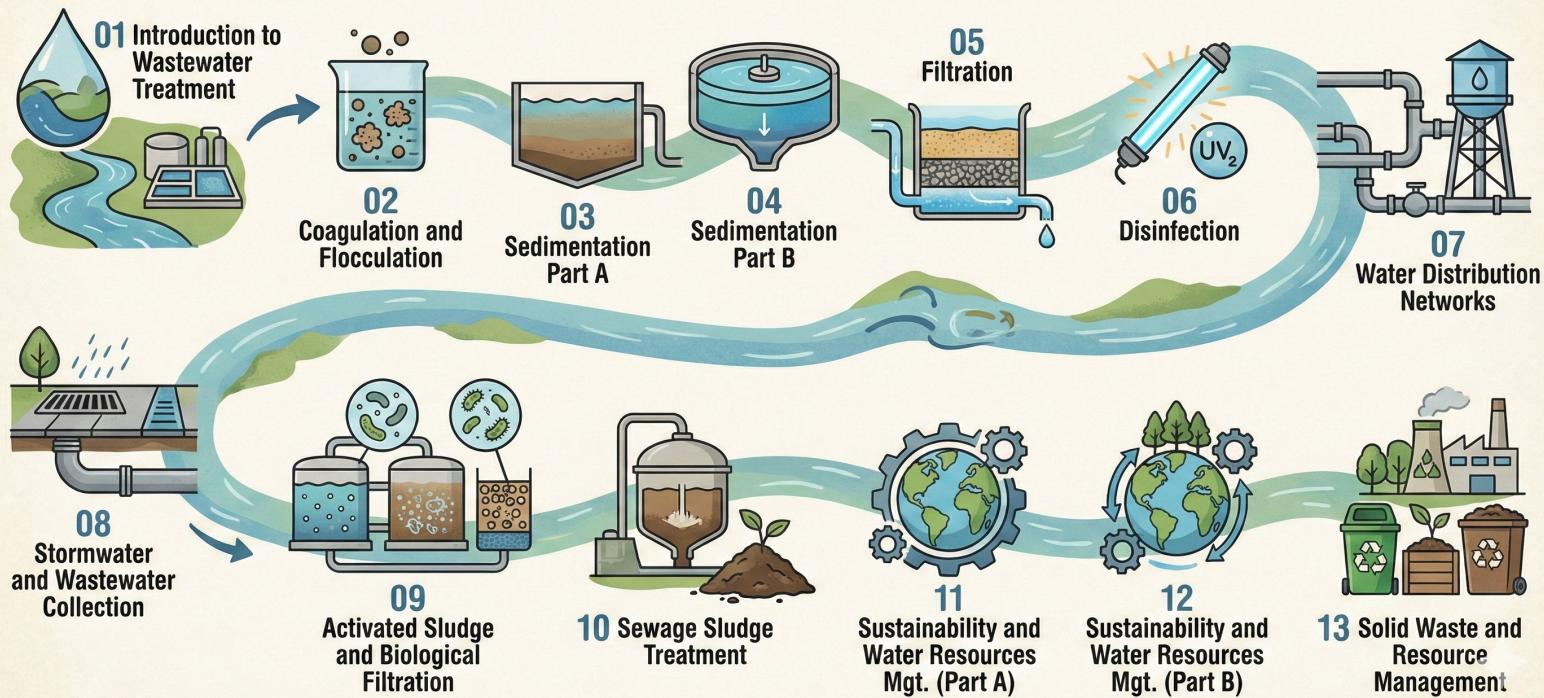


# Table of Content



(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

### FOUNDATIONAL CONCEPTS: SOLIDS & ORGANICS

#### UNDERSTANDING THE SOLIDS MATRIX

**ALL SOLIDS** = **SUSPENDED** + **DISSOLVED**

**ORGANIC (VOLATILE)** Solid will burn at ignition 550°C.

**INORGANIC (FIXED)** Ash remains after ignition.

**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 1µm 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.

**BIOCHEMICAL OXYGEN DEMAND (BOD)** Measures the oxygen consumed by microorganisms to biologically degrade organic matter.

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

**KEY FINDING: ASSESS TREATABILITY WITH THE BOD/COD RATIO**  
If  $BOD_5/\text{COD} > 0.5$ , the wastewater is considered easily biodegradable and suitable for biological treatment.

### 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**  
 $\text{Mass} = 82.015 - 81.923 = 0.092 \text{ g (92 mg)}.$   
 $\text{Concentration} = \frac{92 \text{ mg}}{0.1 \text{ L}} = 920 \text{ mg/L}$
- 2. CALCULATE VOLATILE SOLIDS (VS) CONCENTRATION**  
 $\text{Mass Lost} = 82.015 - 81.975 = 0.040 \text{ g (40 mg)}.$   
 $\text{Concentration} = \frac{40 \text{ mg}}{0.1 \text{ L}} = 400 \text{ mg/L}$
- 3. CALCULATE FIXED SOLIDS (FS) CONCENTRATION**  
 $FS = TS - VS.$  Or you can straightaway calculate "Dish + Ash" - "Dish"  
 $\text{Concentration} = 920 - 400 = 520 \text{ mg/L}$

### CALCULATION GUIDE 2: BOD ANALYSIS

#### BASIC BOD FORMULA

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

D<sub>1</sub>: Initial Dissolved Oxygen (DO)  
D<sub>2</sub>: Final DO  
P: Dilution Factor

#### BOD KINETICS FORMULA

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

L<sub>t</sub>: BOD at time t  
L<sub>u</sub>: 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<sup>-1</sup>

- 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<sub>5</sub>**  
 $\frac{8.4 - 3.7}{0.0167} = 282 \text{ mg/L}$  282 mg/L
- 3. CALCULATE ULTIMATE BOD (L<sub>u</sub>)**  
 $L_u = \frac{BOD_5}{1 - 10^{-kt}} = \frac{282}{1 - 10^{-(0.1 \cdot 45)}} = 412 \text{ mg/L}$
- 4. CALCULATE 20-DAY BOD (L<sub>20</sub>)**  
 $L_{20} = L_u(1 - 10^{-kt}) = 412 * (1 - 10^{-(0.1 \cdot 20)}) = 408 \text{ mg/L}$

# Lecture 2: Coagulation and Flocculation

## The Two-Step Process: Coagulation vs. Flocculation



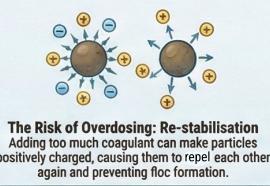
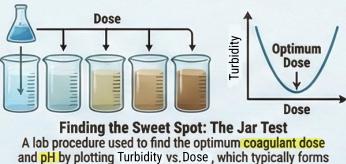
**Coagulation: Destabilize Particles**  
The addition of chemicals (coagulants) under fast mixing conditions to neutralize the charge of colloidal particles.

**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)



## Practical Application & Key Concepts



$$\text{Alum} + \text{Alkalinity} \rightarrow \text{Al(OH)}_3 + \text{CO}_2 \text{ (floc)}$$

**The Chemistry of Coagulation**  
Coagulants like Alum consume the water's natural alkalinity and produce  $\text{CO}_2$ . Insufficient alkalinity causes pH to drop, stopping the process.

**High pH/Alkalinity**      **Low pH**

$\text{Ferric Chloride}$        $\text{Alum}$

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

**Step 2: Calculate Alkalinity Consumed (Moles)**  
 $0.00005 \text{ mol/L Alum} \times 3 = 0.00015 \text{ mol/L of Alkalinity consumed.}$

**Step 3: Convert Consumed Alkalinity to mg/L**  
 $0.00015 \text{ mol/L} \times 100,000 \text{ mg/mol} = 15 \text{ mg/L of Alkalinity consumed.}$

**Step 4: Final Alkalinity**  
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

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

G is mixing intensity, P is power,  $\rho$  is viscosity, and V is tank volume. A typical range for G is 20-70 s<sup>-1</sup>.

**Problem:** Calculate G for a tank ( $V=1600 \text{ m}^3$ ) with a power input of 1080 W and water viscosity of  $1.002 \times 10^{-3} \text{ kg/m}\cdot\text{s}$ .  $G=80 \text{ MLD}$

$$G = \sqrt{\frac{P}{\rho V}} = \sqrt{\frac{1080}{1.002 \times 10^{-3} \times 1600}} \approx 25 \text{ s}^{-1}$$

To find G, first find retention time, t :

$$Q = \frac{V}{t}, t = \frac{V}{Q} = \frac{1600}{1.002 \times 10^{-3}} = 1728 \text{ s}$$

$$G = 25 \times 1728 = 43,200$$

### Pro Tip: Exam Variation

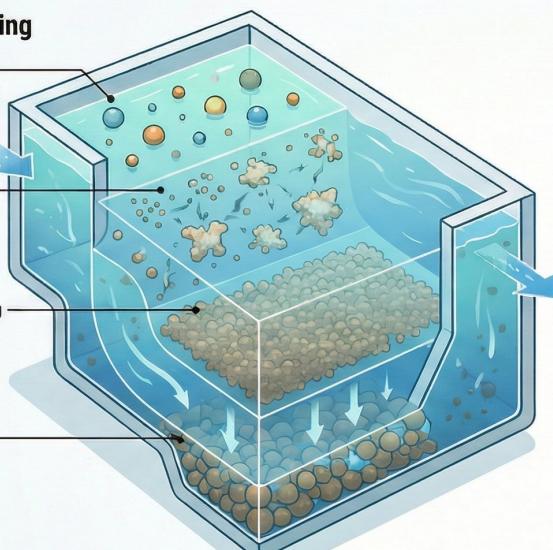
**Solving for Tank Dimensions**  
Some questions give you the optimal G (from a graph) and ask you to calculate a required tank dimension, like Depth.

- How to Solve:**  
1. Read optimal G from the provided graph.  
2. Rearrange the formula to solve for Volume:  
 $G^2 \cdot \rho V \rightarrow V = \frac{G^2}{\rho} \cdot A$   
3. Calculate V, then find the missing dimension e.g., Depth = V / (Length × Width)

# Lecture 3: Sedimentation 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 (flock) 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)

## Key Concepts & Formulas for Ideal Settling

**The Removal Rule**

$$v_s \geq v_o$$

**Surface Overflow Rate ( $v_o$ )**  
This is the critical design parameter representing the upward velocity of water. It is calculated as

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

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

**Stokes' Law (for Settling Velocity,  $v_s$ )**  
 $v_s = \frac{[g(S-1)d^2]}{18v}$   
g = Gravity (9.81 m/s<sup>2</sup>)  
S = Specific Gravity of water (1)  
d = Particle Diameter (in meters)  
v = Kinematic Viscosity of water (m<sup>2</sup>/s)  
→ If given dynamic viscosity,  $\eta$ :  
 $v_s = M/\eta$

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

If  $v_s \geq v_o$ :

The particle settles faster than the water rises.  
Result: 100% Removal.

$$v_s < v_o$$

If  $v_s < v_o$ :

The particle settles slower than the water rises.  
Result: Partial Removal.

$$\text{The percentage removed is } (v_s/v_o) \times 100.$$

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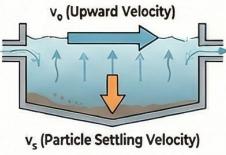
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# Lecture 4: Sedimentation Part B - Analysis and Design

## CORE CONCEPTS & TANK DESIGNS



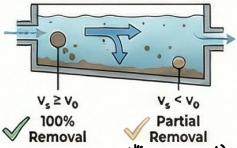
### What is Surface Overflow Rate (SOR or $v_o$ )

The "speed limit" for settling. Particles must settle faster than the upward velocity of the water ( $v_o$ ) to be effectively removed.

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

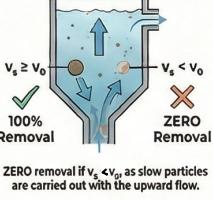
### Horizontal Flow vs. Upflow Clarifiers

#### Horizontal Flow



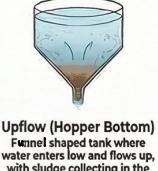
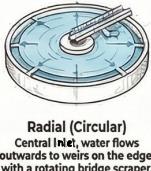
Horizontal flow tanks are more efficient because they can partially remove slow-settling particles.

#### Upflow Clarifier



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

### Common Tank Types

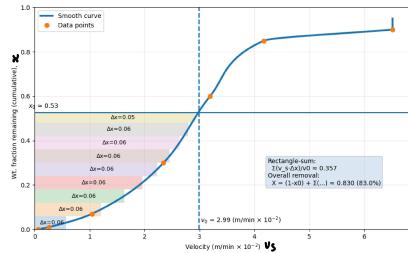


## HOW TO CALCULATE TOTAL REMOVAL (GRAPHICAL METHOD)

### The Master Equation for Total Removal (X)

$$\text{Total Removal} = \left( \frac{\text{Removal of Fast Particles}}{\text{Fast Particles}} \right) + \left( \frac{\text{Partial Removal of Slow Particles}}{\text{Slow Particles}} \right)$$

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



- Step 1:** 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 ( $v_o$ ): Draw a vertical line from the tank's design overflow rate ( $v_o$ ) 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  $v_o$ . The formula is simply  $(1 - x_0)$ .
- Step 4:** Calculate Partial Removal of Slow Particles: This is represented by the area under the curve to the left of the  $v_o$  line. Approximate this by summing the area of small rectangular strips under the curve.
- Step 5:** Find the Total Removal Efficiency ( $X$ ): Add the results from Step 3 and Step 4 to get the total removal efficiency.

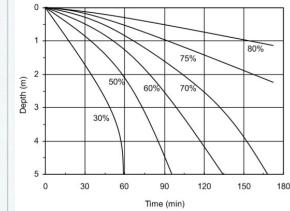
Example Result: For a design  $v_o$  of 43 m/d, the calculation yielded: 0.47 (fast particles) + 0.36 (slow particles) = 0.83, or 83% Total Removal.

## 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:

Iso-removal fractions	Depth (m)
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=60 min

**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. ( $A = \frac{V}{t} \Rightarrow t = \frac{V}{A}$ )

**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  $r_0$ . ( $t = \frac{V}{A} \Rightarrow t = \frac{D}{H}$ )

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

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

eg.  $R_{\text{total}} = 0.5 + \frac{2+3}{2} \cdot 0.1 + \frac{3+4}{2} \cdot 0.1 + \dots$

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 have been removed from syllabus (not examined ~2016)

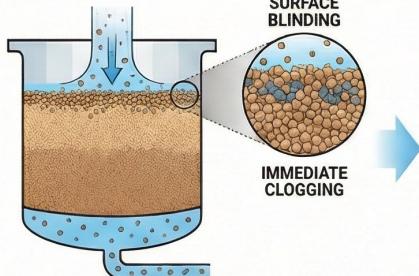
# Lecture 5: Filtration

## CORE FILTRATION CONCEPTS (EXAM THEORY)

### THE DUAL MEDIA ADVANTAGE: WHY ANTHRACITE OVER SAND?

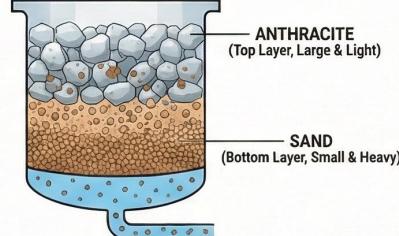
#### PROBLEM: SINGLE SAND FILTER

After backwashing, small sand grains settle at the top, causing immediate clogging, short filter runs, and inefficient use of the filter bed depth.



#### 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.



## 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)	$g$ : Gravity (9.81 m/s <sup>2</sup> )
$k$ : Kozemny constant (~5)	$\phi$ : Shape factor (~0.8)
$v$ : Kinematic viscosity (m <sup>2</sup> /s)	$P_i$ : Mass fraction
$e$ : Porosity (e.g., 0.45)	$d_i$ : Geometric mean diameter (m)
$V$ : Filtration Velocity (m/s)	

which isn't usually given in m/s, have to convert yourself!

### STEP 1: PERFORM THE SIEVE ANALYSIS CALCULATION

Size Range (mm)	$P_i$ (fraction)	Geometric Mean $d_i$ (m)	Term: $\frac{P_i}{d_i^2} (m^{-2})$
3.36 - 2.38	0.02	2.828 x 10 <sup>-3</sup>	2,501
2.38 - 1.68	0.06	1.999 x 10 <sup>-3</sup>	15,006
1.68 - 1.19	0.12	1.414 x 10 <sup>-3</sup>	60,024
1.19 - 0.84	0.40	0.999 x 10 <sup>-3</sup>	400,160
0.84 - 0.59	0.20	0.704 x 10 <sup>-3</sup>	403,551
0.59 - 0.42	0.12	0.497 x 10 <sup>-3</sup>	484,261
0.42 - 0.297	0.08	0.353 x 10 <sup>-3</sup>	641,234
0.297 - 0.110	0.00	-	0
<b>SUM</b>	<b>1.00</b>		$\Sigma = 2.0068 \times 10^6$

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

### STEP 2: WATCH YOUR UNITS!

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

$$5 \text{ m/h} \div 3600 \text{ s/h} = 0.001389 \text{ m/s}$$

### 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 ( $L = 0.7\text{m}$ ), and the summation from the table.

$$\text{FINAL RESULT} \quad 0.191 \text{ m}$$

\*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.

$$\text{Bernoulli's eqn.: } P_1 + \frac{1}{2}\rho u_1^2 + \rho gh_1 = P_2 + \frac{1}{2}\rho u_2^2 + \rho gh_2$$

Fair-Hatch's eqn.

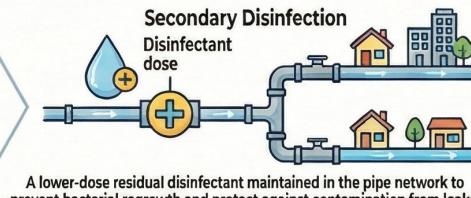
# Lecture 6: Disinfection

## CORE DISINFECTION PRINCIPLES

### Primary Disinfection

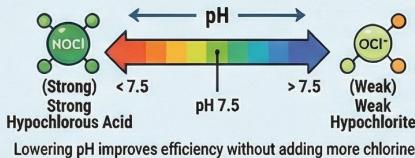


### Secondary Disinfection

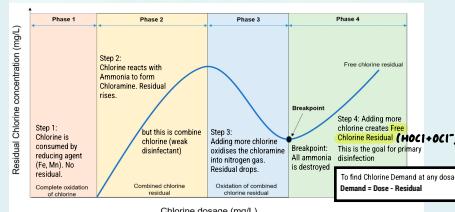


## THE SCIENCE OF CHLORINE

### The pH Effect: Lower pH = Stronger Disinfection



### Breakpoint Chlorination



## CHOOSING YOUR DISINFECTANT: THE BIG 3

Disinfectant	Pros	Cons
Chlorine	<ul style="list-style-type: none"> <li>Cheap</li> <li>effective for bacteria/viruses</li> <li>provides a protective residual</li> </ul>	<ul style="list-style-type: none"> <li>Forms harmful by-products (THMs)</li> <li>pH-dependent</li> <li>ineffective against Cryptosporidium</li> </ul>
Ozone	<ul style="list-style-type: none"> <li>Very strong</li> <li>kills Cryptosporidium</li> <li>improves taste and odor</li> </ul>	<ul style="list-style-type: none"> <li>Expensive</li> <li>complex to generate</li> <li>leaves NO residual</li> <li>can form Bromate by-product</li> </ul>
UV Light	<ul style="list-style-type: none"> <li>Kills Cryptosporidium &amp; Giardia</li> <li>no chemical by-products (no THMs)</li> </ul>	<ul style="list-style-type: none"> <li>Leaves NO residual</li> <li>requires clear water (low turbidity)</li> <li>lamps can foul</li> </ul>

## THE "Ct" CONCEPT: THE CORE CALCULATION

### The Golden Rule of Disinfection

$$Ct_{(\text{calculated})} \geq Ct_{(\text{required})}$$

### What is Ct?

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

### Chick-Watson inactivation kinetics

$$\log(N_0/N) = kCt$$

$$N_0 = \text{initial number of organisms}$$

$$N = \text{number of surviving organisms}$$

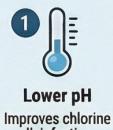
$$\log(N_0/N) = \log \text{inactivation}$$

$$\log(N_0/N) = 1 \quad (10\% \text{ are surviving})$$

$$\log(N_0/N) = 2 \quad (1\% \text{ are surviving})$$

$$\log(N_0/N) = 3 \quad (0.1\% \text{ are surviving})$$

### How Water Quality Impacts Disinfection



### Solving a Typical Ct Problem



Step 1: Find Required Ct  
Use formula or look up value based on pH, temperature, target log removal.



Step 2. Calculate Required Time (t)  
Rearrange: t = Required Ct / Concentration (C).



Step 3. Calculate Max Flow Rate (Q)  
Use tank volume (V) and required time (t): Q = V / t.

C is usually in mg/L  
sometimes they call it Residual!

# Lecture 7: Water Distribution Network

## 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.

$$\text{Leakage} = \text{Total inflow} - \text{Legitimate night consumption}$$

### Pros vs. Cons of DMAs

- ✓ Pros
- Detects bursts quickly by monitoring night flow.
  - Allows for targeted pressure management.

- ✗ Cons
- 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.

## 3. Pressure Management: Reducing Stress on the System

### The FAVOUR Equation: Linking Leakage to Pressure

The relationship is defined as:

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

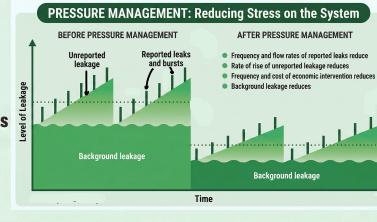
where  $N_1$  is usually greater than 1, meaning a small pressure drop causes a large leakage reduction.

### 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

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

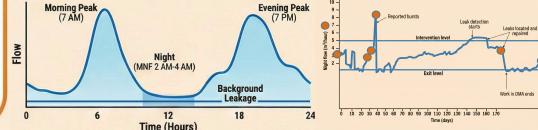


## 2. Minimum Night Flow (MNF): Finding Hidden Leaks

### 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.

### Visualizing Flow Over 24 Hours



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

### What is TOTEX?

Total Expenditure (TOTEX) = Capital Expenditure (CAPEX) + Operational Expenditure (OPEX). This holistic view considers the whole-life cost of an asset.

### 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:**  
 $\text{Risk} = \text{Probability of Failure} \times \text{Consequence of Failure}$

### 5-Step Risk-Based Renewal Process

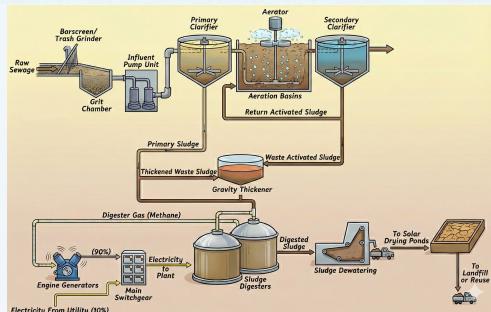
1. Data Collection
  2. Probability Model
  3. Consequence Model
  4. Risk Matrix
  5. Decision
- Gather info on pipe age, material, soil, burst history.
- Use AI/stat to predict failure likelihood.
- Assess the impact of flooding a hospital vs. a field.
- Plot Probability vs. Consequence to visualize high-risk assets.
- 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 gravity. It separates the particulate, suspended 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)
  5. A digester is used to reduce organic matter so that the supernatant meets an effluent discharge standards. (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 CO<sub>2</sub>) 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

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 Q<sub>o</sub>)  
traditional setting: Q<sub>o</sub> = G+DWF  
formula A setting: Q<sub>o</sub> = DWF + 1360P + 2E

## 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  
$$\text{Peak Factor} = 5 \left( \frac{P}{10^4} \right)^{0.2}$$
 (sometimes a, b given: factor =  $\frac{a}{P^{0.2}}$ )

**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)

**Step 2: Find Rainfall Intensity (I)**  
I is found using a given formula  
$$I = \frac{a}{D+b}$$
 
$$I = \frac{\text{rainfall intensity (mm/hr)}}{D + \text{duration (hrs)}}$$

**Step 3: Find Duration (D)**  
Duration is the same as the Time of Concentration (t<sub>c</sub>), calculated as  
$$t_c = \frac{L}{V}$$
 
$$t_c = \frac{\text{length of the pipe}}{\text{flow rate (L/s)}}$$

**Step 4: Find the Peak Flow (Q<sub>p</sub>)**  
$$Q_p = \frac{C \cdot I \cdot A}{t_c}$$
 
$$Q_p = \frac{\text{runoff coefficient} \cdot \text{rainfall intensity} \cdot \text{area}}{\text{time of concentration}}$$

## 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:

1. Calculate DWF: Sum domestic, infiltration, and industrial flows.  $DWF = (P \times G) + I + E$   
Total = 7,250,000 L/day.
2. Convert DWF:  $7,250,000 / 86,400 = 83.9 \text{ L/s}$ .
3. Find Peak Factor:  $P = 37.5$  (in thousands).  
 $\text{Factor} = 5 / (2.78 \cdot 5) = 3.42$ .
4. Calculate Peak Flow:  $83.9 \text{ L/s} \times 3.42 = 203 \text{ L/s}$ .

### 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 =  $250 \text{ L/head/day} = 12,500,000 \text{ L/day}$ .
2. Apply Formula A:  
Setting =  $DWF + 1360P + 2E$ .  
 $= 12,500,000 + (1360 \times 50,000) + (2 \times 0)$   
 $= 80,500,000 \text{ L/day}$
3. Convert to L/s:  $80,500,000 / 86,400 = 932 \text{ L/s}$ .

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

Pipe number	Length (m)	Contributing area (ha)	Flow, q (L/s)	Time of conc., t <sub>c</sub> (min)	Rainfall intensity, Q (mm/hr)	Open capacity, Q <sub>p</sub> (L/s)
1	240	0.8	8.5	8.5	40.3	186.7
2	180	0.6	1.5	6.5	45.5	75.9
3	120	0.4	1.0	4.0	40.8	62.9
4	480	1.0	4	9	39.5	175.7
5	120	0.6	1.0	3.0	37.5	55.4
1, 2	120	0.6	1	11	35.7	377.7

# Lecture 9: Activated Sludge and Biological Filtration

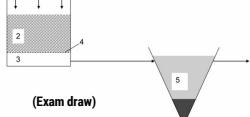
## Two Core Processes: A Head-to-Head Comparison

### 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)



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

## Walkthrough 1: Activated Sludge Design Problem

Goal: Find MLSS concentration (X) and Daily Sludge Production (P<sub>x</sub>)

Given: Flow=5,000 m<sup>3</sup>/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 m<sup>3</sup>/d  
S<sub>0</sub>=250 mg/L  
θ=0.25 days (HRT)

### Step 2: Calculate Tank Volume (V)

V = Q × θ

5,000 × 0.25 = 1,250 m<sup>3</sup>

### Step 3: Calculate MLSS (X)

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

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

### Step 4: Calculate Daily Sludge Production (P<sub>x</sub>)

Rearrange Sludge Age:

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

## Key Performance Indicators & Definitions

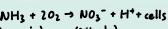
### SLUDGE VOLUME INDEX (SVI)

Measures volume (ml) of sludge after 30 min settling. Indicates settling quality.

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

50-150 mL/g: Good Settling  
>150 mL/g: Sludge Bulking (poor settling)

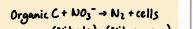
### NITRIFICATION



(Ammonium) (Nitrate) (Aerobic)

Requires Oxygen. (Aerobic)

### DENITRIFICATION



(Nitrate) (Nitrogenous)

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.

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

Q = Flow rate (m<sup>3</sup>/d)  
S<sub>0</sub> = Influent BOD (mg/L or g/m<sup>3</sup>)  
V = Tank Volume (m<sup>3</sup>)  
X = MLSS (mg/L or g/m<sup>3</sup>)

### 2. HYDRAULIC RETENTION TIME (HRT or θ)

Average length of time wastewater stays in the aeration tank.

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

V = Tank Volume (m<sup>3</sup>)  
Q = Flow rate (m<sup>3</sup>/d)

### 3. SLUDGE AGE (SR or θ<sub>c</sub>)

Average time a microorganism stays in the system before removal.

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

V = Tank Volume (m<sup>3</sup>)  
X = MLSS (mg/L or g/m<sup>3</sup>)  
P<sub>x</sub> = Sludge Production Rate (kg/d)  
(P<sub>x</sub> = Q<sub>x</sub> · X<sub>0</sub>)

## Walkthrough 2: Trickling Filter Loading Problem

Goal: Calculate Organic & Hydraulic Loading Rates (DLR & HLR) and check criteria.

Given: Flow=3.2 MI/d, BOD=200 mg/l, Two filters (42m diameter, 2m depth)

### Step 1: Calculate Total Area and Volume

Total Surface Area =  $2 * (\pi * (42/2)^2) = 2,770.8 \text{ m}^2$

Total Volume = Total Area \* Depth =  $2,770.8 * 2 = 5,541.6 \text{ m}^3$

### Step 2: Calculate Organic Loading Rate (OLR)

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

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

Loading rate:  
Organic =  $Q \cdot S_0/V$       0.06 - 0.12 kg BOD/m<sup>3</sup>·d

Hydraulic =  $Q / A_s$       0.25 - 1.2 m<sup>3</sup>/m<sup>2</sup>·d

### Step 3: Calculate Hydraulic Loading Rate (HLR)

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

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

### 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

# Lecture 10: Sewage Sludge Treatment

## Key Concepts & Theory

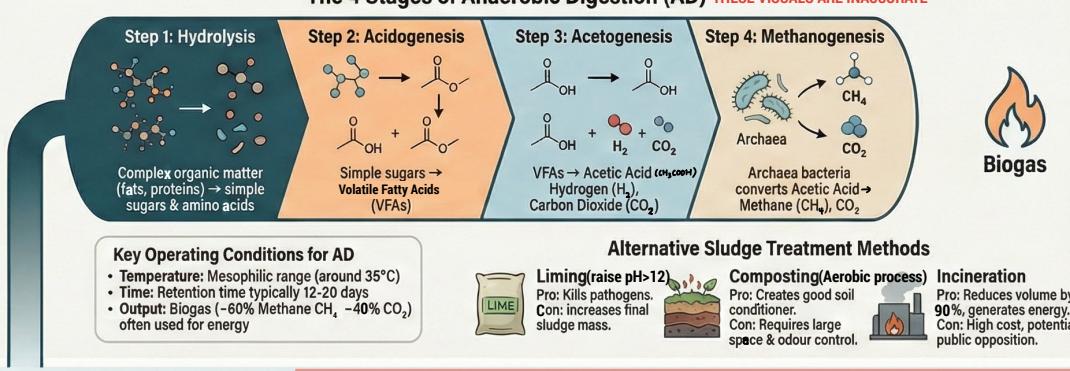
### Primary vs. Secondary Sludge



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



**Secondary Sludge**  
(From Secondary Clarifier)  
Light, flocculent, brown,  
mostly biomass, lower  
solid content (~0.5-2%)



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

#### Key Formulas: Mass & Volume

$$\text{Primary Mass } (M_{ps}) = \epsilon \times SS_{in} \times Q$$

$$\text{Secondary Mass } (M_{ss}) = Y_{obs} \times BOD_{removed} \times Q$$

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

#### Example Problem: Daily Sludge Volume

A WWTP treats 10,000 m<sup>3</sup>/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 tank: Removes 95% of remaining BOD.

Diskard Factor (K\_d) = 0.4 kg SS / kg BOD. Secondary sludge is 0.9% DS.

Calculate Total Daily Sludge Volume (m<sup>3</sup>/d) produced.

$$e: \text{Removal efficiency of primary tank. } SS_{in}: \text{Influent Suspended Solids (mg/L or kg/m}^3\text{). } Q: \text{Flow (m}^3/\text{d).}$$

$$Y_{obs}: \text{Yield coefficient (kg sludge / kg BOD removed). }$$

$$BOD_{removed}: \text{Amount of BOD removed in secondary treatment}$$

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

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

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

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

$$\text{Step 3: Calculate BOD removed after secondary treatment}$$

$$\begin{aligned} \text{Initial BOD (250 mg/L)} \\ \cdot 1 \text{ m}^3 \text{ wastewater removes 35\% BOD after primary (250} \times 0.65 = 162.5 \text{ mg/L)} \\ \cdot \text{secondary treatment removes another 95\% BOD removed in secondary treatment} \\ = 0.95 \times 162.5 = 154.4 \text{ mg/L} = 0.1544 \text{ kg/m}^3 \end{aligned}$$

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

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

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

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

$$\text{Step 5: Calculate Total Daily Volume}$$

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

### Calculation 2: Lab Solids Analysis Walkthrough

#### Key Formulas: Lab Analysis

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

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

#### Step 1: Calculate Total Solids (TS) Concentration

$$\text{Mass of Dry Solids} = 82.015 \text{ g} - 81.923 \text{ g} = 0.092 \text{ g (92 mg)}$$

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

#### Step 2: Calculate Volatile Solids (VS) Concentration

$$\text{Mass of Volatiles (lost on ignition)} = 82.015 \text{ g} - 81.975 \text{ g} = 0.040 \text{ g (40 mg)}$$

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

#### Step 3: Calculate Fixed Solids (Ash)

$$75 - VS = 920 \text{ mg/L} - 400 \text{ mg/L} = 520 \text{ mg/L}$$

# Lecture 11: Sustainability and Water Resource Management Part A

## 1. The Life Cycle Assessment (LCA) Framework



### Life Cycle Assessment (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 m<sup>3</sup> 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  $\text{CO}_2$  equivalents.



### Phase 4: Interpretation

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



Functional Unit:  
The reference unit for comparison (e.g., Treatment of 1 m<sup>3</sup> of wastewater).

System Boundaries:  
Defines the scope, from "Cradle-to-Graue" or "Cradle-to-Gate".

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  $\text{CO}_2$  equivalents (kg  $\text{CO}_2\text{e}$ ).

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

This formula converts different greenhouse gases into a common unit based on their global warming potential relative to  $\text{CO}_2$ .

Greenhouse Gas	IPCC Characterisation Factor
$\text{CO}_2$	1
Methane ( $\text{CH}_4$ )	~28
Nitrous Oxide ( $\text{N}_2\text{O}$ )	~265

## 3. Walkthrough: Calculating a WWTP's Carbon Footprint



EXAMPLE SCENARIO: A WWTP treats 50,000 m<sup>3</sup>/day of wastewater. We will calculate its 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  $\text{CO}_2$  equivalents.

$$\text{CO}_2: 1,200,000 \text{ kg} \times 1 = 1,200,000 \text{ kg } \text{CO}_2\text{e}$$

$$\text{CH}_4: 8,000 \text{ kg} \times 27.2 = 217,600 \text{ kg } \text{CO}_2\text{e}$$

$$\text{N}_2\text{O}: 1,200 \text{ kg} \times 273 = 327,600 \text{ kg } \text{CO}_2\text{e}$$

$$\text{Total Scope 1} = 1,745,200 \text{ kg } \text{CO}_2\text{e/year}$$



### Step 2: Calculate Scope 2 (Indirect Energy Emissions)

Multiply energy consumption by grid emission factors to find the associated carbon footprint.

$$\text{Electricity: } 12,000,000 \text{ kWh} \times 0.233 = 2,796,000 \text{ kg } \text{CO}_2\text{e}$$

$$\text{Natural Gas: } 500,000 \text{ kWh} \times 0.184 = 92,000 \text{ kg } \text{CO}_2\text{e}$$

$$\text{Total Scope 2} = 2,888,000 \text{ kg } \text{CO}_2\text{e/year}$$



### Step 3: Calculate Total Carbon Footprint

Add Scope 1 and Scope 2 emissions together for the final annual total.

$$1,745,200 + 2,888,000 = 4,633,200 \text{ kg } \text{CO}_2\text{e/year}$$



### Step 4: Calculate Specific Footprint

Divide the total footprint by the annual volume of treated water to get the footprint per functional unit (1 m<sup>3</sup>).

$$\text{Total Annual Flow} = 50,000 \text{ m}^3/\text{day} \times 365 \text{ days}$$

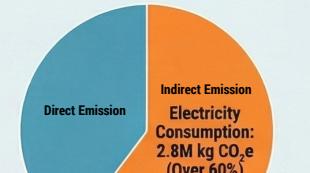
$$= 18,250,000 \text{ m}^3/\text{year}$$

$$\frac{4,633,200 \text{ kg } \text{CO}_2\text{e}}{18,250,000 \text{ m}^3} = 0.254 \text{ kg } \text{CO}_2\text{e/m}^3$$

$$0.254 \text{ kg } \text{CO}_2\text{e/m}^3$$

## 4. Interpretation: Identify the Hotspot & Suggest Improvements

### Hotspot Identified: Electricity Consumption



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

**Solution B: Improve Energy Efficiency**  
Implement measures like replacing old, 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).

# 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 earth.

**TECHNICAL CYCLE:**  
Product can be used rather than consumed. Focus on how each step allow material to remain in use.

**KEY RESOURCE RECOVERY TECHNOLOGIES**

- Carbon: Biogas (via Anaerobic Digestion)
- Phosphorus: Struvite Precipitation (creates fertilizer)
- Nitrogen: Ammonia Stripping
- Water: Membrane Filtration (for water reuse)

**Problem Walkthrough: Closing Mass Balance**

A WWTP treats 12,000 m<sup>3</sup>/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	Wastewater	Outlet
Water	10,000	9,990	9,975
Nitrogen	0	0	0
Phosphorus	0.95	0.95	0.95
Carbon (CO <sub>2</sub> )	2.6	2.6	2.6
Total	10,000	9,990	9,975

**Gas Stream:** Biogas produced = 1.65 m<sup>3</sup>/d. Methane content = 65% (volume basis), density of methane = 0.66 kg/m<sup>3</sup>. Density of carbon dioxide = 1.98 kg/m<sup>3</sup>.

**Gas Emissions:**

Gas	Flow (m <sup>3</sup> /d)	Concentration (%)	Mass (kg/d)
CH <sub>4</sub>	0.51315	65	0.337
Nitrogen (N <sub>2</sub> )	0.665	0.01	0.007
Nitrogen (NO <sub>x</sub> )	0.01	0.01	0.001
Carbon (CO <sub>2</sub> )	0.4	0.01	0.004
Carbon (CO <sub>2</sub> )	0.651	0.01	0.004
Water	9,975	0	0
Phosphorus	0.95	0	0
Carbon	2.6	0	0

*Note: These can be found easily without calculating everything*

**Step 1: Calculate Fugitive Gas Emissions**  
Calculate the mass of Carbon and Nitrogen lost to the atmosphere as leaks.

- Methane (CH<sub>4</sub>):**
  - Total Mass CH<sub>4</sub> = 0.0075 × 7.1 (COD load) = **0.05325 t/d.**
  - Carbon Fraction in CH<sub>4</sub>; 12/(12 + 4) = 0.75.
  - CO<sub>2</sub> Mass: 0.05325 × 0.75 = **0.040 t/d.**
- Nitrous Oxide (N<sub>2</sub>O):**
  - Total Mass N<sub>2</sub>O = 0.02 × 1.0 (N load) = **0.02 t/d.**
  - Nitrogen Fraction in N<sub>2</sub>O: (2 × 14)/(2 × 14 + 16) = 28/44 = 0.636.
  - CO<sub>2</sub> Mass: 0.02 × 0.636 = **0.0127 t/d.**

**Step 2: Calculate Biogas Composition**  
Calculate the mass of Carbon recovered in the Biogas stream.

- Methane (CH<sub>4</sub>):**
  - Volume = 1.656 × 0.66 = 1,017.25 m<sup>3</sup>.
  - Mass = 1,017.25 × 0.66 (density) = 671.4 kg = **0.671 t/d.**
  - Carbon Fraction in CH<sub>4</sub>; 12/(12 + 4) = 0.75.
  - Carbon Mass: 0.671 × 0.75 = **0.503 t/d.**
- Carbon Dioxide (CO<sub>2</sub>):**
  - Volume = 1.656 × 0.35 = 547.75 m<sup>3</sup>.
  - Mass = 547.75 × 1.98 (density) = 1,084.5 kg = **1.085 t/d.**
  - Carbon Fraction in CO<sub>2</sub>; 12/(12 + 32) = 0.275.
  - Carbon Mass: 1,085 × 0.275 = **0.296 t/d.**

**Step 3: Calculate Mass Balance (The "Fill the Gap" Step)**  
Use the previous input + Sum(Outputs). We are solving for the unknown Biosolids.

- Water Balance:**
  - Biosolids<sub>water</sub> = In - (Effluent + Solid Waste)
  - Biosolids<sub>water</sub> = 12,000 - (11,990 + 1.0) = **9 m<sup>3</sup>/d**
- Nitrogen Balance:**
  - Biosolids<sub>N</sub> = In - (Effluent + Gas N<sub>x</sub> + Fugitive N<sub>2</sub>O)
  - Biosolids<sub>N</sub> = 1.0 - (0.05 + 0.65 + 0.0127)
  - Biosolids<sub>N</sub> = 1.0 - 0.7127 = **0.287 t/d**
- Phosphorus Balance:**
  - Biosolids<sub>P</sub> = In - (Effluent)
  - Biosolids<sub>P</sub> = 0.15 - 0.01 = **0.14 t/d**
- Carbon Balance:**
  - Biosolids<sub>C</sub> = In - (Effluent + Solid Waste + Gas CO<sub>2</sub> + Fugitive CH<sub>4</sub> + Biogas C)
  - Biosolids<sub>C</sub> = 2.5 - (0.05 + 0.35 + 0.4 + 0.90 + 0.799)
  - Biosolids<sub>C</sub> = 2.5 - 1.639 = **0.861 t/d**
  - Ratio =  $\frac{0.861}{1.0} \times 100\% = 86.1\%$

**Step 4: Calculate Recovery Rates**  
Treat Biosolids and Biogas as "Recovered Products". Treat Effluent and Emissions as "Losses".

- Water Recovery:**
  - Biosolids Water =  $\frac{9}{12,000} = 0.075\%$
  - Total Input = 12,000
  - (Note: No effluent is discharged to sea, not reused).
- Carbon Recovery:**
  - Recovered = Biosolids C + Biogas C = 0.861 + 0.799 = 1.66 t/d
  - Ratio =  $\frac{1.66}{12,000} = 66.4\%$
- Nitrogen Recovery:**
  - Recovered = Biosolids N = 0.287 t/d
  - Ratio =  $\frac{0.287}{1.0} = 28.7\%$
- Phosphorus Recovery:**
  - Recovered = Biosolids P = 0.14 t/d
  - Ratio =  $\frac{0.14}{0.15} = 93.3\%$

**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?

- Identify the Weakness:**
  - CO<sub>2</sub> has the lowest rates: P (93%), C (68%), N (29%), Water (0.075%).
  - Water is the highest priority for improvement (it is currently treated as waste).
- Suggest Technology:**
  - To turn the effluent (currently "waste") into a "product", we need **Tertiary Treatment**.
  - Combination: Add Ultrafiltration (UF) and Reverse Osmosis (RO) followed by UV disinfection.
- 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

**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.

**Foundational Concepts**

**The Waste Hierarchy (Must Be Memorized in Order)**

1. Prevention/Reduction	2. Reuse	3. Recycling	4. Other Recovery	5. Disposal
(reducing, avoiding the drain of waste, direct re-use without repair)	(checking, cleaning or repairing items so that it can be reuse)	(doesn't include turning waste into fuel)	(e.g., Energy from Waste)	(Landfill/Incineration)

**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)	$15,000,000 \text{ tpa} \times (1 + 0.01)^{10}$	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	25 Plants (Rounded Up)
4. Total Energy	25 Plants × 25 MW/plant	625 MW

**1. Calculate Future Waste Generation**  
 $W_{future} = W_{current} \times (1 + r)^n$   
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  
 $Target Load = W_{future} \times \text{target \%}$  (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.

**Step 1: Account for Sorting Rejects**  
Initial Collection (e.g., 100 tonnes)

**Step 2: Account for Reprocessing Loss**  
From the sorted material, subtract losses that occur during the actual recycling process. Example: 100 tonnes collected × (1 - 0.20 reject rate) = 80 tonnes.  
Example: 100 tonnes collected × (1 - 0.10 process loss) = 72 tonnes.

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