

Environmental Engineering FE CBT Exam

Knowledge: Water and Wastewater with 20 Example Problems

Contents

1 Exam Scope and Treatment-Train Thinking	3
2 Water and Wastewater Characteristics	4
2.1 Common conceptual distinctions	4
3 BOD, COD, DO, and Nutrient Indicators	5
4 Mass Balances and Removal Efficiency	6
5 Hydraulic Residence Time and Loading Rates	7
6 Preliminary Treatment and Headworks	8
7 Sedimentation and Clarification Fundamentals	9
8 Particle Settling and Stokes' Law	10
8.1 Workflow for settling problems	10
9 Coagulation Fundamentals	11
10 Rapid Mix and Flocculation	12
11 Filtration Concepts and Media Properties	13
11.1 Filtration-rate relationship	13
11.2 Head loss and backwash concepts	13
12 Activated Carbon Adsorption	14
12.1 Adsorption isotherms	14
12.2 Breakthrough and fixed-bed behavior	14
13 Membrane Processes	15
13.1 Reverse-osmosis water flux	15
13.2 Membrane recovery and rejection	15
14 Air Stripping and Volatile Contaminants	16
14.1 Henry's law and stripping factor	16
14.2 Transfer units and packed-column height	16
15 Softening and Hardness	17
15.1 Hardness as CaCO_3	17
15.2 Lime-soda ash softening	17
16 Ion Exchange	18
16.1 Ion-exchange capacity	18
16.2 Regeneration concept	18
17 Disinfection and CT	19
17.1 CT concept	19
17.2 Disinfection kinetics	19
18 Activated Sludge Process Overview	20
18.1 Activated-sludge process flow	20
18.2 Mixed-liquor solids and recycle	20
19 Food-to-Microorganism Ratio and Organic Loading	21
19.1 Food-to-microorganism ratio	21
19.2 Organic loading	21
20 Solids Residence Time and Sludge Age	22
20.1 Solids residence time	22
20.2 Why SRT matters	22
21 Secondary Clarification and Recycle	23
21.1 Clarifier solids loading rate	23

Contents (continued)

21.2 Recycle ratio	23
22 Fixed-Film Biological Treatment	24
22.1 Fixed-film vs. activated sludge	24
23 Lagoons and Ponds	25
23.1 Lagoon treatment concepts	25
23.2 Exam distinction	25
24 Aerobic, Anoxic, and Anaerobic Conditions	26
24.1 Aerobic, anoxic, and anaerobic process roles	26
25 Sludge Quantity, Solids Content, and SVI	27
25.1 Solids concentration and sludge volume index	27
26 Aerobic Digestion	28
26.1 Aerobic digestion concepts	28
27 Anaerobic Digestion	29
27.1 Anaerobic digestion concepts	29
27.2 Gas production	29
28 Sludge Thickening and Dewatering	30
28.1 Thickening	30
28.2 Dewatering	30
29 Sludge Disposal, Land Application, and Composting	31
29.1 Land application	31
29.2 Composting and disposal	31
30 Phosphorus Removal by Precipitation	32
30.1 Chemical phosphorus precipitation	32
31 Disinfection Byproducts and Dechlorination	33
31.1 Disinfection byproducts	33
31.2 Dechlorination	33
32 Water Reuse and Conservation	34
32.1 Reuse and conservation concepts	34
33 Process Selection by Contaminant Type	35
33.1 Process selection by contaminant type	35
34 Treatment-Plant Flow and Chemical Dose Calculations	36
34.1 Chemical dose calculations	36
34.2 Unit discipline	36
35 Combined Hydraulic and Solids Design	37
35.1 Hydraulic criterion	37
35.2 Solids criterion	37
35.3 Multiple design constraints	37
36 20 Example Problems	38
37 Reference and Scope Alignment	59

1 Exam Scope and Treatment-Train Thinking

The Water and Wastewater domain is one of the larger FE Environmental content areas. The specification emphasizes seven connected skills: identifying water-quality characteristics, performing mass balances, selecting and analyzing physical processes, applying chemical treatment relationships, analyzing biological systems, handling residual solids, and understanding conservation/reuse.

A useful exam framework is to think in terms of a treatment train. For drinking water, a conventional sequence is source water → coagulation → flocculation → sedimentation → filtration → disinfection → storage/distribution. For municipal wastewater, a typical sequence is preliminary treatment → primary clarification → biological treatment → secondary clarification → disinfection, with a parallel solids train for thickening, stabilization, dewatering, and final use/disposal.

FE strategy. Before calculating, identify the unit operation and write the governing conservation equation. Most quantitative questions reduce to one of four forms: (1) mass balance, (2) hydraulic loading, (3) reaction/kinetic relationship, or (4) equilibrium/partitioning relationship.

Core quantities recur throughout the section:

$$\theta = \frac{V}{Q}, \quad \text{Loading} = QC, \quad \eta = \frac{C_{in} - C_{out}}{C_{in}} \times 100\%.$$

Here θ is hydraulic residence time, V is process volume, Q is flow rate, C is concentration, and η is removal efficiency. In U.S. customary water/wastewater calculations, a common loading shortcut is

$$\text{lb/day} = Q(\text{MGD}) C(\text{mg/L}) (8.34).$$

Always check whether flow is average, peak, recycle, or waste flow before substituting.

2 Water and Wastewater Characteristics

Water-quality characteristics are commonly grouped as physical, chemical, and biological. Physical parameters include temperature, color, taste/odor, turbidity, suspended solids, and particle size. Chemical parameters include pH, alkalinity, hardness, dissolved solids, nutrients, oxygen demand, metals, and organic compounds. Biological parameters include indicator organisms, pathogens, and biomass-related measures.

For wastewater, solids terminology is especially important. Total solids (TS) are the residue after evaporation. Total suspended solids (TSS) are retained by a specified filter; total dissolved solids (TDS) pass through it. Each fraction may be divided into volatile and fixed components. Volatile suspended solids (VSS) are frequently used as an approximation of active/organic biomass in biological processes.

2.1 Common conceptual distinctions

- **Turbidity** is an optical property and is not identical to TSS.
- **BOD** represents oxygen consumed biologically by biodegradable material under specified test conditions.
- **COD** measures chemically oxidizable material and is generally at least as large as BOD for the same sample.
- **Alkalinity** is acid-neutralizing capacity; **hardness** is primarily associated with multivalent cations such as Ca^{2+} and Mg^{2+} .

Concentration units are often effectively interchangeable for dilute aqueous solutions:

$$1 \text{ mg/L} \approx 1 \text{ ppm.}$$

This approximation depends on water density being near 1 kg/L. For load calculations, maintain dimensional consistency instead of relying only on memorized conversion factors.

3 BOD, COD, DO, and Nutrient Indicators

Biochemical oxygen demand (BOD) is a central wastewater-strength parameter. The standard five-day test reports BOD₅. The FE Reference Handbook gives the unseeded test relationship

$$\text{BOD} = \frac{D_1 - D_2}{P},$$

where D_1 and D_2 are initial and final dissolved oxygen (DO) concentrations in the diluted bottle and P is the fraction of wastewater sample in the bottle.

For a seeded dilution,

$$\text{BOD} = \frac{(D_1 - D_2) - (B_1 - B_2)f}{P},$$

where $B_1 - B_2$ accounts for oxygen uptake by the seed and f scales the seed correction.

Nutrients strongly affect biological treatment and receiving-water quality. Nitrogen may appear as organic nitrogen, ammonia, nitrite, and nitrate. Phosphorus may occur in organic and inorganic forms. Excess nitrogen and phosphorus can promote eutrophication.

Exam cues. If the problem gives DO bottle readings and dilution volume, expect a BOD calculation. If it gives influent and effluent nitrogen species plus a carbon-source equation, expect a stoichiometric dose problem. If it asks about eutrophication, focus on nutrient enrichment, algal growth, and subsequent oxygen depletion.

A useful loading relationship for any constituent is

$$L = QC,$$

which becomes $L = 8.34QC$ in lb/day when Q is in MGD and C in mg/L.

4 Mass Balances and Removal Efficiency

The general steady-state mass balance is

$$\text{Input} + \text{Generation} = \text{Output} + \text{Consumption}.$$

For a conservative constituent with no reaction,

$$\sum Q_{in}C_{in} = \sum Q_{out}C_{out}.$$

For a single treatment unit with equal influent and effluent flow and no side streams, the mass removal rate is

$$\dot{m}_{removed} = Q(C_{in} - C_{out}).$$

Removal efficiency is

$$\eta = \frac{C_{in} - C_{out}}{C_{in}}.$$

Mixing problems are common. If streams 1 and 2 combine,

$$C_m = \frac{Q_1C_1 + Q_2C_2}{Q_1 + Q_2}.$$

Do not average concentrations arithmetically unless the flow rates are equal.

Side-stream warning. Recycle and waste streams change the flow and solids balances. In activated sludge, the return activated sludge flow Q_R and waste activated sludge flow Q_w are not optional details; they are often the central unknowns.

For concentration-based process questions, first sketch the process boundary and label each Q and C . Then write one balance per independent constituent. This step prevents the most common FE error: using the correct formula with the wrong process flow.

5 Hydraulic Residence Time and Loading Rates

Hydraulic residence time (HRT) is

$$\theta = \frac{V}{Q}.$$

It expresses the nominal average time fluid remains in a unit. If V is in m^3 and Q in m^3/day , θ is in days. Convert units before calculating.

Surface overflow rate for a clarifier is

$$v_o = \frac{Q}{A_s},$$

where A_s is plan surface area. Weir loading is

$$WOR = \frac{Q}{L_w}.$$

For biological systems, common loadings include

$$\text{Volumetric organic loading} = \frac{Q_0 S_0}{V},$$

$$F/M = \frac{Q_0 S_0}{V X_A}.$$

Here S_0 is influent substrate concentration and X_A is biomass concentration.

Dimensional check. F/M should reduce to mass of food per mass of microorganisms per time, commonly day^{-1} . A surface loading should reduce to volume per area per time, which is dimensionally a velocity.

The same loading concept appears across treatment: flow per area for clarifiers and filters, mass per volume for reactors, mass per area for fixed-film systems, and flow per weir length for clarifier effluent structures.

6 Preliminary Treatment and Headworks

Preliminary treatment protects downstream equipment and removes materials that are difficult to treat biologically. Typical headworks include bar screens, comminutors, grit removal, flow measurement, and sometimes preaeration or equalization.

Screens remove large debris such as rags and plastics. Grit chambers target dense inorganic particles such as sand and gravel while allowing lighter organics to continue. The design objective is therefore selective settling rather than complete solids removal.

Flow equalization dampens short-term variations in flow and concentration. For a completely mixed equalization basin, a transient mass balance can be written as

$$V \frac{dC}{dt} = Q_{in}C_{in} - Q_{out}C,$$

when volume is constant and no reaction occurs. A purely hydraulic equalization problem is often solved by cumulative inflow and outflow volume differences.

Why headworks matter. Preliminary units do not usually provide the major BOD removal credited to primary or biological treatment. Their main value is protecting pumps, preventing clogging, stabilizing downstream hydraulics, and removing grit that would otherwise abrade equipment or accumulate in tanks.

On the FE exam, preliminary-treatment questions are usually conceptual or simple flow/loading calculations rather than detailed equipment design.

7 Sedimentation and Clarification Fundamentals

Sedimentation separates particles by gravity. The FE Reference Handbook emphasizes the surface overflow concept:

$$v_o = \frac{Q}{A_{surface}}.$$

For ideal discrete settling, a particle with terminal settling velocity $v_t \geq v_o$ is theoretically removed completely. Thus clarifier performance depends strongly on plan area, not simply on depth.

Hydraulic residence time is

$$\theta = \frac{V}{Q},$$

and horizontal velocity is

$$v_h = \frac{Q}{A_x}.$$

Weir overflow rate is

$$WOR = \frac{Q}{L_w}.$$

The handbook provides design criteria and notes rectangular basin length-to-width ratios commonly in the range 3:1 to 5:1. Circular and rectangular tanks use different sludge-collection mechanisms, but the governing hydraulic relationships remain the same.

Common trap. If a problem asks what geometric dimension most directly controls ideal settling removal, use surface area. Increasing depth at unchanged surface area and flow increases detention time but does not change ideal overflow rate.

Primary wastewater clarifiers remove settleable solids and associated BOD. Secondary clarifiers separate biological floc from treated effluent and recycle settled biomass to the aeration basin.

8 Particle Settling and Stokes' Law

Settling velocity depends on particle size, density difference, fluid viscosity, and flow regime. The particle Reynolds number is

$$Re = \frac{\rho_f v_t d}{\mu}.$$

For sufficiently small spherical particles in the laminar regime, Stokes' law applies:

$$v_t = \frac{g(\rho_p - \rho_f)d^2}{18\mu} = \frac{g\rho_f(SG - 1)d^2}{18\mu}.$$

The strong d^2 dependence means doubling diameter increases laminar settling velocity by a factor of four, all else equal. Higher viscosity reduces settling velocity; a larger particle-fluid density difference increases it.

The handbook also gives a drag-coefficient approach for other regimes, including $C_D = 24/Re$ for laminar conditions and correlations for transitional and turbulent conditions.

8.1 Workflow for settling problems

1. Determine whether Stokes' law is appropriate or whether a supplied drag relation is needed.
2. Compute v_t .
3. Compare v_t with clarifier overflow rate Q/A if removal is being assessed.
4. Verify the Reynolds-number assumption if the problem requires it.

Avoid confusing terminal settling velocity with horizontal flow velocity. They act in different directions and enter different design checks.

9 Coagulation Fundamentals

Coagulation destabilizes colloidal particles so they can aggregate during flocculation. Common coagulants include aluminum sulfate (alum) and ferric salts. The handbook presents representative reactions such as alum reacting with natural alkalinity to form insoluble aluminum hydroxide floc.

A simplified conceptual sequence is: coagulant addition → hydrolysis/charge neutralization → particle destabilization → collisions → floc growth → settling/filtration.

Coagulant performance is strongly pH-dependent. The handbook's coagulation diagrams show regions for adsorption/charge neutralization, restabilization, and sweep coagulation as a function of pH and metal dose. On the FE exam, such diagrams are used by locating the pH and dose and identifying the governing region.

Alkalinity connection. Metal-salt coagulants consume alkalinity. A water with low alkalinity may require pH/alkalinity adjustment to maintain a favorable coagulation range.

Chemical dose calculations are mass balances:

$$\dot{m}_{chem} = Q C_{dose}.$$

With Q in MGD and dose in mg/L,

$$\dot{m}_{chem}(\text{lb/day}) = 8.34 Q C_{dose}.$$

When purity is less than 100%, divide the required pure-chemical mass by the purity fraction.

10 Rapid Mix and Flocculation

Rapid mix disperses coagulant quickly; flocculation then provides slower, controlled mixing to promote collisions without excessive floc breakage. Mixing intensity is commonly expressed by the velocity gradient G :

$$G = \sqrt{\frac{P}{\mu V}},$$

where P is power delivered to the fluid, μ is dynamic viscosity, and V is basin volume.

The product Gt is a common design index. The FE Reference Handbook gives a typical design order of magnitude of

$$Gt = 10^4 \text{ to } 10^5.$$

For hydraulic mixing, power can be related to head loss as

$$P = \gamma Q H_L.$$

For mechanical mixers, the handbook provides paddle and turbulent impeller power relationships. A generic turbulent impeller form is

$$P = K_T n^3 D_i^5 \rho_f.$$

Interpretation. Large G means intense mixing. Rapid mix uses high intensity and short time; flocculation uses lower intensity and longer time. If a problem gives G and volume, solve backward for power with $P = G^2 \mu V$.

Because viscosity varies with temperature, identical mixer power and basin geometry do not produce identical G at all temperatures.

11 Filtration Concepts and Media Properties

Granular filtration removes suspended particles after clarification or, in some treatment trains, directly after coagulation/flocculation. Important media descriptors are effective size and uniformity coefficient:

$$d_{10} = \text{effective size}, \quad UC = \frac{d_{60}}{d_{10}}.$$

A smaller UC indicates more uniform media.

11.1 Filtration-rate relationship

Filtration rate is the empty-bed approach velocity:

$$v_s = \frac{Q}{A_{plan}}.$$

11.2 Head loss and backwash concepts

As particles accumulate, head loss increases. The FE Reference Handbook includes clean-bed head-loss relations such as the Rose and Carman-Kozeny equations. In conceptual form, head loss increases with media depth and velocity and decreases with larger particle size and higher porosity.

Backwashing expands and cleans the bed. The backwash velocity must be sufficient to fluidize the media but not so large that media are washed out.

Exam emphasis. Expect calculations using Q/A , d_{10} , d_{60}/d_{10} , or a provided head-loss equation. Detailed filter design constants are normally supplied in the electronic reference.

Filtration is a physical separation step; disinfection is still required because removal alone does not guarantee pathogen inactivation.

12 Activated Carbon Adsorption

12.1 Adsorption isotherms

Activated carbon removes dissolved contaminants by adsorption. The FE Reference Handbook provides both Freundlich and Langmuir isotherms.

Freundlich:

$$\frac{x}{m} = KC_e^{1/n},$$

with linearized form

$$\ln\left(\frac{x}{m}\right) = \frac{1}{n} \ln C_e + \ln K.$$

Langmuir:

$$\frac{x}{m} = \frac{aKC_e}{1 + KC_e},$$

where a represents saturation capacity and K is an experimental constant.

12.2 Breakthrough and fixed-bed behavior

For fixed beds, breakthrough occurs when effluent concentration rises to a specified fraction of influent concentration. The handbook defines a sorption-zone depth using breakthrough and exhaustion throughput volumes.

Data interpretation. On a log-log Freundlich plot, slope = $1/n$ and intercept = $\ln K$ if natural logarithms are used. Keep the logarithm base consistent with the form supplied.

Adsorption differs from absorption: adsorption accumulates material at a surface. In treatment practice, powdered activated carbon is dosed into water and later separated; granular activated carbon is commonly used in packed beds.

13 Membrane Processes

Membranes separate constituents using a selective barrier and a driving force. Processes differ by pore size and **13.1 Reverse-osmosis water flux**

mechanism. Microfiltration and ultrafiltration primarily remove particles and macromolecules; reverse osmosis (RO) can reject dissolved ions and small solutes.

For RO, the handbook gives water flux as

$$J_w = W_p(\Delta P - \Delta\pi),$$

where ΔP is hydraulic pressure difference and $\Delta\pi$ is osmotic pressure difference. Net driving pressure is therefore $\Delta P - \Delta\pi$.

Salt flux may be represented as

$$J_s = K_p(C_{in} - C_{out}).$$

Osmotic pressure for electrolyte solutions is written in the handbook in a van't Hoff-type form involving osmotic coefficient, number of ions, concentration, R , and T .

RO insight. Increasing applied pressure above osmotic pressure increases water flux. If applied pressure equals osmotic pressure, the idealized net water-driving force is zero.

13.2 Membrane recovery and rejection

Common FE calculations include flux, membrane area from $Q = JA$, recovery, rejection, and simple mass balances between feed, permeate, and concentrate.

14 Air Stripping and Volatile Contaminants

14.1 Henry's law and stripping factor

Air stripping transfers volatile contaminants from water to air. The equilibrium basis is Henry's law:

$$P_i = HC_i.$$

The handbook also uses a dimensionless Henry constant $H' = H/(RT)$ and defines a stripping factor

$$R_S = H' \frac{Q_A}{Q_W},$$

where Q_A is airflow and Q_W is water flow.

14.2 Transfer units and packed-column height

Packed-column height is commonly expressed as

$$Z = HTU \times NTU,$$

where HTU is height of a transfer unit and NTU is number of transfer units.

Conceptual cue. Air stripping is favored for contaminants with relatively high volatility and favorable Henry-law behavior. It transfers contamination to the gas phase; it does not destroy the contaminant, so off-gas treatment may be required.

When given an air-water mass balance and negligible contaminant in incoming air, the contaminant removed from water appears in the outlet air. Keep molar and mass concentration units consistent with the Henry-law form supplied.

15 Softening and Hardness

15.1 Hardness as CaCO₃

Hardness is associated mainly with calcium and magnesium. It is frequently expressed as mg/L as CaCO₃ to place different species on a common equivalent basis. Carbonate hardness is associated with alkalinity species; noncarbonate hardness is associated with anions such as sulfate or chloride.

15.2 Lime-soda ash softening

Lime-soda ash softening uses precipitation reactions. The handbook lists reactions for carbon dioxide removal, calcium carbonate hardness removal, calcium noncarbonate hardness removal, magnesium hardness removal, excess alkalinity destruction, and recarbonation.

Equivalent weight is

$$EW = \frac{MW}{|z|},$$

where MW is molecular weight and $|z|$ is the number of equivalents per mole for the relevant reaction. Converting a species concentration to an equivalent CaCO₃ basis uses

$$C_{as \text{ CaCO}_3} = C_i \frac{50}{EW_i}.$$

Exam method. Put all hardness and alkalinity components on an equivalent basis before comparing or summing. Stoichiometric chemical demand follows from equivalent relationships; then correct for chemical purity if required.

Recarbonation introduces CO₂ after softening to stabilize water and reduce excessive pH.

16 Ion Exchange

16.1 Ion-exchange capacity

Ion exchange removes ions from water by reversible exchange with ions attached to an insoluble resin. Cation exchange is commonly used for hardness removal; anion exchange can remove negatively charged species. Exhausted resin is regenerated using a concentrated regenerant solution.

A simple capacity balance is

$$M_{removed} = Q C t,$$

and the required resin mass or volume follows from the resin exchange capacity. Because exchange capacity is often expressed in equivalents, convert ionic concentrations to equivalents before using the capacity.

For hardness in mg/L as CaCO_3 ,

$$\text{meq/L} = \frac{C_{as} \text{ CaCO}_3}{50}.$$

Conceptual comparison. Lime-soda softening removes hardness by precipitation and produces sludge. Ion
16.2 Regeneration concept

exchange transfers ions to a resin and creates a concentrated regeneration waste. Membrane softening separates ions across a membrane and creates a concentrate stream.

FE questions may ask for bed service time, total equivalents removed, regenerant need, or identification of the appropriate process for a specified dissolved contaminant.

17 Disinfection and CT

17.1 CT concept

Disinfection targets pathogenic microorganisms. The FE Reference Handbook gives

$$CT_{calc} = C t_{10},$$

where C is residual disinfectant concentration and t_{10} is the contact time exceeded by 90% of the water. An approximate relation is

$$t_{10} = \theta BF,$$

where BF is a baffling factor.

Baffling factors range from low values for poorly mixed basins to 1.0 for ideal plug flow. Thus two basins with the

17.2 Disinfection kinetics

same nominal residence time can have very different effective disinfection contact times.

Log reduction is related to percent removal/inactivation:

$$\text{fraction remaining} = 10^{-L},$$

where L is log reduction. Therefore 3-log corresponds to 99.9% reduction and 4-log to 99.99%.

Exam sequence. Compute $\theta = V/Q$, then $t_{10} = BF \theta$, then $CT = C t_{10}$. Compare with a required CT value if one is provided.

Disinfection efficacy depends on disinfectant, organism, concentration, contact time, temperature, pH, and water quality. The handbook also presents typical removal/inactivation credits for treatment technologies.

18 Activated Sludge Process Overview

18.1 Activated-sludge process flow

Activated sludge is a suspended-growth biological process. Wastewater and microorganisms mix in an aeration basin, then biomass is separated in a secondary clarifier. A portion of settled biomass is returned as return activated sludge (RAS), and excess solids are wasted.

Important variables include influent flow Q_0 , recycle flow Q_R , waste flow Q_w , aeration-basin biomass concentration X_A , return sludge concentration X_r , and waste concentration X_w .

The handbook gives the secondary-clarifier solids balance

$$(Q_0 + Q_R)X_A = Q_e X_e + Q_R X_r + Q_w X_w.$$

If effluent solids are negligible and Q_w is small compared with Q_R , simplified relations may be possible, but only make approximations when justified.

Process logic. RAS maintains biomass concentration in the aeration basin. WAS controls solids inventory and sludge age. Aeration supplies oxygen and mixing. The secondary clarifier performs solids-liquid separation, not the biological oxidation itself.

18.2 Mixed-liquor solids and recycle

The activated-sludge system is analyzed with HRT, solids residence time, F/M , organic loading, recycle ratio, and oxygen requirements.

19 Food-to-Microorganism Ratio and Organic Loading

19.1 Food-to-microorganism ratio

The food-to-microorganism ratio is

$$\frac{F}{M} = \frac{Q_0 S_0}{V X_A}.$$

Use consistent mass units for S_0 and X_A . Because both are often in mg/L, the concentration units cancel if Q/V is expressed per time.

19.2 Organic loading

Volumetric organic loading is

$$L_v = \frac{Q_0 S_0}{V}.$$

Surface organic loading for attached-growth media can be written

$$L_A = \frac{Q_0 S_0}{A_M}.$$

The handbook provides typical activated-sludge operating ranges for process variants. Conventional and completely mixed systems commonly operate at moderate F/M and sludge ages; extended aeration uses lower F/M and longer sludge age.

Interpretation. At fixed biomass inventory VX_A , increasing influent substrate load increases F/M . At fixed food load, increasing MLVSS or basin volume decreases F/M .

For F/M calculations, use MLVSS as the microorganism (biomass) concentration when available, because MLVSS better represents the volatile biological solids fraction. MLSS includes both volatile and fixed inorganic solids; use MLSS as the biomass basis only when the problem explicitly specifies it or when no MLVSS/VSS fraction is provided. Do not convert between MLSS and MLVSS without a stated relationship.

20 Solids Residence Time and Sludge Age

20.1 Solids residence time

Solids residence time (SRT), also called mean cell residence time or sludge age, measures the average time biological solids remain in the system. The handbook gives

$$\theta_c = \frac{V X_A}{Q_w X_w + Q_e X_e}.$$

When effluent solids are negligible,

$$\theta_c \approx \frac{V X_A}{Q_w X_w}.$$

SRT differs from hydraulic residence time:

$$\theta = \frac{V}{Q}.$$

Because solids are recycled, θ_c can be much greater than θ .

Why SRT matters. SRT controls the biological solids inventory and strongly affects process stability, sludge production, and the ability to retain slow-growing organisms such as nitrifiers.

A common FE task is solving for waste sludge flow:

$$Q_w = \frac{V X_A / \theta_c - Q_e X_e}{X_w}.$$

Check that all flows and concentrations are on compatible bases. If V is in m^3 and concentrations in kg/m^3 , the numerator is kg/day when θ_c is in days.

21 Secondary Clarification and Recycle

The secondary clarifier separates activated-sludge solids from treated water. The total hydraulic flow entering the
21.1 Clarifier solids loading rate

clarifier is approximately $Q_0 + Q_R$ (subject to the process configuration). Clarifier solids loading rate is given in the handbook as

$$SLR = \frac{(Q_0 + Q_R)X_A}{A}.$$

21.2 Recycle ratio

Recycle ratio is

$$R = \frac{Q_R}{Q_0}, \quad Q_R = RQ_0.$$

A useful solids balance, neglecting effluent and waste solids for a quick estimate, is

$$(Q_0 + Q_R)X_A \approx Q_R X_r.$$

Solving for recycle ratio gives

$$R \approx \frac{X_A}{X_r - X_A}.$$

Check the denominator. Return sludge concentration X_r must exceed aeration-basin MLSS X_A for a physically reasonable positive recycle ratio.

Clarifier area may be controlled by hydraulic overflow rate, solids loading, or both. The more restrictive area requirement governs.

22 Fixed-Film Biological Treatment

Fixed-film processes grow microorganisms on media rather than maintaining all biomass in suspension. Examples include trickling filters and biotowers. Wastewater passes over or through media, substrate diffuses into the biofilm, and excess solids slough off and are separated downstream.

The FE Reference Handbook provides a biotower fixed-film relationship without recycle in the form

$$\frac{S_e}{S_0} = e^{-kD/q^n},$$

with modified expressions when recycle is present. Here D is media depth, q is hydraulic loading, k is a treatability constant, and n reflects media characteristics.

Hydraulic loading with recycle is based on total flow through the media:

$$q = \frac{Q_0 + Q_R}{A_{plan}}.$$

Fixed-film vs. activated sludge. Fixed-film systems retain organisms on media; activated sludge relies on suspended biomass and clarifier recycle. Both require oxygen for aerobic treatment and both produce excess biomass that must be handled.

Temperature corrections may be applied to kinetic constants when a reference relationship is supplied.

23 Lagoons and Ponds

23.1 Lagoon treatment concepts

Lagoons provide biological treatment with long detention times and relatively low mechanical complexity. Facultative ponds contain an aerobic upper zone and anaerobic lower zone, with photosynthetic oxygen transfer often important near the surface.

The FE Reference Handbook gives a mixed-lagoon series relationship of the form

$$\frac{S}{S_0} = \frac{1}{1 + k_p \theta}$$

for a completely mixed first-order representation. For multiple equal lagoons in series, the relationship can be applied sequentially.

The handbook also provides facultative-pond criteria, including low areal BOD loading, multiple ponds, shallow-to-moderate depth, and long detention time.

Exam distinction. A lagoon problem may be either kinetic (using S/S_0 and $k\theta$) or loading-based (mass BOD per area per day). Read units first; they reveal the intended method.

Long HRT provides process resilience but requires substantial land area. Pond performance is sensitive to temperature, sunlight, mixing, and hydraulic short-circuiting.

24 Aerobic, Anoxic, and Anaerobic Conditions

Biological treatment conditions are distinguished by available electron acceptors. Under aerobic conditions, dissolved oxygen is available. Under anoxic conditions, free dissolved oxygen is absent but oxidized nitrogen such as nitrate can serve as an electron acceptor. Under anaerobic conditions, neither dissolved oxygen nor nitrate is available, and reduced products such as methane may form.

Nitrification oxidizes reduced nitrogen to nitrate under aerobic conditions. Denitrification reduces nitrate to nitrogen gas under anoxic conditions and requires an electron donor. The handbook provides a methanol requirement relation:

$$C_m = 2.47N_o + 1.53N_i + 0.87D_o,$$

where terms correspond to nitrate-N, nitrite-N, and dissolved oxygen concentrations.

Sequence recognition. Biological nitrogen removal generally needs an aerobic zone for nitrification and an

24.1 Aerobic, anoxic, and anaerobic process roles

anoxic zone for denitrification. Anaerobic zones are associated with processes such as digestion and certain biological phosphorus-removal configurations.

A problem that gives nitrate concentration and asks for external carbon demand is signaling use of a stoichiometric donor requirement rather than a hydraulic design equation.

25 Sludge Quantity, Solids Content, and SVI

Treatment residuals must be quantified on both dry-solids and wet-volume bases. The FE Reference Handbook gives wet-sludge specific gravity as

$$S = \frac{W_w + W_s}{W_w/1.00 + W_s/S_s},$$

where W_w and W_s are water and dry-solids weights and S_s is dry-solids specific gravity.

If a sludge contains s percent solids by weight, then dry solids are only $s/100$ of wet sludge mass. Therefore small

25.1 Solids concentration and sludge volume index

changes in percent solids can produce large changes in wet sludge volume.

Sludge volume index (SVI) is

$$SVI = \frac{\text{settled sludge volume (mL/L)} \times 1000}{\text{MLSS (mg/L)}}.$$

SVI is reported in mL/g and is an indicator of activated-sludge settling characteristics.

Common mistake. A 2% solids sludge is 98% water by mass; it is not “2% water.” Convert percent to decimal before computing total wet mass or volume.

Solids handling problems often become straightforward once the dry-solids mass rate is conserved through thickening or dewatering.

26 Aerobic Digestion

26.1 Aerobic digestion concepts

Aerobic digestion stabilizes sludge by prolonged aeration, allowing microorganisms to oxidize biodegradable cell material. The handbook lists design criteria such as sludge retention time, solids loading, oxygen requirements, and expected volatile-solids reduction.

A handbook tank-volume relationship includes influent sludge flow, suspended solids, a primary-sludge BOD term when applicable, digester solids concentration, decay rate, volatile fraction, and solids residence time. On FE problems, the specific equation will typically be available in the reference.

The qualitative effects are intuitive: longer sludge age and favorable temperature generally increase stabilization, while oxygen supply and mixing must be adequate.

Process comparison. Aerobic digestion requires oxygen and consumes energy for aeration. Anaerobic digestion operates without oxygen, produces methane-rich biogas, and is often favored for larger facilities where energy recovery is valuable.

If a problem gives a volatile-solids reduction graph as a function of temperature times sludge age, compute the product first and then read the graph carefully.

27 Anaerobic Digestion

27.1 Anaerobic digestion concepts

Anaerobic digestion stabilizes organic solids without molecular oxygen and produces biogas containing methane. The handbook distinguishes standard-rate and high-rate digestion and provides typical ranges for solids residence time,

27.2 Gas production

volatile-solids loading, digested-solids concentration, volatile-solids reduction, gas production, and methane content.

A simple gas-production calculation is

$$V_{gas} = Y_g M_{VSS,added},$$

where Y_g is gas yield per mass of volatile solids added.

Methane volume is

$$V_{CH_4} = f_{CH_4} V_{gas}.$$

If heating value is supplied, recoverable energy can be estimated from methane quantity times heating value and an efficiency factor.

Loading check. Volatile-solids loading is mass VSS per digester volume per time. If design loading is specified, required volume is $V = M_{VSS}/L_v$.

Anaerobic digestion performance depends strongly on temperature, pH/alkalinity, toxicants, and solids retention. The FE focus is generally on mass balances, loading, retention time, and gas production rather than detailed microbial ecology.

28 Sludge Thickening and Dewatering

28.1 Thickening

Thickening increases solids concentration primarily by removing water while keeping most solids in the sludge stream. Dewatering increases solids concentration further, producing a cake and a liquid sidestream.

For a solids-conserving thickener with negligible solids in overflow,

$$Q_i X_i = Q_u X_u,$$

so

$$Q_u = Q_i \frac{X_i}{X_u}.$$

If concentration rises from 1% to 5%, the sludge flow drops to roughly one-fifth, assuming equal density and negligible solids loss.

28.2 Dewatering

For a dewatering device with solids capture efficiency η_s ,

$$M_{cake,dry} = \eta_s M_{feed,dry}.$$

Wet cake mass is

$$M_{cake,wet} = \frac{M_{cake,dry}}{f_s},$$

where f_s is cake solids fraction.

Exam method. Track dry solids separately from water. Dry-solids mass is usually the conserved quantity; wet sludge volume is derived from solids fraction and density.

Common dewatering technologies include centrifuges, belt filter presses, and drying beds. Polymer conditioning may improve dewatering performance.

29 Sludge Disposal, Land Application, and Composting

After stabilization and dewatering, residual solids may be land-applied, composted, incinerated, or disposed of, depending on quality and regulatory requirements. The FE specification explicitly includes land application and composting within sludge handling.

A land-application loading calculation is fundamentally a mass-per-area balance:

$$A = \frac{M_{annual}}{L_{allowable}},$$

where M_{annual} is annual dry-solids or nutrient mass and $L_{allowable}$ is the permitted application rate.

29.2 Composting and disposal

Composting is an aerobic biological process. Moisture, oxygen, carbon-to-nitrogen ratio, particle size, and temperature influence performance. Bulking agents may be added to increase porosity and adjust moisture or carbon balance.

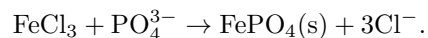
Mass basis. Regulations and agronomic application rates are commonly expressed on a dry-mass or nutrient-mass basis. Do not use wet sludge mass without converting to the required basis.

Treatment choice depends on solids quantity, contaminants, hauling distance, energy use, beneficial-use opportunities, and local requirements.

30 Phosphorus Removal by Precipitation

30.1 Chemical phosphorus precipitation

Chemical phosphorus removal converts dissolved phosphate into insoluble solids that can be separated. The handbook lists representative reactions using ferric chloride, ferrous chloride, and alum. For example,



Stoichiometric calculations follow mole ratios. If one mole of FeCl_3 reacts per mole of phosphate in the selected representation, then

$$\frac{m_{\text{FeCl}_3}}{MW_{\text{FeCl}_3}} = \frac{m_{\text{PO}_4}}{MW_{\text{PO}_4}}.$$

Actual design dose can exceed stoichiometric demand because of competing reactions and process inefficiencies, but an FE stoichiometry question uses the information explicitly given.

Process location. Chemical addition can be arranged before primary clarification, within biological treatment, or before tertiary clarification/filtration, depending on treatment goals.

Precipitation increases solids production, so phosphorus removal is linked directly to the residuals-handling train.

31 Disinfection Byproducts and Dechlorination

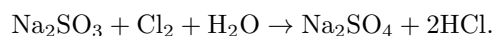
Chlorine is effective and provides a residual, but it can react with natural organic matter and other constituents

31.1 Disinfection byproducts

to form disinfection byproducts. Process selection therefore balances microbial control, residual protection, contact conditions, and byproduct concerns.

31.2 Dechlorination

Wastewater effluent may be dechlorinated before discharge. The handbook gives a sodium sulfite reaction with free chlorine:



Stoichiometric dose is found from molecular weights and reaction coefficients.

Dose logic. First determine the chlorine mass to be neutralized from flow and residual concentration. Next convert to moles (or equivalents), apply the reaction ratio, convert back to mass of dechlorinating chemical, and adjust for purity if needed.

Ultraviolet disinfection does not provide a lasting distribution-system residual. Ozone is a strong oxidant but also does not provide the same persistent residual as chlorination. These distinctions are common conceptual exam targets.

32 Water Reuse and Conservation

32.1 Reuse and conservation concepts

The FE specification includes water conservation and reuse. Conservation reduces demand through efficiency, leak control, metering, pressure management, process optimization, and behavioral or institutional measures. Reuse treats wastewater to a quality suitable for a new application.

Reuse applications may include irrigation, industrial cooling/process water, toilet flushing, groundwater recharge, and potable reuse when advanced treatment and regulatory requirements are met. Treatment level must match exposure and end-use requirements.

A reuse fraction is

$$f_r = \frac{Q_{reused}}{Q_{demand}},$$

and potable-water savings are

$$Q_{saved} = Q_{baseline} - Q_{potable,after}.$$

Water-balance perspective. Reuse changes where water is withdrawn and discharged, but does not eliminate the need to account for losses, concentrate streams, evaporation, and residuals.

For FE questions, expect mass/flow balances and conceptual matching of treatment level to intended reuse rather than jurisdiction-specific regulatory details.

33 Process Selection by Contaminant Type

33.1 Process selection by contaminant type

A fast way to reason through treatment selection is to classify the target contaminant.

Target	Common process logic
Large debris/grit	Screening and grit removal
Settleable suspended solids	Sedimentation/clarification
Fine colloids	Coagulation, flocculation, clarification, filtration
Dissolved hardness ions	Lime-soda softening, ion exchange, membranes
Dissolved organics	Activated carbon, biological treatment, advanced oxidation where applicable
Volatile dissolved compounds	Air stripping
Pathogens	Disinfection plus upstream particle removal
Biodegradable organics	Suspended-growth, fixed-film, or lagoon biological treatment
Nutrients	Biological and/or chemical nutrient removal
Dissolved salts	Reverse osmosis or other desalination processes

Key distinction. A separation process moves contaminants into another stream; a destructive process transforms them. Adsorption, membranes, clarification, and air stripping all create residual or secondary streams that must be managed.

This classification approach is especially useful for qualitative multiple-choice questions.

34 Treatment-Plant Flow and Chemical Dose Calculations

34.1 Chemical dose calculations

Many FE questions combine flow conversion with chemical dosing. The most useful U.S. customary relationship is

$$\dot{m}(\text{lb/day}) = 8.34 Q(\text{MGD}) C(\text{mg/L}).$$

For a commercial solution of mass fraction w ,

$$\dot{m}_{\text{solution}} = \frac{\dot{m}_{\text{pure}}}{w}.$$

If solution density is ρ_s in lb/gal, volumetric feed is

$$Q_{\text{chem}} = \frac{\dot{m}_{\text{solution}}}{\rho_s}.$$

Example structure: a 4 MGD plant needs 25 mg/L alum. Pure alum demand is

$$8.34(4)(25) = 834 \text{ lb/day}.$$

If product is 50% active by mass, solution mass is $834/0.50 = 1668 \text{ lb/day}$.

Unit discipline. Keep concentration and flow units visible through the calculation. Most dose errors come from applying 8.34 when the flow is not in MGD or the concentration is not in mg/L.

The same method applies to chlorine, coagulant, lime, polymer, methanol, and dechlorination chemicals.

35 Combined Hydraulic and Solids Design

Many treatment units must satisfy more than one design criterion. A secondary clarifier, for example, may be sized by both hydraulic overflow rate and solids loading.

35.1 Hydraulic criterion

Hydraulic criterion:

$$A_h = \frac{Q}{v_{o,allow}}.$$

35.2 Solids criterion

Solids criterion:

$$A_s = \frac{(Q_0 + Q_R)X_A}{SLR_{allow}}.$$

The governing area is

$$A = \max(A_h, A_s).$$

Similarly, a basin may need enough volume for HRT and enough area for settling. A filter must satisfy filtration-rate constraints and backwash requirements. A disinfection basin must provide adequate effective t_{10} at peak flow, not just average-flow volume.

Exam pattern. When a problem supplies two independent design limits, calculate both required sizes and choose the more restrictive value. Do not average them.

35.3 Multiple design constraints

This “multiple constraints” pattern is common in engineering design questions and is often more important than algebraic complexity.

36 20 Example Problems

The following 20 problems are original FE-style practice problems based on the equations, terminology, and scope presented in the NCEES FE Environmental specification and FE Reference Handbook. Each solution shows the governing relationship, substitution, and result.

Example Problem 1: Constituent Loading**Problem**

A wastewater plant treats 3.2 MGD with an influent BOD₅ concentration of 220 mg/L. Determine the influent BOD₅ mass loading in lb/day.

Solution

Use the standard water/wastewater loading conversion:

$$L = 8.34QC.$$

$$L = 8.34(3.2)(220) = 5,871 \text{ lb/day}.$$

Answer: $5.87 \times 10^3 \text{ lb/day}$.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 2: Removal Efficiency**Problem**

A primary clarifier receives wastewater containing 240 mg/L TSS and discharges 108 mg/L TSS. What is the percent TSS removal?

Solution

$$\eta = \frac{C_{in} - C_{out}}{C_{in}} \times 100\%$$

$$\eta = \frac{C_{in} - C_{out}}{C_{in}} \times 100\%$$

$$\eta = \frac{240 - 108}{240}(100\%) = 55.0\%.$$

Answer: 55%.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 3: Flow-Weighted Mixing**Problem**

Two streams combine. Stream 1 is 1.5 MGD at 40 mg/L nitrate and Stream 2 is 2.5 MGD at 8 mg/L nitrate. Find the mixed concentration.

Solution

Apply a conservative mass balance:

$$C_m = \frac{Q_1 C_1 + Q_2 C_2}{Q_1 + Q_2}.$$
$$C_m = \frac{1.5(40) + 2.5(8)}{1.5 + 2.5} = 20.0 \text{ mg/L}.$$

Answer: 20.0 mg/L.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 4: Clarifier Surface Area**Problem**

A water-treatment clarifier must handle 2.0 MGD at an allowable surface overflow rate of 800 gpd/ft². Determine required surface area.

Solution

$$A = \frac{Q}{v_o} = \frac{2.0 \times 10^6 \text{ gpd}}{800 \text{ gpd/ft}^2} = 2500 \text{ ft}^2.$$

Answer: $2.50 \times 10^3 \text{ ft}^2$.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 5: Clarifier Weir Loading**Problem**

A circular clarifier treats 0.90 MGD. Its peripheral effluent weir length is 240 ft. Determine the weir overflow rate in gpd/ft.

Solution

$$WOR = \frac{Q}{L_w} = \frac{900,000}{240} = 3750 \text{ gpd/ft.}$$

Answer: 3.75×10^3 gpd/ft.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 6: BOD Test**Problem**

An unseeded BOD bottle contains 15 mL wastewater diluted to 300 mL. Initial DO is 8.8 mg/L and five-day DO is 3.2 mg/L. Determine BOD₅. **Solution**

The wastewater fraction is

$$P = \frac{15}{300} = 0.050.$$

For an unseeded sample,

$$\text{BOD}_5 = \frac{D_1 - D_2}{P} = \frac{8.8 - 3.2}{0.050} = 112 \text{ mg/L}.$$

Answer: 112 mg/L.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 7: Coagulant Dose**Problem**

A 5.0 MGD plant applies alum at 28 mg/L. The delivered liquid product is 48% alum by mass. Find the required solution mass feed in lb/day.

Solution

Pure alum requirement:

$$M_p = 8.34(5.0)(28) = 1167.6 \text{ lb/day.}$$

Solution mass:

$$M_s = \frac{1167.6}{0.48} = 2432.5 \text{ lb/day.}$$

Answer: 2.43×10^3 lb/day of solution.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 8: Mixing Power from Velocity Gradient**Problem**

A rapid-mix basin has volume 45 m^3 , water viscosity $1.0 \times 10^{-3} \text{ Pa}\cdot\text{s}$, and desired velocity gradient $G = 700 \text{ s}^{-1}$. Find power delivered to the water.

Solution

From

$$G = \sqrt{\frac{P}{\mu V}},$$

solve for power:

$$P = G^2 \mu V = (700)^2 (1.0 \times 10^{-3}) (45) = 22,050 \text{ W}.$$

Answer: 22.1 kW.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 9: Filter Area**Problem**

A plant must filter 6.0 MGD at a maximum filtration rate of 4.0 gpm/ft². Determine the minimum total filter area.

Solution

Convert flow to gpm:

$$Q = \frac{6.0 \times 10^6}{1440} = 4166.7 \text{ gpm.}$$

Then

$$A = \frac{Q}{v} = \frac{4166.7}{4.0} = 1041.7 \text{ ft}^2.$$

Answer: $1.04 \times 10^3 \text{ ft}^2$.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 10: Freundlich Adsorption**Problem**

For an adsorbate, the Freundlich constants are $K = 2.5$ and $1/n = 0.40$. Estimate x/m when $C_e = 16$ in units consistent with the fitted isotherm.

Solution

$$\frac{x}{m} = KC_e^{1/n} = 2.5(16)^{0.40}.$$

Since $16^{0.40} = 3.031$,

$$\frac{x}{m} = 7.58.$$

Answer: $x/m \approx 7.58$ in the isotherm's mass-ratio units.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 11: Reverse Osmosis Net Driving Pressure**Problem**

An RO membrane has $\Delta P = 3.20$ MPa and $\Delta\pi = 1.05$ MPa. If $W_p = 1.8 \times 10^{-12}$ kmol/(m²·s·Pa), determine water flux J_w .

Solution

$$J_w = W_p(\Delta P - \Delta\pi).$$

$$\Delta P - \Delta\pi = (3.20 - 1.05) \times 10^6 = 2.15 \times 10^6 \text{ Pa}.$$

$$J_w = (1.8 \times 10^{-12})(2.15 \times 10^6) = 3.87 \times 10^{-6} \text{ kmol/(m}^2 \text{ s)}.$$

Answer: 3.87×10^{-6} kmol/(m² s).

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 12: Disinfection CT**Problem**

A chlorine contact basin has volume 0.60 MG and peak-hour flow 4.0 MGD. Residual chlorine is 1.6 mg/L and the baffling factor is 0.5. Estimate CT .

Solution

Nominal HRT:

$$\theta = \frac{0.60 \text{ MG}}{4.0 \text{ MGD}}(1440) = 216 \text{ min.}$$

Effective contact time:

$$t_{10} = 0.5(216) = 108 \text{ min.}$$

Thus

$$CT = 1.6(108) = 172.8 \text{ mg min/L.}$$

Answer: $\boxed{173 \text{ mg min/L}}$.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 13: Activated Sludge F/M**Problem**

A plant treats 2.5 MGD at influent $\text{BOD}_5 = 180 \text{ mg/L}$. The aeration basin volume is 0.75 MG and MLVSS is 3000 mg/L. Determine F/M in day^{-1} using MLVSS as the biomass basis.

Solution

Because the same concentration and volume units appear in numerator and denominator,

$$F/M = \frac{Q_0 S_0}{V X_A}.$$

$$F/M = \frac{(2.5)(180)}{(0.75)(3000)} = 0.200 \text{ day}^{-1}.$$

Answer: 0.20 day^{-1} .

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 14: Solids Residence Time**Problem**

An aeration basin contains 5000 m³ at 2800 mg/L MLSS. Waste sludge flow is 180 m³/day at 8000 mg/L, and effluent solids are negligible. Estimate SRT.

Solution

$$\mu \sim V X_A$$

$$\nu_c \sim \frac{Q_w X_w}{Q_w X_w}.$$

$$\theta_c = \frac{5000(2800)}{180(8000)} = 9.72 \text{ days.}$$

Answer: 9.7 days.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 15: Return Activated Sludge Ratio**Problem**

Aeration-basin MLSS is 3000 mg/L and return sludge concentration is 9000 mg/L. Neglect effluent and waste solids for a quick recycle estimate. Find $R = Q_R/Q_0$.

Solution

Using

$$R \approx \frac{X_A}{X_r - X_A},$$
$$R = \frac{3000}{9000 - 3000} = 0.50.$$

Answer: $R = 0.50$, or 50% recycle.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 16: SVI**Problem**

A 30-minute settleability test gives a settled sludge volume of 270 mL/L. MLSS is 3000 mg/L. Determine SVI.

Solution

$$SVI = \frac{270 \times 1000}{3000} = 90 \text{ mL/g.}$$

Answer: 90 mL/g.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 17: Sludge Thickening**Problem**

A sludge stream of 120 m³/day at 1.2% solids is thickened to 4.8% solids. Assume negligible solids loss and equal sludge density. Find underflow volume.

Solution

Conserve dry solids:

$$Q_i X_i = Q_u X_u.$$
$$Q_u = 120 \frac{0.012}{0.048} = 30 \text{ m}^3/\text{day}.$$

Answer: 30 m³/day.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 18: Anaerobic Digester Volume**Problem**

A facility sends 2400 kg VSS/day to a high-rate anaerobic digester. The selected volatile-solids loading is 3.0 kg/(m³·day). Determine required digester volume.

Solution

$$V = \frac{M_{VSS}}{L_v} = \frac{2400}{3.0} = 800 \text{ m}^3.$$

Answer: 800 m³.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 19: Methanol Requirement**Problem**

Biologically treated wastewater contains 12 mg/L nitrate-N, 0.5 mg/L nitrite-N, and 1.0 mg/L DO entering denitrification. Estimate methanol requirement using the handbook relationship.

Solution

$$C_m = 2.47N_o + 1.53N_i + 0.87D_o.$$

$$C_m = 2.47(12) + 1.53(0.5) + 0.87(1.0) = 31.275 \text{ mg/L}.$$

Answer: 31.3 mg/L methanol.

Check: Confirm units and physical reasonableness before selecting the final answer.

Example Problem 20: Sequential Treatment Removal**Problem**

A contaminant concentration is 80 mg/L. Clarification removes 50% and a downstream filter removes 80% of what remains. Determine final concentration and overall removal.

Solution

After clarification:

$$C_1 = 80(1 - 0.50) = 40 \text{ mg/L.}$$

After filtration:

$$C_2 = 40(1 - 0.80) = 8 \text{ mg/L.}$$

Overall removal:

$$\eta = \frac{80 - 8}{80} = 0.90 = 90\%.$$

Answer: 8 mg/L final, 90% overall removal.

Check: Confirm units and physical reasonableness before selecting the final answer.

37 Reference and Scope Alignment

This study guide is aligned to the NCEES Fundamentals of Engineering (FE) Environmental CBT examination specification for the Water and Wastewater domain. The specification identifies the following subtopics: water and wastewater characteristics; mass balance and loading rates; physical processes; chemical processes; biological processes; sludge treatment and handling; and water conservation and reuse.

Equations and terminology emphasized in this guide are drawn from the FE Reference Handbook 10.6, particularly the Environmental Engineering section containing wastewater treatment and technologies, water treatment technologies, clarification and settling, filtration, softening and coagulation, activated carbon, air stripping, membrane processes, disinfection, activated sludge, fixed-film treatment, lagoons, and sludge digestion.

The worked examples are newly written practice problems and do not reproduce NCEES examination questions.