NASKAH TUTORIAL

TLB-309
DESAIN PENGOLAHAN BIOLOGI

Semester Ganjil 2022/2023

Disusun Oleh:
Rachmawati S. Dj.

JURUSAN TEKNIK LINGKUNGAN
FAKULTAS TEKNIK SIPIL DAN PERENCANAAN
INSTITUT TEKNOLOGI NASIONAL
2022

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SURAT KETERANGAN

Yang bertandatangan dibawah ini Ketua Program Studi Teknik Lingkungan Fakultas Teknik Sipil dan Perencanaan ITENAS, menerangkan bahwa :

Rachmawati S.DJ, Ir.,M.En.Stud.,Ph.D

Adalah **Pembuat Naskah Tutorial Desain Pengolahan Biologi** Prodi Teknik Lingkungan Periode Semester Ganjil Tahun Ajaran 2022/2023.

Demikian surat keterangan ini kami buat untuk digunakan sebagaimana mestinya.

Bandung, 1 Agustus 2022
Ketua Program Studi Teknik Lingkungan

Dr. M. Rangga Sururi, S.T., M.T

LEMBAR PENGESAHAN

NASKAH TUTORIAL
TLB-309
DESAIN PENGOLAHAN BIOLOGI

Mengetahui
Ketua Jurusan
Teknik Lingkungan

Dr. M. Rangga Sururi, ST, MT

TLB-309
DESAIN PENGOLAHAN BIOLOGI

MINGGU KE-I:
INTRODUCTION TO WASTEWATER TREATMENT AND PROCESS ANALYSIS

RACHMAWATI S. DJ.

SEMESTER GANJIL 2022/2023

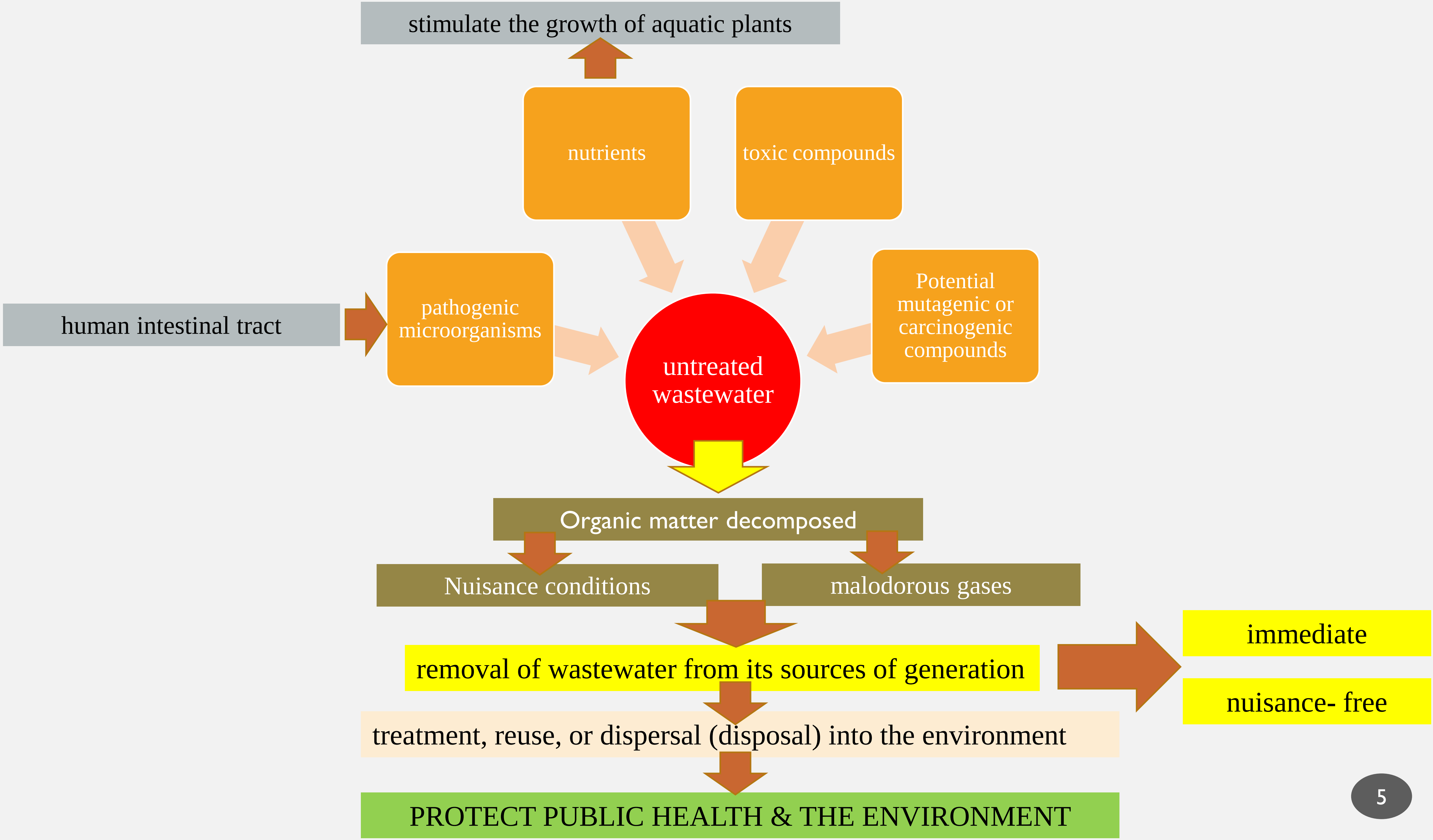
MATERI MINGGU KE-2

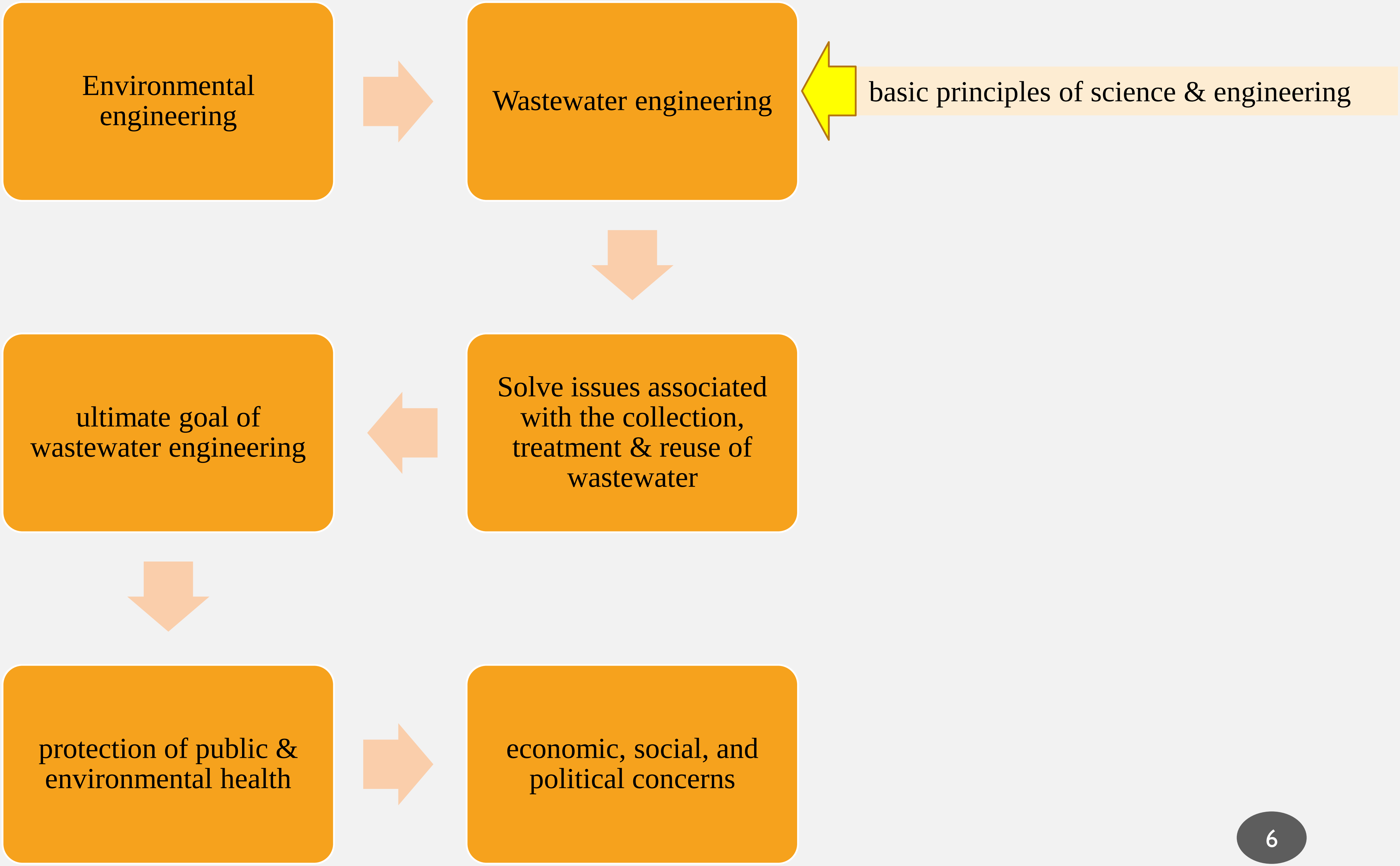
Mg Ke-	Kemampuan Akhir Tiap Tahapan Belajar (SubCPMK)	Penilaian		Bentuk Pembelajaran; Metode Pembelajaran; Penugasan Mahasiswa (estimasi waktu)		Materi Pembelajaran[9)] (Pustaka)	Bobot Penilaian (%)
		Indikator	Teknik				
(1)	(2)	(3)	(4)	Luring (5)	Daring (6)	(7)	(8)
1	Kontrak Perkuliahan	Mahasiswa memahami tentang RPS dan proses pembelajaran dan penilaian yang dilakukan pada mata kuliah ini PB = 1x50 menit					
1-2	SubCPMK 1 Mahasiswa mampu mengidentifikasi kandungan air limbah yang terkait dengan parameter biologi dan membandingkannya dengan baku mutu yang berlaku, memilih metode analisis dan melakukan interpretasi data karakteristik air buangan dengan baik, menghitung neraca massa dalam melakukan desain pengolahan biologi dalam bentuk laporan tugas kelompok	- Ketepatan melakukan identifikasi kandungan air limbah yang terkait dengan parameter biologi - Ketepatan perbandingan dengan baku mutu yang berlaku - Ketepatan pemilihan metode analisis dan interpretasi data air buangan - Ketepatan penyajian dalam bentuk laporan tugas kelompok	Test Nontest/ Tugas 1	Kuliah Diskusi [PB: 1,5 x (3x50')	e-Learning Itenas: 1. file materi SubCPMK 1 (PB, KM). 2. Hasil Tugas Mandiri 1	Materi SubCPMK 1: - Pengenalan terhadap Pengolahan Air Buangan - Analisa proses: Neraca massa, jenis-jenis reaktor, kinetika proses, pemodelan proses pengolahan. - Peraturan terkait baku mutu air limbah domestik (PermenLHK RI No. P.68/Menlhk-Setjen/2016 tentang Baku Mutu Air Limbah Domestik)	14%

INTRODUCTION TO WASTEWATER TREATMENT AND PROCESS ANALYSIS

INTRODUCTION TO WASTEWATER TREATMENT AND PROCESS ANALYSIS

- 1-1: Evolution Of Wastewater Treatment
- 1-2: Evolution Of Regulations Of Significance To Wastewater Engineering
- 1-3: Characeristics Of Wastewater
- 1-4: Classification Of Wastewater Treatment Methods
- 1-5: Application Of Treatment Methods
- 1-6: Status Of Wastewater Treatment In The United States


stimulate the growth of aquatic plants
nutrients
toxic compounds
human intestinal tract
pathogenic microorganisms
untreated wastewater
Potential mutagenic or carcinogenic compounds
Organic matter decomposed
Nuisance conditions
malodorous gases
removal of wastewater from its sources of generation
immediate
nuisance- free
treatment, reuse, or dispersal (disposal) into the environment
PROTECT PUBLIC HEALTH & THE ENVIRONMENT


Environmental engineering
Wastewater engineering
basic principles of science & engineering
Solve issues associated with the collection, treatment & reuse of wastewater
ultimate goal of wastewater engineering
protection of public & environmental health
economic, social, and political concerns

TLB-309
DESAIN PENGOLAHAN BIOLOGI

MINGGU KE-2 & 3:
WASTEWATER CHARACTERISTICS

RACHMAWATI S. DJ.

SEMESTER GANJIL 2022/2023

MATERI MINGGU KE-2

Mg Ke-	Kemampuan Akhir Tiap Tahapan Belajar (SubCPMK)	Penilaian		Bentuk Pembelajaran; Metode Pembelajaran; Penugasan Mahasiswa (estimasi waktu)		Materi Pembelajaran[9)] (Pustaka)	Bobot Penilaian (%)
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WASTEWATER CHARACTERISTICS

WASTEWATER CHARACTERISTICS

2-1 Wastewater Characterization
2-2 Sampling & Analytical Procedures
2-3 Physical Characteristics
2-4 Inorganic Nonmetallic Constituents
2-5 Metallic Constituents
2-6 Aggregate Organic Constituents
2-7 Individual Organic Compounds
2-8 Radionuclides in Wastewater
2-8 Biological Constituents
2-9 Toxicity

PUSTAKA

Utama:

Tchobanoglous, G., Stensel, H. D., Tsuchihashi, R., Burton, F. L., Abu-Orf, M., Bowden, G., & Pfrang, W. Metcalf & Eddy, AECOM (2014). Wastewater Engineering: Treatment and Resource Recovery.

INTRODUCTION

<u>Wastewater nature:</u>

Essential in:

- design & operation of collection, treatment & reuse facilities
- engineering & management of env quality

<u>Standar Methods 2012</u>

the standard reference work for
the characterization of wastewater in the field of environmental engineering

2-1 WASTEWATER CHARACTERIZATION

2-1WASTEWATER CHARACTERIZATION

- Principal constituents in wastewater, derived from:
  - Domestic
  - Municipal
  - industrial sources
- Principal constituents in wastewater:
  - human excreta (i.e feces and urine),
  - shower/bath water,
  - food waste,
  - personal and household maintenance products,
  - a wide variety of other inorganic and organic compounds in trace amounts.
- wide variety of constituents may be found in wastewater → characterize wastewater:
  - physical properties
  - chemical constituents.
  - and biological constituents

WASTEWATER PROPERTIES & CONSTITUENTS

- *many are interrelated; i.e., temperature affects the amounts of gasses dissolved in w/w & the biological activity in the w/w*
- *whether they are aggregate or individual constituents.*

Table 2–1

Common analyses used to assess the constituents found in wastewater[a]

Test[a]	Abbreviation/ definition	Use or significance of test results
Physical characteristics		
Total solids	TS	
Total volatile solids	TVS	
Total fixed solids	TFS	
Total suspended solids	TSS	
Volatile suspended solids	VSS	To assess the reuse potential of a wastewater and to determine the most suitable type of operations and processes for its treatment
Fixed suspended solids	FSS	
Total dissolved solids	TDS (TS − TSS)	
Volatile dissolved solids	VDS	
Total fixed dissolved solids	FDS	
Settleable solids	SS	To determine those solids that will settle by gravity in a specified time period
Particle size	PS	To asses the performance of treatment processes, especially disinfection
Particle size distribution	PSD	To asses the performance of treatment processes
Turbidity	NTU[b]	Used to asses the quality of treated wastewater
Color	Light brown, grey, black	To assess the condition of wastewater (fresh or septic)
Transmittance	%T	To assess the suitability of treated effluent for UV disinfection
Odor	TON	To determine if odors will be a problem
Temperature	°C or °F	Important in the design and operation of biological processes in treatment facilities
Thermal energy content	J/g·°C	Important parameter in the recovery of heat from wastewater
Density	ρ	
Conductivity	EC	Used to assess the suitability of treated effluent for agricultural applications
Inorganic chemical characteristics		
Ammonia	NH_3	
Ammonium	NH_4^+	
Nitrite	NO_2^-	Used as a measure of the nutrients present and the degree of decomposition in the wastewater; the oxidized forms can be taken as a measure of the degree of oxidation.
Nitrate	NO_3^-	
Organic nitrogen	Org N	
Phosphorus, inorganic	Inorg P	Includes orthophosphates and polyphosphates
Orthophosphate	PO_4^{3-}	Simplest of the phosphoric acids salts
Organic phosphorus	Org P	
pH	$pH = -\log[H^+]$	A measure of the acidity or basicity of an aqueous solution

(*continued*)

WASTEWATER PROPERTIES & CONSTITUENTS

Table 2-1 *(Continued)*

Test[a]	Abbreviation/ definition	Use or significance of test results
Inorganic chemical characteristics (continued)		
Alkalinity	$\Sigma(HCO_3^- + CO_3^{2-} + OH^- - H^+)$	A measure of the buffering capacity of the wastewater
Chloride	Cl^-	To assess the suitability of wastewater for agricultural reuse
Sulfate	SO_4^{2-}	To assess the potential for the formation of odors and may impact the treatability of the waste sludge
Metals	As, Cd, Ca, Cr, Co, Cu, Pb, Mg, Hg, Mo, Ni, Se, Na, Zn	To assess the suitability of the wastewater for reuse and for toxicity effects in treatment. Trace amounts of metals are important in biological treatment
Specific inorganic elements and compounds		To assess presence or absence of a specific constituent
Various gases	O_2, CO_2, NH_3, H_2S, CH_4	The presence or absence of specific gases
Organic chemical characteristics		
Five-day biochemical oxygen demand	BOD_5	A measure of the amount of oxygen required to stabilize a waste biologically over a 5-d period
Five-day carbonaceous biochemical oxygen demand	$CBOD_5$	A measure of the amount of oxygen required to stabilize a waste biologically, over a 5-d period, in which nitrogen oxidation is suppressed
Ultimate carbonaceous biochemical oxygen demand	UBOD (also BOD_u, BOD_L)	A measure of the amount of oxygen required to stabilize a waste biologically
Nitrogenous oxygen demand	NOD	A measure of the amount of oxygen required to oxidize biologically the nitrogen in the wastewater to nitrate
Chemical oxygen demand	COD	Often used as a substitute for the BOD test
Total organic carbon	TOC	Often used as a substitute for the BOD test
Specific organic compounds and classes of compounds	MBAS[c], CTAS[d]	To determine presence of specific organic compounds and to assess whether special design measures will be needed for removal
Chemical energy content	MJ/kg COD	To assess the chemical energy in wastewater
Biological characteristics		
Coliform organisms	MPN (most probable number)	To asses potential presence of pathogenic bacteria and effectiveness of disinfection process
Specific microorganisms	Bacteria, protozoa helminths, viruses	To asses presence of specific organisms in connection with plant operation and for reuse
Toxicity	TU_a[e] and TU_c[f]	To assess acute and chronic toxicity of various wastewater samples

[a] Details on the various tests may be found in Standard Methods (2012).
[b] NTU = Nephelometric turbidity unit.
[c] MBAS = Methylene blue active substances.
[d] CTAS = Cobalt thiocyanate active substances.
[e] TU_a = toxic unit acute.
[f] TU_c = toxic unit chronic.

CONSTITUENTS OF CONCERN IN WASTEWATER

- 2^{nd} treatment standards for w/w: removal of biodegradable organics, TSS & pathogens
- stringent standards developed recently: removal of nutrients, heavy metals & priority pollutants
- w/w reused: standards included for removal of refractory organics, heavy metals & dissolved inorganic solids (in some cases)

Table 2-2

Principal constituents of concern in wastewater treatment

Constituent	Reason for importance
Suspended solids	Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged in the aquatic environment.
Biodegradable organics	Composed principally of proteins, carbohydrates, and fats, biodegradable organics are measured most commonly in terms of BOD (biochemical oxygen demand) and COD (chemical oxygen demand). If discharged untreated to the environment, their biological stabilization can lead to the depletion of natural oxygen resources and to the development of septic conditions.
Pathogens	Communicable diseases can be transmitted by the pathogenic organisms that may be present in wastewater.
Nutrients	Both nitrogen and phosphorus, along with carbon, are essential nutrients for growth. When discharged to the aquatic environment, these nutrients can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, they can also lead to the pollution of groundwater.
Priority pollutants	Organic and inorganic compounds selected on the basis of their known or suspected carcinogenicity, mutogenicity, teratogenicity, or high acute toxicity. Many of these compounds are found in wastewater.
Refractory organics	These organics tend to resist conventional methods of wastewater treatment. Typical examples include surfactants, phenols, and agricultural pesticides.
Heavy metals	Heavy metals are usually added to wastewater from commercial and industrial activities and may have to be removed if the wastewater is to be reused.
Dissolved inorganics	Inorganic constituents such as calcium, sodium, and sulfate are added to the original domestic water supply as a result of water use and may have to be removed if the wastewater is to be reused.

2-2SAMPLING & ANALYTICAL PROCEDURES

SAMPLING

Proper sampling and analytical tcchniques are of fundamental importance in the characterization of wastewater

Goals:

To obtain:

- Routine operating data on overall plant performance
- Data used to document given treatment operation/process performance
- Data used to implement proposed new programs
- Data needed for reporting regulatory compliance

SAMPLING

Data collected must be:

1) Representative
2) Reproducible

→ with the same sampling & analytical protocols

3) Defensible

→ Available documentation to validate sampling procedures

→ Data have a known degree of accuracy & precision

4) Useful

→ To meet monitoring plant objectives

SAMPLING

- No universal procedures for sampling
- Must be tailored individually to fit each situation
- Special procedures are necessary to handle sampling problems arising once wastes vary considerably in composition
- Before sampling, the followings have to be developed:

1. A detailed sampling protocol
2. A quality assurance project plan (QAPP) (QA/QC)

SAMPLING: QAPP

Following items have to be specified in QAPP (additional details maybe found in Standard Methods, 2012):

1. Sampling plan
2. Sample types & size
3. Sample labelling & chain of custody
4. Sampling methods
5. Sampling storage & preservation
6. Sample constituents
7. Analytical methods

1. SAMPLING PLAN

1. No of sampling locations
2. No & type of samples
3. Time intervals:
   a) Real-time samples
   b) Time-delayed samples

2. SAMPLE TYPES & SIZE

1. Catch/grab samples
2. Composite samples

or

1. Integrated samples
2. Separate samples for different analyses (e.g. for metals)

Sample size (e.g. volume) required

Grab/catch samples:
- a single discrete sample or individual samples collected **at a specific time**
- most common type of sample & is the sampling technique use for most of labs.

Composite samples:
- collected over time, either by continuous sampling or by mixing discrete samples

3. SAMPLE LABELLING & CHAIN OF CUSTODY

1. Sample labels
2. Sample seals
3. Field log book
4. Chain of custody record
5. Sample analysis request sheets
6. Sample delivery to the lab
7. Receipt & logging of sample
8. Assignment of sample for analysis

Chain of custody record
tracks the transfer of your samples from collection through analysis to ensure its integrity
→ every individual that handles the sample have to record their name, signature, date & time the sample was placed in their custody

4. SAMPLING METHODS

1. Specific techniques
2. Specific equipment

1) Manual
2) Otomatic or
3) Sorbent sampling

Sorbent tubes/traps are widely used in combination with gas chromatographic (GC) analytical methods to monitor the vapour-phase fraction of organic compounds in air. Target compounds range in volatility from acetylene & freons to phthalates & PCBs; and include apolar, polar & reactive species

5. SAMPLING STORAGE & PRESERVATION

1. Type of containers (glass/plastic)
2. Preservation methos
3. Maximum allowable holding times

6. SAMPLE CONSTITUENTS

1. List of parameters to be measured

7. ANALYTICAL METHODS

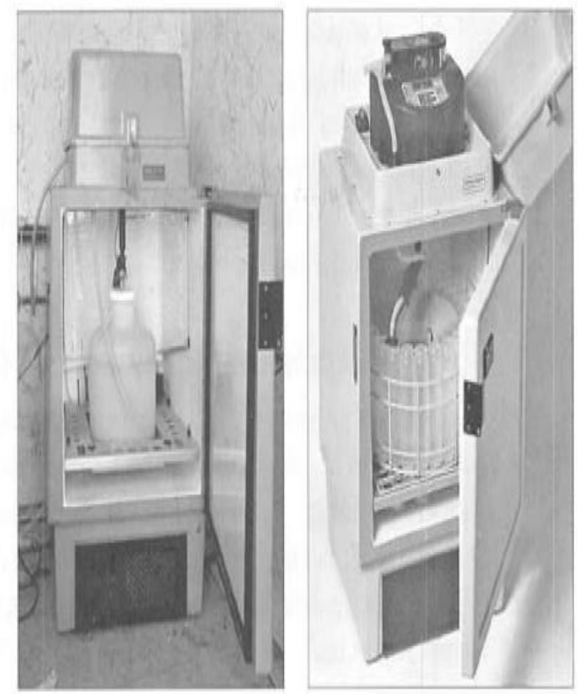
1. List of field & lab test methods & procedures to be used
2. Detection limits for individual methods

DATA INTEGRITY & ASSURANCE

1. Data integrity has to be maintained between sample collection & analysis
2. Sample preservation is important
3. Prompt analysis to avoid sample deterioration → the most positive assurance
4. Provision (Fig 2-2) must be made to preserve samples once there was a lag dictated by analytical & testing conditions between collection & analysis
5. Current methods of sample preservation for analyzing the properties subject to deterioration must be used (Standard Methods, 2012)
6. Probable errors due to sample deterioration must be noted in reporting analytical data

Figure 2-2

Typical refrigerated automatic composite samplers used to collect process and effluent samples over a 24-h period: (a) sampler with single sample bottle in place used to obtain a 24-h composite sample and (b) sampler used to collect individual hourly samples throughout the day. The individual samples can be composited in proportion to flow to obtain flow-weighted mass loading rates. (Courtesy of Teledyne Laboratory & Field Instruments.)



(a) (b)

METHODS OF ANALYSIS

(Precise) quantitative chemical methods:
- gravimetric, volumetric, physicochemical

(More) qualitative biological & physical methods

PHYSICOCHEMICAL

- *Properties other than mass & volume are measured*
- *Instrumental methods of analysis:*

  →Turbidimetry, colorimetry, potentiometry, polarography, adsorption spectrometry, fluorometry, spectroscopy & nuclear radiation

- *Details of the various analysis may be found in Standard Methods 2012, the accepted reference that details the conduct of water and wastewater analyses*

DETECTION LIMIT

- *Must be specified*
- *Defined detection limits in increasing levels order (Standard Methods 2012):*

1. *Instrumental detection level (IDL)*
2. *Lower level of detection (LLD)*
3. *Method detection level (MDL)*
4. *Level of quantification (LOQ)*

1. INSTRUMENTAL DETECTION LEVEL (IDL)

- *Constituent concentration producing signal > 5x the instrument signal/noise ratio*

2. LOWER LEVEL OF DETECTION (LLD)

- *Constituent concentration in reagent water producing a signal (2 x 1.645 s) above the mean of blank analyses*
- *s: standard deviation = SD*

3. METHOD DETECTION LEVEL (MDL)

- *Constituent concentration that once processed through the complete method, produces a signal with a 99% probability that it is different from the blank*

4. LEVEL OF QUANTIFICATION (LOQ)

- *Constituent concentration that produces a signal sufficiently > the blank detected within specified levels by good laboratories during routine operating conditions*
- *Concentration that process a signal 10s > the reagent blank signal*

4. MINIMUM REPORTING LEVEL (MRL)

- *Minimum constituent concentration that can be reported as a quantitative value*

UNITS OF EXPRESSION FOR PHYSICAL AND CHEMICAL PARAMETERS

- To express the analysis results of w/w samples
- Most common units: Table 2-3
- Chemical parameters are usually expressed in the physical unit of mg/L or g/m^3
- Trace concentration: µg/L or ng/L

Table 2-3
Units commonly used to express analytical results

Basis	Application	Unit
Physical analyses:		
Density	Mass of solution / Unit of volume	kg/m^3
Percent by volume	Volume of solute × 100 / Total volume of solution	% (by vol)
Percent by mass	Mass of solute × 100 / Combined mass of solute + solvent	% (by mass)
Volume ratio	Milliliters / Liter	mL/L
Mass per unit volume[a]	Picograms / Liter of solution	pg/L
	Nanograms / Liter of solution	ng/L
	Micrograms / Liter of solution	µg/L
	Milligrams / Liter of solution	mg[a]/L
	Grams / Cubic meter of solution	g/m^3
Mass ratio	Milligrams / 10^9 milligrams	ppb[b]
	Milligrams / 10^6 milligrams	ppm
Chemical analyses:		
Molality	Moles of solute / 1000 grams solvent	mole/kg
Molarity	Moles of solute / Liter of solution	mole/L
Normality	Equivalents of solute / Liter of solution	eq/L
	Milliequivalents of solute / Liter of solution	meq/L

[a] mg/L = g/m^3.
[b] ppb = parts per billion, ppm = parts per million, 10^3 ppb = ppm.
Note: 10^{12} pg = 10^9 ng = 10^6 µg = 10^3 mg = 1 gm.

CONCENTRATION

ppm (a mass to mass ratio) (Eq 2-1)

$$ppm = \frac{{mg}/{L}}{fluid\ specific\ gravity}$$

For dilute system (i.e. in natural waters & w/w) in which 1 L sample = 1 kg:

- mg/L or g/m3 ←→ ppm
- ppb ←→ μg/L
- ppt ←→ ng/L

CONCENTRATION

- Dissolved gases:
  - Chemical constituents
  - ppm_v, μg/m^3 or mg/L
- Conversion between ppm & μg/m^3 : Universal gas law (Eq 2-45)

$$\mu g/m^3 = \frac{(concentration, ppm_v)(mw, g/mole\ of\ gas)(10^6\ \mu g/g)}{(22.414\ x\ 10^{-3}\ m^3/mole\ of\ gas)}$$

- Gases evolving as byproducts of ww treatment e.g. CO_2 & CH_4 (from anaerobic decomposition): L or m^3 or ft^3
- Temperature, odor, hydrogen ion & biological organisms → expressed in other units

USEFUL CHEMICAL RELATIONSHIPS

Used in the analysis & evaluation of w/w test results and in the design of treatment facilities:

1. Mole fraction
2. Electroneutrality
3. Chemical equilibrium
4. Activity coefficient
5. Ionic strength
6. Solubility product

1. MOLE FRACTION

- The ratio of the no of a given solute to the total no of all components in solution
- Important in:
- Solution chemistry
- Mass transfer of gases into & out of liquid (Eq 2-2)

$$x_B = \frac{n_B}{n_A + n_B + \ldots n_N}$$

- Where:
  - x_B = mole fraction of solute B
  - n_A = no of moles of solute A
  - n_B = no of moles of solute B
  - n_N = no of moles of solute N
- See Example 2-1

EXAMPLE 2-1 Determination of Mole Fraction Determine the mole fraction of oxygen in water if the concentration of dissolved oxygen is 10.0 mg/L.

Solution

1. Determine the mole fraction of oxygen using Eq. (2–2) written as follows:

$$x_{O_2} = \frac{n_{O_2}}{n_{O_2} + n_w}$$

a. Determine the moles of oxygen.

$$n_{O_2} = \frac{(10\ \text{mg/L})}{(32 \times 10^3\ \text{mg/mole}\ O_2)} = 3.125 \times 10^{-4}\ \text{mole/L}$$

b. Determine the moles of water.

$$n_w = \frac{(1000\ \text{g/L})}{(18\ \text{g/mole of water})} = 55.556\ \text{mole/L}$$

c. The mole fraction of oxygen is:

$$x_{O_2} = \frac{3.125 \times 10^{-4}}{3.125 \times 10^{-4} + 55.556} = 5.62 \times 10^{-6}$$

2. ELECTRONEUTRALITY

- Principle (Eq 2-3):

$\sum$ cations = $\sum$ anions

- Cations & anions : equivalent weight/L (eq/L) or meq/L
- For a compound (Eq 2-4):
  - equivalent weight (g/eq) = $\frac{molecular\ weigt\ (g)}{Z}$
  - Z:

1) Absolute value of ion charge
2) No of H+ or OH- ions a species can react with or yield in acid-base reaction or
3) Absolute value of the change in valence occurring in an oxidation reduction reaction

2. ELECTRONEUTRALITY

- Eq 2-3 can be used to check the accuracy of the chemical analysis by (Eq 2-5):
- $\% \, difference = 100 \; x \left(\frac{\sum cations - \sum anions}{\sum cations + \sum anions} \right)$
- The acceptance criteria:

Σ anions, meq/L	Acceptable difference
0–3.0	±0.2 meq/L
3.0–10.0	±2%
10–800	5%

From Standard Methods (2012).

- See Example 2-2

EXAMPLE 2–2 Checking the Accuracy of Analytical Measurements The following analysis has been completed on a filtered effluent, from an extended aeration wastewater treatment plant, that is to be used for landscape watering. Check the accuracy of the analysis to determine if the analysis is sufficiently accurate, based on the criteria given above.

Cation	Conc., mg/L	Anion	Conc., mg/L
Ca^{2+}	82.2	HCO_3^-	220.0
Mg^{2+}	17.9	SO_4^{2-}	98.3
Na^+	46.4	Cl^-	78.0
K^+	15.5	NO_3^-	25.6

Solution

1. Prepare a cation-anion balance.

Cation	Conc., mg/L	mg/meq[a]	meq/L	Anion	Conc., mg/L	mg/meq[a]	meq/L
Ca^{2+}	82.2	20.04[b]	4.10	HCO_3^-	220.0	61.02	3.61
Mg^{2+}	17.9	12.15	1.47	SO_4^{2-}	98.3	48.03	2.05
Na^+	46.4	23.00	2.02	Cl^-	78.0	35.45	2.20
K^+	15.5	39.10	0.40	NO_3^-	25.6	62.01	0.41
	Σ cations		7.99		Σ anions		8.27

[a] Molecular weight in grams/Z

[b] For calcium, eq wt = 40.08/2 = 20.04 g/eq or 20.04 mg/meq

2. Check the accuracy of the cation-anion balance using Eq. (2–5).

$$\text{Percent difference} = 100 \times \left(\frac{\Sigma\ \text{cations} - \Sigma\ \text{anions}}{\Sigma\ \text{cations} + \Sigma\ \text{anions}}\right)$$

$$\text{Percent difference} = 100 \times \left(\frac{7.99 - 8.27}{7.99 + 8.27}\right) = -1.72\%$$

For a total anion concentration between 3 and 10 meq/L, the acceptable difference must be equal to or less than 2 percent (see table given above), thus, the analysis is of sufficient accuracy.

Comment If the cation-anion balance is not of sufficient accuracy, the problem may be analytical or a constituent of significant concentration may be missing.

3. CHEMICAL EQUILIBRIUM

- aA + bB ←→ cC + dD (Eq 2-6)
  - a, b, c & d = no of moles of constituents A-D
- Stoichiometry of the reaction:

→ the definition of chemical compounds quantities involved in a reaction, e.g a of A, b of B etc.

- Equilibrium constant K:

→ Numerical value of the products over the reactants once the chemical species come to equilibrium state (Law of mass action) (Eq 2-7)

$$\frac{[C]^c[D]^d}{[A]^a[B]^b} = \mathrm{K}$$

- For a given reaction:

→ The value of K will change with:
  - Temperature
  - Solution ionic strength

3. CHEMICAL EQUILIBRIUM

- [ ] used in Eq 2-7: to donate molar concentrations
- The use of molal concentrations is more correct theoretically, but for dilute solutions in w/w applications, molars are used
- Molals must be used for brine solutions & seawater.
- To account for non ideal conditions due to ion-ion interactions

→ "activity" is used

$$a_i = \gamma\ [C_i] \qquad \text{(Eq 2-8)}$$

- a_i = activity of *i*th ion, mol/L
- γ = activity coefficient for the *i*th ion
- C_i = concentration of *i*th ion in solution, mol/L

- If Eq 2-7 is written in terms of activity & activity coefficients:

$$\frac{[a_C]^c[a_D]^d}{[a_A]^a[a_B B]^b} = \frac{[\gamma_C\, C]^c[\gamma_D D]^d}{[\gamma_A A]^a[\gamma_B B]^b} = \mathrm{K} \qquad \text{(Eq 2-9)}$$

4. IONIC STRENGTH

- A measure of concentration of dissolved chemical constituents
- $I = \frac{1}{2}\sum C_i {Z_i}^2$ (Eq 2-10)
  - Z_i = charge on *ith* ionic species
  - *I* = ionic strength
  - C_i = concentration of the *i*th species, mole/L
  - Z_i = valence (oxidation) no of the *i*th species (see Eq 2-4)

or

- I = 2.5 x 10^{-5} x TDS (Eq 2-11)
  - TDS = mg/L or g/m^3
- Eq 2-11 often used to estimate the I of treated w/w in groundwater recharge applications

5. ACTIVITY COEFFICIENT

- The activity coefficient can be estimated using the following expression, derived from the Debye-Huckel theory, as proposed by Davies (1962):
- Log $\gamma = -0.5\,(Z_i{}^2)\left(\frac{\sqrt{I}}{1+\sqrt{I}} - 0.3\,I\right)$ (Eq 2-12)
  - Z_i = charge on *ith* ionic species
  - *I* = ionic strength
- The above relationship. without the -0.3 *I*. term is often uscd for solutions with an ionic strength that does not exceed 0.1 M. A
- *See Example 2-3*

6. SOLUBILITY PRODUCT

- The equilibrium constant for a reaction involving a precipitate & its contituent ions

  $CaCO_3 \leftarrow\rightarrow Ca^{2+} + CO_3^{2-}$

- Due to the activity of the solid phase is usually = 1:

  $[Ca^{2+}][CO_3{}^{2-}] = K_{sp}$ (Eq 2-14)

  - K_{sp} = solubility product constant
  - K_{sp} will change with temperature of solution

- Written in activity coefficients:

  $\gamma_{Ca^{2+}}[Ca^{2+}]\gamma_{CO_3{}^{2-}}[CO_3{}^{2-}] = K_{sp}$ (Eq 2-15)

- See Example 2-3

EXAMPLE 2-3 Determine the Activity Coefficients and Solubility of Calcium Carbonate

Determine the activity coefficients for the mono and divalent ions in the wastewater given in Example 2-2. Using the value of the activity coefficient for a divalent ion, estimate the equilibrium concentration of calcium in solution needed to satisfy the solubility product for calcium carbonate ($CaCO_3$) at 25°C. The value of the solubility product constant K_{sp} for $CaCO_3$ at 25°C is 5×10^{-9}.

Solution

1. Determine the ionic strength of the wastewater using Eq. (2-10).
   a. Prepare a computation table to determine the summation term in Eq. (2-10) using the data from Example 2-2.

Ion	Conc., C, mg/L	C × 10³, mole/L	z²	cz² × 10³
Ca^{2+}	82.2	2.051	4	8.404
Mg^{2+}	17.9	0.736	4	2.944
Na^{+}	46.4	2.017	1	2.017
K^{+}	15.5	0.396	1	0.397
HCO_3^-	220	3.607	1	3.607
SO_4^{2-}	98.3	1.024	4	4.096
Cl^-	78.0	2.200	1	2.200
NO_3^-	25.6	0.413	1	0.413
Sum				23.876

   b. Determine the ionic strength of the wastewater.

$$I = \frac{1}{2}\Sigma C_i Z_i^2 = \frac{1}{2}(23.876 \times 10^{-3}) = 11.938 \times 10^{-3}$$

2. Determine the activity coefficients for Ca^{2+} and CO_3^{2-}. Because both species have a valance (charge) of 2, the activity of each will be the same.
   a. For monovalent ions

$$\log \gamma = -0.5\,(Z_i)^2\left(\frac{\sqrt{I}}{1+\sqrt{I}} - 0.3I\right)$$

$$\log \gamma = -0.5\,(1)^2\left[\frac{\sqrt{11.938 \times 10^{-3}}}{1+\sqrt{11.938 \times 10^{-3}}} - 0.3(11.938 \times 10^{-3})\right] = -0.0475$$

$$\gamma = 0.896$$

   b. For divalent ions

$$\log \gamma = -0.5\,(2)^2\left[\frac{\sqrt{11.938 \times 10^{-3}}}{1+\sqrt{11.938 \times 10^{-3}}} - 0.3(11.938 \times 10^{-3})\right] = -0.1898$$

$$\gamma = 0.646$$

3. Determine the minimum solubility of calcium using Eq. (2-15).
   a. Because the molar concentrations of calcium and carbonate ions are the same, Eq (2-15) can be written as follows:

$$\gamma^2 [C^2] = K_{sp}$$

   b. Solve for the concentration C.

$$C = \sqrt{\frac{K_{sp}}{\gamma^2}} = \sqrt{\frac{5 \times 10^{-9}}{(0.646)^2}} = 1.09 \times 10^{-4}\ \text{mole/L}$$

   c. Convert the molar concentration of calcium carbonate to mg/L.

$$Ca = 1.09 \times 10^{-4}\ \text{mole/L} \times 40{,}000\ \text{mg/mole} = 4.36\ \text{mg/L}$$

Comment The computed value represents the minimum concentration of calcium that would be required in solution to be in equilibrium with solid calcium carbonate.

2-3 PHYSICAL PROPERTIES

INTRODUCTION

Important physical characteristic:

- -_Total solids
- -_Particle Size, Particle Size Distribution,
- - Turbidity, Color, Transmittance,
- - Temperature, Conductivity

Total solids:

- Floating, settleable, colloidal matter & matter in solution

Others:

-, Density. Specific Gravity. and Specific Weight & Odor

SOURCES OF PHYSICAL PROPERTIES

- Sources of the physical properties used to characterize wastewater:
  - Natural
  - Anthropogenic origin
- Natural physical properties will depend on:
  - the source of the water
  - what treatment it has received prior to distribution as potable water
- Example, the initial temperature of the water will vary depending on whether the source is:
  - surface water
  - groundwater
  - the part of the country
- The specific gravity and weight are inherent properties of natural water
- The other physical properties of wastewater will derived from:
  - the constituents added during usage,
  - commercial and industrial discharges,
  - constituents found in inflow and infiltrating groundwater

SOLIDS

- W/w contains variety of solid materials: from rags to colloidal material
- In w/w characterization: coarse materials are usually removed before the sample is analyzed for solids
- Table 2-4: solids classifications
- Fig 2-3: interrelationship between various solids fractions found in w/w
- Fig 2-4: 1-liter Imhoff cone standard test for settleable solids; noting the vol of solids in mm settled after a specified time period (1 h); typically 60% SS in municipal w/w are settleable
- TS: obtained by evaporating a w/w sample to dryness; and measuring the residue mass
- Filtration step is used to separate TSS from TDS
- Fig 2-5: apparatus to determine TSS
- Fig 2-6: filterable & nonfilterable solids in w/w; and their approximate size range

SOLIDS

Table 2-4

Definitions for solids found in wastewater[a]

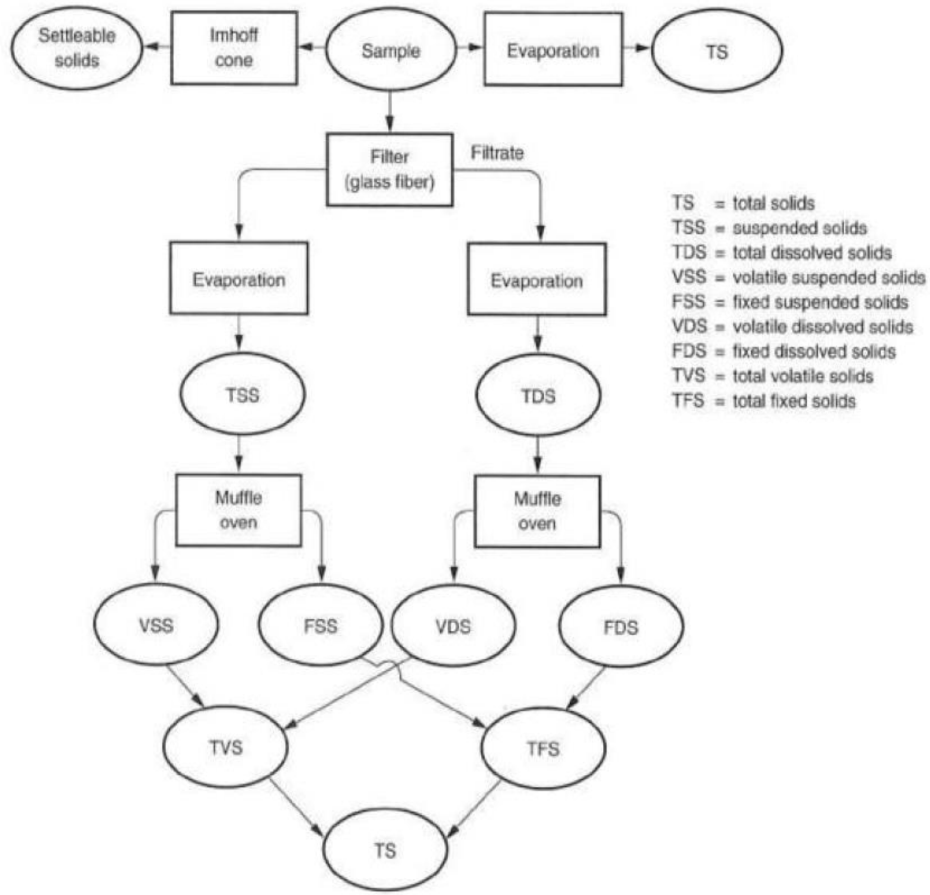
Test[b]	Description
Total solids (TS)	The residue remaining after a wastewater sample has been evaporated and dried at a specified temperature (103 to 105°C)
Total volatile solids (TVS)	Those solids that can be volatilized and burned off when the TS are ignited (500 ± 50°C)
Total fixed solids (TFS)	The residue that remains after TS are ignited (500 ± 50°C)
Total suspended solids (TSS)	Portion of the TS retained on a filter (see Fig. 2-3) with a specified pore size, measured after being dried at a specified temperature (105°C). The filter used most commonly for the determination of TSS is the Whatman glass fiber filter, which has a nominal pore size of about 1.58 μm
Volatile suspended solids (VSS)	Those solids that can be volatilized and burned off when the TSS are ignited (500 ± 50°C)
Fixed suspended solids (FSS)	The residue that remains after TSS are ignited (500 ± 50°C)
Total dissolved solids (TDS) (TS − TSS)	Those solids that pass through the filter, and are then evaporated and dried at specified temperature. It should be noted that what is measured as TDS is comprised of colloidal and dissolved solids. Colloids are typically in the size range from 0.001 to 1 μm.
Total volatile dissolved solids (VDS)	Those solids that can be volatilized and burned off when the TDS are ignited (500 ± 50°C)
Fixed dissolved solids (FDS)	The residue that remains after TDS are ignited (500 ± 50°C)
Settleable solids	Suspended solids, expressed as milliliters per liter, that will settle out of suspension within a specified period of time (see Fig. 2-4)

[a] Adapted from Standard Methods (2012).

[b] With the exception of settleable solids, all solids values are expressed in mg/L.

Figure 2-3

Interrelationships of solids found in water and wastewater. In much of the water quality literature, the solids passing through the filter are called dissolved solids (Tchobanoglous and Schroeder, 1985).



SOLIDS

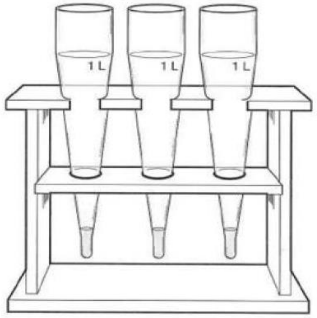
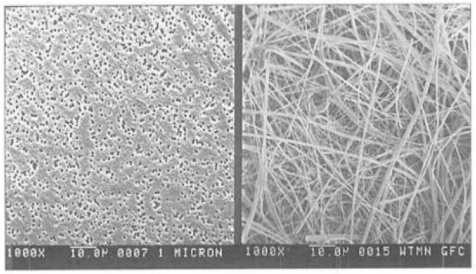


Figure 2-4

Imhoff cone used to determine settleable solids in wastewater. Solids that accumulate in the bottom of the cone after a 60-min settling time are reported as mL/L.

Figure 2-5

Vacuum filtration apparatus used for the determination of total suspended solids. After wastewater sample has been filtered, the preweighed filter paper is placed in an aluminum dish for drying before weighing.



(a) (b)

Figure 2-6

Micrographs of two laboratory filters used for the measurement of suspended solids in wastewater: (a) polycarbonate membrane filter with a nominal pore size of 1.0 μm and (b) glass fiber filter with a nominal pore size of 1.2 μm.

TOTAL SUSPENDED SOLIDS

- TSS test is arbitrary as a filter is used to separate TSS from TDS; depending on the filter paper pore size used:
  - TSS test used filters with nominal pore sizes 0,45 – 2 µm (Fig 2-6)
  - More TSS will be measured as the pore size is reduced
- Important to note the pore size filter used once comparing reported TSS values
- Important to note also : TSS test has no fundamental significance/basis:

1) The measured values of TSS are dependent on the type & pore size filter used
2) Depending on the sample size used, autofiltration (where the SS intercepted by filter also serve as a filter) can occur. Autofiltration will capture smaller particles than otherwise possible and cause an apparent increase in the measured TSS value over the actual value
3) Depending on the particulate matter characteristics, small particles may be removed by adsorption to material already retained by filter
4) TSS is a lump parameter due to the no & size distribution of particles comprising the measured value is unknown

- However:
  - TSS test results are used routinely to assess:
  - conventional treatment process performance
  - The need for effluent filtration in reuse applications
  - TSS is one of the 2 universally used effluent standards (along with BOD) by which treatment plants performance is judged for regulatory control purposes

TOTAL DISSOLVED SOLIDS

- TDS: The solids contained in the filtrate that passes through a filter with a nominal pore size of ≤ 2 μm (Standard Methods, 2012)
- W/w contains a high fraction of colloidal solids
- Colloidal particles sizes in w/w:
  - 0.01 - 1 μm typically (in this text)
  - 0.001 - 1 μm
  - 0.003 - 1 μm
- No of colloidal particles in untreated w/w & after primary sedimentation: 10^8 – 10^{12}/mL
- Distinction between colloidal particles & truly dissolved material that has not been made routinely has led to confusion in:
  - The analysis of treatment plant performance
  - The design of treatment processes

VOLATILE & FIXED SOLIDS

- VS: Material that can be volatilized & burned off once ignited at 500 ± 50^{0}C
- VS: generally presumed to be organic matter
  - Some organic matter will not burn
  - Some inorganics break down at high temperatures
- FS: the residue remaining after a sample has been ignited
- TS, TSS & TDS: comprise of FS & VS
- Ratio of VS to FS: often used to characterize the w/w i.e. the amount of organic present

PARTICLE SIZE & ITS MEASUREMENT

- To understand more about the nature of the particles that comprise the TSS in w/w:
  - Measurement of particle size
  - Analysis of particle size distribution
- Particle size is important in assessing treatment process effectiveness e.g. secondary sedimentation, effluent filtration & disinfection
- Chlorine & UV disinfection effectiveness is dependent on particle size → determination of particle size has become more important → especially with the move toward greater effluent reuse in US
- Biological conversion rate of biodegradable organic particles is dependent on size → information on size of is significant for treatment
- Table 2-5: methods to determine particle size

PARTICLE SIZE & ITS MEASUREMENT

Methods to determine particle size:

Methods based on:

1. Observation & measurement
2. Separation & analysis techniques

Table 2-5

Representative analytical techniques applicable to particle size analysis of wastewater contaminants[a]

Technique	Typical size range, μm
Observation and measurement	
Microscopy	
Light	0.2->100
Transmission electron (TEM)	0.2->100
Scanning electron (SEM)	0.002-50
Image analysis	0.2->100
Particle counters	
Conductivity difference	0.2->100
Equivalent light scattering	0.005->100
Light blockage	0.2->100
Separation and analysis	
Centrifugation	0.08->100
Field flow fractionation	0.09->100
Gel filtration chromatography	<0.0001->100
Sedimentation	0.05->100
Membrane filtration (see Chap. 11)	0.0001-1

[a] Adapted from Levine et al. (1985).

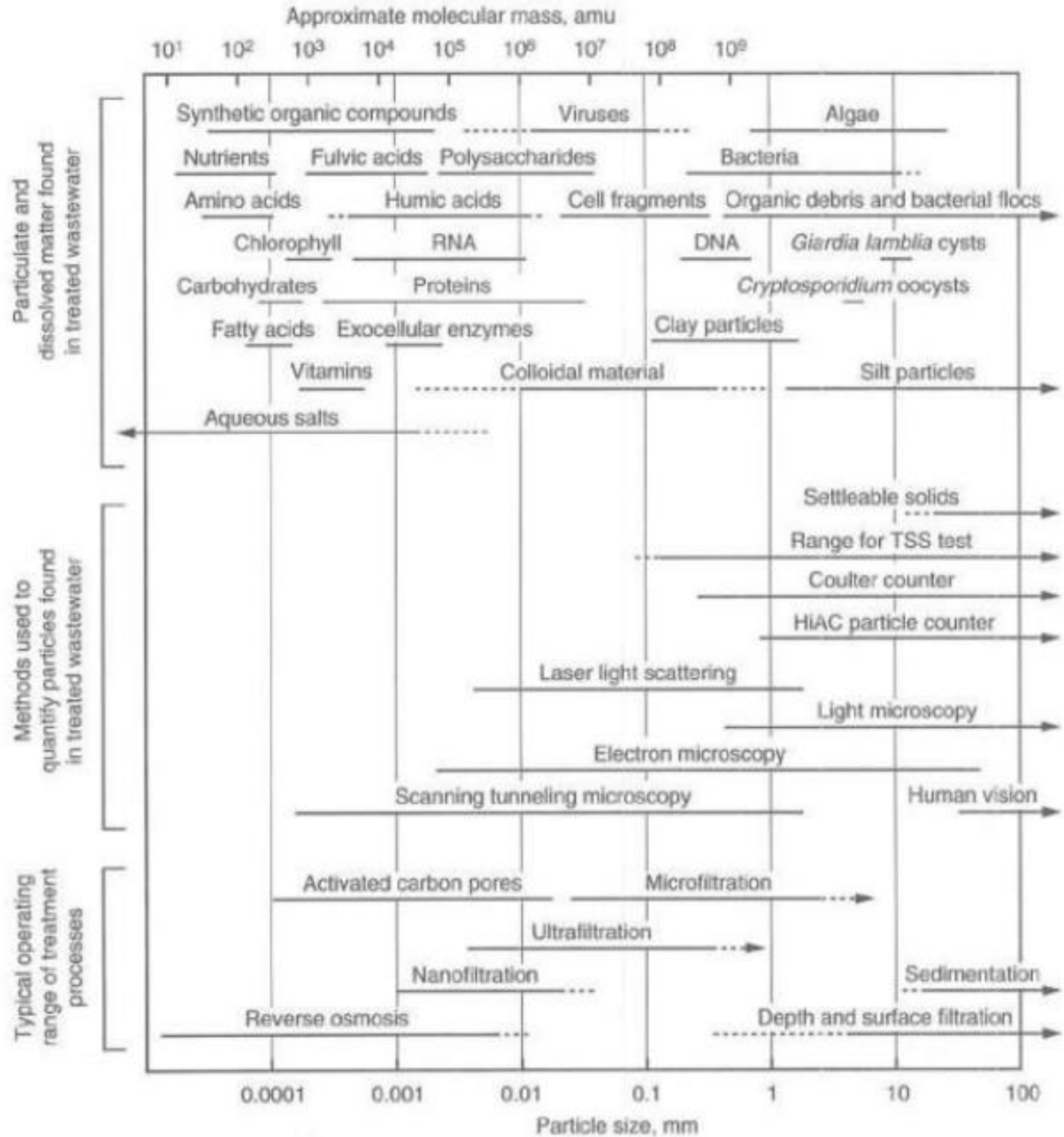
Methods used commonly to study & quantify particles in w/w:

1. Serial filtration
2. Electronic particle counting
3. Direct microscopic observation

Fig 2-7: The principal types of materials that comprise the filterable and non-filterable solids in treated wastewater & their approximate range

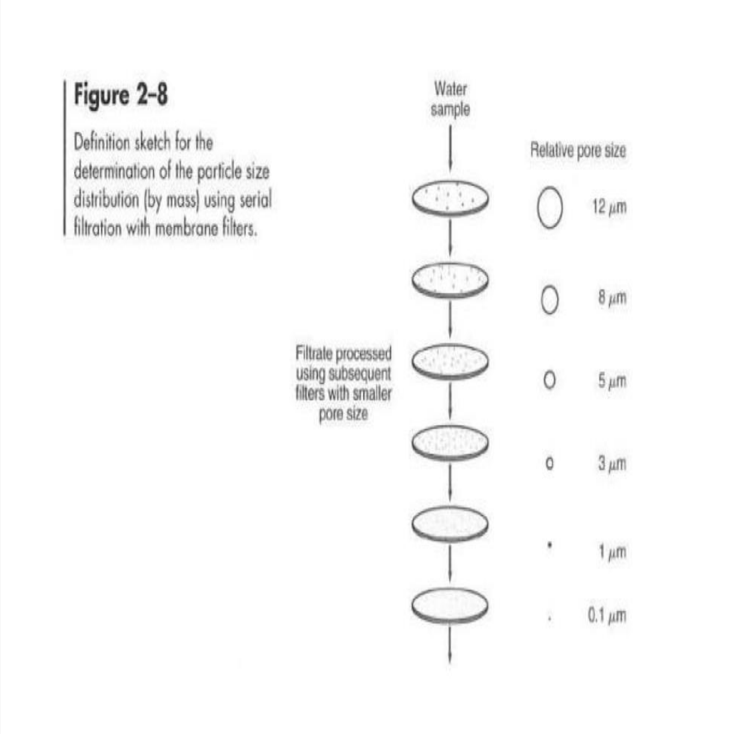
Figure 2–7

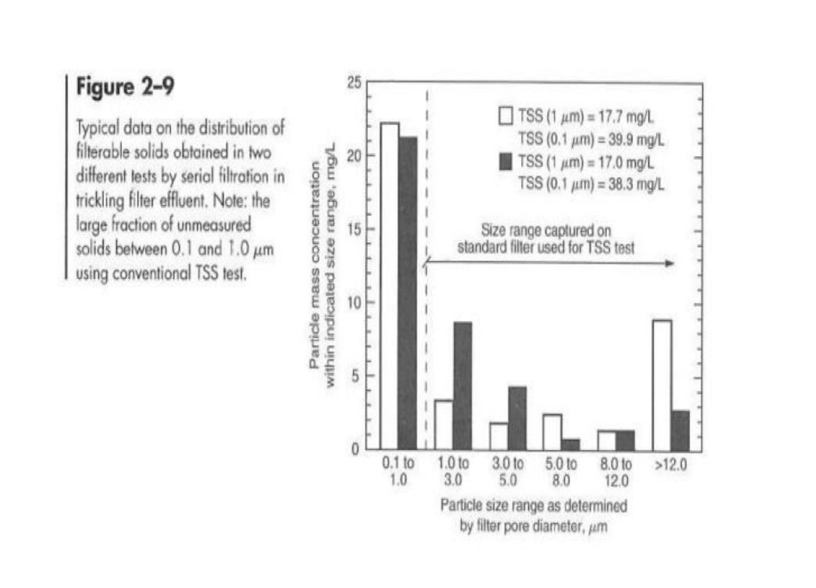
Size ranges of organic constituents in wastewater and size separation and measurement techniques used for their quantification.



1. SERIAL FILTRATION

- Serial filtration may be used to determine an approximate particle size distribution of SS based on mass (Levine et al., 1985)
- A w/w sample is passed sequentially through a series of membrane filters (Fig 2-8) with particular opening of known diameter (typically 12, 5, 5, 3, 1 and 0.1 μm), and the amount of SS retained in each filter is measured.
- Fig 2-9: typical results of such measurement
- Some info gained on the size & distribution of particles
- Little info gained on the nature of individual particles
- Method is useful in assessing the effectiveness of treatment methods (e.g. microfiltration) for residual TSS removal





Interesting point: significant amount of colloidal material found between 0.1-1 μm (Fig 2-9)

2. ELECTRONIC PARTICLE SIZE ANALYZERS

- To understand more about the nature & distribution of particles in w/w, non destructive measurement of particle size & particle distribution is now quite common.
- Yet, electronic particle sizing & counting techniques cannot be used reliably for determining the source or type of particle (e.g., distinguishing between a viable cyst, a nonviable cyst, or a similar size silt particle)
- In electronic particle size counting. particles are counted by diluting a treated w/w sample, and then passing the diluted sample through a calibrated orifice or past laser beams (Fig 2-10).
- As the particles pass through the orifice, the conductivity of the fluid changes owing to the presence of the particle
- The change in conductivity is related to the size of an equivalent sphere
- Similarly, as a particle passes by a laser beam, it reduces the intensity of the laser due to light scattering
- The reduced intensity is correlated to the size of particle
- Table 2-5: the typical size ranges quantifiable with different types of particle size counters
- Most particle counters used in w/w treatment facilities to assess performance have sensors available in different size ranges, i.e. 1.0 - 60 μm or 1 - 350 μm, depending on the manufacturer and application
- Fig 2-11: a typical particle size analysis with a laser type counter with 128 channels
- For disinfection studies, channel sizes are often selected corresponding to the size ranges of interest, i.e Crystoporidium (2-5 μm) and Giardia (5-15 μm)
- Data derived from electronic particle size analyzers can be reported as (Standard Methods, 2012)
  - Particle no by size
  - Surface area & volume
  - Volume fraction corresponding to each particle size range

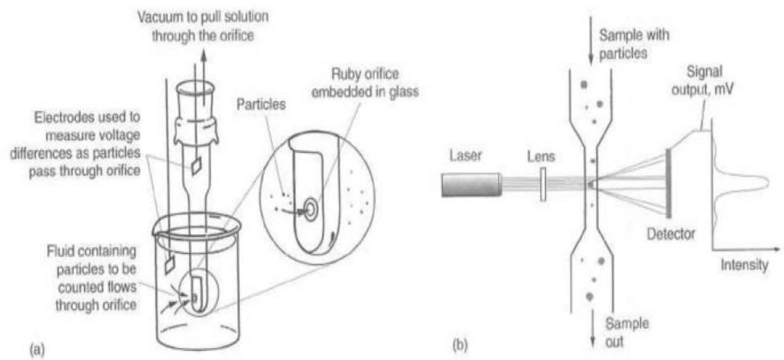


Figure 2–10

Determination of particle size distribution: (a) coulter counter, voltage difference as particle passes through the orifice is used to determine the size of an equivalent spherical particle and (b) laser particle size counter, size of equivalent spherical particle is based on reduced intensity and light scattering as particle passes through light beam.

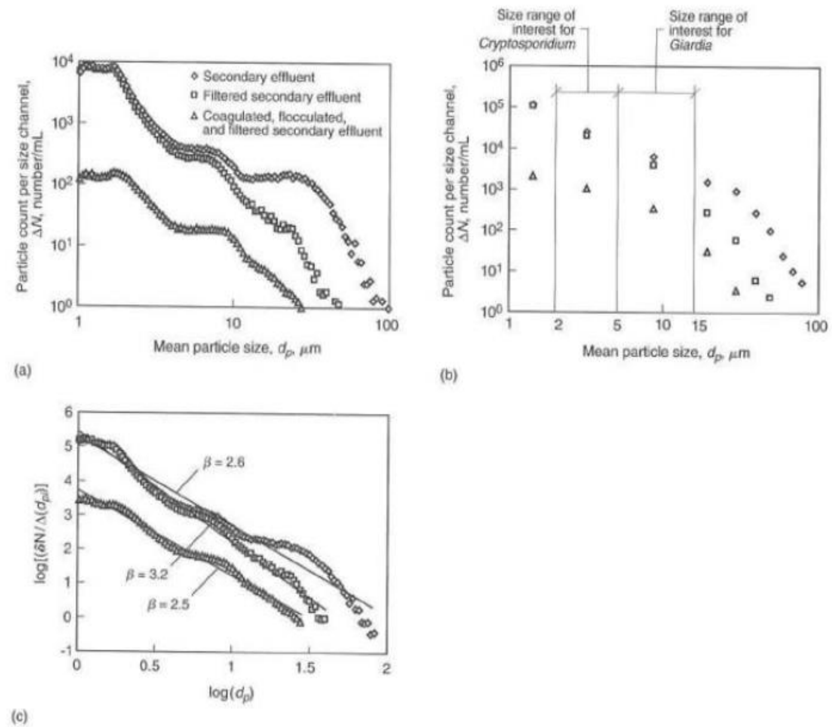


Figure 2–11

Effect the use of chemicals on filter particle size removal performance (a) original data as collected (courtesy of K. Bourgeous, 2005), (b) original data aggregated into selected channel (bin) sizes, and, (c) the original data, plotted functionally according to the power law (see Example 2–4).

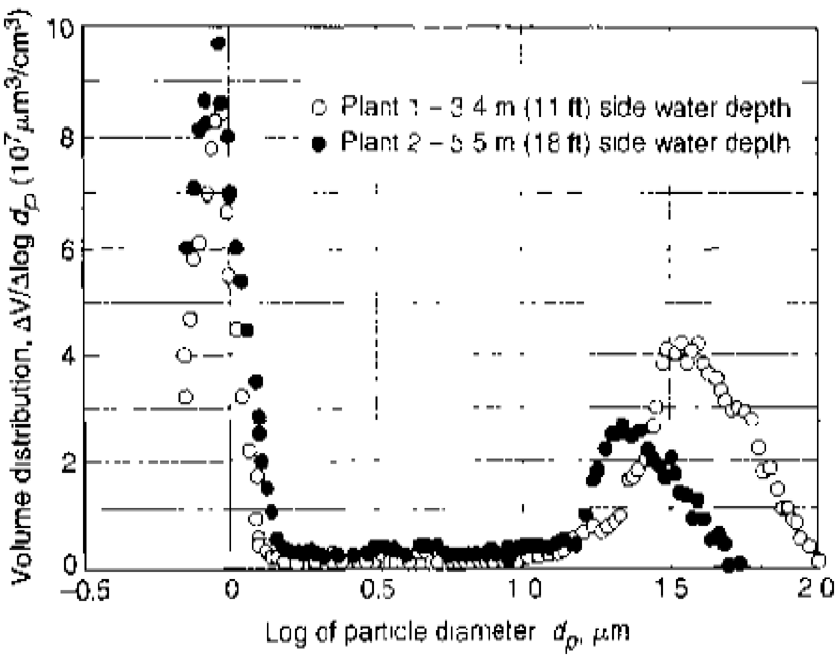


Figure 2–9

Volume fraction of particle sizes found in the effluent from two activated-sludge plants with clarifiers having different side water depths

- The particle size data for small particles are the same
- The particle size data for larger particles are quite different, owing primarily to the design & operation of the secondary clarifiers
- This particle size info is useful in assessing the performance of the secondary sedimentation facilities, effluent filtration, and the potential for chlorine & UV disinfection

3. DIRECT MICROSCOPIC OBSERVATION

- Particles in w/w can also be enumerated by placing a small sample in a particle counting chamber, and counting the individual particles
- Various stain are used to aid in differentiating different types of particles
- Generally impractical on aroutine basis
- Yet the method can be used to quatitatively assess the nature & size of the particles

OPTICAL IMAGING

- A process to quantitatively assessed w/w particles by microscope
- A w/w small sample is placed on a microscope slide
- Images are collected with a video camera attached to microscope, and transmitted to a computer where various measurements can be assessed
- Type of measurements obtained are dependent on the software
- Yet typically include: the mean, minimum, max diameter, aspect ratio (length to width ratio), circumference, surface area, vol & centroid of various particles
- Greatly reduces the times required to measure various characteristics of particles
- But costly

TURBIDITY

- A measure of the light-transmitting properties of water
- Another test used to indicate the quality of waste discharges & natural waters with respect to colloidal & residual suspended matter
- Based on comparison of the intensity of light scattered by a sample to the light scattered by a reference suspension under the same conditions (Standard Methods, 1998)
- Formazin suspensions are used for the primary reference standard
- Results reported as NTU
- Colloidal matter will scatter or absorb light thus prevent its transmission
- Presence of air bubbles in the fluid will cause erroreous turbidity readings
- No relationship between turbiditity and concentration of TSS in untreated w/w generally
- Yet, there is for settled & filtered 2nd effluent from the ASP

TURBIDITY

- $TSS \approx TSS_f\, T$ (Eq 2-16)
  - TSS = mg/L
  - TSS_f = factor to convert NTU to TSS, mg/L TSS/NTU
  - T = turbidity, NTU
- TSS_f will vary for each treatment plant depend on primarily to the operation of the biological treatment process
- TSS_f for settled & filtered 2nd effluent filtered with a a granular medium depth filter typically 2.3-2.4 and 1.3-1.6
- Kawamura = 1.2-1.3

TURBIDITY

- Problem, especially low values in filtered effluent
  - High degree of variability observed depend on:
    - Light source (incandescent light vs light-emitting diodes)
    - Measurement method (reflected vs transmitted light)
  - Light absorbing properties of material
    - Ex: turbidity of lampblack = 0
- Thus: almost impossible to compare turbidity values reported in the literature
- Yet, turbidity readings can be used for process control
- Some on-line turbidity meters used to monitor the performance of microfiltration units are affected by the air used to clean the membranes

COLOR

- Condition was used to describe w/w together with composition & concentration
- Condition: age of w/w determined qualitatively by:
  - Color
  - Odor
- Fresh w/w: usually a light brownish color
- As travel time increases & more anaerobic conditions develop, the color changes sequentially from gray to dark gray, and ultimately to black → septic
- Some add color to domestic w/w
- In most cases, the gray, dark gray & black color is due to the formation of metallic sulfides resulted from the sulfide produced under an aerobic conditions reacts with the metals in the w/w

ABSORPTION/ TRANSMITTANCE

- A measure of the amount of light, of a specified wavelength, absorbed by the constituents in a solution
- Absorbance, using a spectrophotometer & a fixed path length (usually 1 cm):

$$A = \log\left(\frac{I_0}{I}\right) \qquad \text{(Eq 2-17)}$$

  - $A =$ absorbance, absorbance units/cm, a.u./cm
  - I_0 = initial detector reading from the blank (i.e. distileed water) after passing through a solution of kown depth
  - I = final detector reading after passing through a solution containing constituents of interest
- A is measured with a spectrophotometer using specified wavelength typically 254 nm

$$T(\%) = \left(\frac{I_0}{I}\right) \text{x } 100 \qquad \text{(Eq 2-18)}$$

  - $T =$ transmittance

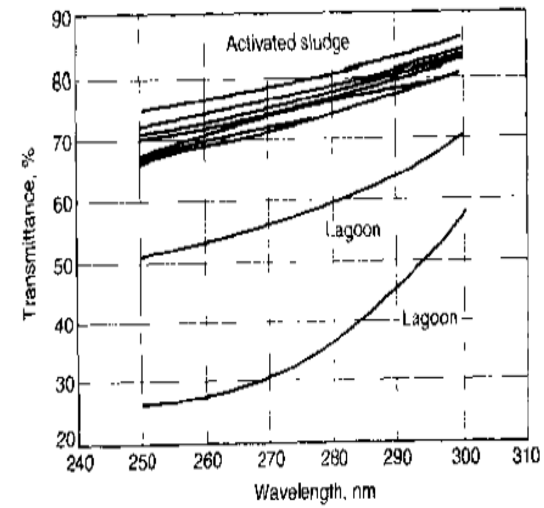
$$T = 10^{a.u./cm} \qquad \text{(Eq 2-19)}$$

- Extreme values (Delahay, 1957):
  - A perfectly transparent solution: $A = 0,\ T = 1$
  - A perfectly opaque solution: $A = 0,\ T = 0$

ABSORPTION/ TRANSMITTANCE

Figure 2-10

Transmittance measured at various wavelengths for activated-sludge effluents and lagoon effluents.



Typical A values for various w/w at 254 nm:

1. Primary = 0.5 to 0.8 /cm
2. Secondary = 0.3 to 0.5/cm
3. Nitrified secondary = 0.25 to 0.45/cm
4. Filtered secondary = 0.02 to 0.40/cm
5. Microfiltration effluent = 0.15 to 0.3/cm
6. Reverse osmosis effluent = 0.05 to 0.2/cm

- % T is affected by all substances in w/w absorbing or scattering light
- Unfiltered & filtered T are measured in w/w in conneetion with the evaluation & desgn of UV disinfection systems
- Principal w/w characteristics affecting % T:
  - Inorganic compounds (copper, iron etc)
  - Organic compounds (organic dyes, humic substances, conjugated ring compounds (benzene & toluene), TSS

ABSORPTION/ TRANSMITTANCE

- Iron is the most importance substance to UV absorbance:
- Dissolved iron can absorb UV light directly
- Iron will adsorb onto SS, bacterial clumps & other organic compound
- Sorbed iron can prevent the UV light from penetrating the particle & inactivating organisms that may be embedded within the particle
- Where iron salts are added, dosage control is extremely important when UV disinfection is to be used
- Organic constituents absorbers ofUV light: compounds with 6 conjugated carbons or 5 or 6 member conjugated ring
- Reduction in T observed during storm events often ascribed to the presence of humic substances from stormwater flows

TEMPERATURE

- w/w temperature is commonly > local water supply due to addition of warm water from households & industrial activities

EFFECTS OF TEMPERATURE

- Important parameter, due to the effect on:
- chemical reactions & reaction rates
- Aquatic life
- The suitability of water for beneficial uses
- Increase temperature → a change in the fish species
- Industry using surface water for cooling purposes concerns with the temperature of intake water
- Oxygen is less soluble in warm water than in cold water
- > temperature → > biochemical reaction rates → < DO in surface water → serious DO depletion in summer
- This magnified by the discharge of significant large quantities of heated water into natural receiving waters
- Sudden change in temperature → a high rate of aquatic life mortality
- Abnormal high temperatures → foster the growth of undesirable water plants & w/w fungus

OPTIMUM TEMPERATURES FOR BIOLOGICAL ACTIVITY

- Optimum temp for bacterial activity: 25-35^{0}C
- Aerobic digestion & nitrification stops at 50^{0}C
- Methane-producing bacteria quite inactive at 15^{0}C
- Autotrophic-nitrifying bacteria cease functioning at 5^{0}C
- Chemoheterotrophic bacteria acting on carbonaceous material is dormant at 2^{0}C

ESTIMATION OF TEMPERATURE EFFECT ON REACION RATES

- Equilibrium constants, solubility product constants & specific reaction rate constants are dependent on temp
- Van't Hoff-Arrhenius relationship:

$$\frac{d\,(\ln k)}{dT} = \frac{E}{RT^2} \qquad \text{(Eq 2-21)}$$

  - k = reaction rate constant
  - T = temp. K= 273.15 + ^{0}C
  - E = reaction constant characteristic (e.g. activation energy), J/mol
  - R = ideal gas constant, 8.314 J/mol.K (1.99 cal/mol.K)
- Integration of Eq 2-21 between the limit T_1 & T_2:

$$\ln\frac{k_2}{k_1} = \frac{E\,(T_2 - T_1)}{R\,T_1 T_2} = \frac{E}{R\,T_1 T_2}(T_2 - T_1) \qquad \text{(Eq 2-22)}$$

- Because most w/w-treatment operations & process are carried aout at/near the ambient temp, $\frac{E}{R\,T_1 T_2}$ may be assumed to be a constant for practical purposes, thus:
- $\ln\frac{k_2}{k_1} = C(T_2 - T_1)$ (Eq 2-23)
- $\frac{k_2}{k_1} = e^{C(T_2 - T_1)}$ (Eq 2-24)
- $\frac{k_2}{k_1} = \theta^{(T_2 - T_1)}$ (Eq 2-24)
- Although θ is assumed to be constant, it will often vary considerably with temp

CONDUCTIVITY

- Electrical conductivity (EC) is a measure of the ability of a solution to conduct an EC
- Because the electrical current is transported by the ions in solution, the conductivity > as ions concentrations >
- Thus, the measured EC value is used as a surrogate measure of TDS
- EC of water is one of the parameters used to determine the suitability of a water for irrigation
- The salinity of treated w/w to be used for irrigation is estimated by measuring the EC
- SI units: millisiemens/meter (mS/m)
- US customary units: micromhos/cm (μmho/cm)
- 1 mS/m = 10 μmho/cm
- $TDS \cong EC\ x\ (0.55\ - 0.70)$ (Eq 2-26)
  - TDS = mg/L
  - EC = dS/m or μmho/cm
- Eq 2-26:
  - does not necessarily apply to raw ww/w or high-strength industrial w/w
  - can be used to check the acceptability of chemical analyses
- $I = 1.6\ x\ 10^{-5}\ \mathrm{x\ EC}$ (Eq 2-27)
- $I =$ dS/m = μmho/cm
- Eq 2-27 is used to estimate I of treated w/w in ground water recharge applications

DENSITY, SPECIFIC GRAVITY & SPECIFIC WEIGHT

Density

- Density of w/w: its mass per unit vol (SI units: g/L or kg/m^3; US units: lb_m/ft^3)
- lb_m : pound-mass (English unit)
- Important characteristics of w/w due to the formation of density currents in sedimentation, chlorine contact tanks & other units
- Density of domestic w/w that does not contain significant amount of industrial waste = water at the same temp

Specific gravity, s_w

- Is used in place of the density
- $s_w = \frac{\rho_w}{\rho_0}$ (Eq 2-28)
  - ρ_w = density of w/w
  - ρ_0 = density of water
- Density & ρ of w/w:
  - temp-dependent
  - Vary with TS concentration

Specific weight, γ

- Of a fluid Is its weight per unit vol
- SI units: kN/m^3
- US units: lb_{ft}/ft^3
- lb_{ft} = pound-force (English unit)
- $\gamma = \rho g$
- At normal temp:: γ = 9.81 kN/m^3 =62.4 lb_{ft}/ft3

2-4 INORGANIC NON METALLIC CONSTITUENTS

- Chemical constituents of w/w:
  - Inorganic
  - Organic
- Inorganic chemical constituents of concern:
  - Nutrinets
  - Non metallic constituents
  - Metal
  - Gases
- Organic chemical constituents of concern:
  - Agregate
  - Individual
- Agregate organic constituents are:
  - comprised of a no individual compounds that cannot be distinguished separately
  - of great significant in the treatment, dispoal & reuse of w/w

TLB-309
DESAIN PENGOLAHAN BIOLOGI

MINGGU KE-4:
PROCESS SELECTION, DESIGN & IMPLEMENTATION

RACHMAWATI S. DJ.

SEMESTER GANJIL 2022/2023

MATERI MINGGU KE-3

Mg Ke-	Kemampuan Akhir Tiap Tahapan Belajar (SubCPMK)	Penilaian		Bentuk Pembelajaran; Metode Pembelajaran; Penugasan Mahasiswa (estimasi waktu)		Materi Pembelajaran (Pustaka)	Bobot Pe-nilai-an (%)
		Indikator	Teknik				
(1)	(2)	(3)	(4)	Luring (5)	Daring (6)	(7)	(8)
3-6	SubCPMK 2 Mahasiswa mampu merancang suatu eksperimen pengolahan biologi dengan mempertimbangkan masalah, tujuan, metode, prosedur yang baik dalam bentuk laporan tugas kelompok	- Ketepatan perancangan eksperimen pengolahan biologi dari aspek masalah, tujuan, metode, prosedur yang baik - Ketepatan penyajian dalam bentuk laporan tugas kelompok	Test Non-test/ Tugas 2	Kuliah Diskusi [PB: 4 x (3x50')]	e-Learning Itenas: 1. file materi SubCPMK 2 (PB, KM). Hasil Tugas Mandiri 2	Materi SubCPMK 2: - Pertimbangan dalam pemilihan proses berdasarkan kinetika reaksi, transfer massa, *loading criteria*, studi *bench-scale* dan skala pilot; - Elemen desain proses: periode perencanaan, diagram alir proses pengolahan, *preliminary sizing*, neraca padatan, *plant layout,* hidrolika, manajemen energi - Metabolisme mikroba, pertumbuhan, energetika, dan *decay*, kinetika pertumbuhan mikroba, pemodelan proses pertumbuhan tersuspensi (*solids retention time,* neraca massa biomass, neraca massa substrat)	34%

WASTEWATER TREATMENT PROCESS SELECTION, DESIGN & IMPLEMENTATION

WASTEWATER TREATMENT PROCESS SELECTION, DESIGN & IMPLEMENTATION

4-2 Considerations in Process Selection

4-4 Elements of Process Design

4-5 Implementation of Wastewater Management Program

4-2 CONSIDERATIONS IN PROCESS SELECTION

INTRODUCTION

- Process selection → detailed evaluation of the various factors → evaluating unit processes and other treatment methods → to meet current and future treatment objectives
- process analysis→ to select the most suitable unit processes & the optimum operational criteria

1) The important factors that must be considered in process selection
2) Consider the basis for process design
3) The impact of treatment plant reliability on the selection of specific treatment process design criteria

IMPORTANT FACTORS IN PROCESS SELECTION

- Each factor is important in its own right
- Some factors require additional attention and explanation
- The most important factor: "process applicability” →
the skill & experience of the design engineer
- .

Table 4–2
Important factors that must be considered when evaluating and selecting unit processes

Factor	Comment
1. Process applicability	The applicability of a process is evaluated on the basis of past experience, data from full-scale plants, published data, and from pilot plant studies. If new or unusual conditions are encountered, pilot plant studies are essential.
2. Applicable flow range	The process should be matched to the expected range of flowrates. For example, stabilization ponds are not suitable for extremely large flowrates, in highly populated areas.
3. Applicable flow variation	Most unit operations and processes have to be designed to operate over a wide range of flowrates. Most processes work best at a relatively constant flowrate. If the flow variation is too great, flow equalization may be necessary.
4. Influent wastewater characteristics	The characteristics of the influent wastewater affect the types of processes to be used (e.g., chemical or biological) and the requirements for their proper operation.
5. Inhibiting and unaffected constituents	What constituents are present and may be inhibitory to the treatment processes? What constituents are not affected during treatment?
6. Climatic constraints	Temperature affects the rate of reaction of most chemical and biological processes. Temperature may also affect the physical operation of the facilities. Warm temperatures may accelerate odor generation and also limit atmospheric dispersion.
7. Process sizing based on reaction kinetics or process loading criteria	Reactor sizing is based on the governing reaction kinetics and kinetic coefficients. If kinetic expressions are not available process loading criteria are used. Data for kinetic expressions and process loading criteria usually are derived from experience, published literature, and the results of pilot plant studies.
8. Process sizing based on mass transfer rates or process loading criteria	Reactor sizing is based on mass transfer coefficients. If mass transfer rates are not available process loading criteria are used. Data for mass transfer coeficients and process loading criteria usually are derived from experience, published literature, and the results of pilot plant studies.
9. Performance	Performance is usually measured in terms of effluent quality and its variability, which must be consistent with the effluent discharge requirements.
10. Treatment residuals	The types and amounts of solid, liquid, and gaseous residuals produced must be known or estimated. Often, pilot plant studies are used to identify and quantify residuals.
11. Sludge processing	Are there any constraints that would make sludge processing and disposal infeasible or expensive? How might recycle loads from sludge processing affect the liquid unit operations or processes? The selection of the sludge processing system should go hand-in-hand with the selection of the liquid treatment system.
12. Environmental constraints	Environmental factors, such as prevailing winds and wind directions and proximity to residential areas, may restrict or affect the use of certain processes, especially where odors may be produced. Noise and traffic may affect selection of a plant site. Receiving waters may have special limitations, requiring the removal of specific constituents such as nutrients.
13. Chemical requirements	What resources and what amounts must be committed for a long period of time for the successful operation of the unit operation or process? What effects might the addition of chemicals have on the characteristics of the treatment residuals and the cost of treatment?
14. Energy requirements	The energy requirements, as well as probable future energy cost, must be known if cost-effective treatment systems are to be designed.
15. Other resource requirements	What, if any, additional resources must be committed to the successful implementation of the proposed treatment system using the unit operation or process being considered?
16. Personnel requirements	How many people and what levels of skills are needed to operate the unit operation or process? Are these skills readily available? How much training will be required?

(continued)

Table 4–2 *(Continued)*

Factor	Comment
17. Operating and maintenance requirements	What special operating or maintenance requirements will need to be provided? What spare parts will be required and what will be their availability and cost?
18. Ancillary processes	What support processes are required? How do they affect the effluent quality, especially when they become inoperative?
19. Reliability	What is the long-term reliability of the unit operation or process being considered? Is the operation or process easily upset? Can it stand periodic shock loadings? If so, how do such occurrences affect the quality of the effluent?
20. Complexity	How complex is the process to operate under routine or emergency conditions? What levels of training must the operators have to operate the process?
21. Compatibility	Can the unit operation or process be used successfully with existing facilities? Can plant expansion be accomplished easily?
22. Adaptability	Can the process be modified to meet future treatment requirements?
23. Economic life-cycle analysis	Cost evaluation must consider initail capital cost and long-term operating and maintenance costs. The plant with lowest Initail capital cost may not be the most effective with respect to operating and maintenance costs. The nature of the available funding will also affect the choice of process
24. Land availability	Is there sufficient space to accommodate not only the facilities currently being considered but possible future expansion? How much of a buffer zone is available to provide landscaping to minimize visual and other impacts?

IMPORTANT FACTORS IN PROCESS SELECTION

Many resources available to determine applicability:

- past experience in similar type projects
- performance data from operating installations,
- published information in technical journals.
- manuals of practice published by the Water Environment Federation (WEF, 2010b),
- process design manuals published by WEF and U.S. EPA
- the results of pilot plant studies

IMPORTANT FACTORS IN PROCESS SELECTION

- Where the applicability of a process of a given situation is unknown or uncertain → pilot plant studies:

→ to determine performance capabilities

→ to obtain design data upon → a full-scale design

IMPORTANT FACTORS IN PROCESS SELECTION

The diverse nature of the information that must be available to make a proper evaluation of unit processes used for the treatment of wastewater:

- process design based on:
    1) reaction kinetics
    2) mass transfer.
    3) the use of loading criteria
- the conduct of bench and pilot plant studies
- process variability
- other factors (Table 4.2)

PROCESS SELECTION BASED ON REACTION KINETICS

Process selection and sizing based on reaction kinetics

↓

defining the nature of the reactions occurring within the process

↓

1. the appropriate values of the kinetic coefficient,
2. the selection of the reactor type

SELECTION OF APPROPRIATE KINETIC RATE EXPRESSION(S) AND COEFFICIENTS

The nature of the reactions occurring within a process must be known to apply the reaction kinetics approach to design

↓

zero, first, retarded first, or second order, or a saturation type

Selection of appropriate kinetic rate coefficients for the process that is to be designed is also based on:

1) literature,
2) experience with the design and operation of similar systems,
3) data derived from pilot plant studies

- significantly different wastewater characteristics occur
- new applications of existing technology
- new process

→ pilot plant testing

SELECTION OF REACTOR TYPES

Operational factors that must be considered in the type of reactor/reactors to be be used in the treatment process:

- the nature of the wastewater to be treated
- the nature of the reaction kinetics governing the treatment process
- special process requirements
- local environmental conditions

SELECTION OF REACTOR TYPES

for biological treatment with the activated sludge process, for zero-order kinetics,

↓

no difference in the size of the reactor required (i.e .$V_{complete\ mix} = V_{plug\ flow}$)

influent wastewater contain toxic constituents that cannot be removed by pretreatment

↓

complete-mix reactor

↓

dilution capacity

filamentous microorganisms growth

↓

plug-now or multistage reactor

↓

control filamentous microorganisms growth

construction, O&M costs → reactor selection

PROCESS SELECTION BASED ON MASS TRANSFER

The principal operations in wastewater treatment involving mass transfer:

- aeration → the addition of oxygen to water
- the drying of biosolids and sludge
- the removal of volatile organics from wastewater
- the stripping of dlssolved constituents
  → ammonia from digester supernatant
- the exchange of dissolved constituents
  → ion exchange

↓

1. Literature
2. Practical experience

PROCESS DESIGN BASED ON LOADING CRITERIA

With:
- the new activated sludge biological treatment process variations
- new aeration equipment

↓

the use of loading factors should be avoided

If appropriate reaction rate expressions & mass transfer coefficients cannot be developed

↓

generalized loading criteria are used frequently

Early design loading criteria for activated sludge biological treatment systems were based on aeration tank capacity [e.g. kg of BOD/m^3 or lb BOD/ft^3]

↓

if a process that is loaded at 10 kg/m3 produces an acceptable effluent
and one loaded at 20 kg/m3 l does not

↓

the successful experience tends to be repeated

Unfortunately:
- records often are not well maintained
- the limits of loading criteria are seldom defined

BENCH-SCALE TESTS AND TEST-BED PILOT-SCALE STUDIES

test-bed :

to describe a physical facility (also a geographic location, urban area, or city) where technologies and concepts can be tested & evaluated

the applicability of a process for a given situation
is unknown, but
the potential benefits of using the process are significant

bench-scale or pilot-scale tests

Bench-scale tests:
conducted in the laboratory with small quantities of the wastewater

Pilot-scale tests:
conducted typically with flows that can vary (0.1-5% of the design flows

pilot-scale tests:

- used typically to denote hydraulic capacity of the facility
- not necessarily the scale of the physical facilities being tested

a full -scale membrane filtration system:
500 microfiltration units

pilot-scale: ≤ 10 units

scale-up issues & computational methods are too complex

The individual units being tested = full-scale installation

BENCH-SCALE TESTS AND TEST-BED PILOT-SCALE STUDIES

- The purpose of conducting pilot-plant studies:

1) to establish the suitability of the process in the treatment of a specific wastewater under specific environmental conditions
2) to obtain the necessary data on which to base a full scale design

- Table 4-3: Factors that should be considered in planning pilot-plant studies for wastewater treatment

The relative importance of the factors (Table 4-3) depend on:
1. specific application
2. reasons for conducting the testing progamm

testing of UV disinfection systems is typically done to:
1. verify manufacturers performance claims
2. quantify effects of effluent water quality constituents on UV performance
3. assess the effects of system & reactor hydraulics on UV performance
4. assess the effects of effluent filtration on UV performance
5. investigate photoreactivation and impacts

Table 4–3

Considerations in setting up pilot-plant testing programs

Item	Consideration
Reasons for conducting pilot testing	Test new process Simulation of another process Predict process performance Document process performance Optimize system design Satisfy regulatory agency requirements Satisfy legal requirements
Pilot plant size	Bench or laboratory-scale model Pilot-scale tests Full- (prototype) scale tests
Nonphysical design factors	Available time, money, and labor Degree of innovation and motivation involved Quality of water or wastewater Location of facilities Complexity of process Similar testing experience Dependent and independent variables
Physical design factors	Scale-up factors Size of prototype Flow variations expected Facilities and equipment required and setup Materials of construction
Design of pilot testing program	Dependent variables including ranges Independent variables including ranges Time required Test facilities Test protocols Statistical design of data acquisition program Phased approach to adjust protocol as data are collected and analyzed

WASTEWATER *DISCHARGE PERMIT REQUIREMENTS*

In most wastewater discharge permits, effluent constituent rcquirements are based on:

7-d and 30-d average concentrations

wastewater treatment effluent quality is variable for a number of reasons (varying organic loads, changing environmental conditions etc.)

it is necessary to ensure that the treatment system is designed:
to produce effluent concentrations ≤ the permit limit

Two approaches in process selection & design:

1. the use of arbitrary safety factors
2. statistical analysis of treatment plant performance to determine a functional relationship between effluent quality & the probable frequency of occurrence

2nd approach → the "reliability concept"

preferred

can be used to provide:

- a consistent basis for analysis of uncertainty
- a rational basis for the analysis of performance & reliability

4-4 ELEMENTS OF PROCESS DESIGN

INTRODUCTION

wastewater flowrate & characteristics

treatment objectives & goals

1. selection of the treatment process
2. selection of the appropriate design coefficients
3. treatment process design

Principal elements of process design:

1. establishing the design period for facilities
2. development of the process flow diagram
3. establishing process design criteria
4. preliminary sizing of treatment units
5. preparation of solids balances
6. site layout considerations
7. evaluation of plant hydraulics (hydraulic profile)
8. energy management

DESIGN PERIOD

the target date when the design capacity of the facilities is reached

may vary for individual components, depending upon:

- the case or
- difficulty of expansion

Table 4-9: Typical design periods for various types of facilities

Longer periods are preferred for structures & hydraulic conduit systems, which cannot be expanded easily

The selection of the design period depends upon:

- growth characteristics
- environmental considerations
- the availability & source of construction funds

Table 4-9

Typical design periods for wastewater treatment facilities

Facility	Planning period range, y
Collection Systems	20–40
Pump stations	
Structures	20–40
Pumping equipment	10–20
Treatment plants	
Process structures	20–40
Process equipment	10–20
Hydraulic conduits	20–40

TREATMENT PROCESS FLOW DIAGRAMS

graphical representations of particular combinations of unit operations & processes

Fig. 4-7(a).: a typical process flow diagram for the treatment of w/w to meet secondary treatment standards, def ned by the U.S. EPA

Depending on the constituents that must be removed

↓

almost limitless number of different flow diagrams can be developed by combining various unit processes

the exact configuration of process units selected depend on:

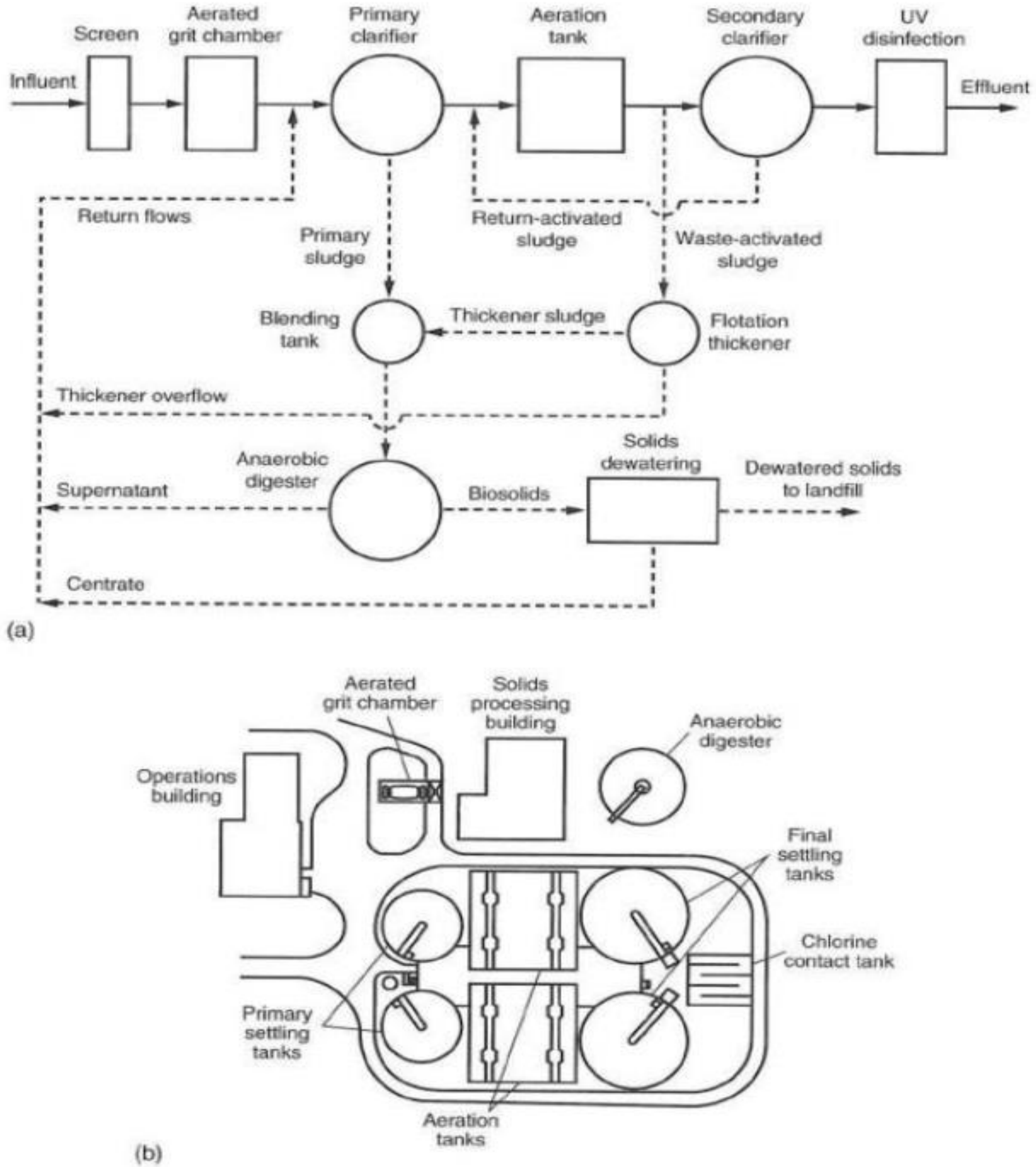
↓

the analysis of the suitability of the types of individual treatment units

- the designer's past experience
- design & regulatory agency policies on the application of specific treatment methods
- the availability of suppliers of equipment for specific treatment methods
- the maximum use that can be made of existing facilities
- initial construction costs
- future O & M costs

Figure 4–7

Wastewater treatment plant designed to meet US EPA secondary wastewater treatment standards (see Table 1–2) (a) schematic flow diagram and (b) schematic layout.



PROCESS DESIGN CRITERIA

- Similar procedures are followed for each unit process
- All the key design criteria should be listed in a summary table

After one or more preliminary processes flow diagram have been developed

↓

determine the process design criteria for the selected treatment processes

↓

the size of the physical facilities can be determined

Ex: process design criteria for the grit chamber
→ hydraulic detention time

most treatment plants are designed to be effective for some time in the future (up to 40 y)

↓

design criteria are given generally for the time:

↓

when the facilities will first be put into operation

for the end of the design period

↓

influenced by:

- projections of the population to be served
- economic studies of cost effectiveness for various design period

PRELIMINARY SIZING

Determine ;

- the number
- size of the physical facilities needed

the hydraulic detention time in the aerated grit chamber (Fig. 4-7(a)) = 3.5 min at peak flowrate

↓

grit chamber volume required would be calculated

Sizing depend on consideration on:

1. physical site constraints
   → round sedimentation tanks or rectangular tanks?
2. Operational
   i.e. flow splitting & load balancing
   → particularly in process trains combining different number of unit processes
   e.g. 2 primary clarifier & 3 aeration tanks
4. Maintenance

In small plants where a single unit is being considered

↓

maintenance of that unit may be a problem

↓

special provisions → temporary storage

SOLIDS BALANCE

should be prepared for:

1. each process flow diagram
2. the average load with appropriate peaking factor applied for maximum loads

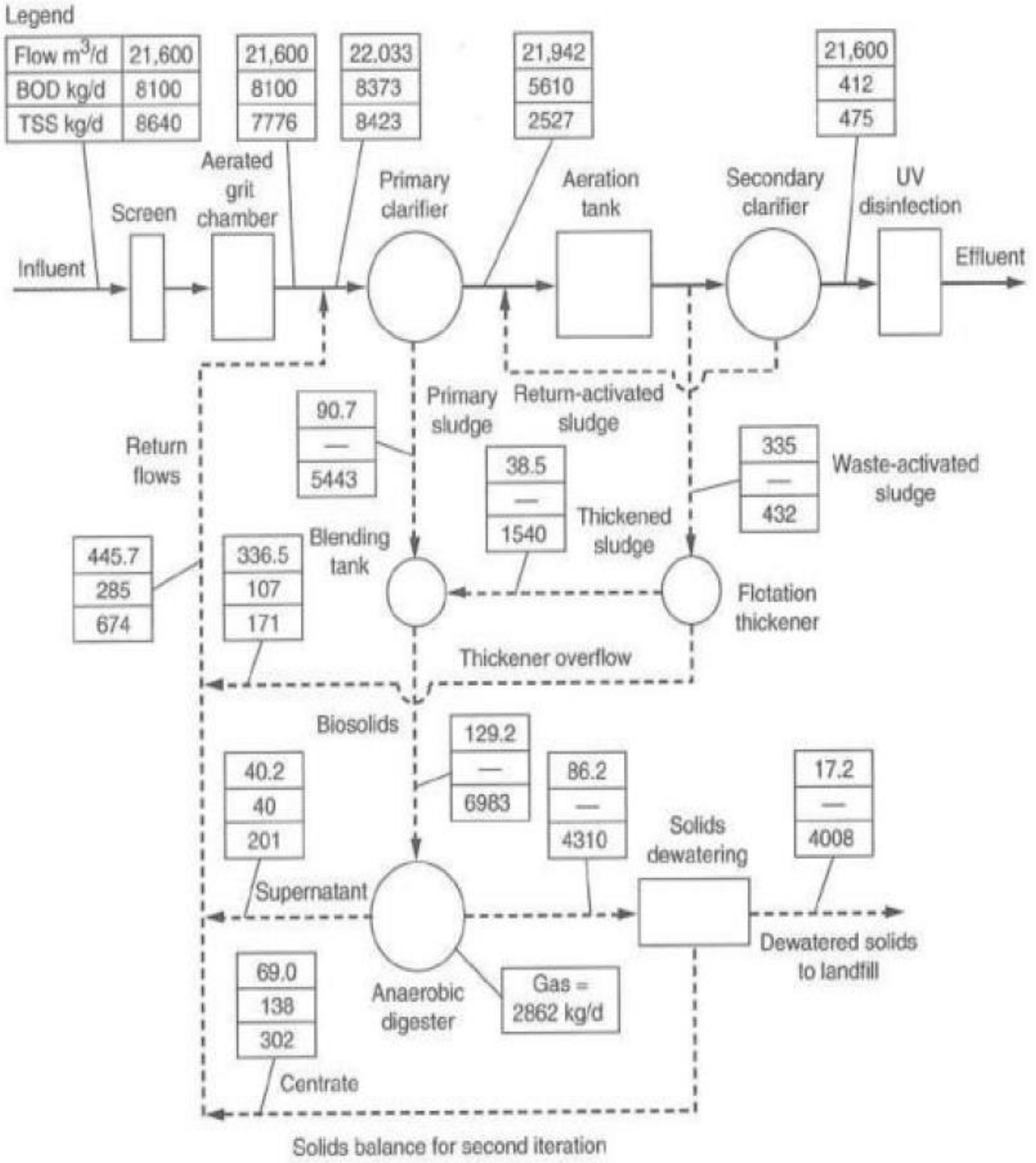
must be available to size:

1. sludge thickening and storage facilities
2. sludge digesters
3. sludge dewatering facilities
4. thermal reduction systems
5. composting facilities
6. sludge piping & pumping equipment & other appurtenant facilities

Fig 4-8:
The solids balance for the flow diagram (Fig.4-7(a)

Figure 4–8

Results of solid mass balance for the treatment process flow diagram shown on Fig. 4–7. Computational details are presented in Sec. 14–7 in Chap. 14.



PLANT LAYOUT

spatial arrangement of the physical facilities required to achieve a given treatment objective

Figs. 4-7(b) and 4-9: physical layouts for a small & large WWTP

- The overall plant layout includes the location of:
    - the control buildings
    - administrative buildings
    - any other necessary structures
- Several different layouts, using computer generated overlays, are normally evaluated before a final selection is made

factors that must be considered when laying out a treatment plant:

1. geometry of the available treatment plant sites
2. topography
3. soil & foundation conditions
4. location of the influent sewer
5. location of the point of discharge
6. plant hydraulics, preferably with straight flow paths between units:
    1) to minimize headloss
    2) to provide symmetry for flow splits
7. types of processes involved
8. Process performance & efficiency
9. transportation access
10. accessibility to operating personnel
11. reliability & economy of operation
12. Aesthetics
13. environmental control
14. provisions for future plant expansion including additional area

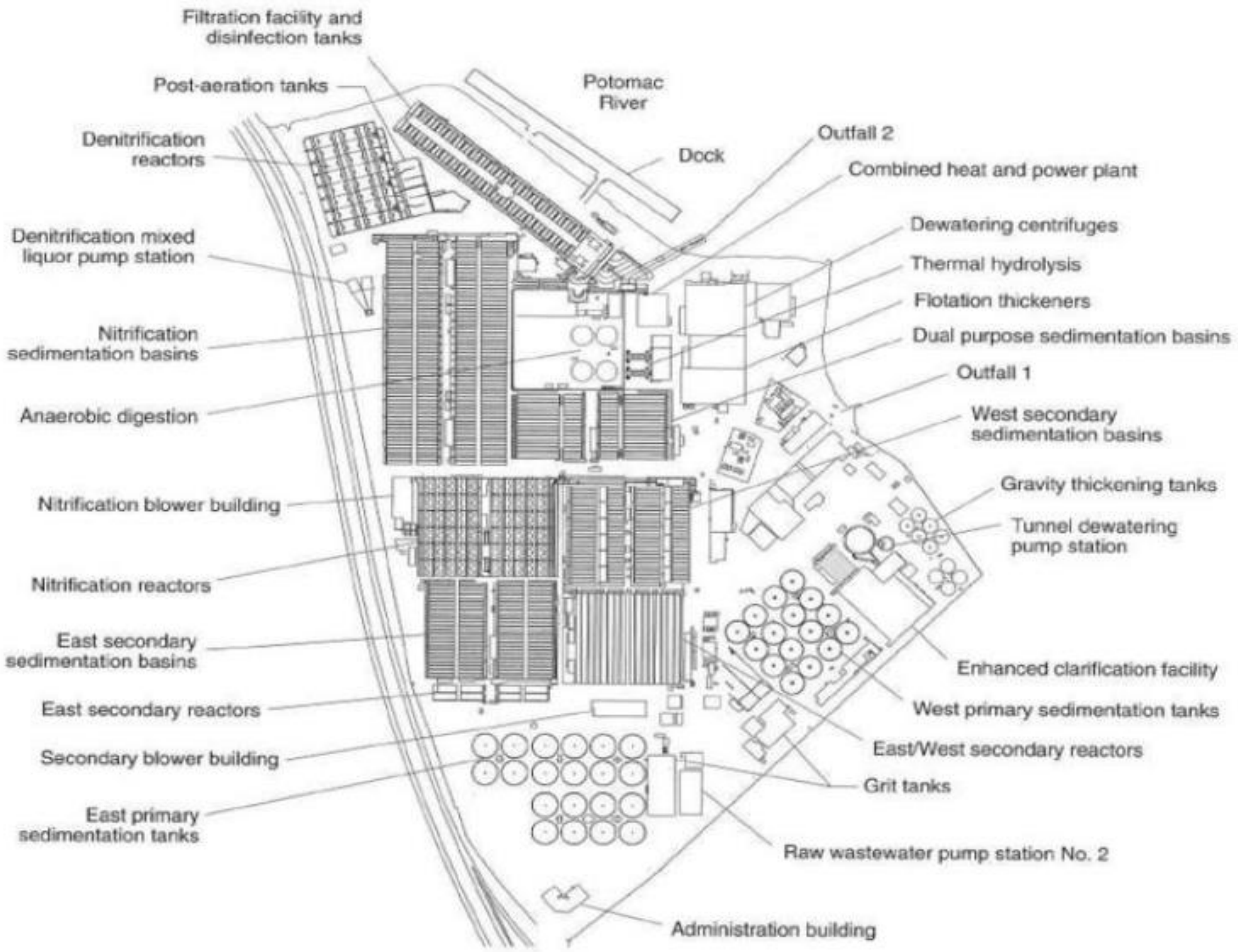


Figure 4–9

Layout of the Blue Plains Advanced Wastewater Treatment Plant with a capacity 16.2 m^3/s (370 Mgal/d) serving the Washington, DC area and environs. (Coordinates: 38.8178 N, 77.0220 W, view at altitude 4 km, also shown on the cover of this book.)

PLANT HYDRAULICS

hydraulic computations & profiles are prepared for:

- average
- peak flowrates

- Hydraulic computations are made to:
  - size the interconnecting conduits & channels
  - compute the headlosses through the plant

In preparing a hydraulic profile, distorted vertical and horizontal scales are commonly used to depict the physical facilities

Table 4-10: Typical ranges of headlosses through treatment units

In designing the plant hydraulic system, consideration needs to be given to:

1. equalizing the flow splitting between the treatment units
2. making provisions for bypassing secondary treatment units at extreme peak flows to prevent loss of biomass
3. provision for removing treatment facilities during periods of sustained low flow
4. minimizing the number of changes in direction of wastewater flow in conduits & channels

Hydraulic profiles are prepared for three reasons:

1. to ensure that the hydraulic gradient is adequate for the w/w to flow through the treatment facilities by gravity
2. To establish the head requirement for the pumps where pumping will be needed
3. To ensure that the plant facilities will not be flooded or backed up during periods of peak flow

Fig. 4- 10: the hydraulic profile for the flow diagram given on Fig. 4-7

PLANT HYDRAULICS

- Hydraulic profile computations → the determination of the headloss → wastewater flow through each of the physical facilities in the process flow diagram
- Specific computational procedures may vary depending on local conditions:

1. if the downstream discharge condition is the control point. → make hydraulic profile by working backward from the control point
2. work from the head end of the plant
3. work from the center in each direction → adjusting the elevations at the end of the computations

- The use of mathematical models & digital computers allow many possible hydraulic conditions to be analyzed

Table 4–10

Typical headlosses across various treatment units[a]

Treatment unit	Headloss range	
	ft	m
Bar Screen	0.5–1.0	0.2–0.3
Grit chambers		
Aerated	1.5–4.0	0.1–1.2
Velocity controlled	1.5–3.0	0.5–0.9
Primary sedimentation	1.5–3.0	0.5–0.9
Aeration tank	0.7–2.0	0.2–0.6
Trickling filter		
Low-rate	10.0–20.0	3.0–6.1
High-rate, rock media	6.0–16.0	1.8–4.9
High-rate, plastic media	16.0–40.0	4.9–12.2
Secondary sedimentation	1.5–3.0	0.5–0.9
Filtration	10.0–16.0	3.0–4.9
Carbon adsorption	10.0–20.0	3.0–6.1
Chlorine-contact tank	0.7–6.0	0.2–1.8

[a] The reported values do not reflect designs optimized for minimum energy usage.

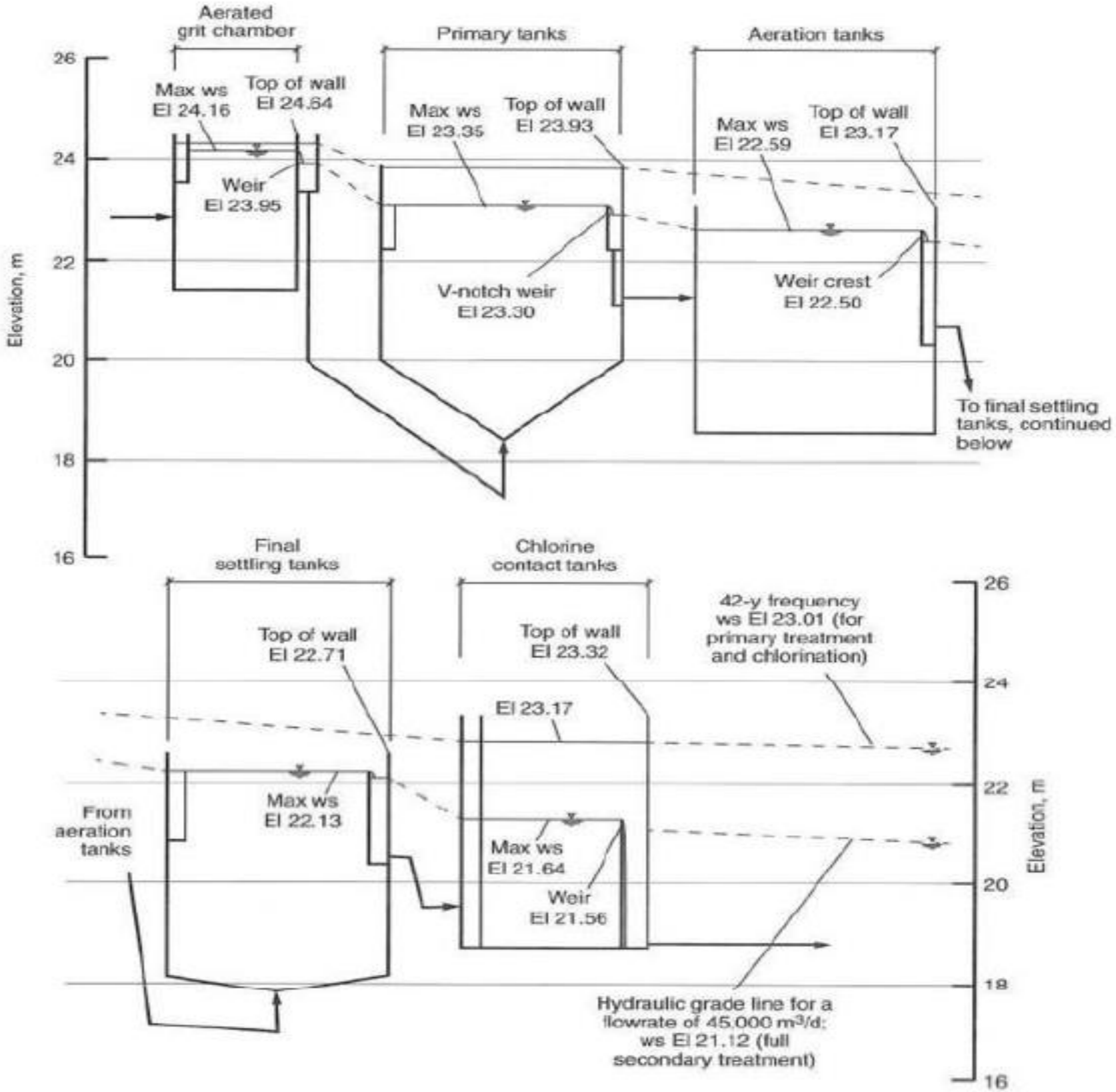


Figure 4–10

Hydraulic profile for wastewater treatment plant shown schematically on Fig. 4–7.
Note: ws = water surface, El = elevation.

ENERGY MANAGEMENT

Typically, 30% of the operating cost of a WWTP is budgeted for energy use

Water and wastewater utilities in the USA consume 2-4% of the total amount of electricity produced (WEF 2010a)

↓

During the next 20-30 y the electricity requirements for WWTP → increase 30-40%

In an era where there are concerns about the adequacy of fuel supplies, cost of energy. and the increasingly higher levels of treatment resulting in increased energy consumption

↓

the design and operation of WWTP is focused increasingly on improving the efficiency of electric energy use and reducing the cost of treatment

↓

the importance of energy usage and procurement in WWTP cannot be overstated

4-5 IMPLEMENTATION OF WASTEWATER MANAGEMENT PROGRAMS

INTRODUCTION

- Many of the major considerations in the overall design process & wastewater management programs are detailed in WEF (2010b)
- The principal elements of a wastewater management program include:

1. Facilities planning
2. Design
3. value engineering
4. Construction
5. startup and operation

- Most major projects having a construction cost over $ 10-20 million typically follow all steps
- Smaller projects (< $ 10 million) may not include the value engineering step.
- although some simplified form of value engineering is highly desirable

FACILITIES PLANNING

a document established to analyze systematically the technical, economic, environmental & financial factors necessary to select a cost-effective wastewater management plan

While the facilities plan itself may include an EIA on major projects, the EIA is usually a separate document

The scope of the facilities plan include:

1. defining the problem
2. identifying life expectancies of major elements (usually 20-25 y for equipment and 50 y for structures)
3. defining. developing & analyzing alternative treatment & disposal systems
4. selecting a plan
5. outlining an implementation plan including financial arrangements, and a schedule for design & construction

The ultimate objective of a facilities plan:
a well-defined, cost-effective, and environmentally sound project capable of being implemented and being acceptable to tax payers and regulatory authorities

DESIGN

the approach used generally for designing a facility consists of:

1. conceptual design
2. preliminary design
3. special studies
4. final design

1. Conceptual design is used to:
- finalize the preliminary design criteria used in the facilities plan
- establish preliminary facilities layouts
- define the necessary field investigations required i.e. surveys & geotechnical studies

2. Preliminary design:
- is an expansion of the conceptual design
- defines fully the facililies to be included in the project so that final design can proceed

3. Special studies may include field studies or testing necessary for the development of design criteria

4. Final design involves the production of:
- the detailed contract plans
- specifications used to bid and build the project

Mitigation measures may also be included in the design to reduce or lessen unavoidable environmental impacts

VALUE ENGINEERING (VE)

an intensive review of a project to determine best value. or value Improvement, which may or may not result in cost reduction

The purpose of the VE analysis:
to obtain the best project at the least cost without sacrifying quality or reliability

Depending on the size & complexity of the project, the VE effort may vary from one team & review session to multiple teams and reviews

For large projects, 2 review sessions are usually held, each lasting about one week:

1. 20-30% stage of design completion
2. 65-75% stage.

The VE team members are senior professionals who are not involved with the design of the project

CONSTRUCTION

The quality of the design plans & specifications are often measured by:

1. case of integration of new facilities into existing sites
2. clarity of presentation that allows contractors to submit bids with small allowances for undefined or unforeseen conditions
3. Specification of high quality materials of construction to ensure a long useful life of the facilities
4. timely completion of the work
5. minimization of changes required during construction

CONSTRUCTION CONSIDERATIONS

- In the preparation of the final plans & specifications, the design engineer must consider many of the details of construction
- Some of the principal considerations:
  1. how will the plant be built
  2. how will it interface with existing facilities
  3. what will be the materials of construction
- The buildability of a set of plans will be reflected in the bid price and the number of changes that must be made during construction.
- Numerous changes can result in costly change orders
- Integrating a new facility with an existing one may present problems in:
  1) maintaining operations during construction
  2) continuing treatment at a level that will not violate discharge permit requirements
  3) avoiding safety hazards to personnel.
- The construction contract must define clearly how these issues are addressed

- In selecting materials of construction, 3 principles are fundamental to the engineering design of process oriented facilities:
  1. durability- the life of the equipment is expected to last at least 20 y, and up to 50 Y for structures
  2. reliability-good quality materials and equipment to minimize maintenance & replacement
  3. Environmental suitability- realizing that wastewater and its attendant chemicals may be corrosive

  → most process structures are constructed of reinforced concrete and other materials of construction are selected based upon their corrosion-resistant properties

CONSTRUCTION & PROGRAM MANAGEMENT

Techniques used to ensure timely construction of the project in accordance with the plans and specifications include:

1. construction management
2. program management

- Construction management usually provides review of the contract plans & specifications and management oversight of the construction contractor's operations
- The purposes of construction management are to:
  1. verify the technical adequacy, operability. and constructability of the plans & specifications before construction begins
  2. establish construction schedules consistent with the program objectives and to optimize cash resources
  3. review the contractor's operation to ensure conformance with the plans & specifications
  4. control change orders and possible construction claims

- Program management differs from construction management → provides a single source of responsibility & authority (accountable to the owner) for the management, planning, engineering, permitting, financing, construction, and startup operations of the total wastewater management program
- Program management is often used in very large projects or projects that are privatized

FACILITIES STARTUP AND OPERATION

One of the principal tools used for plant startup, O & M
→ the O&M manual

to provide treatment system personnel with:

- the proper understanding
- recommended operating techniques & procedures references necessary to
- efficiently operate & maintain their facilities

The design engineer usually has the lead responsibility in preparing the O&M manual

Some of the principal concerns in wastewater engineering relate to the:

1. Startup
2. Operation
3. Maintenance of treatment plans

The challenges facing the design engineer & treatment plant operator:

1. providing. operating, and maintaining a treatment plant that consistently meets its performance requirements
2. managing O & M costs within the required performance levels
3. maintaining equipment to ensure proper operation & service
4. training operating personnel

the design has to be done with the operations in mind
the plant has to be operated in accordance with the design concept

TLB-309
DESAIN PENGOLAHAN BIOLOGI

MINGGU KE-5:
TANGKI ALIRAN RATA-RATA
(*FLOW & CONSTITUENT LOAD EQUALIZATION*)

RACHMAWATI S. DJ.

SEMESTER GANJIL 2022/2023

MATERI MINGGU KE-11

Mg Ke-	Kemampuan Akhir Tiap Tahapan Belajar (SubCPMK)	Penilaian		Bentuk Pembelajaran[7)]; Metode Pembelajaran[8)]; Penugasan Mahasiswa (estimasi waktu)		Materi Pembelajaran[9)] (Pustaka)	Bobot Penilaian[10] (%)
		Indikator[5)]	Teknik[6)]				
(1)	(2)	(3)	(4)	Luring (5)	Daring (6)	(7)	(8)
11-14	SubCPMK 4 Mahasiswa mampu merancang unit pengolahan biologi secara detail (reaktor tersuspensi/terlekat, pengendap lumpur, sistem batch/sistem kontinyu) yang terintegrasi berdasarkan konsep resource recovery dalam bentuk laporan tugas kelompok	Ketepatan perancangan	Test Nontest/ Tugas 4	Kuliah Diskusi [PB: 4 x (3x50')]	e-Learning Itenas: 1. file materi SubCPMK 4 (PB, KM). Hasil Tugas Mandiri 4	Materi SubCPMK4: Proses pengolahan biologi anaerob secara tersuspensi dan terlekat; Proses pengolahan lumpur: anaerobic digestion, aerobic digestion Nutrient recovery: pemulihan/recovery fosfat dan amonium	38%

INTRODUCTION

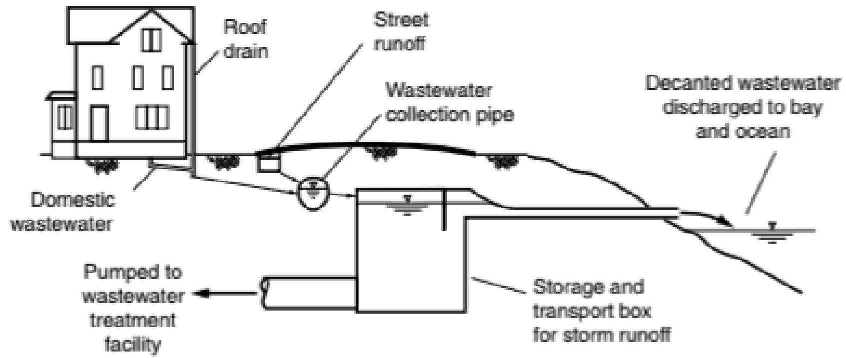
A method used to:

- overcome the operational problems caused by flow rate variations
- improve the performance of the downstream processes
- reduce the size & cost of downstream treatment facilities

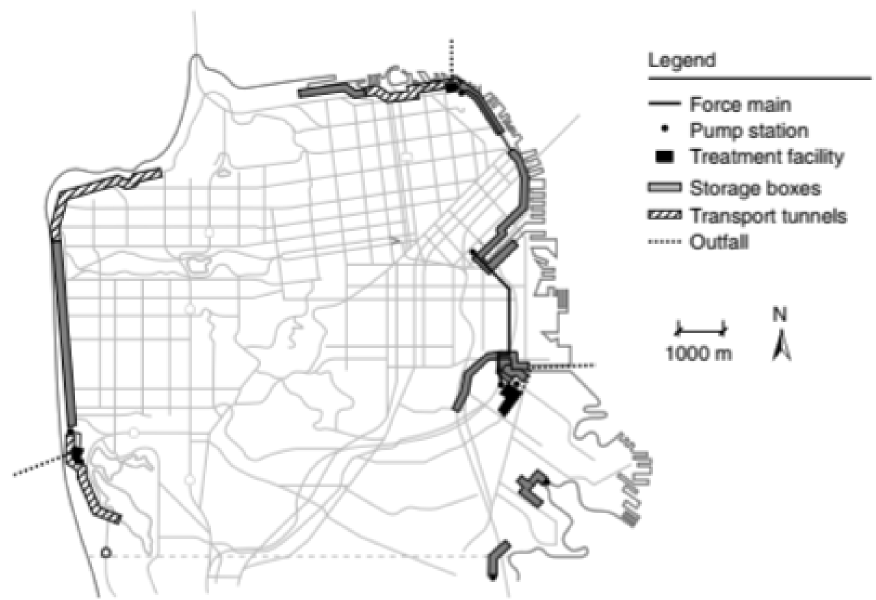
load equalization is a method used to reduce capital & operating cost of downstream treatment facilities

Figure 3–19

Details of combined collection system in the City of San Francisco, CA. (a) domestic wastewater, water from roof drains, and street runoff are collected in a combined collection system. Excess stormwater is discharged to large stormwater transport/storage boxes and tunnels. Once the stormwater flow has receded and treatment capacity becomes available, the wastewater from the storage boxes is treated before being discharged to San Francisco Bay or the Pacific Ocean, and (b) location of transport/storage boxes and tunnels around the periphery of the city (courtesy of City of San Francisco, CA).



(a)



(b)

DESCRIPTION/ APPLICATION OF *FLOW EQUALIZATION*

Flow Equalization:

- The damping of flow rate variations to achieve a constant or nearly constant flow rate
- Can be applied in a number of different situations
- Depending on the characteristics of the collection system

The principal applications are for the equalization of:

1) Dry-weather flows to reduce peak flows & loads
2) Wet-weather flows in sanitary collection systems experiencing inflow & infiltration, or
3) Combined storm water & sanitary system flows

APPLICATION IN W/W TREATMENT

In-line equalization
Off-line equalization
Fig. 3-20

1) In-line equalization

- All of the flow passes through the equalization basin
- → to achieve a considerable amount of constituent concentration & flow rate damping

2) Off-line equalization

- Only the flow above some predetermined flow limit is diverted into the equalization basin.
- Although pumping requirements are minimized, the amount of constituent concentration damping is considerably reduced.
- Sometimes used to capture the "first flush' from combined collection systems.

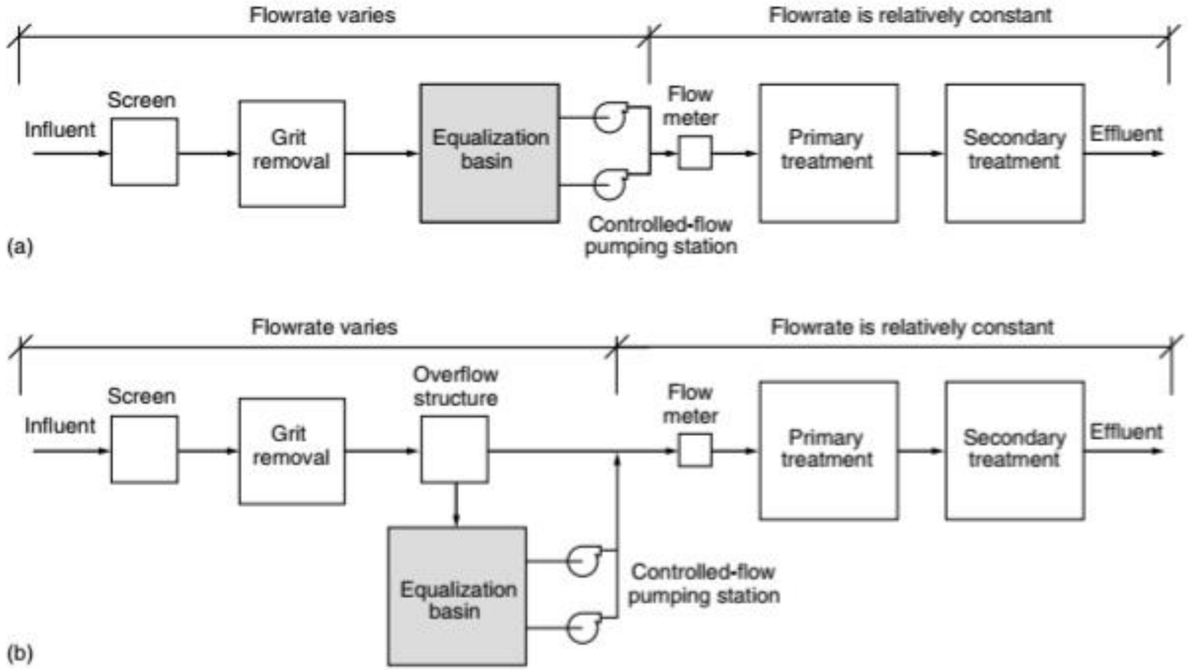


Figure 3–20

Typical wastewater treatment plant flow diagram incorporating flow equalization (a) inline equalization and (b) offline equalization.

PRINCIPAL BENEFITS

Attractive option for upgrading the performance of over loaded treatment plants

1) Biological treatment is enhanced

→ shock loadings are eliminated/minimized

→ inhibiting substances can be diluted

→ pH can be stabilized

2) The effluent quality & thickening performance of secondary sedimentation tanks following biological treatment is improved through improved consistency in solids loading & the elimi nation

of flow surges

3) Effluent filtration, or other tertiary treatment systems surface area or volumetric requirements are reduced; performance is improved; and for filtration systems more uniform filter-backwash cycles are possible by lower hydraulic loading.

4) In chemical treatment, dampening of mass loading improves chemical feed control & process reliability.

DISADVANTAGES

1) Relatively large land areas/sites are needed
2) Potential for odors
3) Additional operation & maintenance is required
4) Increased capital cost

DESIGN CONSIDERATIONS

1. Where in the treatment process flowsheet should the equalization facilities be located?
2. What type of equalization flow sheet should be used, in-line or off-line?
3. What is the required basin volume?
4. What are the features that should be incorporated into design?
5. How can the deposition of solids & potential odors be controlled?

LOCATION OF EQUALIZATION FACILITIES

The optimal location must be determined for each system

The optimum location will vary with:

1. The characteristics of the collection system
2. The wastewater to be handled
3. Land requirements & availability
4. The type of treatment required

→detailed studies should be performed for several locations throughout the system.

1. adjacent to WWTP
2. after primary treatment &
   before biological treatment
3. before primary settling & biological systems

LOCATION OF EQUALIZATION FACILITIES

1. adjacent to WWTP
   → necessary to evaluate how they could be integrated into the treatment process flowsheet

2. after primary treatment &
   before biological treatment
   → causes fewer problems with solid deposits & scum accumulation

3. before primary settling & biological systems
   → The design must provide:
   a) Sufficient mixing
      → to prevent solids deposition & concentration variations
   b) Aeration
      → to prevent odor problems

IN-LINE OR OFF-LINE EQUALIZATION

- In-Line Equalization:

  → Possibly achieve considerable damping of constituent mass loadings to the downstream processes

- Off-Line Equalization:

  → Achieve only slight damping

DETERMINATION OF VOLUME REQUIREMENTS FOR THE EQUALIZATION BASIN

- Using an inflow cumulative volume diagram
  → the cumulative inflow vs the time of the day
- The average daily flowrate
  → plotted on the same diagram
  → the straight line drawn from the origin to the endpoint of the diagram

Fig. 3- 21

DETERMINING THE REQUIRED VOLUME

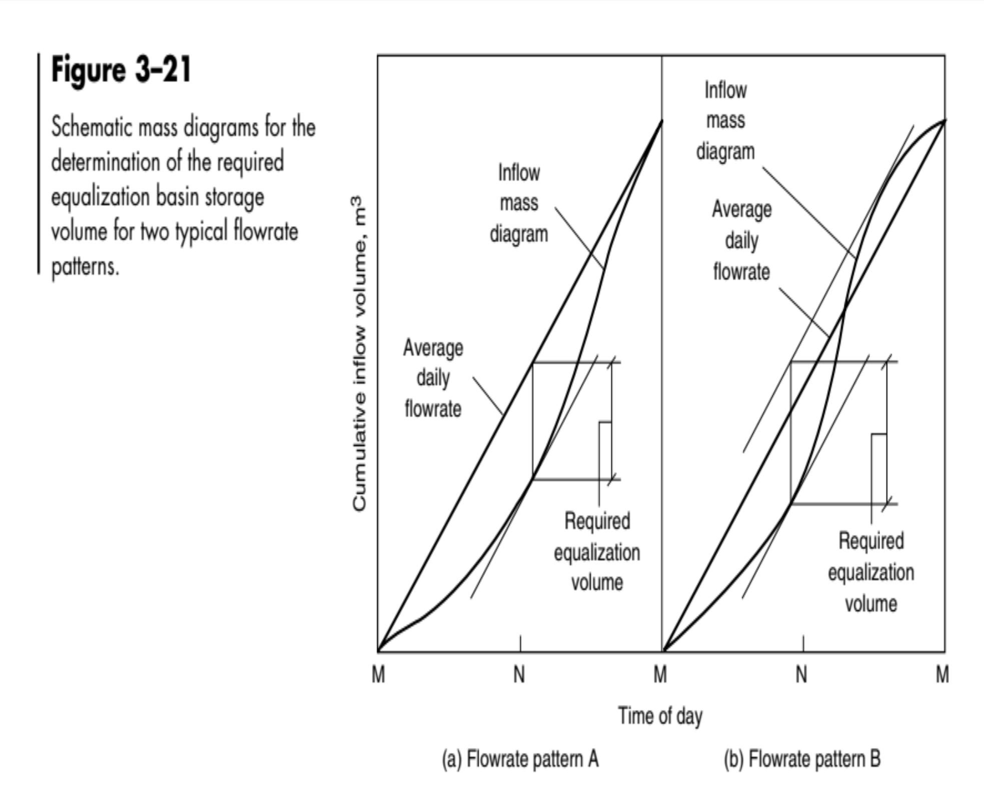
FIG. 3-21a & b

- A line parallel to the coordinate axis, defined by the average daily flow rate, is drawn tangent to the mass inflow curve.
- Required volume = the vertical distance from the point of tangency to the straight line representing the average flowrate (Fig. 3-21a).
- Fig. 3-21b: If the inflow mass curve goes above the line of average flowrate, the inflow mass diagram must be bounded with two lines parallel to the average flowrate line and tangent to extremities of the inflow mass diagram.
- Required vol = vertical distances between 2 lines.

EXAMPLE 3-10

- Procedure:
  - The average hourly volume were subtracted from the volume flow occurring each hour.
  - The resulting cumulative volumes are plotted
  - The low & high points of the curve would be determined using a horizontal line.

PHYSICAL INTERPRETATION OF THE DIAGRAMS



Flow pattern A

- At the low point of tangency

  → storage basin is empty

- Beyond this point

  → the basin begin to fill because the slope of the inflow mass diagram > average daily flowrate

- The basin continues to fill

  → until full at midnight

Flow pattern B

The basin is filled at the upper point of tangency

VOLUME OF EQUALIZATION BASIN

Would be > theoretically determined:

1. Continuous operation of aeration & mixing equipment will not allow complete drawdown, although special structures can be built.
2. accommodate the concentrated plant recycle streams that are expected, if such flows are returned to the equalization basin

   → not recommended unless the basin is covered

   → odors problem
3. Some contingency should be provided for unforeseen changes in diurnal flow.

> 10-20% theoretical value, depending on the specific conditions

EXAMPLE 3–10 **Determination of Flowrate Equalization Volume Requirements and Effects on BOD Mass Loading** For the flowrate and BOD concentration data given in following table, determine (1) the inline storage volume required to equalize the flowrate graphically (Note: the analytical spreadsheet solution is left to the reader) and (2) the effect of flow equalization on the BOD mass loading rate.

	Given data		Derived data	
Time period	Average flowrate during time period, m^3/s	Average BOD concentration during time period, mg/L	Cumulative volume of flow at end of time period, m^3	BOD mass loading during time period, kg/h
M–1	0.275	150	990	149
1–2	0.220	115	1782	91
2–3	0.165	75	2376	45
3–4	0.130	50	2844	23
4–5	0.105	45	3222	17
5–6	0.100	60	3582	22
6–7	0.120	90	4014	39
7–8	0.205	130	4752	96
8–9	0.355	175	6030	223
9–10	0.410	200	7506	295
10–11	0.425	215	9036	329
11–N	0.430	220	10,584	341
N–1	0.425	220	12,114	337

(continued)

(*Continued*)

Time period	Given data		Derived data	
	Average flowrate during time period, m^3/s	Average BOD concentration during time period, mg/L	Cumulative volume of flow at end of time period, m^3	BOD mass loading during time period, kg/h
1–2	0.405	210	13,572	306
2–3	0.385	200	14,958	277
3–4	0.350	190	16,218	239
4–5	0.325	180	17,388	211
5–6	0.325	170	18,558	199
6–7	0.330	175	19,746	208
7–8	0.365	210	21,060	276
8–9	0.400	280	22,500	403
9–10	0.400	305	23,940	439
10–11	0.380	245	25,308	335
11–M	0.345	180	26,550	224
Average	0.307			213

Note: $m^3/s \times 35.3147 = ft^3/s$
$m^3 \times 35.3147 = ft^3$
$mg/L = g/m^3$.

Solution

Solution

1. Determine the volume of the inline basin required for the flow equalization.
   a. The first step is to develop a cumulative volume curve of the wastewater flowrate expressed in cubic meters. The cumulative volume curve is obtained by converting the average flowrate (q_i) during each hourly period to cubic meters, using the following expression, and then cumulatively by summing the hourly values to obtain the cumulative flow volume.

   $$\text{Volume, m}^3 = (q_i, \text{ m}^3/\text{s})(3600 \text{ s/h})(1.0 \text{ h})$$

   For example, for the first three time periods shown in the data table, the corresponding hourly volumes are as follows:

   For the time period M–1:

   $$V_{M-1} = (0.275 \text{ m}^3/\text{s})(3600 \text{ s/h})(1.0 \text{ h}) = 990 \text{ m}^3$$

   For the time period 1–2:

   $$V_{1-2} = (0.220 \text{ m}^3/\text{s})(3600 \text{ s/h})(1.0 \text{ h}) = 792 \text{ m}^3$$

   The cumulative flow, expressed in m^3, at the end of each time period is determined as follows:

   At the end of the first time period M–1:

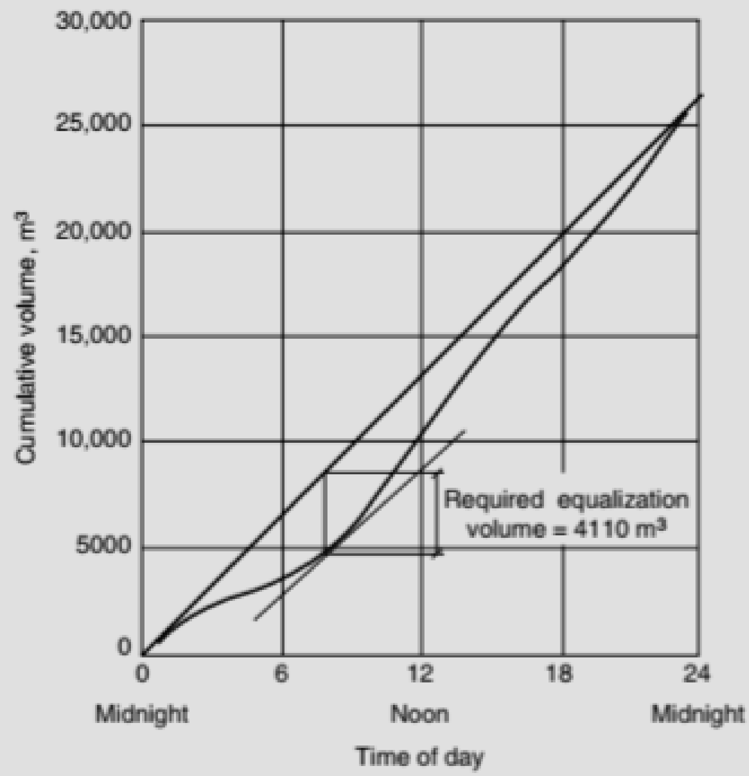
   $$V_1 = 990 \text{ m}^3$$

   At the end of the second time period 1–2:

   $$V_2 = 990 + 792 = 1782 \text{ m}^3$$

The cumulative flows for all the hourly time periods are computed in a similar manner (see derived data in data table)

b. The second step is to prepare a plot of the cumulative flow volume, as shown in the following diagram. As will be noted, the slope of the line drawn from the origin to the end point of the inflow mass diagram represents the average flowrate for the day, which in this case is equal to 0.307 m^3/s.



c. The third step is to determine the required inline storage volume. The required storage volume is determined by drawing a line parallel to the average flowrate tangent to the low point of the inflow mass diagram. The required volume is represented by the vertical distance from the point of tangency to the straight line representing the average flowrate. Thus, the required volume is equal to

Volume of equalization basin, $V \sim 4100\ m^3$ (144,790 ft^3)

2. Determine the effect of the equalization basin on the BOD mass loading rate. Although there are alternative computation methods, perhaps the simplest way is to perform the necessary computations starting with the time period when the equalization basin is empty. Because the equalization basin is empty at about 8:00 a.m., the necessary computations will be performed starting with the 8–9 time period.
   a. The first step is to compute the liquid volume in the equalization basin at the end of each time period. The volume required is obtained by subtracting the equalized hourly flowrate expressed as a volume from the inflow flowrate also expressed as a volume. The volume corresponding to the equalized flowrate for a period of 1 h is $0.307\ m^3/s \times 3600\ s/h = 1106\ m^3$. Using this value, the volume in storage is computed using the following expression:

$$V_{sc} = V_{sp} + V_{ic} - V_{oc}$$

where V_{sc} = volume in the equalization basin at the end of current time period
V_{sp} = volume in the equalization basin at the end of previous time period
V_{ic} = volume of inflow during the current time period
V_{oc} = volume of outflow during the current time period

Thus, using the values in the original data table, the volume in the equalization basin for the time period 8–9 is as follows:

$$V_{sc} = 0 + 1278\ m^3 - 1106\ m^3 = 172\ m^3$$

For time period 9–10:

$$V_{sc} = 172\ m^3 + 1476\ m^3 - 1106\ m^3 = 542\ m^3$$

The volume in storage at the end of each time period has been computed in a similar way (see following computation table)

Time period	Volume of flow during time period, m³	Volume in storage at end of time period, m³	Average BOD concentration during time period, mg/L	Equalized BOD concentration during time period, mg/L	Equalized BOD mass loading during time period, kg/h
8–9	1278	172	175	175	193
9–10	1476	542	200	197	218
10–11	1530	966	215	210	232
11–N	1548	1408	220	216	239
N–1	1530	1832	220	218	241
1–2	1458	2184	210	214	237
2–3	1386	2464	200	209	231
3–4	1260	2618	190	203	224
4–5	1170	2680	180	196	217
5–6	1170	2746	170	188	208
6–7	1188	2828	175	184	203
7–8	1314	3036	210	192	212
8–9	1440	3370	280	220	243
9–10	1440	3704	305	245	271
10–11	1368	3966	245	245	271
11–M	1242	4102	180	230	254
M–1	990	3986	150	214	237
1–2	792	3972	115	196	217
2–3	594	3160	75	179	198
3–4	468	2522	50	162	179
4–5	378	1794	45	147	162
5–6	360	1048	60	132	146
6–7	432	374	90	119	132
7–8	738	0	130	126	139
Average					213

Note: $m^3 \times 35.3147 = ft^3$
$kg \times 2.2046 = lb$
$g/m^3 = mg/L$

b. The second step is to compute the average concentration leaving the storage basin. Using the following expression, which is based on the assumption that the contents of the equalization basin are mixed completely, the average concentration leaving the storage basin is

$$C_{oc} = \frac{(V_{ic})(C_{ic}) + (V_{sp})(C_{sp})}{V_{ic} + V_{sp}}$$

where C_{oc} = average concentration of BOD in the outflow from the storage basin during the current time period, g/m^3 (mg/L)

V_{ic} = volume of wastewater inflow during the current period, m^3

C_{ic} = average concentration of BOD in the inflow wastewater volume, g/m^3

V_{sp} = volume of wastewater in storage basin at the end of the previous time period, m^3

C_{sp} = concentration of BOD in wastewater in storage basin at the end of the previous time period, g/m^3

Using the data given in column 2 of the above computation table, the effluent concentration is computed as follows:
For the time period 8–9:

$$C_{oc} = \frac{(1278\ m^3)(175\ g/m^3) + (0)(0)}{1278\ m^3}$$

$$= 175\ g/m^3\ (mg/L)$$

For the time period 9–10:

$$C_{oc} = \frac{(1476\ m^3)(200\ g/m^3) + (172\ m^3)(175\ g/m^3)}{(1476 + 172)\ m^3}$$

$$= 197\ mg/L$$

All the concentration values computed in a similar manner are reported in the above computation table.

c. The third step is to compute the hourly mass loading rate using the following expression:

$$\text{Mass loading rate, kg/h} = \frac{(C_{ac}, \text{g/m}^3)(q_i, \text{m}^3/\text{s})(3600 \text{ s/h})}{(1000 \text{ g/kg})}$$

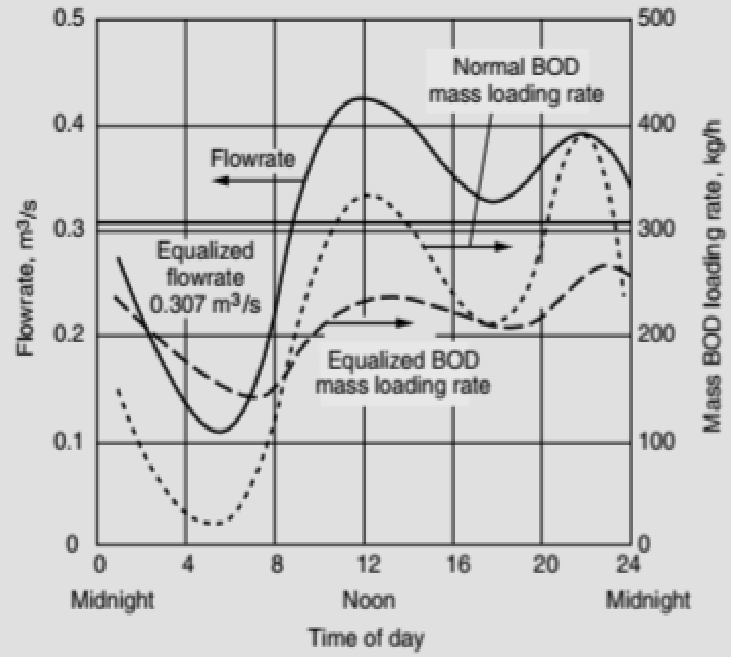
For example, for the time period 8–9, the mass loading rate is

$$\frac{(175 \text{ g/m}^3)(0.307 \text{ m}^3/\text{s})(3600 \text{ s/h})}{(1000 \text{ g/kg})} = 193 \text{ kg/h (426 lb/h)}$$

All hourly values are summarized in the computation table. The corresponding values without flow equalization are reported in the original data table.

d. The effect of flow equalization can be shown best graphically by plotting the hourly unequalized and equalized BOD mass loading (see the following plot). The following flowrate ratios, derived from the data presented in the table given in the problem statement and the computation table prepared in Step 2a, are also helpful in assessing the benefits derived from flow equalization:

Ratio	BOD mass loading	
	Unequalized	Equalized
$\frac{\text{Peak}}{\text{Average}}$	$\frac{439}{213} = 2.06$	$\frac{271}{213} = 1.27$
$\frac{\text{Minimum}}{\text{Average}}$	$\frac{17}{213} = 0.08$	$\frac{132}{213} = 0.62$
$\frac{\text{Peak}}{\text{Minimum}}$	$\frac{439}{17} = 25.82$	$\frac{271}{132} = 2.05$



Comment Where inline flow equalization basins are used, additional dampening of the BOD mass loading rate can be obtained by increasing the volume of the basins. Alternatively, offline storage can be used to further reduce the variability of the BOD mass loading rate to the biological treatment process. Although the flow to a treatment plant was equalized in this example, flow equalization would be used, more realistically, in locations with high infiltration/inflow or peak stormwater flows.

BASIN CONFIGURATION & CONSTRUCTION

Principal factors that must be considered:

1. Basin geometry
2. Basin construction including cleaning, access & safety
3. Mixing & air requirements
4. Operational appurtenances
5. Pump & pump control systems

I. BASIN GEOMETRY

The importance of basin geometry varies
→ depend on in-line or off-line equalization is used

- If in-line equalization is used to dampen both the flow & mass loadings
- → important to use a geometry that allows the basin to function as a continuous-flow stirred-tank reactor
- Elongated designs should be avoided
  - Elongated = unusually long in relation to its width
- Inlet & outlet configurations should be arranged to minimize short circuiting.
- Discharging the influent near the mixing equipment usually minimizes short circuiting.

- If the geometry of the basins is controlled by the available land area & elongated geometry must be used
- → use multiple inlets & outlets
- Provisions should be included in the basin design for access by cleaning equipment i.e. front-end loaders.
- Multiple compartments → to reduce cleaning costs & for odor control.

2. BASIN CONSTRUCTION

- Basin construction:
  1. Earthen → least expensive
  2. Concrete
  3. Steel construction
- Depending on local conditions, the interior side slopes → 3:1 – 2: 1.
- Fig 3-22
- Liner → prevent groundwater contamination

- Basin depth

  → vary, depend on:
  1. Land availability
  2. groundwater level
  3. topography
- If a liner used in areas of high groundwater

  → effects of hydraulic uplift on the liner must be considered.
- Free board

→depends on:

1. surface area of the basin
2. local wind conditions

2. BASIN CONSTRUCTION

- If a floating aerator is used to provide mixing & prevent septicity & odor formation

  → minimum operating level is needed to protect the aerator

  → minimum water depth: 1.5 – 2 m (5 -6 ft).
- floating aerators → concrete pad should be provided below the aerators to minimize erosion
- Riprap, soil cement or a partial concrete layer → prevent wind-induced erosion in the upper portion of the basin.
- Fencing → prevent public access to the basins.

2. BASIN CONSTRUCTION

Drainage facilities

- Should be provided in areas of high groundwater → prevent embankment failure
- Top of the dikes should be of adequate width → further ensure a stable embankment
- The use of an adequate dike width

→ facilitate the use of mechanical equipment for maintenance

→ reduce construction costs, especially once mechanical compaction equipment is used.

2. MIXING & AIR REQUIREMENTS

Mixing requirements

- For both in-line & off-line equalization basins:

  → generally requires proper mixing and aeration
- Mixing equipment should be sized to:
  1. blend the contents of the tank
  2. prevent deposition of solids in the basin
- Grit removal
  → preceding the equalization basin
  (where possible)
  → minimize mixing requirements
- For a medium-strength municipal wastewater (Table 3-18)
  → SS = 210 mg/L:
  → mixing requirements: 0.004 -0.008 kW/m^3 (0.02 -0.04 $hp/10^3$ gal) of storage

2. MIXING & AIR REQUIREMENTS

Air requirements

- To prevent the wastewater from becoming septic & odorous.
- To maintain aerobic conditions, air should be supplied at a rate of 0.01-0.015 m^3/m^3.min (1.25-2.0 $ft^3/10^3$ gal.min).
- In equalization basins that follow primary sedimentation and have short detention times (< 2 h), aeration may not be required

Mechanical aerators

- Baffling → ensure proper mixing, especially for a circular tank.
- Low-level shutoff controls → protect the aerators in the event of excessive level drawdown
- Equipped with legs or draft tubes
- → once the tanks is dewatered periodically
- → allow them to come to rest on the bottom of the basin without damage
- Diffused air systems may be used for mixing & aeration i.e. static tube, jet, aspirating aerators

4. OPERATIONAL APPURTENANCES

1) Facilities for flushing any solids & grease that may tend to accumulate on the basin walls
2) An emergency overflow in the case of pump failure
3) A high-water take off for the removal of floating material & foam
4) Water sprays:
   a) to prevent the accumulation of foam on the sides of the basin
   b) to aid in scum removal

Solids removed from equalization basins should be returned on the head of the plant for processing

PUMP & PUMP CONTROL SYSTEMS

Pump

- Required due to flow equalization imposes an additional head requirement
- May:

1. precede

   → pumping into the equalization tank is generally preferred for reliability of treatment operation

2. follow equalization
3. or both:

   → will be required in some cases

Pump control systems

- For offline flow equalization designed for the control of wet-weather peak flows:
  1. *pump-in* configuration

     → may have very high & costly pumping requirements
  2. a gravity-in, *pump out* configuration

     → if the hydraulic grade line allows

     → the most cost-effective

pump out are usually << *pump-in*

- Flow system:

1. once gravity discharge from the basin is used

   → an automatic controlled flow-regulating device is required
2. once basin effluent pumps are used

   → instrumentation should be provided to control the preselected equalization rate

- A flow-measuring device should be provided on the outlet of the basin to monitor the equalized flow

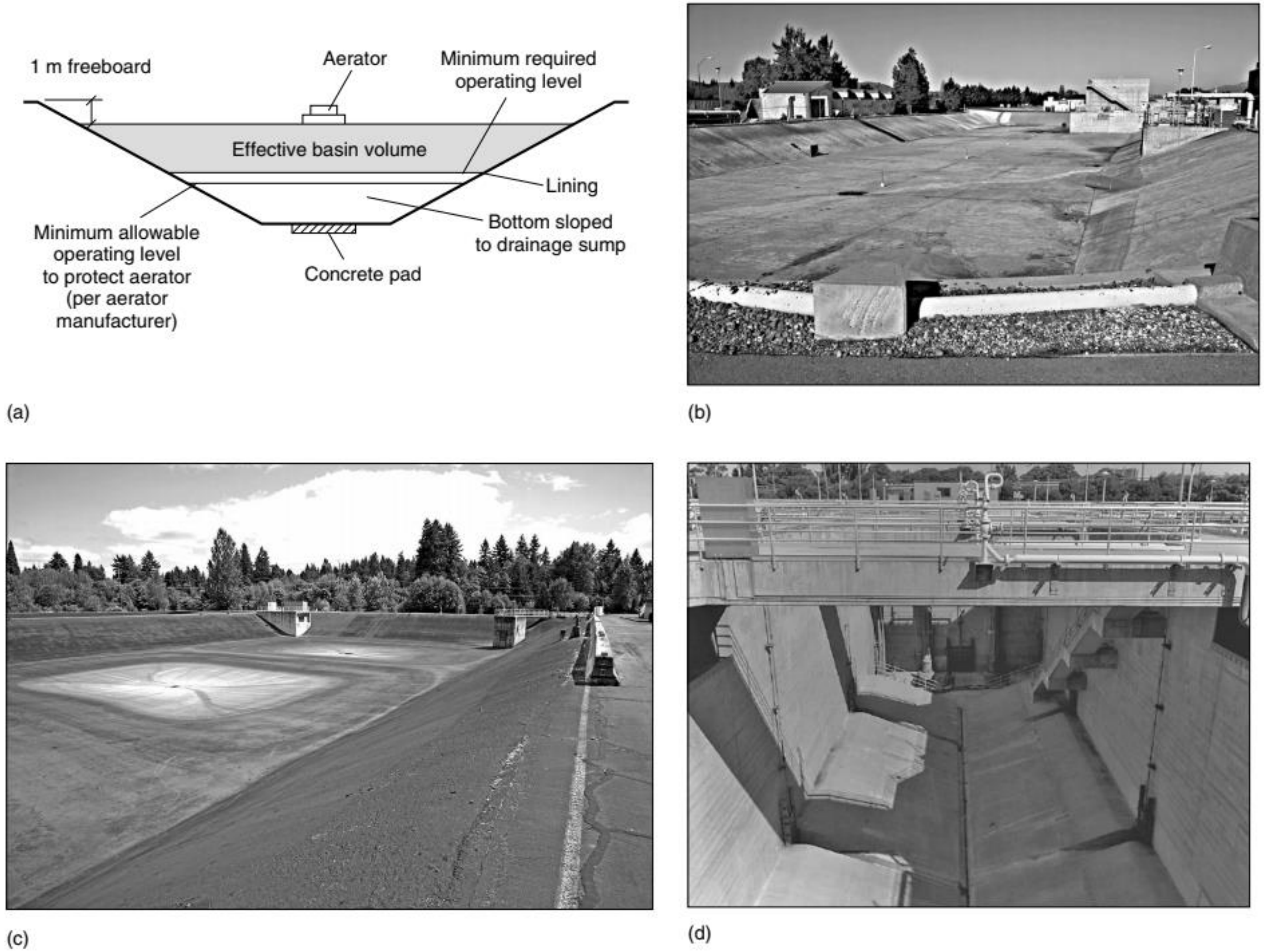


Figure 3–22

Typical flow equalization basins: (a) typical cross-section shallow flow equalization basins, (b) and (c) shallow lined earthen basins, and (d) deep concrete basin.

EQUALIZATION 0F CONSTITUENT MASS LOADING RATES

1. BOD
2. TSS

another approach to enhance biological treatment

Benefits:

1. improved biological treatment

→ shock constituent loadings:

   1) eliminated or
   2) minimized

2. improved utilization of aeration equipment
3. reduced peak power requirements
4. reduced capacity of aeration blowers & related equipment

PROCESS DESCRIPTION

accomplished most effectively with **offline storage facilities**

- A portion of the flow is diverted during the period when the constituent concentrations are high:
  1. in the mid to late morning
  2. early evening hours
- The diverted flow & constituents are fed back into the system during periods when the aeration facilities are not used fully:
  1. in the late evening
  2. early morning hours

- Information must be available on the typical variation in the:
  1. flowrate and
  2. constituent concentrations
- Flowrate metering is routine.
- New online continuous SS meters are now available
- The quantity of flow that must be diverted would be based on:
  1. a control strategy utilizing flowrate &TSS measurements
  2. an appropriate algorithm

RECENT DEVELOPMENT

primary effluent filtration utilization

- An old idea that has resurfaced

→ the availability of new filter technologies

- The primary effluent filtration would only be used during periods:

→ when influent concentrations is increasing:

1. in the mid to late morning hours or
2. in the early evening hours

- The mostly organic solids in the filter backwash water would be diverted to a relatively small storage facility
- The organic solids from the storage facility would then be returned to the treatment process during periods:

→ when the aeration equipment is underutilized

1. in the late evening
2. early morning hours

- The diverted organic solids could also be send to a fermenter

→ for the production of volatile fatty acids

→ needed for enhanced phosphorus removal

EQUALIZATION OF SLUDGE & BIOSOLIDS PROCESSING RETURN FLOWS

Return flows from solids processing operations:

1. sludge thickening
2. digester supernatant
3. centrate &/ filtrate from biosolids dewatering

to the headworks of the biological treatment process for reprocessing

↓

More restrictive w/w treatment standards:

1. This practice is difficult to achieve low discharge limits
   → especially for nitrogen & phosphorus
2. The impact of return flows is even greater
   → most of the return flows are reintroduced during the daytime hours
   → when the biosolids dewatering facilities are normally operated

EQUALIZATION 0F SLUDGE & BIOSOLIDS PROCESSING RETURN FLOWS

- The need to improve plant performance has lead to the implementation of:

1. flow equalization

   → used most commonly at smaller WWTP

2. &/ separate treatment facilities for return flows

   → more common at larger WWTP

- Small WWTP:
- designed to capture all of the return flows during the day:

→ the stored return flows can be added to the plant inflow

→ over a 12-h period:

1. starting in the evening hours or
2. when the incoming loadings to the plant are reduced

- If space is limited:

→ may only be possible to reduce the peak of the return flows

- Use of inactive treatment process tankage has proven to be effective
- The separate treatment of return flows is considered in Chap. 15

TLB-309
DESAIN PENGOLAHAN BIOLOGI

MINGGU KE-11:
SUSPENDED GROWTH BIOLOGICAL TREATMENT PROCESSES

RACHMAWATI S. DJ.

SEMESTER GANJIL 2022/2023

8. *SUSPENDED GROWTH BIOLOGICAL TREATMENT PROCESSES*

8-1 INTRODUCTION TO THE ACTIVATED SLUDGE PROCESS

- *Historical Development* of *Activated Sludge* Process
- *Basic Process Description*
- *Evolution of the Conventional Activated Sludge Process*
- *Nutrient Removal Processes*

8-2 WASTEWATER CHARACTERIZATION

- *Key Wastewater Constituents for Process Design*
- *Measurement Methods for Wastewater Characterization*
- *Recycle Flows ond Loadings*

- 8-3 FUNDAMENTALS OF PROCESS SELECTION, DESIGN, AND CONTROL
- *Overall Considerations in Treatment Process Implementalion*
- *Important Factors in Process Selection and Design*
- *Process Control*
- *Operational Problems in Activated Sludge Systems with Secondary Clarifiers*
- *Operational Problems with MBR Systems*

MATERI MINGGU KE-11

Mg Ke-	Kemampuan Akhir Tiap Tahapan Belajar (SubCPMK)	Penilaian		Bentuk Pembelajaran[7)]; Metode Pembelajaran[8)]; Penugasan Mahasiswa (estimasi waktu)		Materi Pembelajaran[9)] (Pustaka)	Bobot Penilaian[10] (%)
		Indikator[5)]	Teknik[6)]				
(1)	(2)	(3)	(4)	Luring (5)	Daring (6)	(7)	(8)
11-14	SubCPMK 4 Mahasiswa mampu merancang unit pengolahan biologi secara detail (reaktor tersuspensi/terlekat, pengendap lumpur, sistem batch/sistem kontinyu) yang terintegrasi berdasarkan konsep resource recovery dalam bentuk laporan tugas kelompok	- Ketepatan perancangan	Test Nontest/ Tugas 4	Kuliah Diskusi [PB: 4 x (3x50')]	e-Learning Itenas: 1. file materi SubCPMK 4 (PB, KM). Hasil Tugas Mandiri 4	Materi SubCPMK4: Proses pengolahan biologi anaerob secara tersuspensi dan terlekat; Proses pengolahan lumpur: anaerobic digestion, aerobic digestion Nutrient recovery: pemulihan/recovery fosfat dan amonium	38%

WORKING TERMINOLOGY

Activated sludge process

- Biological treatment process
- that involves the conversion of organic matter and/or other constituents in the wastewater
- to gases and cell tissue
- by a large mass of aerobic microorganisms maintained in suspension by mixing and aeration
- The microorganisms form flocculent particles that are separated from the process effluent in a sedimentation tank (clarifier)
- and are returned subsequently to the aeration process or wasted.

WORKING TERMINOLOGY

Aerobic (oxic) processes

- Biological treatment processes
- that occur in the presence of free dissolved oxygen
- oxygen is consumed by aerobic microorganisms in oxidation/reduction reactions
- to produce energy for cell growth and cell maintenance.

An-aerobic processes

- Biological treatment processes
- that occur in the absence of oxygen

Anoxic process

- Biological treatment process
- that occurs in the absence of free dissolved oxygen
- where nitrate & nitrite are used as the main electron acceptors
- in biological oxidation/reduction reactions
- denitrification is an example of an anoxic process

WORKING TERMINOLOGY

Biomass

- The total mass of solids in a reactor
- consisting mainly of organic matter & microorganisms

Biological nutrient removal (BNR)

- The removal of nitrogen and phosphorus in biologicol treatment processes

Denitrification

- The biological process
- by which nitrate/ nitrite is reduced to nitrogen & other gaseous end products

Nitrification

- The 2-step biological process
- by which nitrogen (mostly in the form of ammonia) is converted to nitrite and then to nitrate

WORKING TERMINOLOGY

Hindered settling

- Settling which occurs
- when the AS flocs interfere with each other as they settle

Facultative processes

- Biological treatment processes
- In which the organisms can function
- in the presence or absence of molecular oxygen

Membrane bioreactor (MBR)

- A process
- that combines a suspended growth process with a membrane separation system within the process aeration tank
- Membrane separation is accomplished by either microfiltration/UF

Membrane flux

- The rate of flow across a membrane per unit of surface area ($L/m^2.h$)

WORKING TERMINOLOGY

Mixed liquor suspended solids (MLSS)

- The biomass
- Contained in a treatment reactor
- used to bring about the treatment of the organic material in ww

Sequencing batch reactor (SBR)

- A batch fill & draw ASTP
- Involves a treatment of fill, react, settling, supernatant decanting and idle
- AS aeration & liquid solids separation occurs in the same tank

Sludge production

- The amount of solids
- produced during the biological processing of ww
- including influent nonbiodegradable solids & the biomass
- resulting from the conversion of organic

Solids retention time (SRT) = sludge age

- The average period of time
- In which solids remain in a suspended growth process

WORKING TERMINOLOGY

Sludge yield

- The amount of solids
- produced relative to the amount of BOD or COD removed
- during the biological processing of ww

Staged process

- Processes
- which occur with > 1 independent reactor
- or compartment in series

Surface overflow rate

- The hydraulic flowrate applied relative to the clarifier surface area ($m^3/m^2.d$)

Volumetric organic loading rate

- The amount of BOD or COD applied to the aeration tank volume per day (e.g. kg BOD or COD/m^3.d)

WORKING TERMINOLOGY

Suspended growth processes

- Biological treatment processes
- In which microorganisms responsible for the conversion of organic matter or other constituents in the ww
- to gases & cell tissue
- are maintained in suspension within the liquid

Readily biodegradable COD (rbCOD)

- Dissolved biodegradable organic substrates which are removed by bacteria much faster than colloidal or particulate degradable COD
- The rbCOD impacts spatial oxygen demand, EBPR, removal efficiency and denitrification rates

Enhanced biological phosphorus removal (EBPR)

- Removal of phosphorus
- by extraordinary storage in bacteria
- selected in anaerobic/aerobic process configuration
- and subsequent solids separation

- Theory of biological ww treatment: Chap. 7.
- Biological treatment processes classification:
  1. Aerobic suspended growth
  2. Anaerobic suspended growth
  3. Attached growth
  4. Combinations

- Chapter 8 focuses on: suspended growth treatment processes, example:

1. activated sludge process → BOD & nitrification
2. nitrogen & phosphorus removal

- Aerated lagoon, non-aerated lagoons, stabilization

→ used mainly for small rural communities

→ sufficient land is available

→ discharge requirements may not be as stringent as in urban areas

8-1 INTRODUCTION TO THE ACTIVATED SLUDGE PROCESS

To provide a basis for the process designs:

- A brief summary of the historical development of the ASP
- A description of the basic process
- A brief review of the evolution of the ASP
- An overview of recent process developments

1) HISTORICAL DEVELOPMENT OF ASP

- ASP used now routinely for the biological treatment of mMunicipal & industrial ww

1) 1880s in England →Dr. Angus Smith:
- Investigated the aeration of ww in tanks
- Hastened the oxidation of the organic matter

2) 1910→ Black & Phelps:
- A considerable reduction in putrescibility
- By forcing air into ww in basins

3) 1912 & 1913→ Clark & Gage
- Growths of organisms could be cultivated in bottles & tanks
- Partially filled with roofing slate spaced 25 mm apart
- The growth greatly increased the purification

4) Manchester Sewage Works → Ardern & Lockett:
- The sludge played an important part in the results obtained by aeration

↓

ASP

- Involved the production of activated mass of mo capable of aerobic stabilization of organic material in ww (Metcalf & Eddy, 1935)

2) BASIC PROCESS DESCRIPTION

ASP important features:

- the formation of flocculent settleable solids that can be removed by gravity settling in sedimentation tanks

The basic ASP consists of 3 basic components:

1. A reactor:
   the mo responsible for treatment are kept in suspension & aerated
2. Liquid-solids separation unit
   → a sedimentation tank
3. A recycle system:
   Returning solids removed from the liquid-solids separation unit back to the reactor

- Numerous process configurations have evolved employing these components
- Most cases:
- ASP is employed in conjunction with:
- Physical & chemical processes used for:
- the preliminary & primary treatment of ww
- Post treatment: disinfection & filtration

2) BASIC PROCESS DESCRIPTION

Preceded by primary sedimentation

- Most AS plants have been used to treat ww that have been pretreated by primary sedimentation (Figs. 8-1 (a) & (b)
- Primary sedimentation→ most efficient at removing settleable solids
- Biological process → essential for removing:
  a) Soluble
  b) Colloidal
  c) Particulate (suspended) organic substances
- For:
  a) Nitrification & denitrification
  b) Biological phosphorus removal

Not using primary sedimentation

- For treating ww from smaller-sized communities:

  → primary treatment is often not used

  → more emphasis placed on simpler & less operator-intensive treatment methos
- In hot climates:

  → primary treatment is omitted

  → odor problems from primary tanks & sludge is significant

- Modifications of conventional ASP
  a) Sequencing batch reactors
  b) Oxidation ditch systems
  c) Membrane biorecators

3) EVOLUTION OF THE CONVENTIONAL ASP

Before 1980s:

- Principal objective of ASP aimed mainly at achieving a "2nd treatment" standrad of 85% BOD & TSS removal

After:

- More stringent discharge limits
- The removal of nutrients (nitrogen & phosphorus)

ASP & design considerations have evolved responding to:

1. The need for higher-quality effluents from WWTPs
2. The need to remove nutrients
3. Increased discoveries & understanding of microbial processes & fundamentals
4. Technological advances in equipment. materials, electronics & process control
5. The continual need to reduce capital & operating & energy costs for municipalities & industries

Many ASP used today & in the future may incorporate:

- Nitrification
- Biological nitrogen removal
- Biological phosphorus removal

Reactors used typically in series, operated under:

- Aerobic
- Anoxic
- Anaerobis conditions

General types of ASPs used (Fig. 8-1):

- Plug flow
- Complete mix
- Sequencing batch reactor

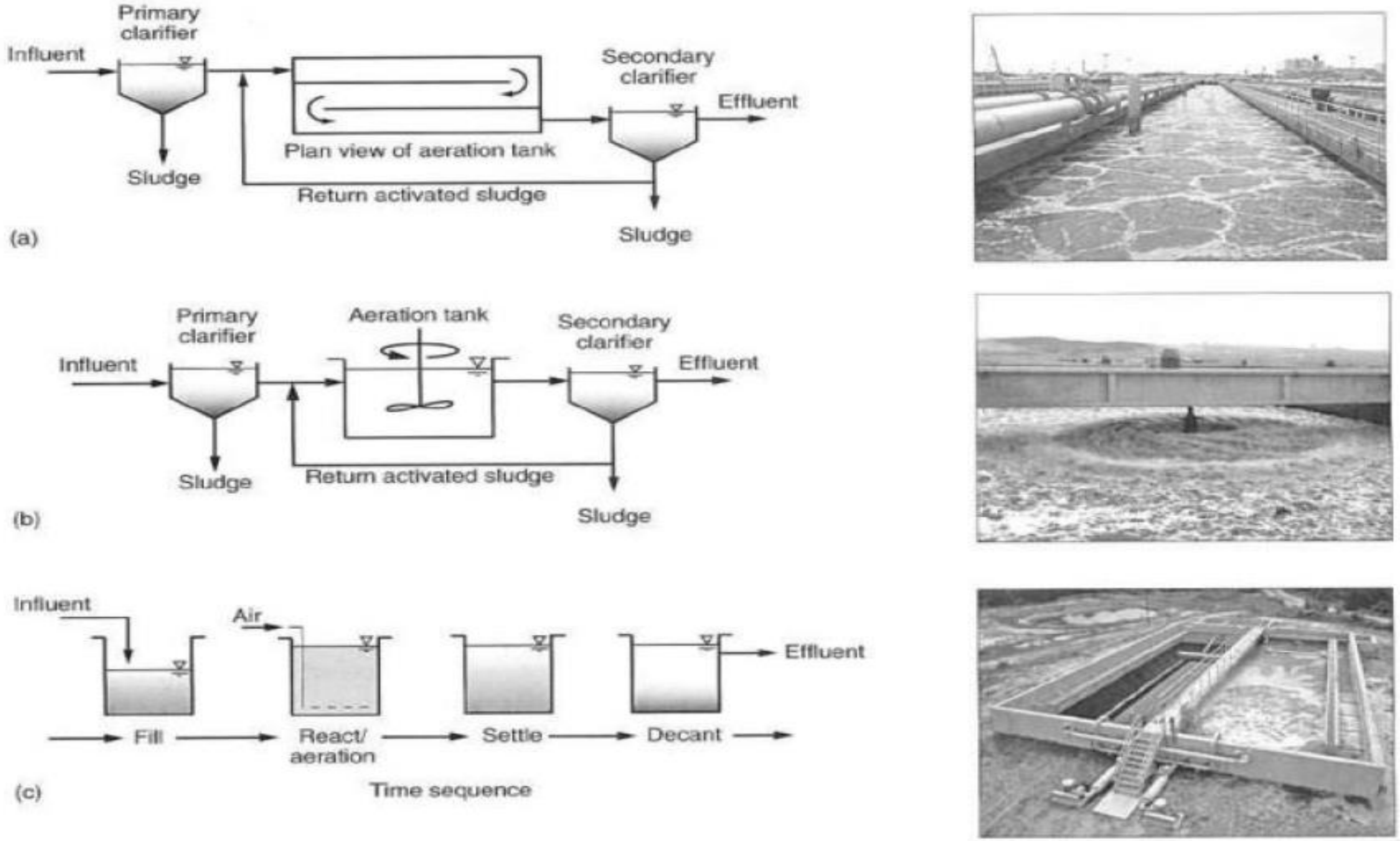


Figure 8–1

Typical activated sludge processes with different types of reactors: (a) schematic flow diagram of plug-flow process and view of plug-flow reactor, (b) schematic flow diagram of complete-mix process and view of complete-mix activated sludge reactor, and (c) schematic diagram of sequencing batch reactor process and view of sequencing batch reactor.

PLUG FLOW PROCESS CONFIGURATIONS

Large length to width ratios (typically > 10:1)

- ASP was common used early 1920s – late 1970s
- Fig 8-1 9a)
- Discharge of industrial wastes to domestic ww collection systems increased in late 1960s
- The use of plug flow process:

→ Problematic once industrial wastes were introduced

→ Toxic effects of the discharges

COMPLETE MIX PROCESS CONFIGURATIONS

Due to the larger volume allowed for greater dilution
→ mitigation toxic discharges effects

- Common type of ASP in 1970s –early 1980s → single-stage, complete-mix AS (CMAS) processes (Fig. 8-1 (b) (Mc kinney, 1962)
- Some nitrification applications:
- Two-stage systems
- Each stage consisting of an aeration tank & clarifier
- 1st stage → BOD removal
- 2nd stage → nitrification

COMPARING PLUG FLOW & COMPLETE MIX PROCESS CONFIGURATIONS

Mixing regimes & tank geometry are quite different

CMAS

- Mixing of the tank contents is sufficient
- The concentrations of mixed-liquor constituents:
    - Soluble substances (COD, BOD, NH4-N)
    - Colloidal
    - Suspended solids
- Do not vary with location in the aeration basin

PLUG FLOW

- Involves long, narrow aeration basins
- Concentration of soluble substances, colloidal & suspended solids varies along the reactor length
- Does not exist in reality
- Depending on the type of aeration system:
    - Back mixing of the mixed liquor can occur
- Depending on the layout of the reactor & system reaction kinetics:
    - Nominal plug flow may be described more appropriately by the series of complete-mix reactors (Chapter 4)

SEQUENCING BATCH PROCESS CONFIGURATION

A fill-draw type of reactor system
involving a single complete-mix reactor
where all steps of ASP occur

Mixed liquor remains in the reactor during all cycles

↓

Eliminating the need for separate sedimentation tanks

- Used more widely by late 1970s
- Especially for smaller communities & industrial installations with intermittent flows

↑

- Development of simple inexpensive program logic controllers (PLCs)
- Availability of level sensors & automatically operated valves

Recent years → larger cities

OTHER ASP

- Oxidation ditch (1950s)
- Contact stabilization (1950s)
- Krause process (1960s)
- Pure oxygen activated sludge (1970s)
- Orbal process (1970s)
- Deep shaft aeration (1970s)
- SBR process (1980s)

DEVELOPMENT OF SELECTORS

Biological selector (Davidson, 1957)
Select for good settling "floc-forming" activated sludge over filamentous bacteria

- ASP designs before & until late 1970s
- → plug flow & complete mix (Fig 8-1 (a) & (b)
- → solids settling problems in 2nd clarifiers
- → proliferation of filamentous-type bacteria

Smaller single or multi-staged aerated reactors
in front of the main AS treatment aeration basin

Sngle or multi-staged anoxic or anaerobic reactors
before the main aerator tank
To select for conditions
For denitrification of nitrite or
Phosphorus storing bacteria

MEMBRANE BIORECATOR (MBR) PROCESS CONFIGURATION

An AS system with membrane located at the end of AS basin (s) for liquid-solids separation in lieu of using secondary clarifiers (Fig 8-2)

- In the integrated MBR system (Fig 8-2):
  - The key component: microfiltration/UF membrane
  - Immersed directly into the AS reactor
  - The membranes are mounted in modules (cassettes) that can be lowered into the bioreactor
- The modules comprised of:
  - Membranes
  - Support structure for membranes
  - Feed inlet & outlet connections
  - An overall support structure

- Membranes subjected to a vacuum (< 50 kPa):
  - draws water (permeate) through the membrane
  - retaining solids in the reactor
- Compressed air is introduced through a distribution manifold at the base of membrane module:

1) To minimize the accumulation of solids & fouling the membranes exterior
   - As the air bubble rise to the surface
   - Scouring of the membrane occurs
2) Air also provides oxygen to maintain aerobic conditions & solids suspension within the reactor

IMPLEMENTATION OF MBR PROCESS

The use of UF & MF membranes in MBR systems for AS treatment well accepted in late 1990s & early 2000s

Membranes units located outside the AS tanks

- 1969:
  - US Patent issued to Dorr-Oliver
  - For a process integrating CMASP with membrane technology
- Membrane separation for AS treatment first demonstrated in 1974 by Dorr-Oliver:
  - Not economically feasible for widespread used
  - Initial design: Cross-flow membranes separation units located outside the AS tanks
  - High energy requirements for pumping mixed liquor across the membrane to control fouling

Membranes units located inside the AS tanks

- Using coarse bubbles aeration (late 1980s):
- Less energy intensive
- Led to future MBR applications
- Lower energy MBR system first commersialized with flat membranes by Kubota for WWT in Japan (1990)
- 1993: MBR system using Zenon's hollow fiber ZeeWeed system installed in Canada
- 1998: First MBR installation for biological WWT in US

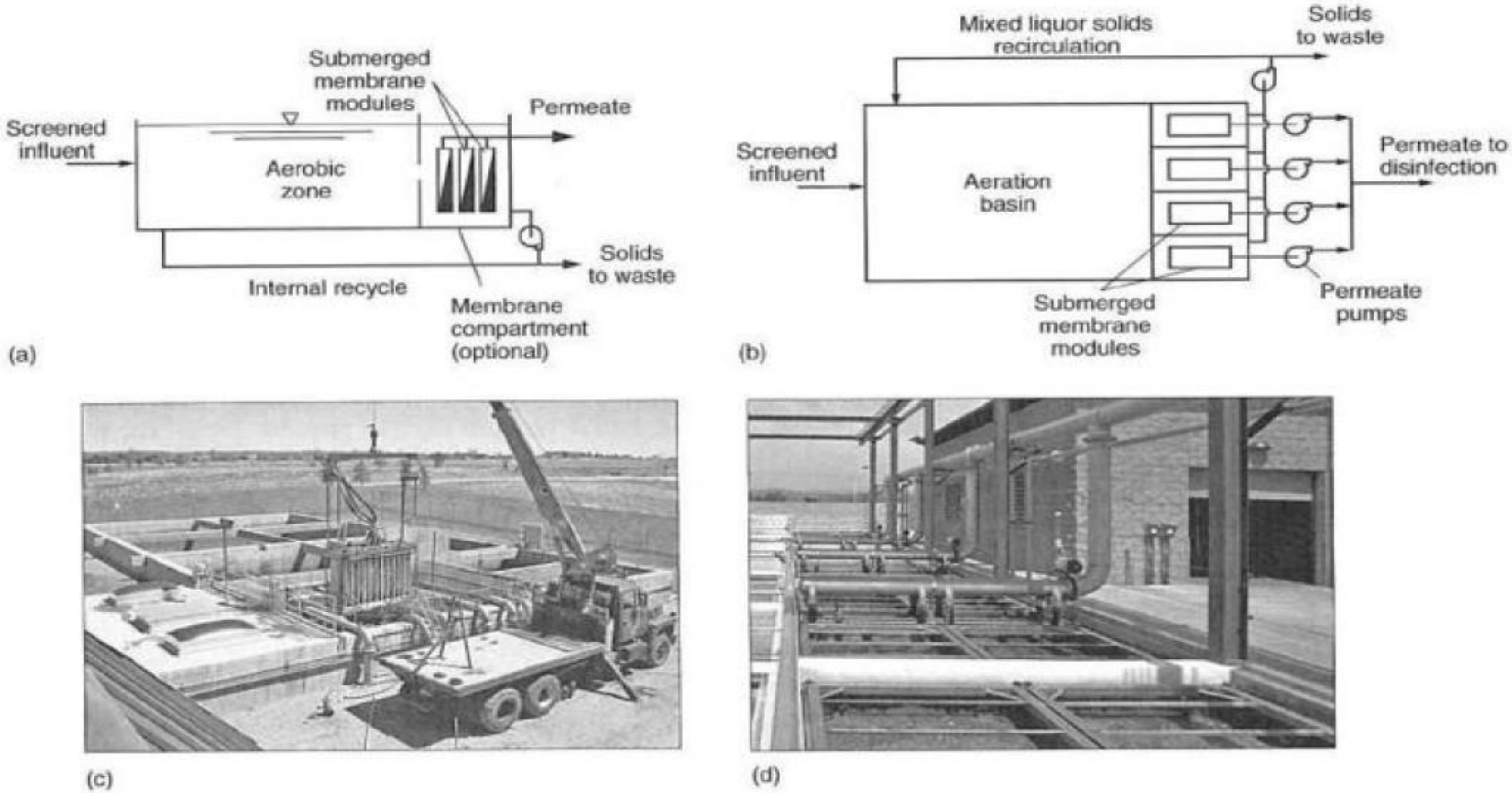


Figure 8–2

Membrane bioreactor (MBR). A multi-staged activated sludge system with membranes for liquid-solids separation: (a) section through MBR with separate compartment for the membranes, (b) plan view of MBR, (c) view of membrane cassettes being placed in separate compartment, and (d) view of separate membrane compartment.

MBR PROCESS ADVANTAGES & DISADVANTAGES

Membrane liquid-solids separation vs ASP with gravity clarifiers

Advantages

1) ≤ area requirement (<50%) due to:
   a) Operation with higher mixed liquor concentration (typically 1000-12000)
   b) Reduced space for membrane separation
2) Simpler process operation with no concers about the effect of filamentous AS
3) A reclaimed water quality effluent due to complete SS capture across the membrane separation
4) A lower disinfection dose requirement due to low turbidity effluent

Disadvantages

1) Increased energy cost
2) The need for future membrane replacement
3) The cleaning & operational demands for membrane fouling control

MBR PROCESS APPLICATIONS

1) For domestic WWT
2) Water reuse

→ Ranging in flows:

   a) From small housing developments & apartments
   b) To large centralized WWT facilities:
      - Largest facility in US: Q average design = 117,000 m3/d

3) Industrial WWT (food & beverage processing, chemical plants, automotive plants, dairy WW, oil refinery WW, landfill leachate & pharmaceuticals, anaerobic treatment processes)

MBR PROCESS ADVANTAGES & DISADVANTAGES

Membrane liquid-solids separation vs ASP with gravity clarifiers

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Disadvantages

1) Increased energy cost
2) The need for future membrane replacement
3) The cleaning & operational demands for membrane fouling control

NUTRIENT REMOVAL PROCESSES

- Over the past 10 years, achieving higher nutrient (N & P) removals has gained importance in the implementation of AS

⇩

- Biological nutrient-removal configurations

⇩

- AS with 2nd clarifiers or
- Membranes for solid-liquid separation

⇩

- Based on the same fundamental principles of biological treatment

New nutrient removal designs:

- The use of internal recycle from the aeration or anoxic tanks to upstream reactors (Fig 8-3)

⇩

In the past

- From the 2nd clarifier underflow to the head of the AS aeration tank (Fig 8-1 (a) & (b)

- Process efficiency benefits using reactors in series & staged reactors

⇩

- Recognized & implemented in full-scale design

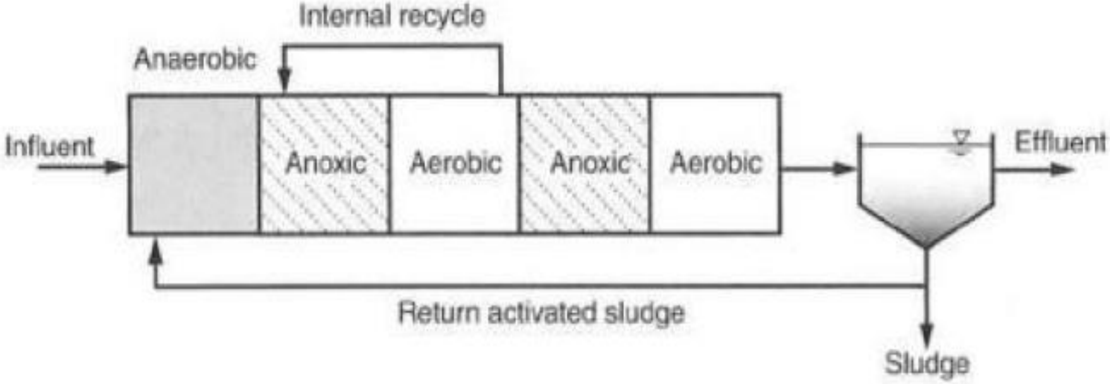
Design & operation of AS nutrient removal processes become more complex

⇩

Computer modelling

⇩

Important tool to evaluate AS performance in nutrient removal application



(a)

(b)

Figure 8–3

Modified Bardenpho process with stage reactors for biological nitrogen removal and enhanced biological phosphorus removal: (a) schematic diagram of staged process and (b) view of a Modified Bardenpho treatment plant in Palmetto, FL; the first of its type in the United States built in 1979. (From H. D. Stensel.) (Coordinates 27.5256 N 82.5959 W, view at altitude 360 m, since then, an oxidation ditch has been built alongside.)

8-2 WASTEWATER CHARACTERIZATION

The most critical step in the ASP design process

ASP design requires determining:

1) Influent characteristics of the ww
2) Aeration tank volume
3) Sludge production rate
4) Oxygen supply rate needed
5) Effluent concentration of important parameters

WW characterization:

1. Essential for predicting performance for biological nutrient-removal processes
2. An important element in the evaluation of existing facilities for:
   a) Optimizing performance
   b) Available treatment capacity

Flowrate characterization → important:

a) Diurnal
b) Seaseonal
c) Wet-weather flowrate variations (Chapter 3)

W/o comprehensive WW characterization: Facilities may be:

a) Under
b) Overdesigned

→

a) Inadequate or
b) Inefefcient treatment

KEY WASTEWATER CONSTITUENTS FOR PROCESS DESIGN

WW characteristics of importance in ASP design can be group into:

1. Carbonaceous constituents
2. Nitrogenous compounds
3. Phosphorus compounds
4. TSS & VSS
5. Alkalinity

Desktop designs

- Typical ww constituents quantified for
- use in desktop design of WWT processes; Table 8-1
- Desktop designs based on assuming steady-state operating conditions
- Useful to determine reasonable values for the key AS design parameters listed above

Simulation models with differential equations

1. For BNR processes with multiple reactors in series (including anaerobic, anoxic & aerobic zones) and internal recycle streams
2. For process analyses under variable flowrate & load conditions

- The number of ww constituents evaluated must be increased
- Table 8-2: considered constituents
- IWA ASP simulation models

KEY WASTEWATER CONSTITUENTS FOR PROCESS DESIGN

- Symbol used:
  - S= soluble
  - C = colloidal
  - X = particulate
  - T = total individual constituents (S + C + X)
- Subscripts:
  - S = biodegradable
  - I = nonbiodegradable/inert
- Other subscripts: to indicate the specific constituents under S & X
- For the simulation odels, the carbonaceous material is quantified in terns of COD
- Unit for concentration = mg/L (in text); and g/m3 (=mg/L) (in examples, for ease of use in process computations → eliminating 1 unit conversion step

Table 8–1

Example of typical domestic wastewater characterization parameters and typical values

Component	Concentration, mg/L[a]
COD	508
sCOD	177
BOD	200
TSS	195
VSS	150
TKN	35
NH_4-N	20
NO_3-N	0
Total phosphorus	5.6
Alkalinity	200 (as $CaCO_3$)

[a] Typical medium strength wastewater, from Table 3–18.

Table 8-2

Definition of terms used to characterize important wastewater constituents used for the analysis and design of biological wastewater treatment processes

Constituent[a,b]	Symbol[c]	Definition
BOD		
BOD		Total 5-d biochemical oxygen demand
sBOD		Soluble 5-d biochemical oxygen demand
UBOD		Ultimate biochemical oxygen demand
COD		
TCOD	COD_t	Total chemical oxygen demand
bCOD		Biodegradable chemical oxygen demand
pCOD		Particulate chemical oxygen demand
sCOD		Soluble chemical oxygen demand
nbCOD		Nonbiodegradable chemical oxygen demand
rbCOD	S_S	Readily biodegradable chemical oxygen demand
bsCOD		Biodegradable soluble chemical oxygen demand
$b_{COL}COD$	X_{COL}	Biodegradable colloidal chemical oxygen demand
sbCOD	X_S	Slowly biodegradable chemical oxygen demand
bpCOD	X_{SP}	Biodegradable particulate chemical oxygen demand
nbpCOD	X_I	Nonbiodegradable particulate chemical oxygen demand
nbsCOD	S_I	Nonbiodegradable soluble chemical oxygen demand
Nitrogen		
TKN		Total Kjeldahl nitrogen
bTKN		Biodegradable total Kjeldahl nitrogen
sTKN		Soluble (filtered) total Kjeldahl nitrogen
ON		Organic nitrogen
NH_4-N	S_{NH4}	Ammonia nitrogen
bON		Biodegradable organic nitrogen
nbON		Nonbiodegradable organic nitrogen
pON		Particulate organic nitrogen
bpON	X_{NS}	Biodegradable particulate organic nitrogen
nbpON	X_{NI}	Nonbiodegradable particulate organic nitrogen
sON		Soluble organic nitrogen
bsON	S_{NS}	Biodegradable soluble organic nitrogen
nbsON		Nonbiodegradable soluble organic nitrogen
TP		Total phosphorus
PO^4	S_{PO4}	Orthophosphate
bpP	X_P	Biodegradable particulate phosphorus
nbpP	X_{PI}	Nonbiodegradable particulate phosphorus
bsP	S_P	Biodegradable soluble phosphorus
nbsP	S_{PI}	Nonbiodegradable soluble phosphorus
Suspended solids		
TSS		Total suspended solids
VSS		Volatile suspended solids
nbVSS		Nonbiodegradable volatile suspended solids
iTSS		Inert total suspended solids

[a] Note: b = biodegradable; i = inert; n = non; p = particulate; s = soluble.
[b] Measured constituent values, based on the terminology given in this table, will vary depending on the technique used to fractionate a particular constituent.
[c] Commonly used symbol for constituents in IWA activated sludge models.

CARBONACEOUS CONSTITUENTS

Measured by BOD or COD analysis → critical to the ASP design

BOD:
common parameter to characterize carbonaceous constituents in ww

COD:
Biodegradable carbonaceous parameter in most comprehensive computer simulation design models

Higher concentrations of degradable COD/BOD result in:

1. Larger aeration tank volume
2. Greater required oxygen transfer rates
3. Greater rates of sludge production

- In the models:
- COD mass balance is used to account for the fate of carbonaceous COD material between the amount:

1) Oxidized
2) In the effluent
3) In waste solids as biomass or nondegraded influent VSS

- Fig 8-4 & Table 8-2: various forms of COD in ww
- Fig 8-5: measurement methods & relative amounts of different forms of COD

Figure 8–4

Fractionation of COD and wastewater. Information on the COD fractions is used in computer simulation models for activated sludge processes.

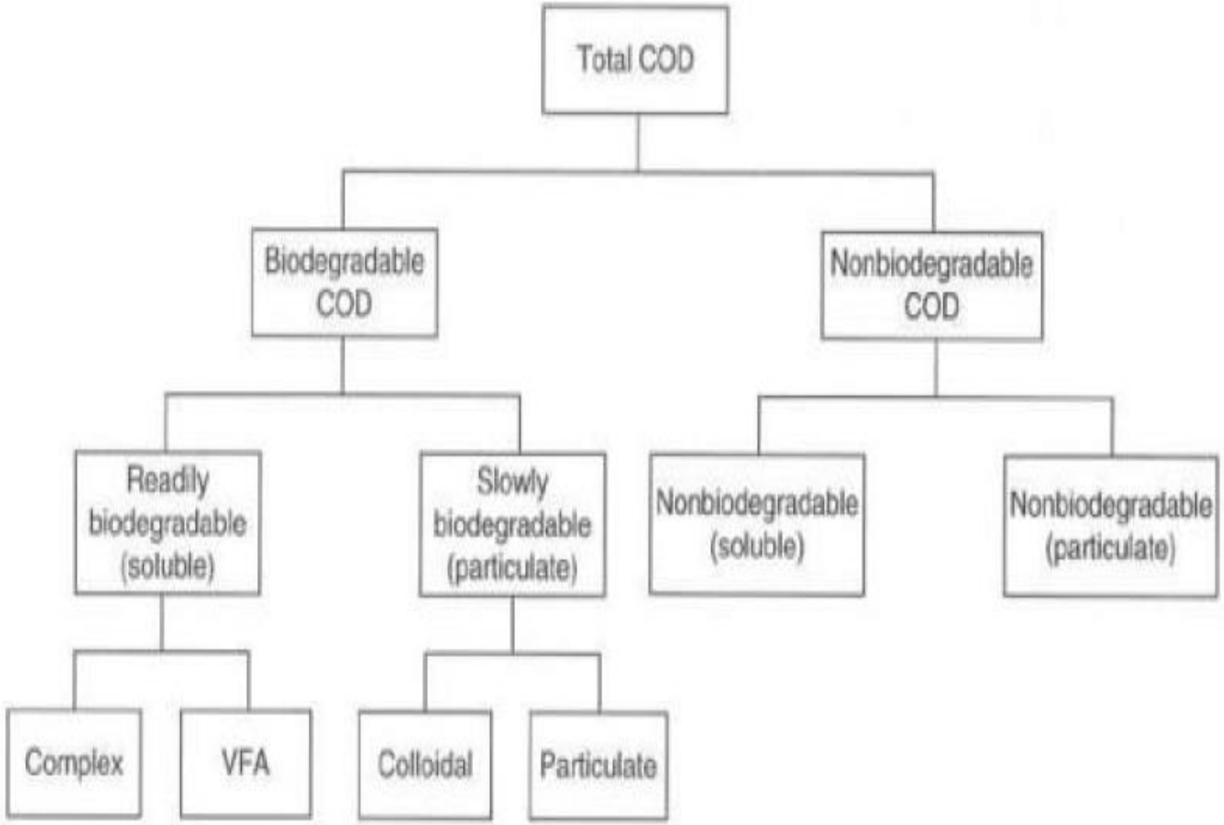
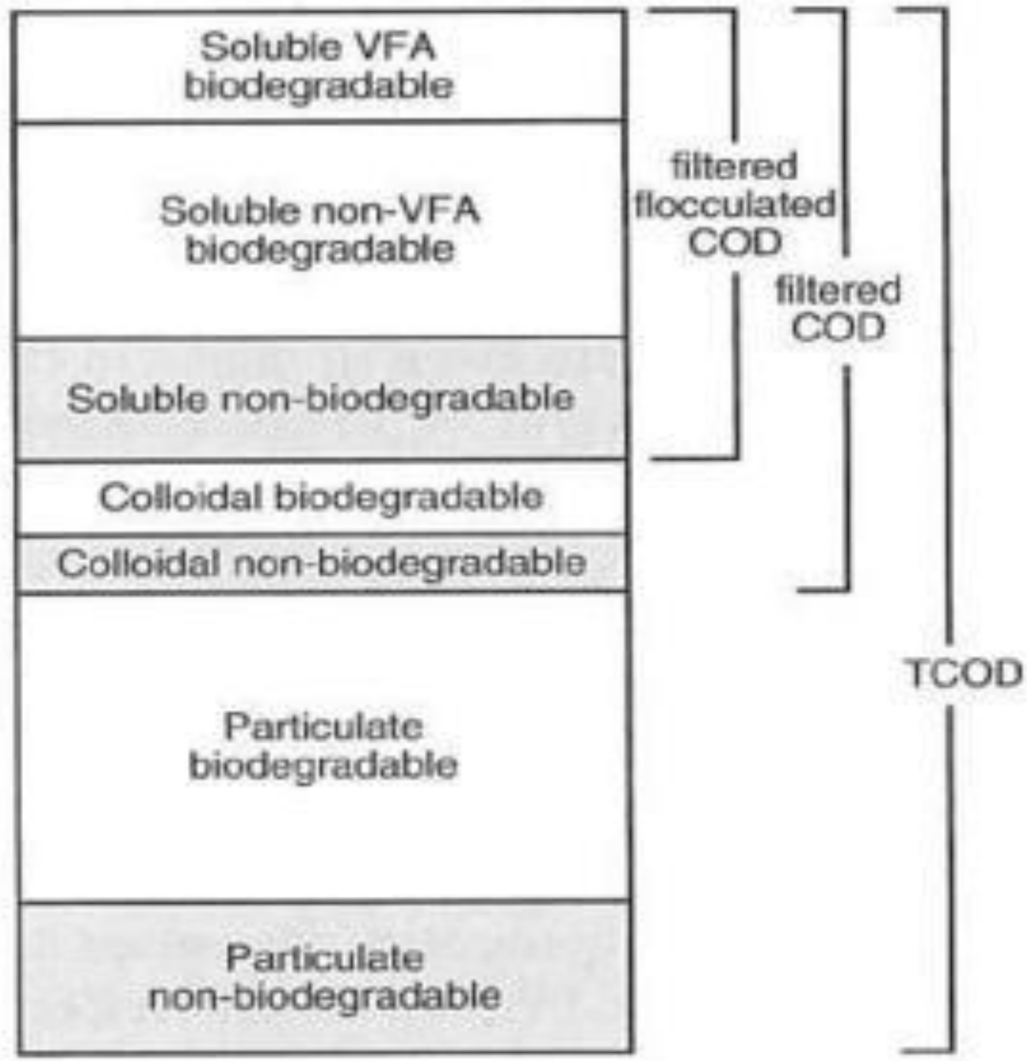


Figure 8–5

Schematic of COD components and separation methods used to obtain components.



COD FRACTIONS

Some portion of the COD is not biodegradable

Biodegradable COD

1. Dissolved (soluble)
2. Particulate:
   1) Colloidal
   2) SS

Nonbiodegradable COD

1. Dissolved (soluble) → ASP effluent
2. Particulate:
   1) Colloidal
   2) SS

} Total sludge production

Total COD = the sum of the ww characterization constituents

TCOD = rbCOD + sbCOD + nbsCOD + nbpCOD

$COD_T = S_S + X_S + S_I + X_I$

$X_S = X_{COL} + X_{SP}$

rbCOD → Assimilated quickly by biomass

sbCOD → Must first dissolved by extracellular enzymes → Assimilated at much slower rates

rbCOD →
- AS biological kinetics
- process performance
- Table 8-3

rbCOD, sbCOD → ASP design

Table 8–3

Biological processes affected by readily biodegradable COD (rbCOD) concentration in influent wastewater

Process	Effect of rbCOD
Activated sludge aeration	For plug flow or staged aeration zones, there will be a higher oxygen demand toward the front of the tank with higher fraction of rbCOD in the influent COD.
Biological nitrogen removal	For preanoxic tank, there will be a higher denitrification rate with a higher fraction of rbCOD in the influent COD. Can result in smaller anoxic tank volume.
Enhanced biological phosphorus removal	Greater influent rbCOD concentration results in a greater amount of enhanced biological phosphorus removal.
Activated sludge selector	Higher fraction of rbCOD in influent COD provides more COD for floc-forming bacteria in selector. Can have a greater impact on improving sludge volume index (SVI).

EFFECTS OF rbCOD ON THE PROCESS DESIGN & PERFORMANCE

Conventional plug-flow or staged aerobic AS reactor:

- Greater oxygen transfer rate is required in the front of the aeration tank → greater influent rbCOD

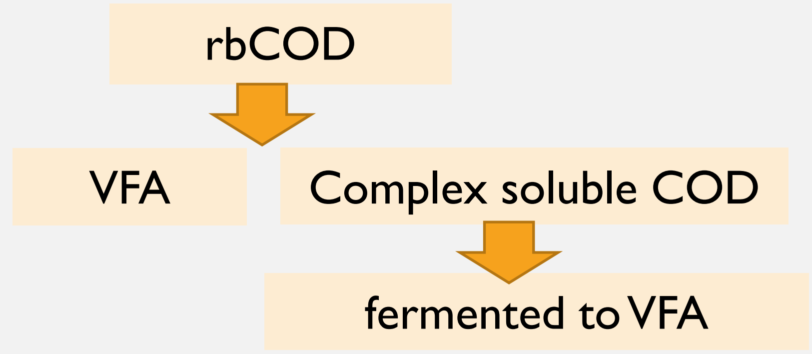
Denitrification rate in preanoxic zones in biological nitrogen-removal processes:

- rbCOD is consumed before the aeration zone
- rbCOD >>> → faster nitrate reduction rate

EBPR:

- rbCOD converted rapidly ti acetate via fermentation in the anaerobic zone for uptake by the phosphorus-storing bacteria
- rbCOD concentration in influent ww must be known to predict more accurately the performance of EBPR

- Fig 8-4: further step in the characterization of the influent COD



bCOD/BOD RATIO

BOD TEST DATA → to obtain total bCOD

Grady et al (1999): bCOD/BOD RATIO > UBOD/BOD

↓

Not all bCOD is oxidized in the BOD test

↓

Some bCOD converted into biomass

↓

Can still remain as cell debris & active cells
at the end of the long incubation time for UBOD determination

bCOD/BOD RATIO

- For domestic ww with UBOD/BOD = 1.5
  - → bCOD/BOD = 1.6 to 1.7
  - → depend on the biomass yield and cell debris fraction
- Based on:
  - The bCOD consumed in the BOD test equals the oxygen consumed (UBOD) + the oxygen equivalent of the remaining cell debris after long-term incubation
  - $bCOD = UBOD + 1.42(f_d)(Y_H)bCOD$

$$\frac{bCOD}{BOD} = \frac{UBOD/BOD}{1.0 - 1.42 f_d (Y_H)}$$

  - f_d = fraction of cell mass remaining as cell debris, g/g
  - synthesis yield coefficient for heterotrophic bacteria, g VSS/g COD
- Ex: using value of typical domestic ww:
- UBOD/BOD = 1.5, f_d = 0.15. Y_H = 0.40 → bCOD/BOD = 1.64

nbVSS

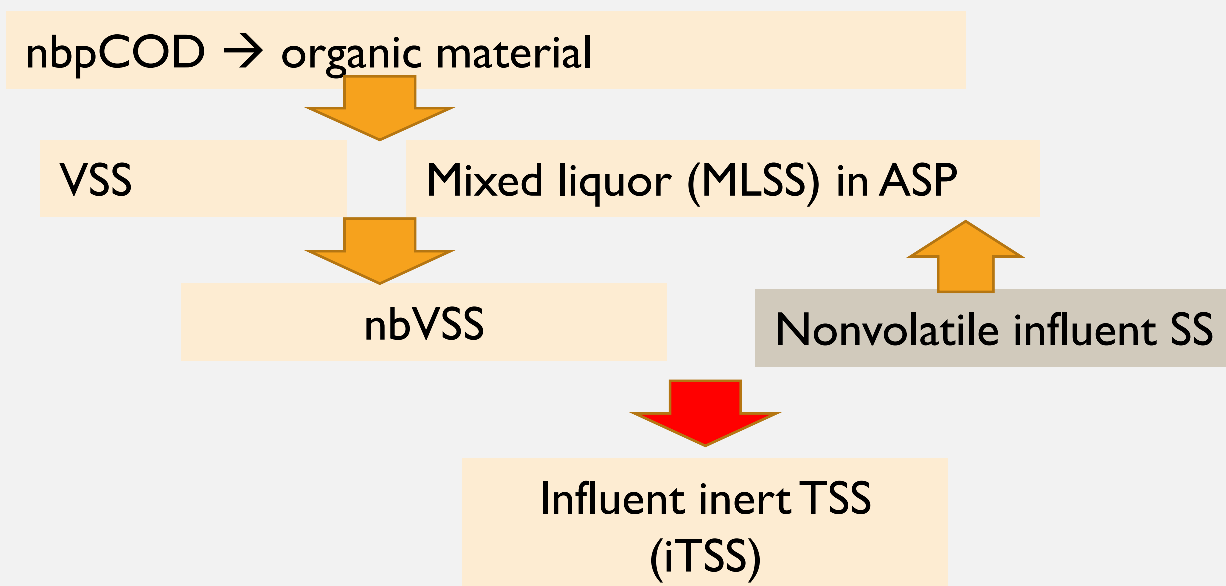
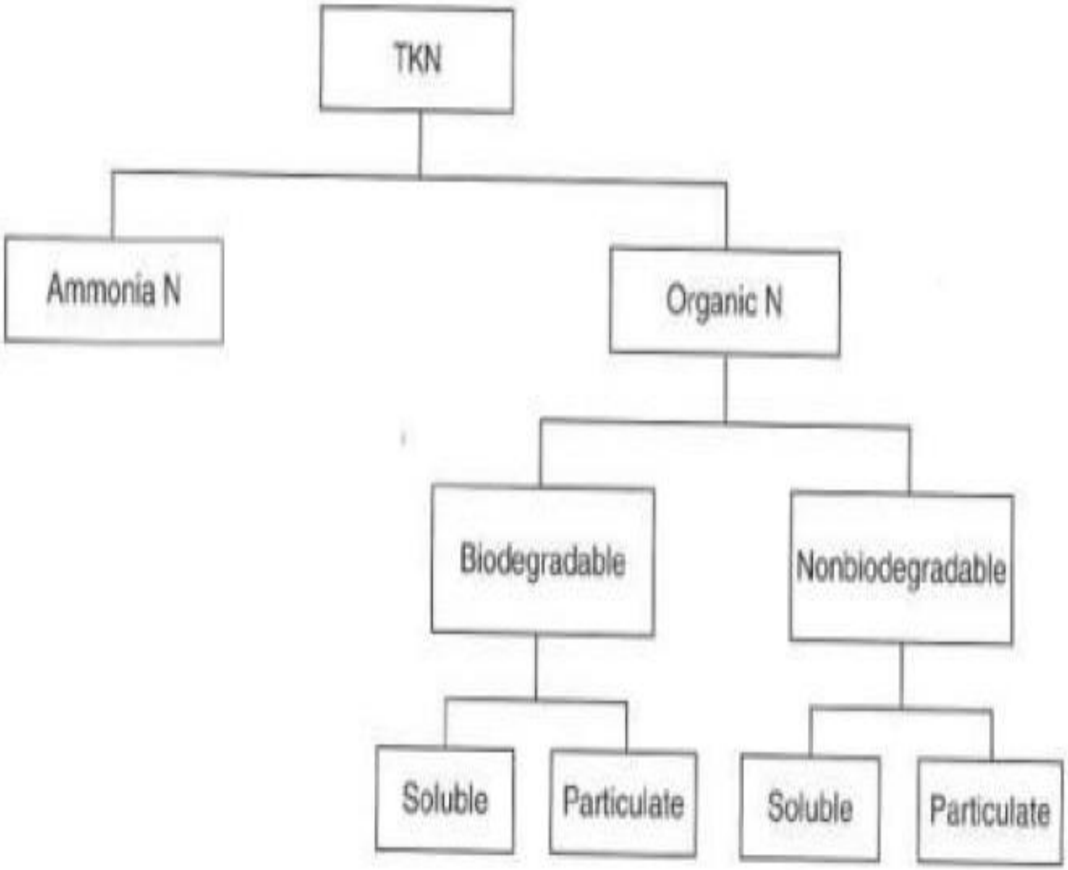

nbpCOD → organic material
VSS
Mixed liquor (MLSS) in ASP
nbVSS
Nonvolatile influent SS
Influent inert TSS
(iTSS)

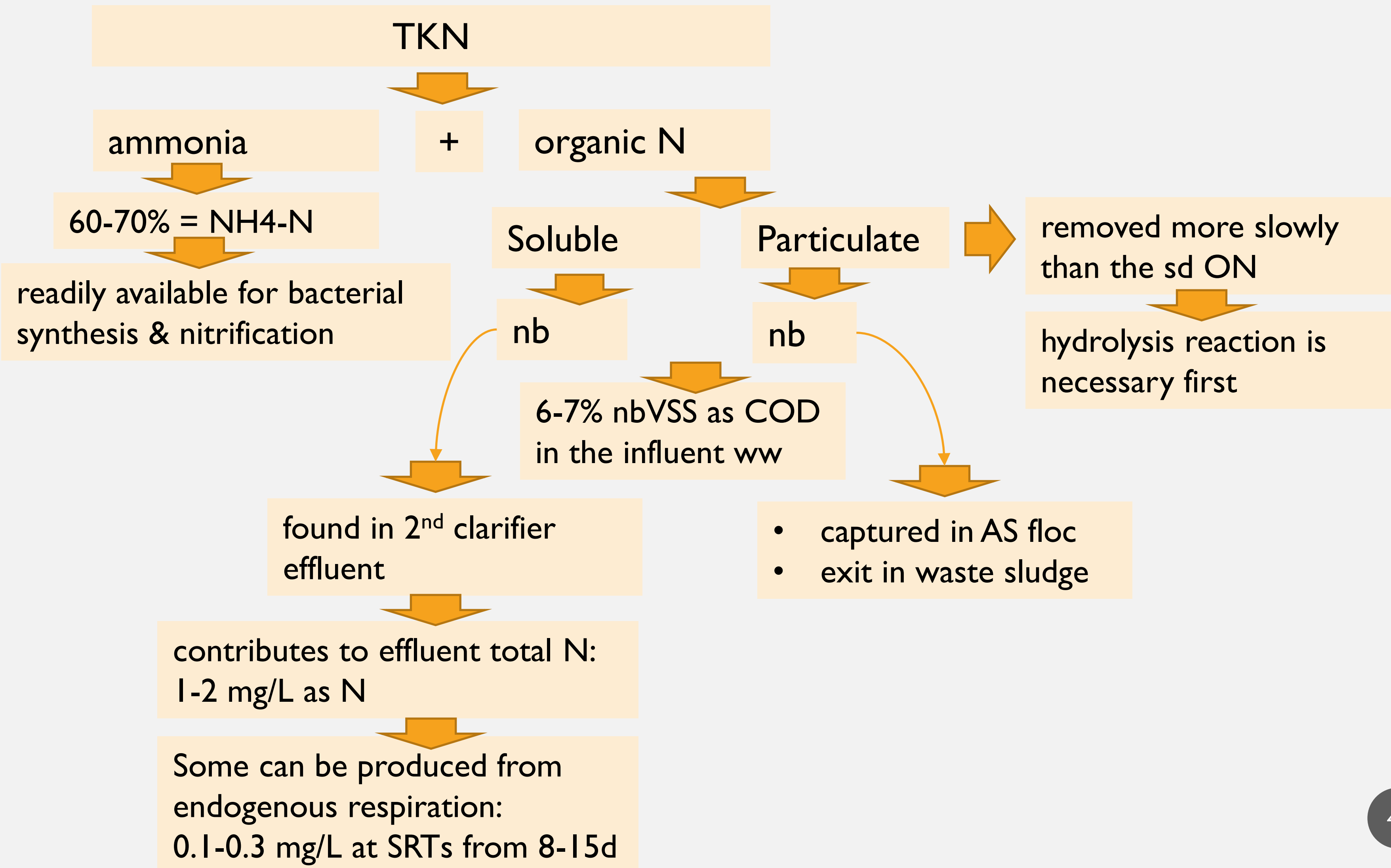
Figure 8-6

Fractionation of nitrogen in wastewater. Information on the nitrogen fractions is used in the detailed design of nitrification and denitrification processes.



NITROGENOUS CONSTITUENTS

- Fig 8-6: the composition of nitrogen in ww



ALKALINITY

- Important ww characteristic
- Affects the performance of biological nitrification processes
- Adequate alkalinity is needed to achieve complete nitrification
- Once ww sample is not available:
  - Total alkalinity may be estimated from information on the alkalinity of the potable water
  - Plus
  - alkalinity contributed through domestic use

MEASUREMENT METHODS FOR WW CHARACTERIZATION

- Special procedures are used to quantify:
- rbCOD
- nbVSS
- Solube organic N (sON)
- nbON

RECYCLE FLOWS & LOADINGS

- Impact of recycle flows must also be quantified & included in defining the influent ww characteristics to ASP
- Possible sources of recycle flows:
  - Digester supernatant flows (if settling & decanting are practiced in the digestion operation)
  - Recycle of centrate/filtrate from solids dewatering equipment
  - Backwash water from effluent filtration processes
  - Water from odor-control scrubbers
- Depending on the source, a significant BOD, TSS, NH4-N load may be added to the influent ww

RECYCLE FLOWS & LOADINGS

- Compared to untreated ww or primary clarifier effluent, BOD/VSS ratio is often much lower for recycle streams
- A significant NH4-N load can be returned to the influent ww from anaerobic digestion-related processes
- 1,000-2,000 mg/L NH4-N are possible in centrate/filtrate from the dewatering anaerobically digested solids
- Thus the ammonia load from a return flow of about one-half percent of influent flow can increase the influent TKN load to ASP by 10-20%
- Mass balance (for flow & important constituent) should be done in all cases

8-3 FUNDAMENTALS OF PROCESS SELECTION, DESIGN & CONTROL

- To introduce:

1. Overall considerations in treatment process implementation
2. Important factors in process section & design
3. Process control issues
4. Operational problems associated with:
   1) the AS 2nd clarifier process
   2) MBR process

1. OVERALL CONSIDERATIONS IN TREATMENT PROCESS IMPLEMENTATION

- Selection of ASTP:
- Based on a review of a number of local factors
- Table 8-4: Principal factors
- Relative importance is site specific
- Current & future treatment needs typically driven by regulatory requirements regarding the impact of the point discharge to surface or groundwater or reclaimed water quality

Table 8–4

General considerations for the selection of the type of suspended growth reactor

Factor	Description
Treatment needs	Treatment requirements and process selection can be categorized according to effluent discharge water quality needs, which may range from secondary treatment for BOD removal, nitrification to achieve low effluent ammonia concentration, anoxic-aerobic processes to provide nitrogen removal, and anaerobic-anoxic-aerobic processes to provide nitrogen and phosphorus removal.
Future treatment needs	Potential future treatment needs can have an impact on present process selection. For example, if water reuse is anticipated in the future, the process selection should favor designs that can easily accommodate nitrogen removal and effluent filtration.
Sludge settleability	Activated sludge *selector* designs can be used that control filamentous bacteria growth that leads to poor sludge settling and thickening in secondary clarifiers. Some selector designs are inherent in nitrogen and phosphorus removal processes.
Effect of reaction kinetics	Both completely-mixed and plug flow reactor configurations with similar volumes have been commonly used for BOD removal designs as both require a minimum SRT to provide acceptable sludge settling properties. Staged-reactors or plug flow designs can exploit reaction kinetic advantages for nitrification or preanoxic tanks to result in less volume than that for a single completely-mixed tank. Such designs require that the aeration equipment provides a high enough oxygen transfer rate in the first stage or at the front of a plug-flow tank to meet the oxygen demand for BOD removal and nitrification. The aeration equipment design must account for different oxygen demand rates along the length of the aeration tank. The oxygen demand is less variable and lower in completely-mixed tanks.
Wastewater characteristics	Wastewater characteristics are affected by contributions from domestic and industrial sources and inflow/infiltration flows. Large variations in wastewater concentrations due to wet weather or seasonal loads can affect process selection. Wastewater alkalinity and pH are also important for nitrification and enhance biological phosphorus removal processes.
Local environmental conditions	Temperature is an important environmental condition that affects treatment performance and lower rates occur at lower temperatures. The size of the facility and plant staffing are also important and smaller plants with less staffing favor processes that are simpler to operate and are more robust to influent wastewater variations. Concerns for aesthetics for facilities with close neighbors can affect process selection.
Toxic or inhibitory substances	Industrial pretreatment standards and enforcement provide substantial protection against biological process upsets from toxic or inhibitory substances disposed into the collection system. If potential exists for shock industrial toxic loads, completely-mixed activated sludge processes with greater design safety factors are considered.
Space	Space limitations for new or existing plant retrofits often limits the candidate processes that can be considered. Membrane bioreactors, integrated fixed film activated sludge, and biological aerated filter processes are good candidates for limited space.
Cost	Construction and operating costs are very important considerations in selecting the type and size of biological reactors. Because the associated settling facilities are an integral part of the activated sludge process, the selection of the reactor and the solids separation facilities must be considered as a unit.

2. IMPORTANT FACTORS IN PROCESS SECTION & DESIGN

Consideration must be given to:

- Type of ASP process & reactor configuration
- Applicable kinetic relationships
- SRT & loading
- Sludge production rate
- Oxygen demand rate & transfer
- Nutrient requirements
- Other chemical requirements
- AS settling characteristics
- Liquid-solids separation of mixed liquor
- Effluent characteristics

SELECTION OF ASP & REACTOR CONFIGURATION

- Depend on treatment needs required to meet effluent discharge limits
- Reactor type:

1. Plug flow
2. Complete-mix
3. Batch (SBR)

- Critical element of ASP performance:
- settleability of MLSS that depend on the nature of mo comprising MLSS
- Filamentous bacteria proliferation → MLSS biological flocs do not settle well
- → high solids levels in 2^{nd} clarifiers
- → loss of solids in final clarifier overflow
- Bulking sludge → poor settling sludge

FILAMENTOUS BULKING

- Prior to 1970s → considered as an inevitable consequence of ASP
- 1973:
- Staged vs complete-mx AS reactors
- → selectors
- → control filamentous bulking
- → improve sludge-settling characteristics
- Common design element of ASP

SELECTION OF SRT & LOADING CRITERIA

Certain design & operating parameters distinguish 1 ASP from another:

- SRT → basic design & op parameter
- F/M ratio (F/mo ratio)
- Volumetric organic loading rate

Comparison to historical data & typical observed operating conditions

SRT

- Average period of time during which the sludge has remained in the system
- Most critical parameter for AS design & op
- Affects:

1. Treatment process performance
2. Aeration tank volume
3. Sludge production
4. Oxygen requirements

- For BOD removal: SRT = 3-5 d depend on mixed liquor temp
- At 18-25C: SRT ≈ 3d where:

1. only BOD removal is required
2. Discourage nitrification
3. Eliminate the associated oxygen demand

- To limit nitrification: SRT ≤ 1d
- At 10C: SRT = 5-6d for BOD removal only
- Table 8-5: temp & other factors affecting SRT

Table 8-5

Typical minimum SRT ranges for activated sludge treatment[a]

Treatment goal	SRT range, d	Factors affecting SRT
Removal of soluble BOD in domestic wastewater	1–2	Temperature
Conversion of particulate organics in domestic wastewater	2–5	Temperature
Develop flocculent biomass for treating domestic wastewater	2–3	Temperature
Provide complete nitrification	3–18	Temperature/inhibitory substances
Biological phosphorus removal	2–4	Temperature
Aerobic digestion of waste activated sludge	20–40	Temperature
Degradation of xenobiotic compounds	5–50	Temperature/specific bacteria/compounds

[a] SRT is based on aerobic volume.

SLUDGE PRODUCTION

- Methods to determine sludge production as SRT function:

1. Estimate of an observed sludge production yield from domestic awter published data
2. Ww characterization information

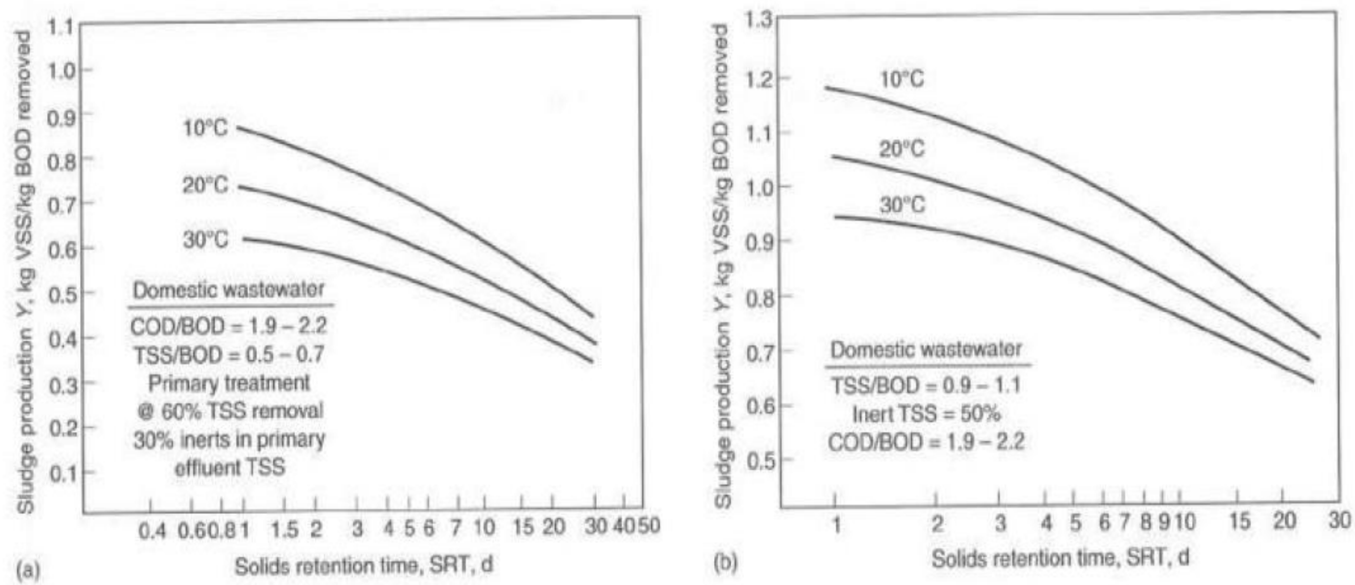


Figure 8-7

Net solids production as a function of solids retention time (SRT) and temperature: (a) with primary treatment and (b) without primary treatment.

- Biomass loss by more endogenous respiration → SRT >>> → observed yield <<<
- >>> temp → >>> endogenous respiration → <<< yield
- No primary treatment used → >>> nbVSS remains in the effluent ww → >>> yield

Temp correction value, ϴ, for endogenous respiration:

- 1.04 (20-30C)
- 1.12 (10-20C)