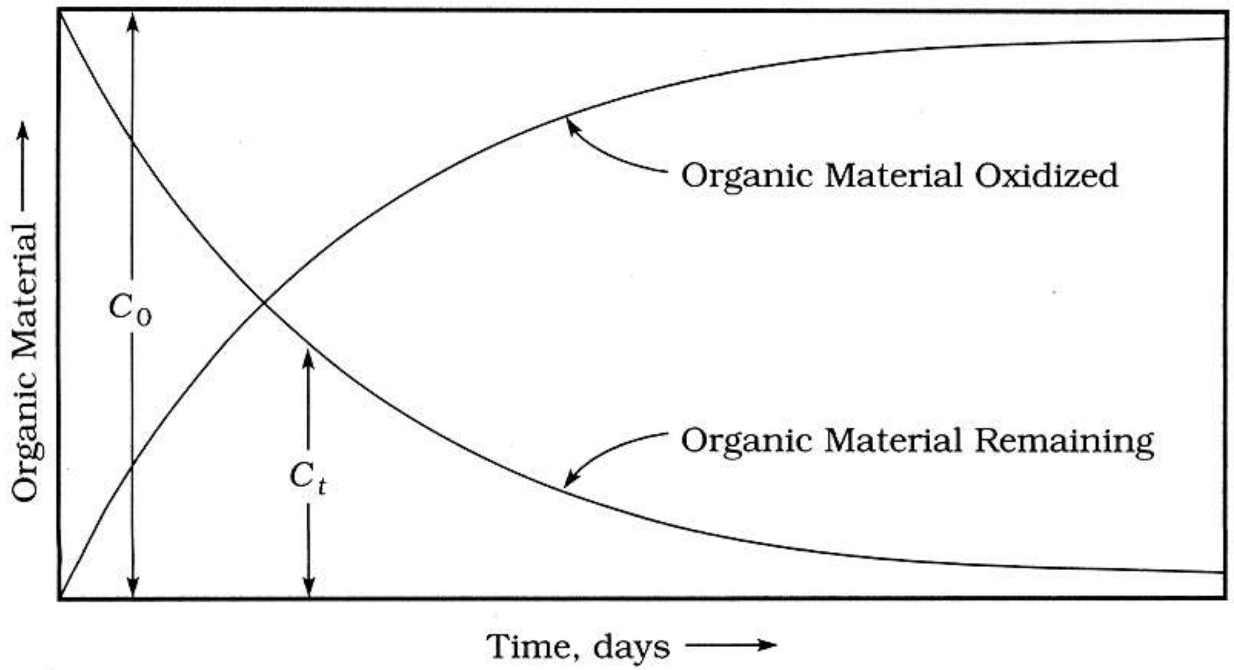


FIGURE 5.7 ***First-Stage or Carbonaceous Demand***

Since the amount of organic material used is proportional to the amount of oxygen required, $C \propto L$, where L is the BOD remaining at time t. Similarly, $C_0 \propto L_0$; thus Eq.(5.8) may be expressed as

$$\frac{L}{L_0} = e^{-k_1 t} = 10^{-K_1 t} \qquad (5.9)$$

where

L = BOD remaining at time t

L_0 = ultimate first-stage or carbonaceous BOD

k_1 = rate constant to the base e

t = test duration

K_1 = rate constant to the base 10

Thus, from Eq.(5.9), $L = L_0 e^{-k_1 t}$ and $L = L_0 10^{-K_1 t}$. The BOD exerted up to a given time, y, is $y = L_0 - L_0 e^{-k_1 t}$ or $y = L_0 - L_0 10^{-K_1 t}$, or

$$y = L_0\left(1 - e^{-k_1 t}\right) \tag{5.10}$$

$$y = L_0\left(1 - 10^{-K_1 t}\right) \tag{5.11}$$

where y is the BOD exerted up to time t, and $K_1 = 0.434 k_1$.

For typical municipal wastewaters, k_1 (base e) varies from about 0.23 to 0.70 day^{-1} at 20°C, the average value being 0.39 day^{-1}.

EXAMPLE 5.1 ***BOD* Test**

A wastewater has a BOD_5 of 200 mg/l, and the k_1 value is 0.34 day^{-1}. Determine the ultimate first-state BOD, L_0.

SOLUTION From the previous equations,

$$y = L_0\left(1 - e^{-k_1 t}\right)$$

or

$$200 = L_0\left[1 - e^{-(0.34)5}\right]$$

from which $L_0 = \boxed{245 \text{ mg/l.}}$

The BOD_5 requires five days duration, whereas the COD requires about 4 or 5 hours.

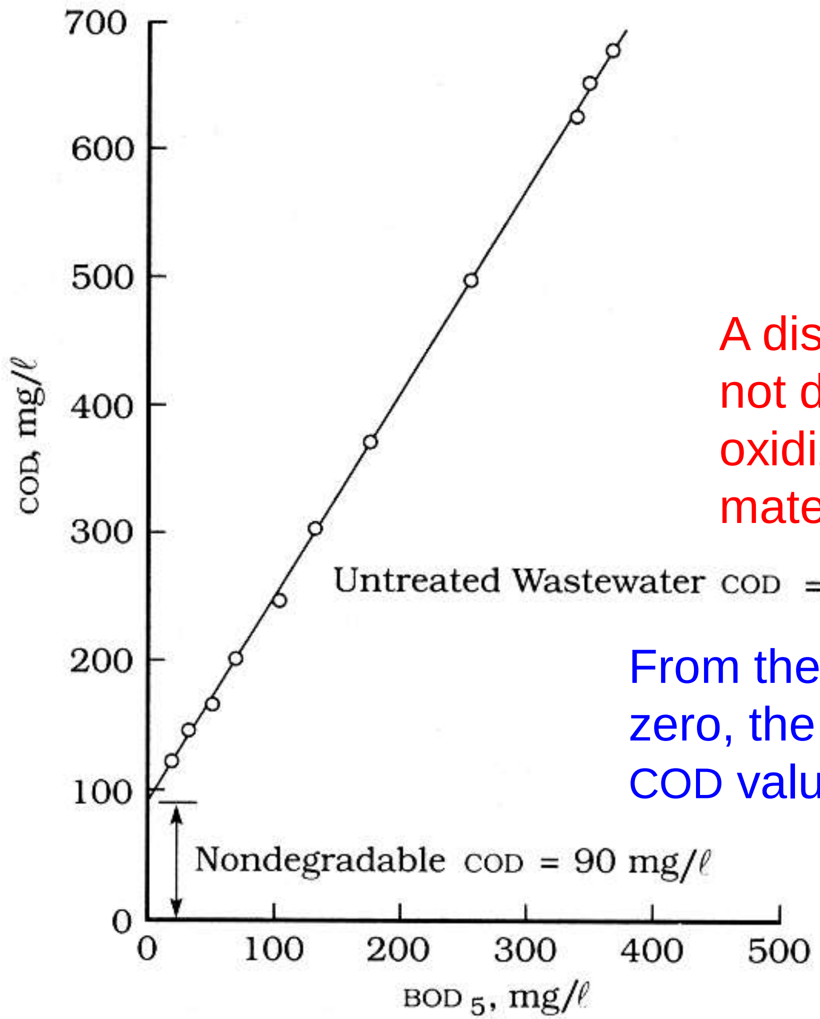


FIGURE 5.8 ***Relationship between BOD₅ and COD for a Soluble Organic Industrial Wastewater***

For a particular wastewater or effluent, a correlation graph of BOD_5 values versus COD values from numerous samples can be made, and the BOD_5 value can then be estimated if the COD value is known.

A disadvantage of the COD test is that it does not differentiate between the biologically oxidizable and the biologically resistant organic materials – that is, the nondegradable COD.

From the correlation graph, when the BOD_5 value is zero, the line intersects the *y*-axis, and the intersect COD value is the nondegradable COD.

The nondegradable COD is the COD not degradable within the wastewater treatment plant, and it appears in the plant effluent.

Effluent Requirements

To maintain a certain quality in the receiving water body of water, two methods of control have been used.

- Receiving-water standards
  - Surface water quality
  - Groundwater quality
- Effluent standards

Industrial Effluent Standards

Parameters	Units	Standard Values
1. pH	-	5.5-9.0
2. Total Dissolved Solids (TDS)	mg/l	• not more than 3,000 mg/l depending on receiving water or type of industry under consideration of PCC but not exceed 5,000 mg/l • not more than 5,000 mg/l exceed TDS of receiving water having salinity of more than 2,000 mg/l or TDS of sea if discharge to sea
3. Suspended solids (SS)	mg/l	not more than 50 mg/l depending on receiving water or type of industry or wastewater treatment system under consideration of PCC but not exceed 150 mg/l

Industrial Effluent Standards

Parameters	Units	Standard Values
8. Fat, Oil & Grease (FOG)	mg/l	not more than 5.0 mg/l depending of receiving water or type of industry under consideration of PCC but not exceed 15.0 mg/l
9. Formaldehyde	mg/l	not more than 1.0
10. Phenols	mg/l	not more than 1.0
11. Free Chlorine	mg/l	not more than 1.0
12. Pesticides	mg/l	not detectable
13. Biochemical Oxygen Demand (BOD)	mg/l	not more than 20 mg/l depending on receiving water or type of industry under consideration of PCC but not exceed 60 mg/l
14. Total Kjedahl	mg/l	not more than 100 mg/l depending on

Industrial Effluent Standards

Heavy metals	Units	Standard Values
1. Zinc (Zn)	mg/l	not more than 5.0
2. Chromium (Hexavalent)	mg/l	not more than 0.25
3. Chromium (Trivalent)	mg/l	not more than 0.75
4. Copper (Cu)	mg/l	not more than 2.0
5. Cadmium (Cd)	mg/l	not more than 0.03
6. Barium (Ba)	mg/l	not more than 1.0
7. Lead (Pb)	mg/l	not more than 0.2
8. Nickel (Ni)	mg/l	not more than 1.0
9. Manganese (Mn)	mg/l	not more than 5.0
10. Arsenic (As)	mg/l	not more than 0.25

Objectives of Biological Treatment

For domestic wastewater, the objectives are to

- transform (i.e., oxidize) dissolved and particulate biodegradable constituents into acceptable end products,
- capture and incorporate suspended and nonsettleable colloidal solids into a biological floc and biofilm,
- transform or remove nutrients, such as nitrogen and phosphorus, and
- in some cases, remove specific trace organic constituents and compounds.

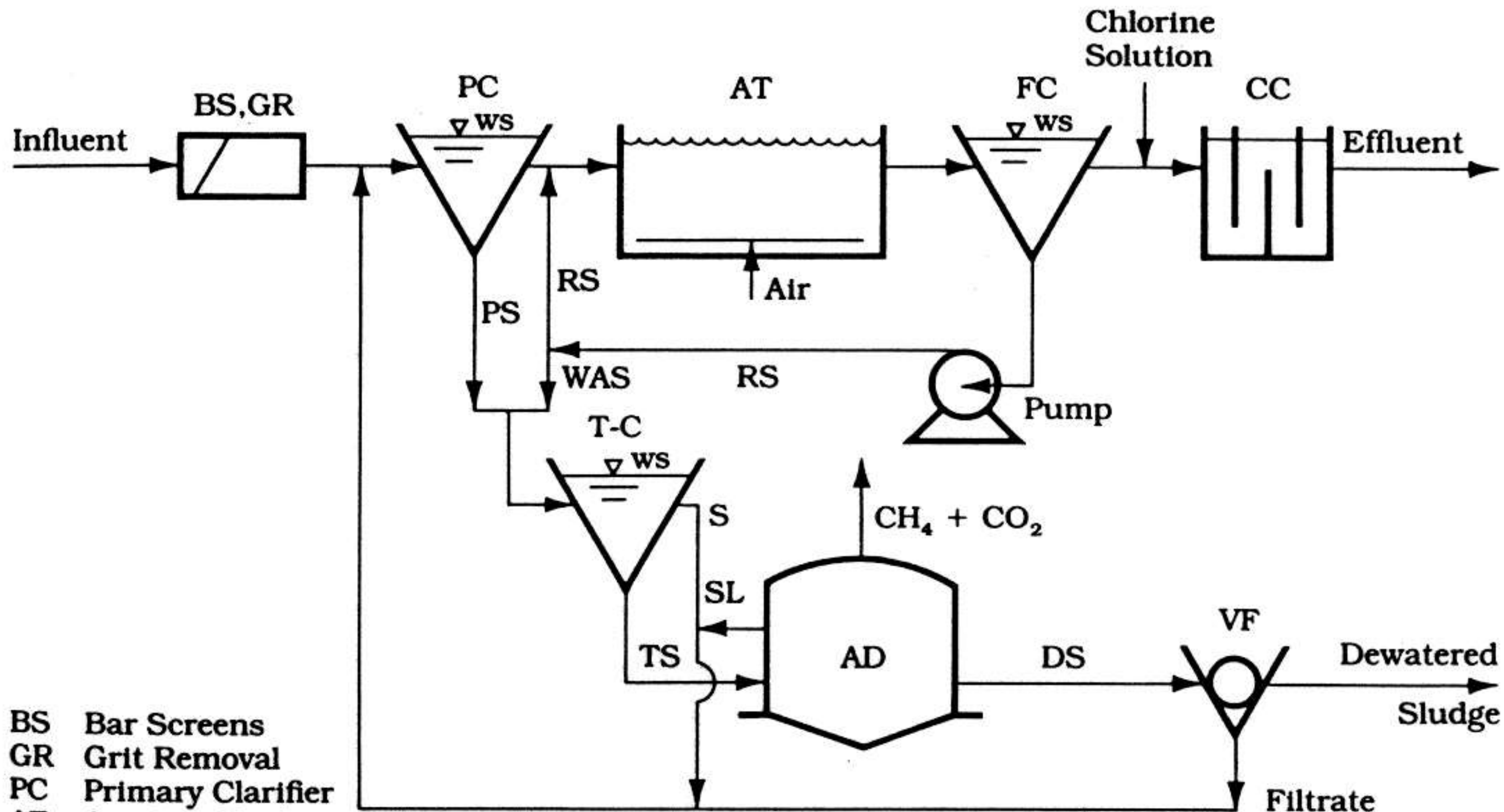
Objectives of Biological Treatment

For industrial wastewater, the objective is to

- remove or reduce the concentration of organic and inorganic compounds. Because some of the constituents and compounds found in industrial wastewater are toxic to microorganisms, pretreatment may be required before the industrial wastewater can be discharged to a municipal collection system.

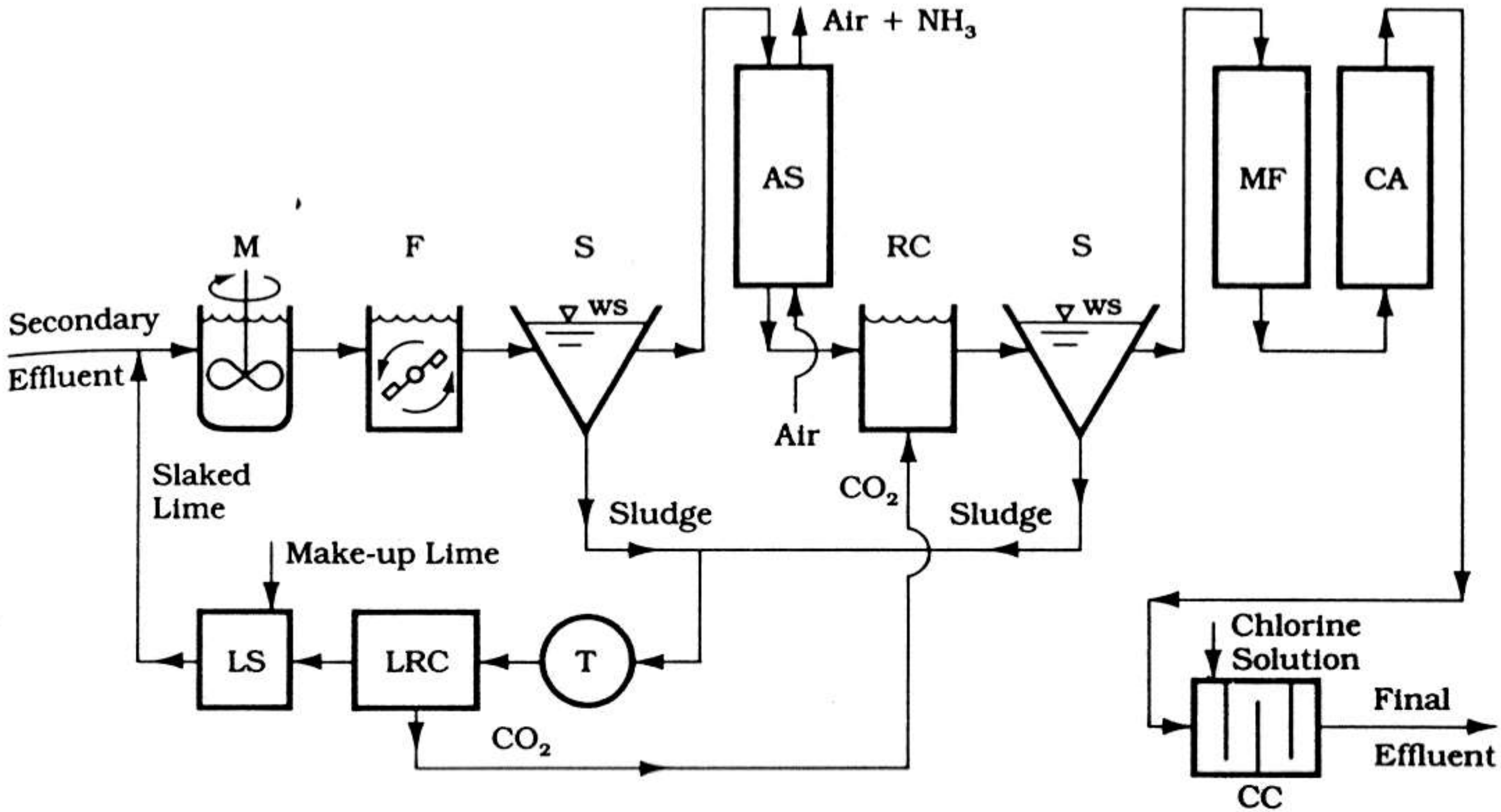
For agricultural irrigation return wastewater, the objective is to

- remove nutrients, specifically nitrogen and phosphorus, that are capable of stimulating the growth of aquatic plants.



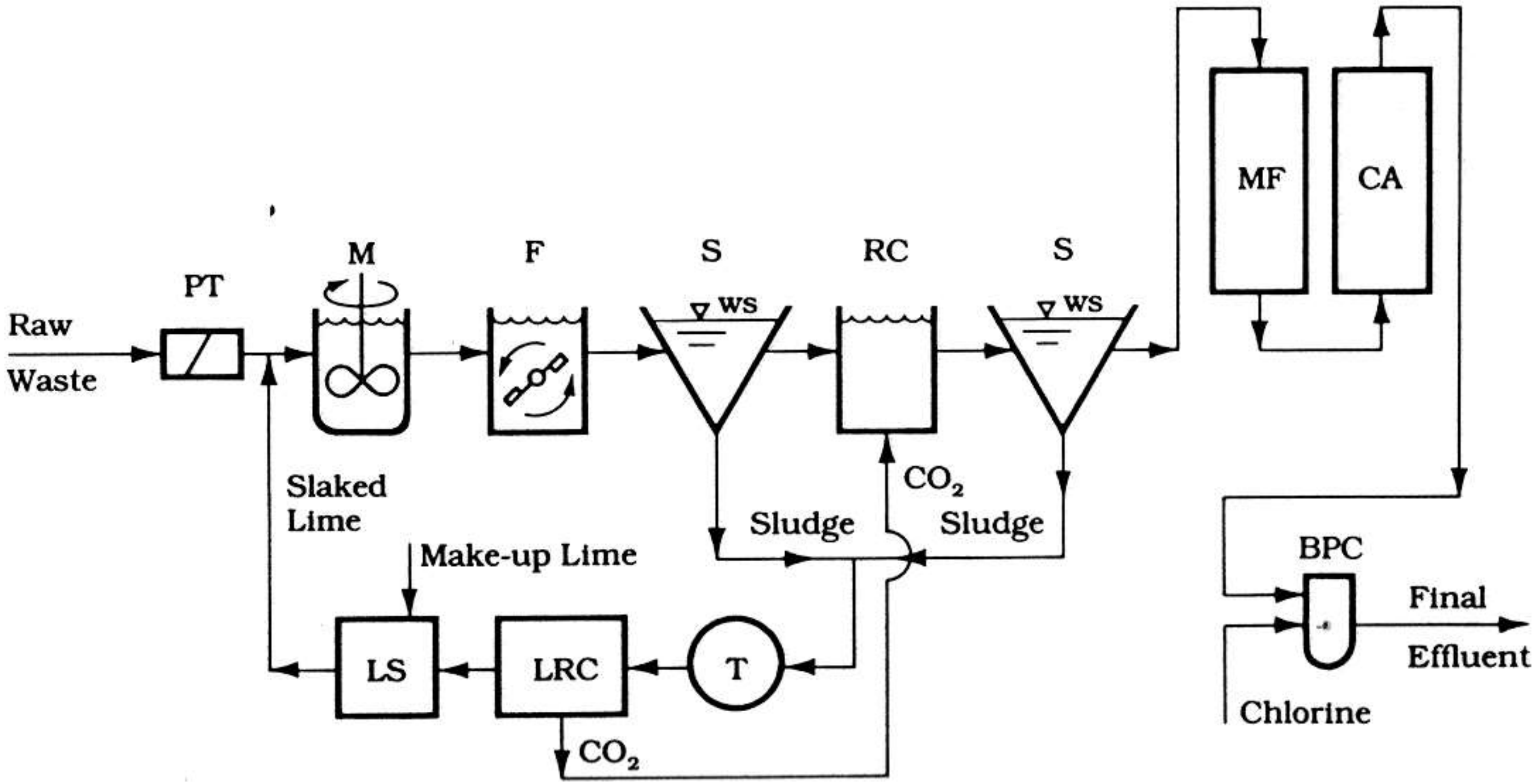
BS	Bar Screens
GR	Grit Removal
PC	Primary Clarifier
AT	Aeration Tank
FC	Final Clarifier
CC	Chlorine Contact
PS	Primary Sludge
RS	Return Sludge
WAS	Waste Activated Sludge
T-C	Thickener-Clarifier
TS	Thickened Sludge
S	Supernatant
AD	Anaerobic Digester
SL	Supernatant Liquor
DS	Digested Sludge
VF	Vacuum Filter

FIGURE 6.5 *Activated Sludge Plant for a Municipal Wastewater*



M	Mixing
F	Flocculation
S	Settling
AS	Ammonia Stripping
RC	Recarbonation
MF	Multimedia Filtration
CA	Carbon Adsorption
CC	Chlorine Contact
T	Thickening
LRC	Lime Recalcination
LS	Lime Slaking

FIGURE 6.6 *Tertiary Treatment of a Secondary Effluent by Physical-Chemical Methods*

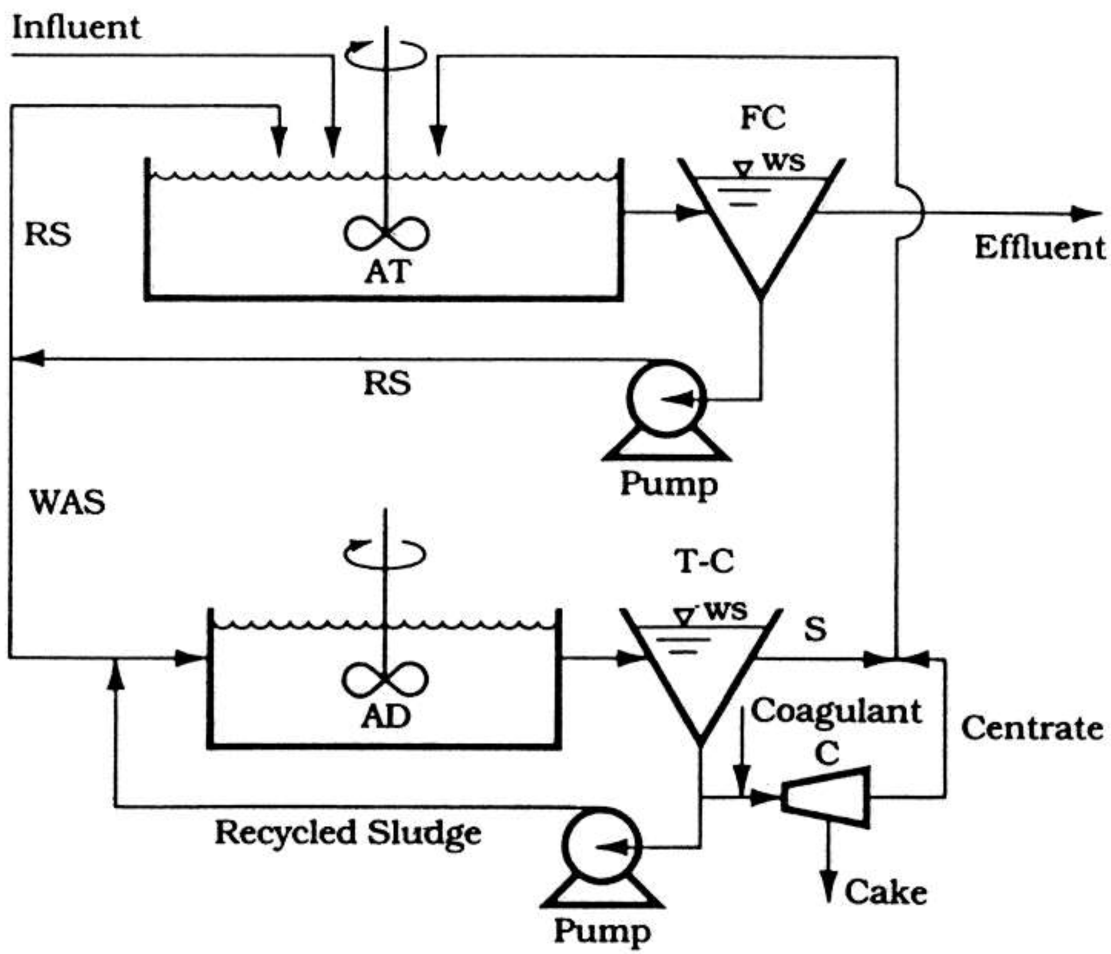


PT Preliminary Treatment
M Mixing
F Flocculation
S Settling

RC Recarbonation
MF Multimedia Filtration
CA Carbon Adsorption
BPC Breakpoint Chlorination

T Thickening
LRC Lime Recalcination
LS Lime Slaking

FIGURE 6.7 *Physical-Chemical Treatment of Raw Municipal Wastewater*



AT	Aeration Tank	AD	Aerobic Digester
FC	Final Clarifier	T-C	Thickener-Clarifier
RS	Return Sludge	S	Supernatant
WAS	Waste Activated Sludge	C	Centrifuge

FIGURE 6.8 *Completely Mixed Activated Sludge Plant for an Industrial Wastewater*

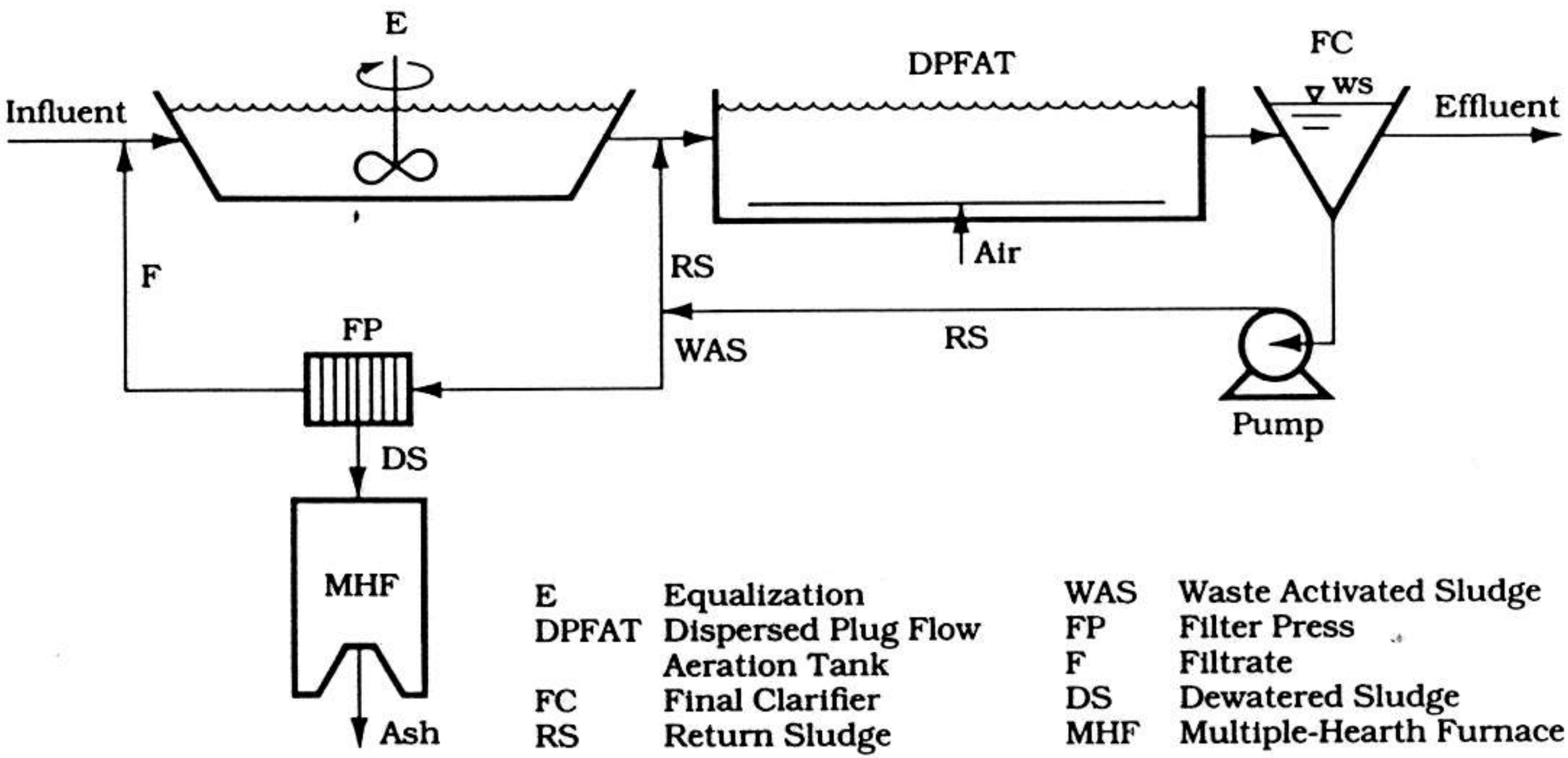


FIGURE 6.9 *Dispersed Plug-Flow Activated Sludge Plant for an Industrial Wastewater*

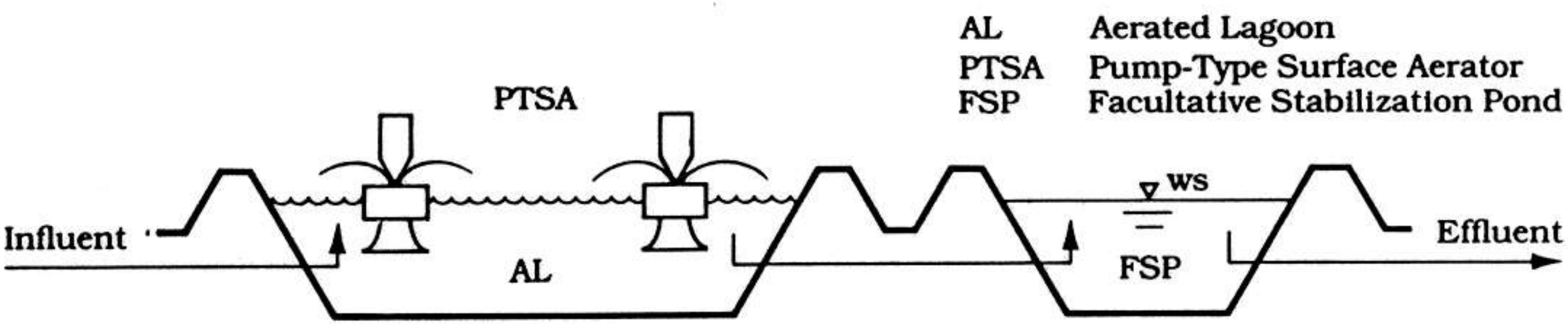


FIGURE 6.10 *Aerated Lagoon System for an Industrial Wastewater*