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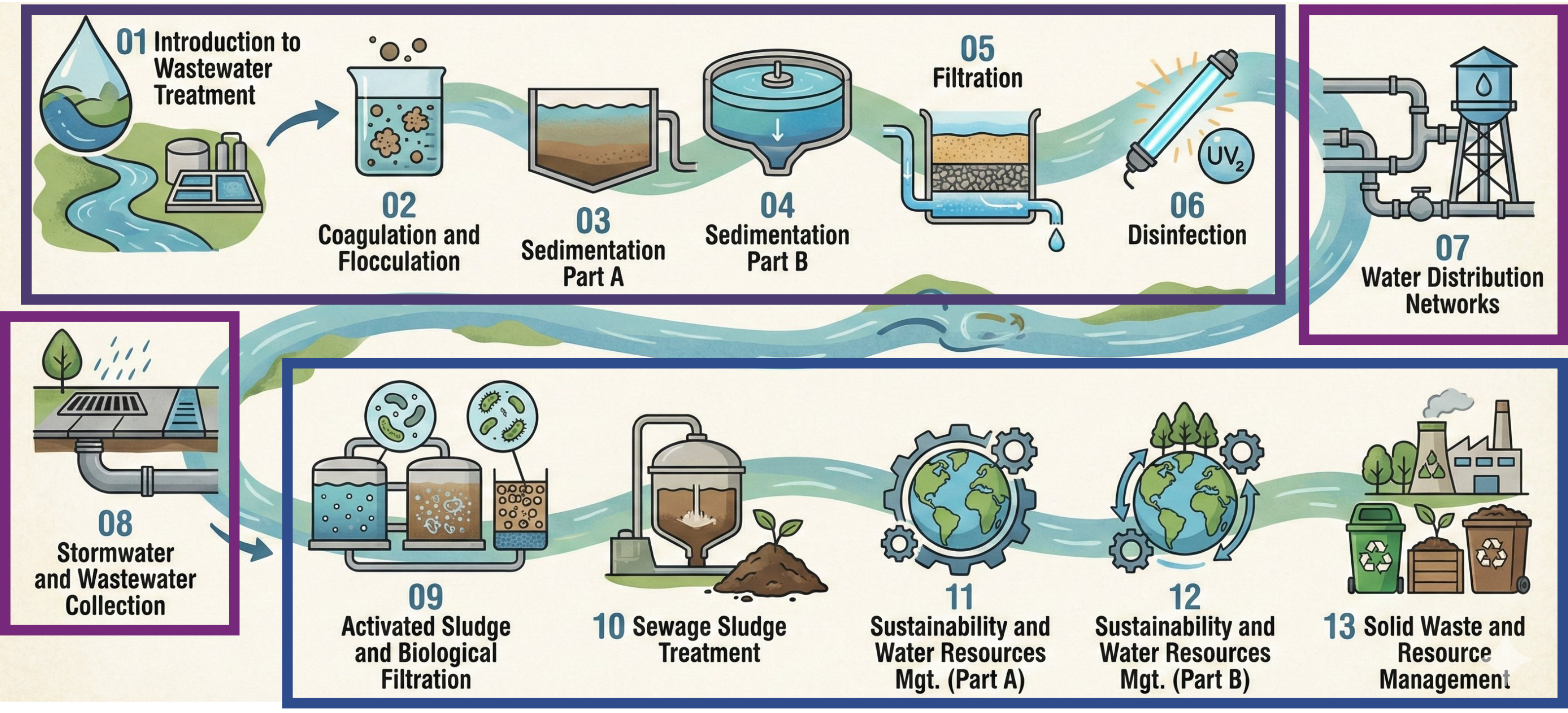


(L1 - L6: Traditional Water Treatment Process, L7 - L8: Water Distribution Network Management, L9 - L13: Post Treatment Phase)

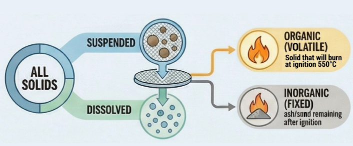
NOTE THAT THIS NOTE IS ENTIRELY GENERATED BY AI, WITH LOTS OF MODIFICATION BY MYSELF, CORRECTING ERROR AND HALLUCINATIONS. HOWEVER I CANT GUARANTEED IT IS PERFECT AND THERE MIGHT BE SOME ERROR HIDDEN, AND I WOULD DEFINITELY APPRECIATE ANY REPORTS OF ERROR IF YOU CAN FIND ONE. THANKS.

Lecture 1: Introduction to Wastewater Treatment

Factors affecting water use could include:
- Population growth
- Population demographics
- Tourism
- Climate
- Types of water users
- Economic conditions
- Environmental protection and conservation measures
- Management practices

FOUNDATIONAL CONCEPTS: SOLIDS & ORGANICS

UNDERSTANDING THE SOLIDS MATRIX



* all solids are after evaporating at 105°C!

		particulate		soluble
	TS	= TSS	+	TDS
	‖	‖		‖
organic	VS	= VSS (particulate organic, eg. bacteria)	+	VDS (soluble organic, eg. sugar)
550°C in Temp.	+	+		+
inorganic	TFS	= FSS (particulate inorganic, eg. sand, silt)	+	FDS (soluble inorganic, eg. salts)
			1μm in size	

T : Total
S : Solids or Suspended
D : Dissolved
V : Volatile
F : Fixed

- **TOTAL SOLIDS (TS)**: All material remaining after **evaporating** water from a sample at 105°C.
- **TOTAL SUSPENDED SOLIDS (TSS)**: Solids large enough to be trapped by a standard 1 μm filter.
- **TOTAL DISSOLVED SOLIDS (TDS)**: Solids small enough to pass through the filter.
- **VOLATILE SOLIDS (VS)**: The organic portion of solids, which burns off during ignition at 550°C.
- **FIXED SOLIDS (FS)**: The inorganic ash or sand that remains after ignition at 550°C.

BOD vs. COD: MEASURING ORGANIC CONTENT

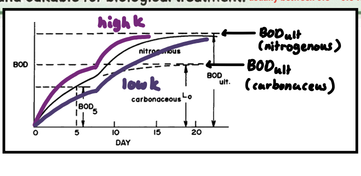
BIOCHEMICAL OXYGEN DEMAND (BOD)
Measures the oxygen consumed by microorganisms to biologically degrade organic matter
BOD_5 :Measure over 5 days
BOD_{ult}:Total demand (estimated)

VS

CHEMICAL OXYGEN DEMAND (COD)
Measures the oxygen equivalent to chemically **oxidises organic matter** using a strong chemical agent; takes only a few hours.

$BOD_5 < BOD_{ult} < COD$

KEY FINDING: ASSESS TREATABILITY WITH THE BOD/COD RATIO
If **$BOD_5/COD > 0.5$**, the wastewater is considered easily biodegradable and suitable for biological treatment. *usually between 0.3 ~ 0.8 for untreated municipal wastewater



CALCULATION GUIDE 1: SOLIDS ANALYSIS

EXAMPLE PROBLEM WALKTHROUGH
(BASED ON A 100 mL (0.1 L) SAMPLE)

EMPTY DISH	DISH + DRY SOLIDS	DISH + ASH
81.923 g	82.015 g (TS)	81.975 g (FS)
EMPTY DISH MASS: 81.923 g	DISH + DRY SOLIDS (AT 105°C): 82.015 g	DISH + ASH (AT 550°C):

1. CALCULATE TOTAL SOLIDS (TS) CONCENTRATION

Mass = 82.015 - 81.923 = 0.092 g (92 mg).

$$\text{Concentration} = \frac{92\ \text{mg}}{0.1\ \text{L}} = 920\ \text{mg/L}$$

2. CALCULATE VOLATILE SOLIDS (VS) CONCENTRATION

Mass Lost = 82.015 - 81.975 = 0.040 g (40 mg).

$$\text{Concentration} = \frac{40\ \text{mg}}{0.1\ \text{L}} = 400\ \text{mg/L}$$

3. CALCULATE FIXED SOLIDS (FS) CONCENTRATION

FS = TS - VS. Or you can straightaway calculate "Dish + Ash" - "Dish"

Concentration = 920 - 400 = 520 mg/L

*IF INSTEAD OF WEIGHT OF DISH, IT'S WEIGHT OF GLASS FIBRE FILTER DISH:
THE RESULTS WOULD BE TSS, VSS, AND VSS (CAUSE WHAT LEFT ON THE FILTER IS SUSPENDED SOLIDS)

CALCULATION GUIDE 2: BOD ANALYSIS

BASIC BOD FORMULA

$$BOD_5 = \frac{D_1 - D_2}{P}$$

D_1: Initial Dissolved Oxygen (DO)
D_2: Final DO
P: Dilution Factor

If "seed" bacteria are added to the dilution water, you must subtract their oxygen demand.

$$BOD_5 = \frac{(D_1 - D_2) - (B_1 - B_2)f}{P}$$

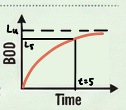
B_1, B_2: DO of the control (seed only) bottle.
f: Ratio of seed in sample vs. control (usually 1).

BOD KINETICS FORMULA

$$L_t = L_u(1 - 10^{-kt})$$

*Lu here is carbonaceous

L_t: BOD at time t (days)
L_u: Ultimate BOD
k: Reaction rate constant



EXAMPLE PROBLEM WALKTHROUGH

5 mL WASTEWATER SAMPLE ADDED TO 300 mL BOTTLE | INITIAL DO = 8.4 mg/L | FINAL DO = 3.7 mg/L | k = 0.1 d^{-1}

1. CALCULATE DILUTION FACTOR (P)

$$P = \frac{\text{Volume of Wastewater}}{\text{Total Volume}} = \frac{5\ \text{mL}}{300\ \text{mL}} = 0.0167$$

2. CALCULATE BOD_5

$$\frac{8.4 - 3.7}{0.0167} = 282\ \text{mg/L}$$

282 mg/L

3. CALCULATE ULTIMATE BOD (L_u)

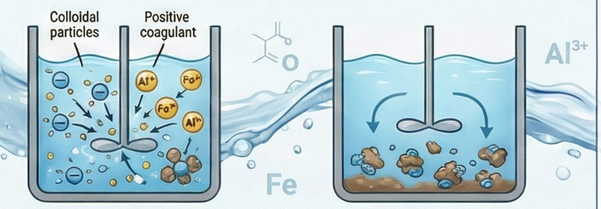
$$L_u = \frac{BOD_5}{1 - 10^{-kt}} = \frac{282}{1 - 10^{-(0.1*5)}} = 412\ \text{mg/L}$$

4. CALCULATE 20-DAY BOD (L_{20})

$$L_{20} = L_u(1 - 10^{-kt}) = 412 * (1 - 10^{-(0.1*20)}) = 408\ \text{mg/L}$$

Lecture 2: Coagulation and Flocculation

The Two-Step Process: Coagulation vs. Flocculation



Coagulation: Destabilize Particles

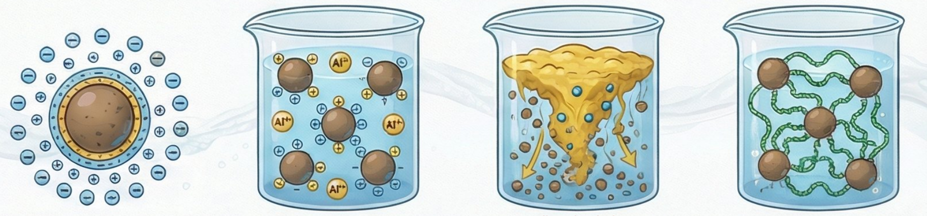
The addition of chemicals (coagulants) under fast mixing conditions to neutralize the charge of colloidal particles.

Van Der Waals force overcome electrostatic repulsion (colloidal particles are usually negatively charged)

Flocculation: Build Flocs

A slow mixing process that causes destabilized particles to collide and form larger, settleable aggregates called "floc ".

The 4 Mechanisms of Coagulation (Exam Favorite)



1. Diffuse Layer Compression

High ionic strength in the water compresses the electrical double layer around particles, reducing repulsive forces.

2. Charge Neutralization

Positively charged coagulant ions (like Al^{3+} or Fe^{3+}) adsorb onto negatively charged particles, neutralizing them.

Specific pH and coagulant dosage

3. Sweep Flocculation (Preferred Method)

A high coagulant dose creates a metal hydroxide precipitate that physically "sweeps" particles down as it settles.

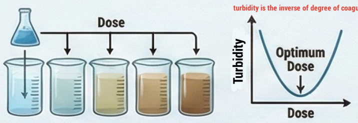
$Al(OH)_2^+ + H_2O \leftrightarrow Al(OH)_3(s) + H^+$

4. Inter-particle Bridging

Long polymer chains attach to multiple particles at once, physically bridging them together like a net.

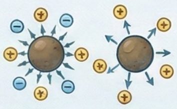
Practical Application & Key Concepts

turbidity is the inverse of degree of coagulation



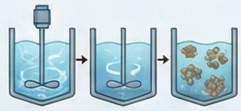
Finding the Sweet Spot: The Jar Test

A lab procedure used to find the optimum coagulant dose and pH by plotting **Turbidity** vs. **Dose**, which typically forms a U-shaped curve.



The Risk of Overdosing: Re-stabilisation

Adding too much coagulant can make particles positively charged, causing them to repel each other again and preventing floc formation.



Smart Mixing: Tapered Flocculation

Using a series of tanks with decreasing mixing Intensity (G) to **first** build large flocs and then prevent them from breaking apart.

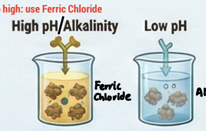
Alum + Alkalinity ⟶ $Al(OH)_3$ (floc) + CO_2

The Chemistry of Coagulation

Coagulants like Alum consume the water's natural alkalinity and produce CO_2. Insufficient alkalinity causes pH to drop, stopping the process.

*pH too low: add alkalinity; pH too high: use Ferric Chloride

buffering chemical: lime/soda ash



When to Use Ferric Chloride

For water with high pH or high alkalinity, Ferric Chloride is often preferred over Alum because it works effectively over a wider pH range.

Exam Calculation 1: Alkalinity Consumption

Problem: 30 mg/L of Alum (Molar Mass 600) is added to water with 100 mg/L of Alkalinity (Molar Mass 100). 1 mole of Alum consumes 3 moles of Alkalinity. Find the final alkalinity.

Step 1: Convert Alum Dose to Moles/L

$\frac{30 \text{ mg/L}}{600{,}000 \text{ mg/mol}}$ = 0.00005 mol/L of Alum.

Step 2: Calculate Alkalinity Consumed (Moles)

0.00005 mol/L Alum × 3 = 0.00015 mol/L of Alkalinity consumed.

Step 3: Convert Consumed Alkalinity to mg/L

0.00015 mol/L × 100,000 mg/mol = 15 mg/L of Alkalinity consumed.

Step 4: Final Alkalinity is 85 mg/L

Initial (100 mg/L) – Consumed (15 mg/L) = 85 mg/L remaining.

if initial < 15 mg/L
→ floc wouldn't form
→ add lime / soda ash.

Exam Calculation 2: Velocity Gradient (G)

The Velocity Gradient (G) Equation

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

G is mixing intensity, P is power, μ is viscosity, and V is tank volume. A typical range for G is 20-70 s^{-1}.

Problem: Calculate G for a tank (V=1600 m^3) with a power input of 1080 W and water viscosity of 1.002 x 10^{-5} kg/m-s. Flow(Q)=80ML/d

$$G = \sqrt{\frac{P}{\mu V}} = \sqrt{\frac{1000}{1.002 \times 10^{-3} \times 1600}} \approx 25 s^{-1}$$

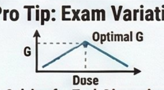
to find Gt, first find retention time, t:

$$Q = \frac{V}{t}, \quad t = \frac{V}{Q} = \frac{1600}{0.926} = 1728 s$$

$Gt = 25 \times 1728 = 43{,}200$ (Typical Gt = 10^4 to 10^5)

* Gt (dimensionless)
retention time

Pro Tip: Exam Variation



Solving for Tank Dimensions

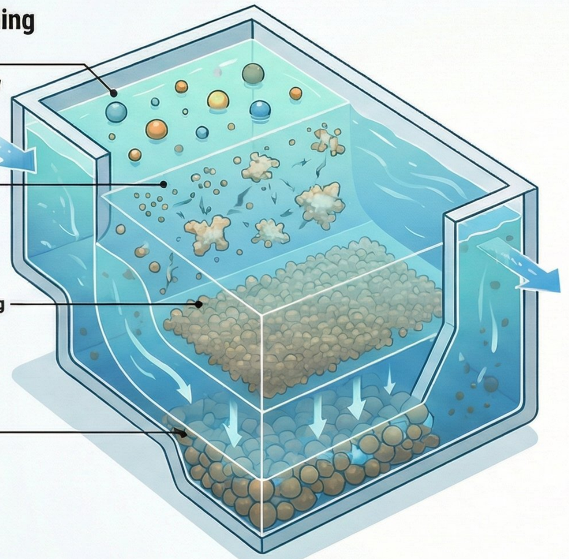
Some questions give you the optimal G (fium a graph) and ask you to calculate a required tank dimension, like Depth.

How to Solve

1. Read optimal G from the provided graph.
2. Rearrange the formula to solve for Volume: $G^2 = P/\mu V \rightarrow V = P/\mu G^2$
3. Calculate V, then find the missing dimension e.g., Depth = V /(Length × Width)

Lecture 3: Sendimentation Part A - Discrete Settling

The 4 Types of Settling



Type I: Discrete Settling

Individual particles settle independently without interacting. Their size, shape, and density remain constant.

(Example: Grit removal)

Type II: Flocculent Settling

Particles collide and aggregate (flocculate) as they settle, increasing in size and settling faster with depth.

(Example: Alum or Iron floc)

Type III: Hindered (Zone) Settling

Particle concentration is high, causing them to hinder (block) each other and settle as a unified "blanket" with clear water above.

(Example: Sludge thickening)

Type IV: Compression Settling

Concentration is so high that particles are in physical contact. Settling occurs as the weight of the particles squeezes water out

(Example: Bottom of a sludge tank)

Particle concentration from high to low.
Can occur in a same tank, from high to low.

Key Concepts & Formulas for Ideal Settling

Surface Overflow Rate (v_0)

This is the oritical design parameter representing the upward velocity of water. it is calculated as

$$v_0 = \frac{\text{Flow Rate (Q)}}{\text{Surface Area (A)}}$$

(covered next chapter)

The Removal Rule

$v_s \geq v_0$

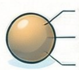
$v_s < v_0$

If $v_s \geq v_0$:
The particle setties faster than the upward velocity
Result: 100% Removal.

If $v_s < v_0$:
The particle settles slower than the upward velocity
Result: Partial Removal.
The percentage removed is $(v_s / v_0) \times 100$.

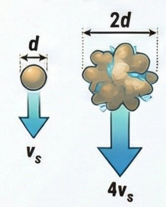
Stokes' Law (for Settling Velocity, v_s)

$$v_s = \frac{[g(S-1)d^2]}{18v}$$



g = Gravity (9.81 m/s^2)
S = Specific Gracity of
d = Particle Diameter (In meters)
v = Kinematic Viscosity of water (m^2/s)
→ if given dynamic viscosity, μ:
$v = \mu/\rho$

Theory Explained: Why Coagulation Works



Velocity is Proportional to Diameter Squared ($v_0 \propto d^2$). This relationship from Stokes Law is the key. Coagulation combines small particles into larger flocs, significantly increasing diameter (d).

Double the Size, Settle 4x Faster

Because of the squared relationship, a small increase in particle diameter leads to a massive increase in settling velocity, making treatment much more efficient.

Exam Problem Walkthrough: Calculating Settling Distance

1. Convert All Units to SI

Ensure all measurements are in meters (m) and seconds (s). (Example: 0.2 mm becomes 0.2 x 10^{-3}m; 10 minutes becomes 600 s).

2. Calculate Settling Velocity (v_s)

Plug the converted values into Stokes' Law. in the example, this yields v_s = 0.00382 m/s.

3. CRUCIAL CHECK - Reynolds Number

Stokes' Law is only valid for laminar flow (Re < 1). You must check this for full marks.

Formula: Re = (v_s · d) / v.

(Example: Re = 0.67, which is < 1, so the law is valid).

4. Calculate Distance Settled

Use the simple formula: **Distance = Velocity × Time.**

(Example: 0.00282 m/s × 600 s = 2.29 meters).

Question: How far would a discrete spherical particle of diameter **0.2 mm** and specific gravity **1.2** settle in **10 minutes**? Water temp is 15°C (Kinematic viscosity $v = 1.14 \times 10^{-6} m^2/s$).

Advanced Exam Method: Total Removal Calculation

1. Calculate v_s for Each Particle Size

For a given table of particle fractions, use Stokes' Law to find the settling velocity for every particle diameter listed.

2. Compare Each v_s to the Tank's v_0

For each particle size, determine if its settling velocity is greater or less than the tank's specified surface overflow rate.

3. Calculate Removal for Each Fraction

Particles with $v_s \geq v_0$ are 100% removed. For particles with $v_s < v_0$, the fraction removed is v_s / v_0.

4. Calculate Total Removal

Sum the removals:

Total = Σ(mass fractions for 100% removed particles) + ∑(mass fraction of partially removed particle × $[v_s / v_0]$).

(covered next chapter)

Why actual % of particle removal is less than settling column test?
- Inlet/outlet turbulence
- Wind effects
- Density currents from temperature gradients
- Equipment movement (may cause velocity gradients)
- Settling tank hydraulics (possible short-circuiting)
- Sludge storage volume is insufficient

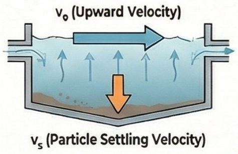
What happened to % of particle removed if Q increased? (eg. by 25%)

Q increases, v0 increases, less particle with vs > v0
Particle removed will be reduced by (1 - 1/1.25) × 100 = 20%

How to overcome?
Bring new sendimentation tank online.
Flow balancing tank added at inlet to maintain same flow rate.

Lecture 4: Sendimentation Part B - Analysis & Design

CORE CONCEPTS & TANK DESIGNS



What is Surface Overflow Rate (SOR or v_0)

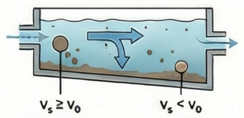
The "speed limit" for settling.

Particles must settle faster than the upward velocity of the water (v_0) to be effectively removed.

Calculated as Flow Rate (Q) / Surface Area (A).

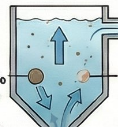
Horizontal Flow vs. Upflow Clarifiers

Horizontal Flow



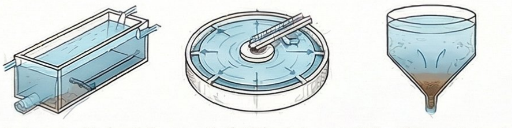
Horizontal flow tanks are more efficient because they can partially remove slow-settling particles.

Upflow Clarifier



ZERO removal if $v_s < v_0$, as slow particles are carried out with the upward flow.

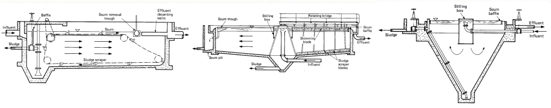
Common Tank Types



Rectangular (Horizontal)
Inlet at one end, outlet weir at the other, with a sludge scraper on the bottom.

Radial (Circular)
Central Inlet, water flows outwards to weirs on the edge, with a rotating bridge scraper.

Upflow (Hopper Bottom)
Funnel shaped tank where water enters low and flows up, with sludge collecting in the pointed bottom.



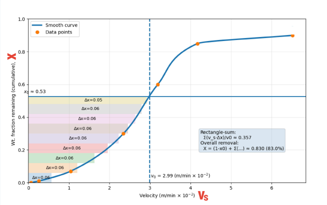
HOW TO CALCULATE TOTAL REMOVAL (GRAPHICAL METHOD)

(this is a settling column test)

The Master Equation for Total Removal (X)

Total Removal = (Removal of Fast Particles) + (Partial Removal of Slow Particles)

Formula: $X = (1 - x_0) + \int_0^{x_0} \frac{v_s}{v_0}\,dx$; or $X = (1 - x_0) + \sum \frac{\Delta x \cdot v_{s,avg}}{v_0}$



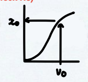
NOTE: If question gives a table as below,

Particle size (mm)	0.10	0.08	0.07	0.06	0.04	0.02	0.01
Mass fraction greater than size (%)	10	15	40	70	93	99	100

we need to first convert the table into x (Fraction ≤ size)

Particle size (mm)	0.01	0.02	0.04	0.06	0.07	0.08	0.10
Mass fraction smaller than size X	0.00	0.01	0.07	0.30	0.60	0.85	0.90
V_s (m/min × 10^-2)	0.07	0.26	1.05	2.37	3.23	4.22	6.59

Step 1: (you will need to find v_s first, and check Re)
Plot the Settling Curve: Using data from a settling column test, plot the fraction of particles remaining, x on the y-axis against their settling velocity, v_s on the x-axis.



Step 2:
Read off Cut-off Fraction (v_s): Draw a vertical line from the tank's design overflow rate (v_0) on the x-axis up to your curve. The y-value at this intersection is x_0.

Step 3:
Calculate Removal of Fast Particles: This is the fraction of particles with a settling velocity greater than v_0. The formula is simply $(1 - x_0)$.

Step 5:
Find the Total Removal Efficiency (X): Add the results from Step 3 add step 4 to get the total removal efficiency.

Step 4:
Calculate Partial Removal of Slow Particles: This is represented by the area under the curve to the left of the v_0 line. Approximate this by summing the area of small rectangular strips under the curve.

Example Result: For a design v_0 of 43 m/d, the calculation yielded: 0.47 (fast particles) + 0.36 (slow particles) = 0.83, or 83% Total Removal.

*Remember that this area still needs to be divided by v_0 before added with "$1 - x_0$"

Alternative method: Trapezoidal area method

Particle size (mm)	0.01	0.02	0.04	0.06	0.07	0.08	0.10
Mass fraction smaller than size X	0.00	0.01	0.07	0.30	0.60	0.85	0.90
V_s (m/min × 10^-2)	0.07	0.26	1.05	2.37	3.23	4.22	6.59

0.516
2.99

v0 = 2.99 × 10^-2 m/min
find x0 of v0 by linear interpolating:

$$\frac{0.60 - 0.30}{3.23 - 2.37} = \frac{x0 - 0.30}{2.99 - 2.37}$$

x0 = 0.516

$v_{s,n}$ $v_{s,n+1}$ Δx

$$\sum v_{s,avg} \times \Delta x = \tfrac{1}{2}(0.07+0.26)(0.01-0.00) + \tfrac{1}{2}(0.26+1.05)(0.07-0.01) + \tfrac{1}{2}(1.05+2.37)(0.30-0.07) + \tfrac{1}{2}(2.37+2.99)(0.516-0.30)$$
$$= 1.01313$$

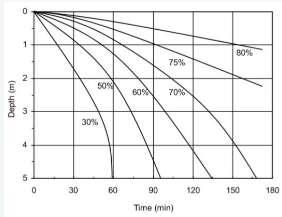
$$X = 1 - x_0 + \frac{\sum v_{s,avg} \times \Delta x}{v_0}$$
$$= 0.823 = 82.3\%$$

HOW TO CALCULATE TOTAL REMOVAL (ISO-REMOVAL CURVES)

Understanding Iso-Removal Curves

This is an alternative data format showing contour lines of equal removal percentage on a grid of tank depth vs. time.

example of an Iso-Removal Curve:



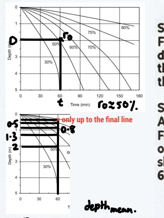
sometimes in exam it gives in the form of a table:

Table 2.1

Iso-removal fractions	Depth (m) *this is Dmean
50-60%	2.25
60-70%	1.35
70-75%	0.80
75-80%	0.60

(detention time = 60 min)

this table basically gives the value of all curves at t=60min



eg. $R_{total} = 0.5 + \left(\frac{\frac{2+1.3}{2}}{2} \times 0.1 + \frac{\frac{1.3+0.8}{2}}{2} \times 0.1 + \ldots\right)$

Step 1:
Determine Key Parameters: You will need the tank's total depth (D) and the detention time (t), which is calculated as Tank Volume / Flow Rate. ($Q = \frac{V}{t} \rightarrow t = \frac{V}{Q}$)

Step 2:
Find the Base Removal (r_0): On the graph, find your detention time (t). The value of the iso-removal curve that intersects the bottom of the tank (depth D) at that time is your r_0. (eg: t=60 min, D=2m)

Step 3:
Add Partial Removal Fractions:
For each iso-removal curve obove r_0, add a fraction of its removal contribution. This is calculated for each slice between curves (e.g., between the 50% and 60% lines). Formula:

$$R_{total} = r_0 + \sum \left[\frac{\text{Depth}_{mean}}{\text{Tank Depth}} \cdot (r_n - r_{n-1})\right]$$

In words: Add the base removal (r_0) to the sum of each additional removal percentage (e.g., 60%-50%) multiplied by the ratio of its average depth to the total tank depth.

this section might been removed from syllabus (last examined ~2021)

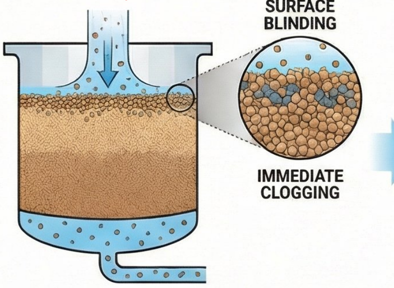
Issues increasing headloss overtime (too quickly):
- Upstream issues (eg. coagulation, flocculation, sendimentation) not removing sufficient particle. Optimise them.
- Backwash may not fully clean the filter. Test backwash rate.
- Shape and porosity of the filter media changes over time. Replace them.

Lecture 5: Filtration

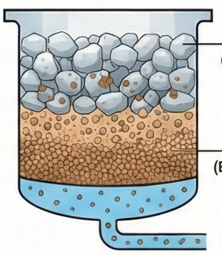
CORE FILTRATION CONCEPTS (EXAM THEORY)

THE DUAL MEDIA ADVANTAGE: WHY ANTHRACITE OVER SAND?

PROBLEM: SINGLE SAND FILTER
After backwashing, small sand grains settle at the top, causing immediate clogging, short filter runs, and inefficient use of the filter bed depth.
*known as "Surface Blinding"



SOLUTION: DUAL MEDIA FILTER
A top layer of large, light Anthracite traps coarse particles, while a bottom layer of small, heavy Sand traps fine particles. The density difference ensures the layers automatically re-stratify correctly after every backwash. Allows for TRUE DEPTH FILTRATION.

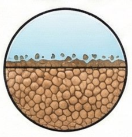


FACTORS AFFECTING HEADLOSS (h_L)

THESE INCREASE HEADLOSS ⇧
- Higher Flow Rate (V)
- Deeper Bed (L)
- Colder Water (higher viscosity μ)
- Angular/Jagged Media (higher shape factor ϕ)

THESE DECREASE HEADLOSS ⇩
- Larger Grain Size (d)
- Higher Porosity (e, more empty space)

WHAT IS FILTER RIPENING?



Initial period post-backwash; "too clean" and particle pass through too easily
Ripening is the period where particles begin to attach to the media; these particles acts as a filter for other particles, improving efficiency.
Water is filtered to waste during ripening

WHEN TO BACKWASH A FILTER?

- Headloss becomes too high (water can't pass through)
- Particle Breakthrough (High Turbidity)
- Maximum Time Limit (e.g., 48 hours).

THE HEADLOSS CALCULATION (A STEP-BY-STEP GUIDE)

THE FAIR-HATCH EQUATION

$$h_L = \frac{36kv(1-e)^2LV}{ge^3\phi^2} \times \sum\left(\frac{P_i}{d_i^2}\right)$$

KEY VARIABLES TO KNOW

- h_L: Headloss (m)
- k: Kozeny constant (~5)
- v: Kinematic viscosity (m²/s)
- e: Porosity (e.g., 0.45)
- V: Filtration Velocity (m/s)
- g: Gravity (9.81 m/s²)
- ϕ: Shape factor (~0.8)
- P_i: Mass fraction
- d_i: Geometric mean diameter (m)

watch out! usually given in m/h. Have to convert yourself!

STEP 1: PERFORM THE SIEVE ANALYSIS CALCULATION

Size Range (mm)	P_i (mass %)	Geometric Mean d_i (m)	Term: P/d_i^2 (m⁻²)
3.36 - 2.38	0.02	2.828 x 10⁻³	2,501
2.38 - 1.68	0.06	1.999 x 10⁻³	15,006
1.68 - 1.19	0.12	1.414 x 10⁻³	60,024
1.19 - 0.84	0.40	0.999 x 10⁻³	400,160
0.84 - 0.59	0.20	0.704 x 10⁻³	403,551
0.59 - 0.42	0.12	0.497 x 10⁻³	484,261
0.42 - 0.297	0.08	0.353 x 10⁻³	641,234
0.297 - 0.210	0.00	-	0
SUM	1.00		Σ = 2.0068 x 10⁸

Convert sieve data into the summation term.
Engine of the calculation.
Convert diameters to meters.

Example question:

Size of opening (mm)	% Mass retained
3.36	0
2.38	2
1.68	6
1.19	12
0.84	40
0.59	20
0.42	12
0.297	8
0.210	0

2.38 opening means 3.36-2.38 there is 2% mass

to find geometric mean,
$d_i = \sqrt{3.36 \times 2.38}$
$= 2.828$ mm
$= 2.828 \times 10^{-3}$ m

⚠ STEP 2: WATCH YOUR UNITS!

Most common mistake: Velocity. Convert from m/hour to m/s.

5 m/h ÷ 3600 s/h = 0.001389 m/s

STEP 3: PLUG IN VALUES AND SOLVE

$$h_L = \frac{36(5)(1.004{\times}10^{-6})(1-0.45)^2(0.001389)}{(9.81)(0.45)^3(0.8)^2} \times (2.0068 \times 10^6)$$

Substitute known values, including constants, porosity, velocity, bed depth (L = 0.7m), and the summation from the table.

FINAL RESULT **0.191 m**

*Tip: If you get a huge or tiny number, double-check your unit conversions, especially for diameter (mm to m).

ADVANCED CONCEPT: CONNECTING EQUATIONS

HEADLOSS (h_L) → BERNOULLI'S EQUATION

How Headloss Relates to Bernoulli's Equation: The headloss (h_L) in the Carman-Kozeny/Fair-Hatch equation is the "Losses" term in Bernoulli's energy equation. It quantifies the pressure drop caused by friction as water flows through the filter media.

bernoulli's eqn.:

$$P_1 + \tfrac{1}{2}\rho u_1^2 + \rho g h_1 = P_2 + \tfrac{1}{2}\rho u_2^2 + \rho g h_2 + \underbrace{h_L}_{\text{Fair Hatch's } h_L}$$

*THMs can be reduced by:
- remove precursor better by tweaking coagulations/flocculation
- switching to an alternative primary disinfectant
- add air stripping (but not preferred)

Ideal disinfectant:
i) Toxic to microorganisms
ii) Soluble in water and cell tissues
iii) Stable – can be stored prior to use
iv) Non-toxic to higher forms of life (at dose and residual used
v) Effective over the range of temperature and pH
vi) Should be able to penetrate surfaces (i.e. cell walls)
vii) Should be available in large amounts, reasonable $$
viii) Safe to handle
ix) Leave a measurable residual

Lecture 6: Disinfection

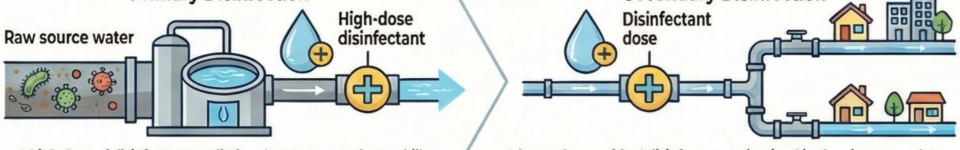
CHOOSING YOUR DISINFECTANT: THE BIG 4

price, effectiveness, by-product, strength, generation, taste, residual

Disinfectant	Pros	Cons
Cl_2 Chlorine	• Cheap • effective for bacteria/viruses • provides a protective residual	• Forms harmful by-products (THMs) • pH-dependent • ineffective against Cryptosporidium
ClO_2 Chlorine Dioxide	• Does not react with Ammonia • Much stronger than Chlorine. No strong disinfection dependence on pH. • Taste and odour control • Does not form THMs (unless excess chlorine present)	• Generation need to be well controlled to minimise excess free chlorine • Must be generated on sites (unstable) • Costs more than Chlorine
O_3 Ozone	• Very strong • kills Cryptosporidium • improves taste and odor • does not form halogenated byproducts (e.g. THMs)	• Expensive • complex to generate • leaves NO residual • can form Bromate by-product
UV Light	• Kills Cryptosporidium & Giardia • no chemical by-products (no THMs) • competitive costs • small space requirement	• Leaves NO residual • requires clear water (low turbidity) • lamps can foul • no taste control • doesn't remove colour

*Multi-barrier philosophy is we can use multiple disinfectant that covers each other weaknesses like UV and Chlorine.

CORE DISINFECTION PRINCIPLES

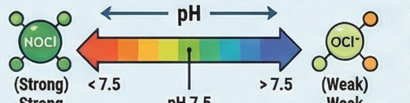


A high dose of disinfectant applied at the treatment plant to kill pathogens like bacteria, viruses, and protozoa in the raw water.

A lower-dose residual disinfectant maintained in the pipe network to prevent bacterial regrowth and protect against contamination from leaks.

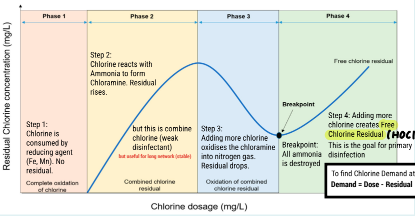
THE SCIENCE OF CHLORINE

The pH Effect: Lower pH = Stronger Disinfection



Lowering pH improves efficiency without adding more chlorine.

Breakpoint Chlorination



To find Chlorine Demand at any dosage:
Demand = Dose - Residual

THE "Ct" CONCEPT: THE CORE CALCULATION

The Golden Rule of Disinfection

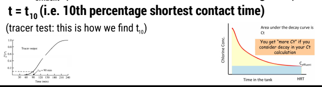
Ct (calculated) ≥ Ct (required)

*C usually given, find t = V/Q [min] | *find from table or equation

What is Ct?

Product of disinfectant Concentration (C, in mg/L) and effective contact time (t, in minutes), messuring overall disinfection power.

$C = C_{effluent}$ (i.e. disinfection concentration leaving tank)
$t = t_{10}$ (i.e. 10th percentage shortest contact time)
(tracer test: this is how we find t_{10})



*C (Concentration) is also sometime called Residual

How Water Quality Impacts Disinfection

1. **Lower pH** Improves chlorine disinfection
2. **Higher Temperature** improves disinfection (reactions are faster) required Ct decreases disinfection kinetic speeds up
3. **More Organic Matter** worsens disinfection (uses up chlorine) chlorine reacts with oxidisable organic compounds forms chloride no disinfecting power
   Also form THMs
4. **More Ammonia** (NH_3) Worsens disinfection (uses up chlorine) chlorine reacts with ammonia forms Chloramine (weak)

Chick-Watson inactivation kinetics

log(No/N) = kCt

No = initial number of organisms	log(No/N) = 1 (10% are surviving)
N = number of surviving organisms	log(No/N) = 2 (1% are surviving)
log(No/N) = log inactivation	log(No/N) = 3 (0.1% are surviving)

Solving a Typical Ct Problem

5. **Step 1: Find Required Ct** Use formula or look up value based on pH, temperature, target log removal. and concentration
6. **Step 2. Calculate Required Time (t)** Rearrange: t = Required Ct / Concentration (C).
   C is usually in mg/L also known as (chlorine) Residual or (chlorine) concentration
7. **Step 3. Calculate Max Flow Rate (Q)** Use tank volume (V) and required time (t): Q = V / t.

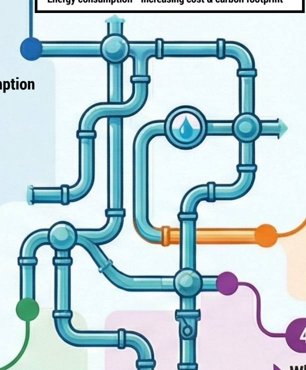
Find Ct(required) is easy, just use given formula.
Given Ct(required) and to find Ct of different target log:
eg. Ct (target 4 log inactivation) = 214
find target 3 log inactivation's Ct.

log(No/N) = kCt
4 = k(214) | 3 = 0.01869Ct
k = 0.01869 | Ct = 160.5
3 log's Ct

*NOTE: If specific pH (e.g. 7.3) is between two columns (7.0 and 7.5), you must linearly interpolate between the values to find Ct from the table.

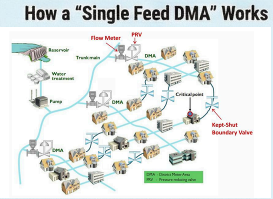
Lecture 7: Water Distribution Network

Operational challenges in managing water distribution network. (AISLE)
- Aging Infrastructure (~100 years old)
- Implementation of Real Time Control
- Service to Customer - water quality, increasing demand
- Leakage - Prevention and Detection (~25-30%)
- Energy consumption - increasing cost & carbon footprint



1. District Metered Areas (DMAs): The Most Common Question

How a "Single Feed DMA" Works



Main Purpose: Quantifying Leakage

DMAs are used to calculate the **Net Night Flow (NNF)**, which helps Isolate and measure water loss in a specific zone.

Leakage = Total inflow - Legitimate night consumption

What is a DMA?

A discrete, permanently hydraulically isolated area of a water network, typically serving 1000–3000 properties.

Only one single inlet, and closing boundary valves to neighbouring area

Pros vs. Cons of DMAs

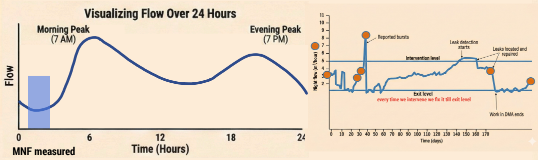
Pros
- **Detects bursts quickly** by monitoring night flow.
- Allows for **targeted pressure management.**
- Water Quality Management

Cons
- **Low Resilience:** If the inlet pipe fails, the entire area loses its water supply.
- **Water Quality Risk:** Closed valves create "**dead** ends," leading to water stagnation and sedimentation.
- Higher energy losses

2. Minimum Night Flow (MNF): Finding Hidden Leaks

The Golden Hours for Leak Detection are 2 AM - 4 AM

During this period, legitimate customer water consumption is at its lowest and most stable, making flow from leaks much easier to identify.



MNF measured between 2am - 4am

(Flow across one day) | (Minimum night flow for months)

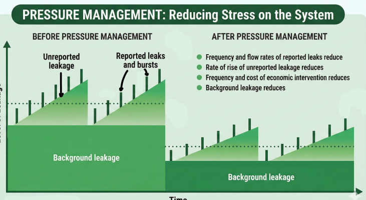
3. Pressure Management: Reducing Stress on the System

The FAVOUR Equation: Linking Leakage to Pressure

The relationship is defined as:

$$Q_{leak} \propto P^{N_1},$$

where N1 is usually greater **than 1**, meaning a small pressure drop causes a large leakage reduction.



Lower Pressure = Lower Leakage & Fewer Bursts

Reducing and stabilizing pressure has multiple direct benefits for the network's health and efficiency.

Top 3 Benefits of Pressure Control

1. Reduces background leakage.
2. Lowers burst frequency by preventing surges (water hammer). **Keeping pressure stable (calm)**
3. Extends the life of pipes and assets.

4. TOTEX & Risk: The Modern Approach to Pipe Renewal

What is TOTEX?

Total Expenditure (TOTEX) = Capital Expenditure (CAPEX) (building new things) + Operational Expenditure (OPEX) (running things).

This holistic view considers the whole-life cost of an asset.

Ways to enchance TOTEX efficiency in an aging water supply infrastructure:
a. Improve asset performance monitoring and modelling. **(opex)**
b. Implement pressure control/reduction within the water supply network as it reduces leakage and pipe failures. **(capex)**
c. Optimise pump scheduling (the operation of pumps) to reduce energy use. **(opex)**
d. Implement a risk-based pipe replacement and rehabilitation. **(capex)**

Strategy Shift: Replace Risky Pipes, Not Old Pipes

Modern asset management prioritizes pipes based on their risk profile rather than simply their age.

The Risk Calculation:
Risk = Probability of Failure × Consequence of Failure

5-Step Risk-Based Renewal Process

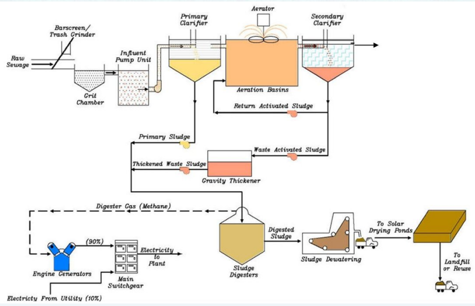
1. **Data Collection** Gather info on pipe age, **material**, soil, burst history.
2. **Probability Model** Use AI/stats to predict failure **likelihood**
3. **Consequence Model** Assess the impact of a failure e.g., flooding a hospital vs. a field).
4. **Risk Matrix** Plot Probability vs. Consequence to visualize high-risk assets.
5. **Decision** Prioritize and replace pipes in the high probability, high-consequence zone first.

Lecture 8: Stormwater and Wastewater Collection

A visual summary of key definitions, formulas, and step-by-step calculation methods for high-probability exam questions.

The Wastewater Treatment Plant (WWTP) Process Flow

A High-Probability Exam Question
Memorize the stages and their functions.



1. **A bar screen** is a mechanical filter for large objects removal, such as rags, plastics etc. (Pretreatment)
2. **A grit chambers** are basins to remove the inorganic particles to prevent damage to the pumps, and to prevent their accumulation in sludge digesters. (Pretreatment)
3. **A primary clarification** objective is suspended solids (SS) removal from wastewater under the sole influence of gravity. Settleable solids and floatable materials elimination is intended. (Primary Treatment)
4. **An aeration tank** uses microbes to remove soluble matter convert it to biomass and stabilise compounds. (Secondary Treatment) Activated Sludge
5. **A secondary clarifier** is to settle microorganisms so that the supernatant meets an effluent discharge standard. (Secondary Treatment)
6. **A gravity thickener** is to reduce water content in the secondary sludge. (Sludge Treatment)
7. **An anaerobic digester** is to convert organic biomass into biogas (mainly methane and CO2) for energy recovery. (Sludge Treatment)
8. **A sludge dewatering system** is to separate sludge into liquid ("the centre") and solid components for waste minimization. (Sludge Treatment)
9. (There is no tertiary treatment here e.g. **filtration / nutrient removal (N, P) / disinfection / polishing**.)

1. **Primary Treatment:** The objective is to remove large solids and suspended particles through sedimentation, producing sludge.
2. **Secondary Treatment:** The goal is to biologically degrade dissolved and suspended organic matter using microorganisms, further reducing the organic load.
3. **Tertiary Treatment:** This stage aims to remove any remaining impurities, including nutrients, and to disinfect the effluent before it is discharged into the environment.

Core Concepts & Definitions

Dry Weather Flow (DWF)
The average daily flow in a sewer during seven consecutive days without rain.

Formula:

$$DWF = PG + I + E$$

P = Population
G = Domestic consumption per person (L/head/day)
I = Infiltration (groundwater leaking into pipes)
E = Trade Effluent (industrial waste)

Combined Sewer Overflow (CSO)
A safety valve in older sewer systems that combines rainwater and sewage in one pipe

CSO Role 1: Hydraulic Protection
Prevent flooding at the WWTP by diverting excess flow during heavy rain into river/sea

CSO Role 2: Environmental Protection
Design to retain as much solid/ pollutant as possible (first flush) and only spill diluted water

What is the "First Flush"?
The highly polluted initial surge of stormwater that washes accumulated dirt from surfaces and must be captured for treatment

CSO setting: (i.e. Retained flow Qo)
traditional setting: $Q_o = 6 \times DWF$
formula A setting: $Q_o = DWF + 1360P + 2E$

other excess flow get spill, into a CSO storage. In which can hold a certain amount of volume before spilling into the river/sea

The Two Key Calculation Methods

Method 1: Foul Sewer Design (Wastewater)
Used to calculate the peak wastewater flow to size the sewer pipe correctly.

Step 1: Calculate Average DWF
Use the formula $DWF = (P \times G) + I + E$ convert the final value from L/day to L/s by dividing by $24 \times 60 \times 60$ (86,400)

Step 3: Calculate Peak Flow
Multiply the **DWF** by a Peak Factor, often calculated using **Babbitt's Formula**
Peak Factor = 5 / (P^0.2).
sometimes a, b given: factor $= \frac{a}{P^b}$

Babbitt's Formula Alert!
In this formula, the Population **P** must be in **thousands.** For 50,000 people, use P=50.

Method 2: Storm Sewer Design (The Rational Method)
A common method used to calculate the peak stormwater runoff

Step 1: Apply the Rational Formula

$$Q = 2.78 \cdot C \cdot i \cdot A$$

where Q is flow (L/s)

Rational Formula Variables
C = Runoff coefficient (0.0 to 0.1, 0.7 to 0.9 for urban)
i = Rainfall intensity (mm/hr)
A = Area (hectares)
2.78 is a unit coversion constant

Step 2: Find Rainfall Intensity (i)
I is found using a given formula
$i = \frac{a}{D+b}$ i - rainfall intensity (mm/hr), D - duration (min), a, b - constants

Step 3: Find Duration (D)
Duration is the same as the Time of Concentration (t_c), calculated as
t_c = time of entry (t_e) + time of flow (t_f)
t_e: time for rain to run off the road into pipe
t_f: time for water to travel through the pipe. (length ÷ velocity)

Worked Exam Problems

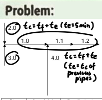
Problem 1: Foul Sewer Peak Flow Calculation
Problem: For a population of 37,500, calculate the DWF and then the Peak Flow.
Solution: *Sometimes I will be given as a % of P×G
1. **Calculate DWF:** Sum domestic, infiltration, and industrial flows. **DWF = (P×G) + I + E**
Total = 7,250,000 L/day.
2. **Convert DWF:** 7,250,000 / 86,400 = **83.9 L/s.**
3. **Find Peak Factor:** P = 37.5 (in thousands).
Factor = $5/(37.5^{0.2}) = 2.42$
4. **Calculate Peak Flow:** 83.9 L/s × 2.42 = **203 L/s.**

(Problem 1 is about how big sewage flow is)

Problem 2: CSO Setting Calculation
Problem: Determine the flow at which a CSO spills using Formula A for a **population of** 50,000.
Solution:
1. **Calculate DWF:** 80,000 people = 250 L/head/d = 12,500,000 L/day.
2. **Apply Formula A:**
Setting = DWF + 1360P + 2E.
= 12,500,000 + (1360×50,000) + (2×0)
= 80,500,000 L/day
3. **Convert to L/s:** 80,500,000 / 86,400 = **932 L/s.**

(Problem 2 is about how much combined flow is retained before the excess is spilled)

Problem 3: Storm Sewer Network (Rational Method)
Problem:



Pipe	Length (m)	Contributing impervious area (ha)
1.0	240	0.8
2.0	180	0.6
3.0	120	0.2
4.0	480	1.6
1.1	120	0.2
1.2	120	0.4

Q = 2.78CiA
C = 1, te = 5 min,
v = 2.0 m/s
i = 750/(10 + D)

Pipe number	Pipe length (m)	Contributing area (ha)	Time of flow, t_f (min)	Time of conc., t_c (min)	Rainfall intensity (mm·hour^{-1})	*Pipe capacity, Q ($l \cdot s^{-1}$)*
1.0	240	0.8	2	8.5	40.5	*180.1*
2.0	180	0.6	1.5	6.5	45.5	*75.9*
3.0	120	0.2	1	6	46.9	*26.1*
4.0	480	1.6	4	9	39.5	*175.7*
1.1	120	0.2	1	10	37.5	*354.5*
1.2	120	0.4	1	11	35.7	*377.1*

eg. Pipe 2:
$t_f = \frac{l}{v} = \frac{180}{2} = 90s = 1.5min$
$t_c = 1.5min + 5min = 6.5min$
$I = \frac{750}{10+6.5} = 45.5 mm/h$
$Q = 2.78(1)(45.5)(0.6) = 75.9 l/s$

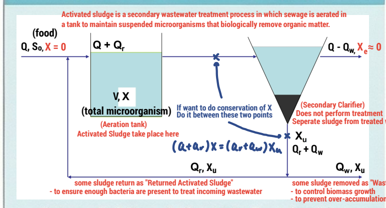
eg Pipe 1:
$t_f = \frac{240}{2} = 120s = 2min$
$t_c = 2min + \underbrace{6.5min}_{} = 8.5min$
for te it takes maximum of tc of previous pipes that it connects to!
$I = \frac{750}{10+8.5} = 40.5 mm/h$
$Q = 2.78(1)(40.5)\underbrace{(0.8+0.6+0.2)}_{} = 180.1 l/s$
for A it takes the sum of all previous pipes that it connects to!

(Problem 3 is about how big stormwater flow is)

Lecture 9: Activated Sludge and Biological Filtration

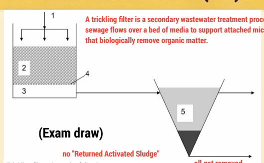
Two Core Processes: A Head-to-Head Comparison

ACTIVATED SLUDGE (AS)



- **Suspended Growth** (bacteria float freely)
- **High Power** (aeration pumps)
- **Complex Operation** (requires monitoring)
- **Small Footprint** (compact)
- **Common Issues:** Sludge Bulking (poor settling)

TRICKLING FILTER (TF)



Trickling filters have the following components:
1. a dosing system for applying wastewater
2. a bed of randomly packed solid media
3. an underdrainage system for wastewater collection
4. a ventilation system for supplying oxygen
5. a system for separating the detached biofilm (humus) from treated effluent

- **Attached Growth** (biofilm on media)
- **Low Power** (gravity, natural ventilation)
- **Simple Operation**
- **Large Footprint** (significant space)
- **Common Issues:** Flies, odors, filter clogging

Key Performance Indicators & Definitions

SLUDGE VOLUME INDEX (SVI)
Measures volume (mL) of 1 gram of sludge after 30 min settling. Indicates settling quality.

$$SVI = \frac{\text{Settled Volume (mL/L)} \times 1000}{\text{MLSS (mg/L)}}$$

50-150 mL/g: Good Settling
>150 mL/g: Sludge Bulking (poor settling)
due to growth of filamentous bacteria
- low F/M, low oxygen, low nutrients, low pH

$$\boxed{X_u = \frac{1}{SVI}}$$

NITRIFICATION
$NH_3 + 2O_2 \rightarrow NO_3^- + H^+ + \text{cells}$
(Ammonia) (Nitrate)

Requires Oxygen. **(Aerobic)**

DENITRIFICATION
Organic C + $NO_3^- \rightarrow N_2$ + cells
(Nitrate) (Nitrogen gas)

Requires no oxygen **(Anoxic)** needs carbon source.

The Activated Sludge "Holy Trinity": Essential Formulas

1. F/M RATIO
(Food-to-Microorganism)
Daily food (BOD) supplied to microorganisms (MLSS). Typical range: 0.2 – 0.5 kg BOD/kg MLSS·d.
low to medium ratio (bacteria: minor starving phase)

$$F/M = \frac{Q \cdot S_0}{V \cdot X}$$

Q = Flow rate (m³/d)
S_0 = Influent BOD (mg/L or g/m³) BOD after primary!
V = Tank Volume (m³)
X = MLSS (mg/L or g/m³)

2. HYDRAULIC RETENTION TIME
(HRT or θ)
Average length of time wastewater stays in the aeration tank.

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

V = Tank Volume (m³)
Q = Flow rate (m³/d)

if no sludge return:
mass in = mass out
$QX = \cancel{(Q-Q_w)X_e} + Q_w X_u$
$\theta_c = \frac{VX}{Q_w X_u} = \frac{VX}{QX} = \frac{V}{Q} = \theta$

3. SLUDGE AGE
(SRT or θ_c)
Average time a microorganism stays in the system before removal.

$$\theta_c = \frac{V \cdot X}{P_x}$$

V = Tank Volume (m³)
X = MLSS (mg/L or g/m³)
P_x = Sludge Production Rate (kg/d)
$(P_x = Q_w X_u + \underbrace{(Q-Q_w)X_e}_{\text{0 if we treat } X_e \neq 0})$

*FOR UNIT JUST REMEMBER: EVERY CONCENTRATION MG/L OR G/M³; ALL TIME UNIT DAY

Walkthrough 1: Activated Sludge Design Problem

Goal: Find MLSS concentration (X) and Daily Sludge Production (P_x)
Given: Flow=5,000 m³/d, Influent BOD=250 mg/l, F/M=0.3, HRT=6 hours, Sludge Age=6 days

Step 1: Critical Unit Conversions
Q=5,000 m³/d
S_0 = **250 mg/L**
θ=0.25 days **(HRT)**

Step 2: Calculate Tank Volume (V)
V = Q × θ
5,000 × 0.25 = 1,250 m³

Step 3: Calculate MLSS (X)
Rearrange F/M: $X = \frac{Q \cdot S_0}{V \cdot F/M}$

$$X = \frac{5{,}000 \cdot 250}{1{,}250 \cdot 0.3} = \mathbf{3{,}333\ mg/L}$$

Step 4: Calculate Daily Sludge Production (P_x)
Rearrange Sludge Age:

$$P_x = \frac{V \cdot X}{\theta_c} = \frac{1{,}250 \cdot 3.333}{6} = \mathbf{694\ kg/day}$$

Walkthrough 2: Trickling Filter Loading Problem

Goal: Calculate Organic & Hydraulic Loading Rates (DLR & HLR) and check criteria.
Given: Flow=3.2 Ml/d, BOD=200 mg/l, Two filters (42m diameter, 2m depth)

Step 1: Calculate Total Area and Volume
Total Surface Area = 2 * (π * (42/2)²) = 2,770.8 m²
Total Volume = Total Area * Depth = 2,770.8 * 2 = 5,541.6 m³

Step 2: Calculate Organic Loading Rate (OLR)

$$OLR = \frac{\text{Total BOD Load}}{\text{Total Volume}}$$

$$OLR = \frac{3.2 \cdot 10^3 \cdot 200 \cdot 10^{-3}}{5{,}541.6} = 0.115 \text{ kg BOD/m}^3\cdot d$$

Step 3: Calculate Hydraulic Loading Rate (HLR)

$$HLR = \frac{\text{Total Flow}}{\text{Total Surface Area}}$$

$$HLR = \frac{3{,}200}{2{,}770.8} = \mathbf{1.15\ m^3/m^2 \cdot d}$$

Step 4: Check Results Against Criteria
OLR (0.115) within 0.06-0.12 range: **OK**
HLR (1.15) within 0.25-1.2 range: **OK**

Loading rate:		
Organic	$= Q\,S_0/V$	0.06 - 0.12 kg BOD/m³·d
Hydraulic	$= Q / A_s$	0.25 - 1.2 m³/m²·d

OLR and F/M difference is OLR doesn't divide by X, as we can't measure or control MLSS concentration on the biofilm

Lecture 10: Sewage Sludge Treatment

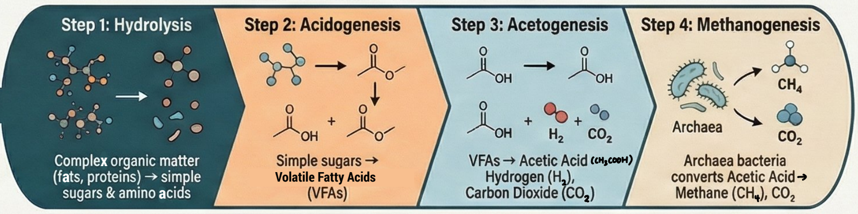
Key Concepts & Theory

Primary vs. Secondary Sludge

Primary Sludge
(From Primary Settlement)
Granular, grey, odorous, higher solid content (~4-6%)
Contains Inorganic solids (grit) and settleable organics.
(generated by gravity)

Secondary Sludge
(From Secondary Clarifier)
Light, flocculent, brown, mostly biomass, lower solid content (~0.5-2%)
(generated by converting BOD to activated biomass)

The 4 Stages of Anaerobic Digestion (AD) THESE VISUALS ARE INACCURATE



Biogas

Key Operating Conditions for AD

- **Temperature:** Mesophilic range (around 35°C)
- **Time:** Retention time typically 12-20 days
- **Output:** Biogas (~60% Methane CH_4 ~40% CO_2) often used for energy

Alternative Sludge Treatment Methods

Liming (raise pH>12)
Pro: Kills pathogens.
Con: increases final sludge mass.

Composting (Aerobic process)
Pro: Creates good soil conditioner.
Con: Requires large space & odour control.

Incineration
Pro: Reduces volume by **90%**, generates energy.
Con: High cost, potential public opposition.

Calculation 1: Sludge Production Walkthrough (How much sludge is produced?)

Key Formulas: Mass & Volume

Primary Mass (M_{ps}) = $\varepsilon \times SS_{in} \times Q$ (suspended solid removed in primary: $\varepsilon \times SS_{in}$)

Secondary Mass (M_{ss}) = $Y_{obs} \times BOD_{removed} \times Q$ (BOD removed in secondary: $BOD_{removed}$)

$$\text{Sludge Volume } (V_{sludge}) = \frac{\text{Mass of Dry Solids}}{\text{density of Sludge} \times \text{\%Dry solids}}$$

ϵ: Removal efficiency of primary tank.
SS_{in}: Influent Suspended Solids (mg/L or kg/m^3).
Q: Flow (m^3/d).
Y_{obs}: Yield coefficient (kg sludge / kg BOD removed).
$BOD_{removed}$: Amount of BOD removed in secondary treatment

Example Problem: Daily Sludge Volume

A WWTP treats **10,000 m^3/d** of wastewater.

Influent SS = **300 mg/L**.

Influent BOD = **250 mg/L**.

Primary Tank: Removes 60% of SS and 35% of BOD.
Primary sludge is **5% Dry Solids (DS)**.

Secondary Treatment: Removes 95% of remaining BOD.
Yield (Y_{obs}) = **0.4 kg SS / kg BOD**. Secondary sludge is **0.8% DS**.

Calculate Total Daily Sludge Volume (m^3/d) produced.

Step 1: Calculate Primary Sludge Mass (M_{ps})

$0.6 \times (0.3\ kg/m^3) \times (10,000\ m^3/d) = 1,800\ kg/day$

Step 2: Calculate Primary Sludge Volume (V_{ps})

$$\frac{1,800}{1000 \times 0.05} = 36\ m^3/day$$

Step 3: Calculate BOD removed in secondary treatment
Initial BOD (250 mg/L)
- primary treatment removes 35%
BOD after primary (250×0.65=162.5mg/L)
- secondary treatment removes another 95%
BOD removed in secondary treatment
= 0.95×162.5=154.4mg/L=0.1544kg/m³

Step 3: Calculate Secondary Sludge Mass (M_{ss})

$0.4 \times (0.1544\ kg/m^3) \times (10,000\ m^3/d) = 617.6\ kg/day$

Step 4: Calculate Secondary Sludge Volume (V_{ss})

$$\frac{617.6}{1000 \times 0.008} = 77.2\ m^3/day$$

Step 5: Calculate Total Daily Volume

$36\ m^3/day + 77.2\ m^3/day = 113.2\ m^3/day$

Calculation 2: Lab Solids Analysis Walkthrough

Key Formulas: Lab Analysis

$$\text{Total Solids (TS)} = \frac{\text{Mass Dried @ 105°C - Mass Dish}}{\text{Sample Volume}}$$

$$\text{Volatile Solids (VS)} = \frac{\text{Mass Dried @ 105°C - Mass Burnt @ 500°C}}{\text{Sample Volume}}$$

Example Problem: Solids Concentration

For a 100 mL sample:

- Dish = 81.923 g
- Dish + Dry Solids = 82.015 g
- Dish + Ash = 81.975 g

Step 1: Calculate Total Solids (TS) Concentration

Mass of Dry Solids = 82.015 g - 81.923 g = 0.092 g (92 mg)

$$TS = \frac{92\ mg}{0.1\ L} = 920\ mg/L$$

Step 2: Calculate Volatile Solids (VS) Concentration

Mass of Volatiles (lost on ignition) = 82.015 g - 81.975 g = 0.040 g (40 mg)

$$VS = \frac{40\ mg}{0.1\ L} = 400\ mg/L$$

Step 3: Calculate Fixed Solids (Ash)

TS - VS = 920 mg/L - 400 mg/L = 520 mg/L

(covered in chapter 1)

Lecture 11: Sustainability and Water Resource Management Part A

1. The Life Cycle Assessment (LCA) Framework

Life Cycle Assesament (LCA)
A methodology (ISO 14040/14044) for assessing the environmental impacts associated with all stages of a product's life.

Phase 1: Goal & Scope
Define the purpose, the functional unit (e.g., 'Treatment of 1 m³ of wastewater'), and the system boundaries.

Phase 2: Inventory Analysis (LCI)
Collect data on all inputs (energy, materials) and outputs (emissions, waste) for the system.

Phase 3: Impact Assessment (LCIA)
Convert the inventory data into potential environmental impacts, such as converting methane to CO_2 equivalents.

Phase 4: Interpretation
Identify significant issues ("hotspots"), draw conclusions, and make recommendations for improvement.

Essential LCA Vocabulary

Functional Unit: The reference unit for comparison (e.g., Treatment of 1 m³ of wastewater).

Cradio-to-Grave
Cradle-to-Oate
System Boundaries: Defines the scope, from "Cradle-to-Grave" or "Cradle-to-Gate".
raw material extraction to disposal
extraction to the factory gate (before use)

Hotspot: The stage or process with the largest environmental impact.

2. The Calculation: Carbon Footprint Formula

Carbon Footprint (Global Warming Potential - GWP)
A measure of the total greenhouse gas emissions caused by an activity, expressed as a single unit: kg CO_2 equivalents (kg CO_2e).

$$\text{Total GWP} = \sum \left(\text{Mass of Emission} \times \text{Characterisation Factor} \right)$$

This formula converts different greenhouse gases into a common unit based on their global warming potential relative to CO_2.

Greenhouse Gas	IPCC Characterisation Factor
Carbon Dioxide (CO_2)	1
Methane (CH_4)	~28
Nitrous Oxide (N_2O)	~265

3. Walkthrough: Calculating a WWTP's Carbon Footprint

EXAMPLE SCENARIO: A WWTP treats 50,000 m³/day of wastewater. We will calculate it's total annual carbon footprint and specific footprint per cubic meter of water treated.

Step 1: Calculate Scope 1 (Direct Emissions)
Convert all direct gas emissions from the plant into CO_2 equivalents.

CO_2: 1,200,000 kg × 1 = **1,200,000 kg CO_2e**
CH_4: 8,000 kg × 27.2 = **217,600 kg CO_2e**
N_2O: 1,200 kg × 273 = **327,600 kg CO_2e**

Total Scope 1 = 1,745,200 kg CO_2e/year

Step 2: Calculate Scope 2 (Indirect Energy Emissions)
Multiply energy consumption by grid emission factors to find the associated carbon footprint.

Electricity: 12,000,000 kWh × 0.233 = **2,796,000 kg CO_2e**
Natural Gas: 500,000 kWh × 0.184 = **92,000 kg CO_2e**

Total Scope 2 = 2,888,000 kg CO_2e/year

Step 3: Calculate Total Carbon Footprint
Add Scope 1 and Scope 2 emissions together for the final annual total.

1,745,200 + 2,888,000 = **4,633,200 kg CO_2e/year**

Step 4: Calculate Specific Footprint
Divide the total footprint by the annual volume of treated water to get the footprint per functional unit (1 m³).

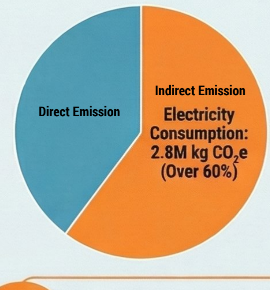
Total Annual Flow = 50,000 m³/day × 365 days = 18,250,000 m³/year

$$\frac{4,633,200\ kg\ CO_2e}{18,250,000\ m^3} = 0.254\ kg\ CO_2e/m^3$$

0.254 kg CO_2e/m³

4. Interpretation: Identify the Hotspot & Suggest Improvements

Hotspot Identified: Electricity Consumption



Solution A: Decarbonise Power
Install on-cite renewable energy like solar panels or switch to a green electricity tariff from the provider.

Solution B: Improve Energy Efficiency
Implement measures like replecing oid, inefficient pumps and optimising the aeration control systems.

Solution C: Generate Your Own Energy
Install an Anaerobic Digester to convert sludge into biogas, which can be used to generate electricity and heat (CHP).

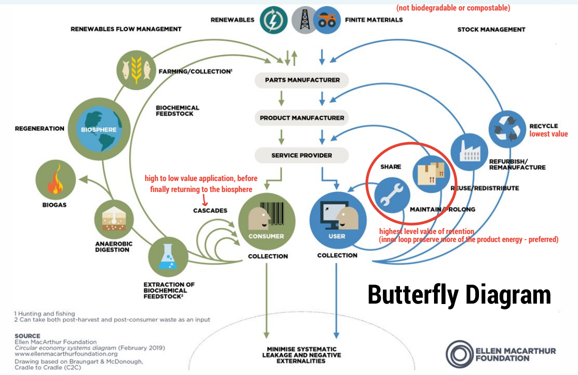
What is a sensitivity analysis?
After hotspots are identified, sensitivity analysis test how changes/modification in key assumptions (such as using renewable energy) affect the final environmental impact results.

Lecture 12: Sustainability and Water Resource Management Part B

THE CORE THEORY: TWO CYCLES OF THE CIRCULAR ECONOMY

BIOLOGICAL CYCLE:
Material that can biodegrade and safely return to biosphere
(single use before returning to biosphere, cannot be reuse for the same purpose)

TECHNICAL CYCLE:
Product that can be used rather than consumed. Focus on how each step allow material to remain in use.
(not biodegradable or compostable)



KEY RESOURCE RECOVERY TECHNOLOGIES

- **Carbon:** Anaerobic Digestion (creates biogas); Fine Sieves (creates cellulose)
- **Phosphorus:** Struvite Precipitation (creates fertiliser)
- **Nitrogen:** Nitrogen Stripping (creates ammonia)
- **Water:** Membrane Filtration (for water reuse); Reverse Osmosis

Problem Walkthrough: Closing Mass Balance

A WWTP treats **12,000 m^3/d**. You are given inlet loads, some outlet data, emission factors, and biogas data. You need to close the mass balance (complete the table) and calculate recovery rates. Which resource has the greatest potential for improvement, and what technology could be used?

Inlet				Outlet			
Wastewater Inlet	Water	12,000	m^3/d	Wastewater Effluent	Water	11,990	m^3/d
	Nitrogen	1.0	t/d		Nitrogen	0.05	t/d
	Phosphorus	0.15	t/d		Phosphorus	0.01	t/d
	Carbon (COD)	2.5 (7.1)	t/d (t/d)		Carbon	0.05	t/d
				Grit, Screenings, FOG (solid waste)	Water	1.0	m^3/d
					Carbon	0.35	t/d
				Gas Emissions	Carbon (CO_2)	0.4	t/d
					Carbon (CH_4)	0.05325	t/d
					Nitrogen (N2)	0.65	t/d
					Nitrogen (N2O)	0.02	t/d
				Biogas	Carbon (CO2)	1.085	t/d
					Carbon (CH4)	0.671	t/d
				Biosolids	Water		m^3/d
					Nitrogen		t/d
					Phosphorus		t/d
					Carbon		t/d

these can be found easily without doing mass balance.

only these two are recovered when finding recovery rate.

- CH_4 emission factor – 0.0075 t CH_4 / tCOD inlet
- N_2O emission factor – 0.02 tN_2O / tN inlet
- 1,565 m3/d biogas produced, methane content of 65% (volume basis), density of methane (0.66 kg/m3), density of carbon dioxide (1.98 kg/m3)

THE CALCULATION FRAMEWORK

The Golden Rule: Mass Balance

Mass IN = Mass OUT

example:

Mass_{in} = Effluent + Gas Emission + Biogas + Biosolids

Measuring Success: The Recovery Rate

$$\text{Recovery Rate (\%)} = \frac{\text{Mass Recovered as Product}}{\text{Mass Input}} \times 100$$

What Counts as "Recovered"?

- **Biogas:** Always recovered.
- **Biosolids:** Only if used as fertilizer.
- **Treated water:** Only if reused, not discharged to sea.

Step 1: Calculate Fugitive Gas Emissions

Calculate the mass of Carbon and Nitrogen lost to the atmosphere as leaks.

1. **Methane (CH_4):**
   - Total Mass $CH_4 = 0.0075 \times 7.1$ (COD load) $=$ **0.05325 t/d.**
   - Carbon Fraction in CH_4: $12/(12+4) = 0.75$.
   - **Carbon Mass:** $0.05325 \times 0.75 = \mathbf{0.040\ t/d}$.
2. **Nitrous Oxide (N_2O):**
   - Total Mass $N_2O = 0.02 \times 1.0$ (N load) $=$ **0.02 t/d.**
   - Nitrogen Fraction in N_2O: $(2 \times 14)/((2 \times 14) + 16) = 28/44 = 0.636$.
   - **Nitrogen Mass:** $0.02 \times 0.636 = \mathbf{0.0127\ t/d}$.

Step 2: Calculate Biogas Composition

Calculate the mass of Carbon recovered in the Biogas stream.

1. **Methane (CH_4):**
   - Volume = $1{,}565 \times 0.65 = 1{,}017.25\ \text{m}^3$.
   - Mass = $1{,}017.25 \times 0.66$ (density) $= 671.4$ kg $=$ **0.671 t/d.**
   - Carbon Fraction in CH_4: $12/(12+4) = 0.75$.
   - **Carbon Mass:** $0.671 \times 0.75 = \mathbf{0.503\ t/d}$.
2. **Carbon Dioxide (CO_2):**
   - Volume = $1{,}565 \times 0.35 = 547.75\ \text{m}^3$.
   - Mass = 547.75×1.98 (density) $= 1{,}084.5$ kg $=$ **1.085 t/d.**
   - Carbon Fraction in CO_2: $12/(12+32) = 12/44 = 0.273$.
   - **Carbon Mass:** $1.085 \times 0.273 = \mathbf{0.296\ t/d}$.

Step 3: Biosolids Mass Balance (The "Fill the Gap" Step)

Use the principle: Input = Sum(Outputs).
We are solving for the unknown Biosolids value.

1. **Water Balance:**
   $\text{Biosolids}_{water} = \text{In} - (\text{Effluent} + \text{Solid Waste})$
   $\text{Biosolids}_{water} = 12{,}000 - (11{,}990 + 1.0) = \mathbf{9\ m^3/d}$
2. **Nitrogen Balance:**
   $\text{Biosolids}_N = \text{In} - (\text{Effluent} + \text{Gas } N_2 + \text{Fugitive } N_2O)$
   $\text{Biosolids}_N = 1.0 - (0.05 + 0.65 + 0.0127)$
   $\text{Biosolids}_N = 1.0 - 0.7127 = \mathbf{0.287\ t/d}$
3. **Phosphorus Balance:**
   $\text{Biosolids}_P = \text{In} - (\text{Effluent})$
   $\text{Biosolids}_P = 0.15 - 0.01 = \mathbf{0.14\ t/d}$
4. **Carbon Balance:**
   $\text{Biosolids}_C = \text{In} - (\text{Effluent} + \text{Solid Waste} + \text{Gas } CO_2 + \text{Fugitive } CH_4 + \text{Biogas } C)$
   $\text{Biosolids}_C = 2.5 - (0.05 + 0.35 + 0.4 + \underset{CH_4}{0.040} + \underbrace{0.799}_{\underset{CH_4}{0.503}\ \underset{CO_2}{0.296}})$
   $\text{Biosolids}_C = 2.5 - 1.639 = \mathbf{0.861\ t/d}$

Step 4: Calculate Recovery Rates

Treat Biogas and Biosolids as "Recovered Products". Treat Effluent and Emissions as "Losses".

1. **Water Recovery:**
   $\frac{\text{Biosolids Water}}{\text{Total Input}} = \frac{9}{12{,}000} = \mathbf{0.075\%}$
   (Note: This assumes effluent is discharged to sea, not reused).
2. **Carbon Recovery:**
   Recovered = Biosolids C + Biogas C = 0.861 + 0.799 = 1.66 t/d
   $\text{Rate} = \frac{1.66}{2.5} = \mathbf{66.4\%}$
3. **Nitrogen Recovery:**
   Recovered = Biosolids N = 0.287 t/d
   $\text{Rate} = \frac{0.287}{1.0} = \mathbf{28.7\%}$
4. **Phosphorus Recovery:**
   Recovered = Biosolids P = 0.14 t/d
   $\text{Rate} = \frac{0.14}{0.15} = \mathbf{93.3\%}$

Step 5: Interpretation & Improvement Strategy

This is the final part of the exam question (usually worth 2-4 marks).

Question: Which resource has the greatest potential for improvement, and what technology could be used?

1. **Identify the Weakness:**
   - Compare the rates: P (93%), C (66%), N (29%), Water (0.075%).
   - **Water** is the clear priority for improvement (it is currently treated as waste).
2. **Suggest Technology:**
   - To turn the effluent (currently "waste") into a "product", we need **Tertiary Treatment**.
   - **Configuration:** Add **Ultrafiltration (UF)** and **Reverse Osmosis (RO)** followed by UV disinfection.
3. **Suggest Use Case:**
   This treated water can be used for **non-potable applications**: Irrigation (agriculture/parks), Industrial process water, or Toilet flushing.

Lecture 13: Solid Waste and Resource Management

Foundational Concepts

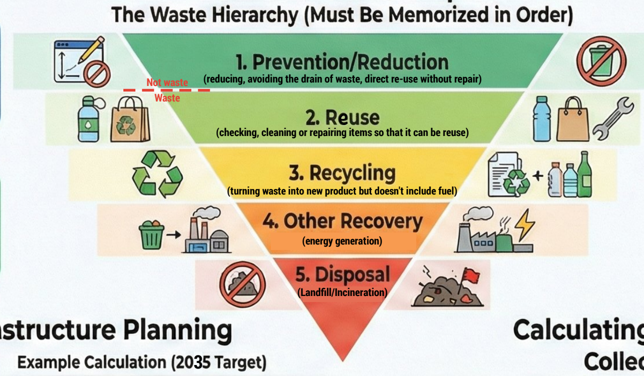
Municipal Solid Waste (MSW)

Waste from households plus similar waste from commercial or institutional sources that is collected by the municipality.

End-of-Waste Status

The point at which waste undergoes a recovery operation and is officially considered a product, not waste.

The Waste Hierarchy (Must Be Memorized in Order)



Solid Recovered Fuel (SRF)

A fuel produced by shredding and dehydrating solid waste, commonly used in energy-intensive industries like cement kiln

Plastic Pollution Terms

- **Leakage:** Waste that escapes the management system.
- **Macroplastics (>5mm)** degrade into **Microplastics (<5mm)**.

The Main Calculation: Infrastructure Planning

4-Step Logic for Planning

This process determines how many new facilities (e.g., Energy from Waste plants) are needed to meet future waste diversion targets.

Example Calculation (2035 Target)

Step	Calculation	Result
1. Future Waste (2035)	15,000,000 tpa × $(1 + 0.01)^{10}$	16,569,000 tpa
2. Target Mass (60%)	16,569,000 tpa × 0.60	9,941,400 tpa
3. Number of Plants	9,941,400 tpa / 400,000 tpa/plant = 24.85	25 Plants (Rounded Up)
4. Total Energy	25 Plants × 25 MW/plant	625 MW

1. Calculate Future Waste Generation

$$W_{future} = W_{current} \times (1+r)^n$$

W: Waste amount (tonnes per annum, tpa).
r: Growth rate (decimal, e.g., 1% = 0.01).
n: Number of years.

2. Calculate the Target Mass to Treat

Multiply the future waste generation by the target diversion percentage

Target Load= W_{future} × target % (eg. 60%)

3. Calculate the Number of Plants

$$N = \frac{\text{Target Load}}{\text{Plant Capacity}}$$

Always round the result UP to the next whole number.

4. Calculate Total Energy Output

Multiply the final number of plants by the energy generated per plant.

Calculating the 'True' Recycling Rate

Collection Rate vs. True Rate

The initial amount collected for recycling is not what's actually recycled. True rates must account for losses.

Initial Collection (e.g., 100 tonnes)

Step 1: Account for Sorting Rejects
Subtract contamination and other rejects at the sorting facility. Example: 100 tonnes collected × (1 - 0.20 reject rate) = 80 tonnes.

Step 2: Account for Reprocessing Loss
From the sorted material, subtract losses that occur during the actual recycling process. Example: 80 tonnes × (1 - 0.10 process loss) = 72 tonnes.

72%
Final Net Recycling Rate: 72%
The final mass (72t) divided by the initial mass (100t) gives the true rate, which is much lower than a misleading 100% "collection rate".

Why True Recycling Rate is less than Collection Rate?
Collection rate measures all material collected for recycling.
True recycling rates accounts for losses due to contamination, processing inefficiencies.