Unit 7: Water

Engineering Chemistry — DI01000071

Milav Dabgar

Lecturer, Dept of ECE
GP Palanpur

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Water Quality · Hardness · Softening Methods
Boiler Feed Water · Desalination · Wastewater Treatment

Unit 7 Overview: Water

Topics Covered

- Water quality parameters
- DO, BOD, COD
- Hardness: types, units, causes
- Lime-soda process
- Zeolite/Permutit process
- Ion exchange process
- Reverse osmosis
- Boiler feed water treatment
- Desalination methods
- Municipal water treatment
- Sewage treatment

Exam Weightage

≈15% of paper

Frequently asked:

- Hardness numericals (ppm, mg/L, °F, °Cl)
- Lime-soda process reactions
- Zeolite process (regeneration)
- BOD vs COD distinction
- Reverse osmosis principle
- Boiler troubles (scale, priming)
- Drinking water treatment flowchart

Physical Parameters

- **Turbidity:** Suspended particles scattering light (NTU); drinking water <1 NTU
- **Color:** True (dissolved) vs apparent (suspended); Hazen units
- **Odour & taste:** H S (rotten egg), algal metabolites
- **Temperature:** Affects DO, reaction rates, aquatic life
- **TDS:** Total Dissolved Solids (mg/L); drinking water <500 mg/L

Chemical Parameters

- **pH:** 6.5–8.5 for drinking water
- **Hardness:** Ca^{2} , Mg^{2} content (mg/L as CaCO)
- **Alkalinity:** OH , CO ^{2} , HCO content
- **Chloride:** <250 mg/L (taste threshold)
- **Nitrate:** <45 mg/L (infant methemoglobinemia risk)
- **Fluoride:** 0.6–1.5 mg/L (dental health)

DO, BOD and COD

Dissolved Oxygen (DO)

DO: Amount of O dissolved in water
Saturation: ~9 mg/L at 20°C, 1 atm

Significance:

- $>$6 mg/L: good for fish
- $<$4 mg/L: stressed aquatic life
- $<$1 mg/L: anaerobic (septic)

Reduced by: high temp, organic pollution, algal decay

BOD (Biochemical Oxygen Demand):
O consumed by microbes to decompose organic matter in water at 20°C in 5 days (BOD)
High BOD → high pollution
Clean water: $<$1 mg/L; sewage: 200–400 mg/L

COD (Chemical Oxygen Demand):
O equivalent of all oxidisable matter (organic + inorganic) using K Cr O
COD $>$ **BOD** always
Measures total oxidisable load faster (2 hrs vs 5 days)

BOD/COD ratio: $>$0.6 →

biodegradable waste

Hardness of Water: Definition & Types

Definition

Hardness: Property of water that prevents lathering with soap and causes scale in boilers

Caused by: Dissolved salts of Ca^{2} and Mg^{2}

Soap reaction:
$2RCOONa + CaCl_2 \rightarrow (RCOO)_2Ca \downarrow + 2NaCl$
(scum/curd formed — waste of soap)

Types of Hardness:

Temporary hardness:
Caused by $Ca(HCO\ )\ $, $Mg(HCO\ )$
Removed by boiling:
$$Ca(HCO_3)_2 \xrightarrow{\Delta} CaCO_3 \downarrow + H_2O + CO_2$$

Permanent hardness:
Caused by $CaCl$, $MgCl$, $CaSO$, $MgSO$
Not removed by boiling
Removed by chemical/ion exchange methods

Total hardness = Temporary + Permanent

Units of Hardness & Interconversion

Hardness Units

ppm (mg/L): mg of CaCO equivalent per litre

Degree French (°F): $1°F = 10$ mg CaCO /L

Degree Clark (°Cl): $1°Cl = 14.3$ mg CaCO /L

Degree German (°d): $1°d = 17.8$ mg CaCO /L

Equivalence:
$1°Cl = 1.43°F = 0.8°d$

Conversion to CaCO equivalents:

$$\text{Hardness (ppm)} = \frac{\text{Amount of salt (mg/L)} \times 100}{\text{Mol. wt. of salt}}$$

Example:

CaSO $= 68$ mg/L; MW $= 136$

$$\text{Hardness} = \frac{68 \times 100}{136} = 50 \text{ ppm}$$

Unit classification:

Soft	<75	ppm
Moderately hard	75–150	ppm
Hard	150–300	ppm
Very hard	>300	ppm

Hardness Numerical: Worked Example

Problem

Water contains: Ca(HCO) = 16.2 mg/L, MgCl = 19 mg/L, CaSO = 13.6 mg/L, MgSO = 12 mg/L

Find: (a) Temporary hardness (b) Permanent hardness (c) Total hardness in ppm and °F

Solution: (MW: Ca(HCO) =162, MgCl =95, CaSO =136, MgSO =120)

Salt	mg/L	Formula	CaCO equiv
Ca(HCO)	16.2	$\frac{16.2\times100}{162}$	10 ppm (temp)
MgCl	19.0	$\frac{19\times100}{95}$	20 ppm (perm)
CaSO	13.6	$\frac{13.6\times100}{136}$	10 ppm (perm)
MgSO	12.0	$\frac{12\times100}{120}$	10 ppm (perm)
Total			**50 ppm**

Temp. hardness = 10 ppm;

Perm. = 40 ppm; Total = 50 ppm

In °F: 50/10 = **5F**

Lime-Soda Process for Water Softening

Reagents & Reactions

Lime Ca(OH) removes:

- Free CO : $CO_2 + Ca(OH)_2 \rightarrow CaCO_3 \downarrow + H_2O$
- Temp. Ca^2 : $Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + 2H_2O$
- Temp. Mg^2 : $Mg(HCO_3)_2 + 2Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + Mg(OH)_2 \downarrow + 2H_2O$
- Perm. Mg^2 : $MgCl_2 + Ca(OH)_2 \rightarrow Mg(OH)_2 \downarrow + CaCl_2$

Soda Na CO removes:

- Perm. Ca^2 : $CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 \downarrow + 2NaCl$
- Perm. CaSO : $CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 \downarrow + Na_2SO_4$

Process:
Cold or hot lime-soda

- **Cold:** 15–30°C; residual hardness 50–80 ppm
- **Hot:** 80–100°C; residual hardness 15–25 ppm

Advantages:

- Cheap reagents
- Large scale treatment
- Removes iron/manganese too

Disadvantages:

- Large sludge disposal
- Not suitable for very high hardness
- Requires skilled operation

Zeolite (Permutit) Process

Principle

Zeolite: Sodium alumino-silicate (Na Al Si O · xH O), represented as Na Ze

Softening:
$Na_2Ze + CaCl_2 \rightarrow CaZe + 2NaCl$
$Na_2Ze + MgSO_4 \rightarrow MgZe + Na_2SO_4$

Ca^2 /Mg^2 replaced by Na (no hardness)

Regeneration: Exhausted zeolite treated with 10% NaCl brine:
$CaZe + 2NaCl \rightarrow Na_2Ze + CaCl_2$

Advantages:

- Simple operation, no sludge
- Complete softening possible
- Regeneration is easy (NaCl)
- Compact equipment

Disadvantages:

- Cannot remove turbidity
- Cannot handle acidic water ($pH < 6$ destroys zeolite)
- Adds Na — not suitable for cardiac patients
- High silica/turbid water clogs zeolite

Synthetic: Dowex, Amberlite — sulfonated polystyrene resin zeolites

Ion Exchange (Deionization) Process

Process

Water passed through two columns:

Column 1 — Cation exchanger (RH):
$R\text{-}H_2 + CaCl_2 \rightarrow R\text{-}Ca + 2HCl$
All cations (Ca^{2} , Mg^{2} , Na) replaced by H

Column 2 — Anion exchanger (R'OH):
$R'\text{-}OH_2 + H_2SO_4 \rightarrow R'\text{-}SO_4 + 2H_2O$
All anions (Cl , SO ^{2} , HCO) replaced by OH

H + OH $\rightarrow$ H O $\rightarrow$ **demineralized water**

Regeneration:
Cation resin: dilute HCl or H SO
Anion resin: dilute NaOH

Advantages:

- Produces ultra-pure water
- Removes all dissolved salts
- Used in pharmaceutical, electronic, boiler feed

Disadvantages:

- Expensive resins
- Frequent regeneration if high TDS
- Does not remove organics/bacteria

Reverse Osmosis (RO)

Principle

Osmosis: Water moves from low to high solute concentration through semipermeable membrane

RO: Apply pressure > osmotic pressure on saline side → water forced through membrane → purified water collected

Membrane: Thin-film composite (TFC) — polyamide on polysulfone support; pore size ∼0.0001 μm

Operating pressure: Brackish water: 5–20 bar; Seawater: 50–80 bar

What RO removes:

- Dissolved salts (TDS reduction >95%)
- Bacteria, viruses
- Heavy metals (Pb, As, Hg)
- Nitrates, fluorides
- Organic compounds

Advantages:

- No chemicals required
- Compact, scalable
- Drinking water, desalination

Disadvantages:

- 30–50% water waste (reject stream)
- Membrane fouling
- Pre-treatment needed

Boiler Feed Water: Requirements & Problems

Requirements

Boiler feed water must be:

- Free from hardness (scale-forming salts)
- Low dissolved O (corrosion prevention)
- Low dissolved CO
- Low TDS (carry-over prevention)
- Neutral to slightly alkaline (pH 8–9)
- Free from suspended solids

Boiler Troubles

Scale/Sludge: Deposition of CaSO , CaCO on boiler walls → poor heat transfer → overheating → explosion risk

Priming: Carrying liquid water droplets with steam (due to dissolved salts/suspended matter → *foamy water*)

Foaming: Stable foam in boiler due to oil, alkali, organic matter

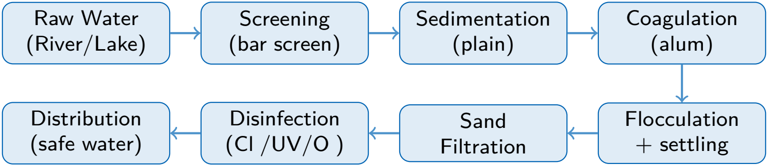
Caustic embrittlement: Leaks near rivets expose metal to NaOH → stress corrosion cracking

Corrosion: Dissolved O , CO attack boiler metal

Prevention of Boiler Troubles

Problem	Cause	Prevention/Treatment
Scale	CaSO , CaCO , Mg(OH) deposition	Soften feed water; internal conditioning (NaPO , tannin); blowdown
Sludge	Loose precipitates; MgCO , Fe(OH)	Coagulants; frequent blowdown
Priming	High TDS, suspended matter, foamy water	Purify feed water; reduce boiler load; antifoam agents
Foaming	Oil, alkali, dissolved organics	Remove oil; control alkalinity (pH 8–9)
Caustic embrittlement	NaOH concentration in crevices	Add Na SO (ratio Na SO :NaOH $>$2.5); rivet welding
O corrosion	Dissolved O	Deaeration (heating); add hydrazine (N H) or sodium sulfite
CO corrosion	Dissolved CO in condensate	Add volatile amines (cyclohexylamine); mechanical deaeration

Municipal Drinking Water Treatment



Key steps explained:

- **Coagulation:** Alum Al (SO) $\rightarrow$ Al(OH) gel adsorbs colloidal particles
- **Disinfection (chlorination):** Cl + H O $\rightarrow$ HOCl + HCl; HOCl kills pathogens; residual Cl maintained 0.2–0.5 mg/L
- **Breakpoint chlorination:** Add Cl until all NH oxidized + free Cl residual appears

Sewage Treatment Process

Primary Treatment

Screening: Bar/fine screens remove large solids

Grit chamber: Sand, grit settle out

Primary sedimentation: Organic suspended solids settle as primary sludge

Removes: 50–65% suspended solids, 30–40% BOD

Secondary Treatment

Biological: Microorganisms decompose dissolved organics

Trickling filter: Sewage sprinkled on stone bed with biofilm

Activated sludge: Sewage + returned activated sludge aerated in tank; bacteria degrade BOD

Secondary clarifier removes biomass
Removes: 85–95% BOD

Tertiary: Nutrient removal (N, P), advanced filtration, disinfection → reclaimed water

Desalination of Seawater

Thermal Methods

Multi-Stage Flash (MSF):
Seawater heated $\rightarrow$ flashed through successive chambers at decreasing pressure $\rightarrow$ steam condensed as fresh water
Energy intensive; large scale

Multi-Effect Distillation (MED):
Each effect uses latent heat from previous; more efficient than MSF

Vapour Compression (VC):
Steam compressed $\rightarrow$ condensed $\rightarrow$ heat reused

Membrane Methods

RO (Reverse Osmosis):
Most energy-efficient for seawater (50–80 bar); dominant technology today

Electrodialysis (ED):
Ion-selective membranes; DC voltage drives ions through membranes; best for brackish water ($<$5000 ppm TDS)

Comparison:
RO: 3–4 kWh/m^3 (seawater)
MSF: 10–15 kWh/m^3

Water Softening Methods: Comparison

Feature	Lime-Soda	Zeolite	Ion Exchange
Reagent	Ca(OH) + Na CO	NaCl (regeneration)	HCl/H SO + NaOH
Removes	Ca^{2} , Mg^{2} , Fe, CO	Ca^{2} , Mg^{2} only	All dissolved ions
Residual hardness	15–80 ppm	Nearly zero	Nearly zero (DM water)
Sludge	Yes (large)	No	No
Scale/turbidity	Also removes	Cannot handle	Cannot handle
Adds Na	No	Yes	No
Cost	Low	Moderate	High
Output water	Softened	Softened	Demineralized
Best use	Municipal, industrial	Domestic, industrial	Boiler feed, lab, pharma

Numerical: Lime-Soda Requirement

Worked Example

Problem: A water sample contains:
Ca(HCO) = 32.4 mg/L   MgSO = 24 mg/L   MgCl = 19 mg/L
Find the amount of lime and soda required per litre.

Solution: (MW: Ca(HCO) =162, MgSO =120, MgCl =95, Ca(OH) =74, Na CO =106)

Lime required:
For Ca(HCO) : $\frac{32.4}{162} \times 74 = 14.8$ mg/L
For MgSO : $\frac{24}{120} \times 74 = 14.8$ mg/L
For MgCl : $\frac{19}{95} \times 74 = 14.8$ mg/L
Total lime = 44.4 mg/L

Soda required:
For MgSO $\rightarrow$ produces CaSO : $\frac{24}{120} \times 106 = 21.2$ mg/L
For MgCl $\rightarrow$ produces CaCl : $\frac{19}{95} \times 106 = 21.2$ mg/L
Total soda = 42.4 mg/L

Boiler Scale: Formation & Harmful Effects

Scale-Forming Salts

Hard scale (difficult to remove):
CaSO $\leftarrow$ solubility decreases with temp
CaSiO , MgSiO — very hard

Soft scale (easier to remove):
CaCO , Mg(OH) , MgSiO

$Ca(HCO_3)_2 \xrightarrow{\Delta} CaCO_3 \downarrow + H_2O + CO_2$
$Mg(HCO_3)_2 \xrightarrow{\Delta} MgCO_3 + H_2O + CO_2$
$MgCO_3 + H_2O \rightarrow Mg(OH)_2 \downarrow + CO_2$

Effects of Scale:

- Thermal insulation: scale ($k \approx$ 0.1–2 W/mK) vs steel ($\approx$ 50 W/mK) $\rightarrow$ poor heat transfer
- Overheating of boiler walls $\rightarrow$ metal weakening
- Risk of explosion
- Increased fuel consumption
- Reduced boiler efficiency and lifespan

Scale Removal:

Mechanical scraping, acid pickling (2% HCl), EDTA chelation treatment

Internal Conditioning of Boiler Water

Problem	Chemical Added	Action
Scale (CaSO , CaCO)	Sodium phosphate (Na PO)	Forms soft, non-adherent Ca (PO) sludge → removed by blowdown
Scale (general)	Sodium hexametaphosphate (calgon)	Sequestration — keeps Ca^2 /Mg^2 in solution as complex
Scale/sludge conditioning	Tannin, lignin	Sludge stays fluid and non-adherent
O corrosion	Hydrazine N H	$N_2H_4 + O_2 \rightarrow N_2 + 2H_2O$; no TDS increase
O corrosion	Sodium sulfite Na SO	$2Na_2SO_3 + O_2 \rightarrow 2Na_2SO_4$; low pressure boilers only
Caustic embrittlement	Sodium sulfate Na SO	Ratio Na SO :NaOH $>$ 2.5 fills crevices
Foaming/priming	Anti-foam agents (castor oil derivatives)	Breaks surface foam

Chlorination: Disinfection of Water

Chemistry of Chlorination

$Cl_2 + H_2O \rightleftharpoons HOCl + HCl$

HOCl (hypochlorous acid) is the active germicide

$HOCl \rightleftharpoons H^+ + OCl^-$

At pH 6–7: HOCl dominant (more effective)

At pH > 8.5: OCl dominant (40$\times$ less effective)

Residual Cl : 0.2–0.5 mg/L maintained in distribution network

Breakpoint Chlorination:

As Cl dose increases:
1. Cl reacts with NH $\rightarrow$ chloramines (combined Cl)
2. Chloramines oxidized $\rightarrow$ N at breakpoint
3. Beyond breakpoint: free Cl residual appears

Free Cl is 25$\times$ more effective than combined Cl

Alternatives to Cl :

Ozone (O) — powerful, no by-products, no residual
UV radiation — physical, no chemicals
Chloramine — longer residual, less THM formation

ClO — effective against

Cryptosporidium

Water Quality Standards & Water-Borne Diseases

Water-Borne Diseases

Disease	Pathogen
Cholera	Vibrio cholerae
Typhoid	Salmonella typhi
Hepatitis A	HAV virus
Polio	Poliovirus
Dysentery	Shigella / E. coli
Giardiasis	Giardia lamblia
Cryptosporidiosis	Cryptosporidium

BIS/WHO Drinking Water Standards

Parameter	Limit
pH	6.5–8.5
Turbidity	$<$1 NTU
TDS	$<$500 mg/L
Total hardness	$<$200 mg/L
Chloride	$<$250 mg/L
Fluoride	0.6–1.5 mg/L
Nitrate	$<$45 mg/L
Iron	$<$0.3 mg/L
Arsenic	$<$0.01 mg/L
Residual Cl	0.2–0.5 mg/L
Coliform	0 per 100 mL

Sludge Treatment & Disposal

Sludge from Treatment Plants

Primary sludge: Settled raw organics (high BOD)

Secondary sludge: Excess biomass from biological treatment (activated sludge)

Sludge digestion (anaerobic): Methanogens convert organics → biogas (60–70% CH_4 + 30% CO_2)

Digested sludge: Stabilized, less odorous; can be used as fertilizer (biosolids)

Sludge Disposal Options:

- **Land application:** Biosolids as agricultural fertilizer (if heavy metal limits met)
- **Landfill:** Dewatered cake disposal
- **Incineration:** High energy; reduces volume 90%
- **Composting:** Combined with wood chips → soil amendment

Biogas utilization:

Biogas from sludge digestion powers treatment plant — typical plant can be 50–70% energy self-sufficient

Hardness Numericals: Practice Set

Problems

Q1. Find hardness in ppm if water contains CaCl = 111 mg/L and MgSO = 60 mg/L.
$CaCl: \frac{111 \times 100}{111} = 100$ *ppm; MgSO :* $\frac{60 \times 100}{120} = 50$ *ppm; Total* = ***150 ppm***

Q2. Convert 150 ppm hardness to °F and °Cl.
$°F = 150/10 =$ **15F**; $°Cl = 150/14.3 =$ **10.5Cl**

Q3. Water has temporary hardness 50 ppm and permanent 80 ppm. What is total hardness in °F?
Total = 130 ppm; $°F = 130/10 =$ **13F**

Q4. CaSO = 27.2 mg/L in water. Calculate hardness.
MW of CaSO = 136; Hardness $= \frac{27.2 \times 100}{136} =$ **20 ppm**

Zeolite Process Numerical

Worked Example

Problem: A zeolite softener contains 1000 litres of zeolite with exchange capacity of 5500 litres of water of hardness 100 ppm per cubic metre of zeolite. How many litres of 10% NaCl solution are needed to regenerate it?

Solution:

Volume softened $= 5500$ L per m^3 $\times$ 1 m^3 $= 5500$ L

Hardness $= 100$ ppm $= 100$ mg $CaCO$ per litre

Total $CaCO$ equivalent $= 5500 \times 100 = 550{,}000$ mg $= 550$ g

$CaCO$ equivalent moles $= \frac{550}{100} = 5.5$ mol

Reaction: $CaZe + 2NaCl \rightarrow Na\ Ze + CaCl$

NaCl required $= 2 \times 5.5 = 11$ mol $= 11 \times 58.5 = 643.5$ g

Volume of 10% NaCl $= \frac{643.5}{0.10 \times 1000} = \mathbf{6.435\ L}$

Advanced Water Treatment Technologies

Ultrafiltration (UF):
Membrane pore size 0.01–0.1 μm
Removes bacteria, viruses, colloids
No disinfectant needed

Nanofiltration (NF):
Pore size 0.001–0.01 μm
Removes divalent ions (hardness), organic molecules
Between UF and RO

Ozonation:
O — strong oxidant ($E^\circ = 2.07$ V)
Destroys micropollutants (pesticides, pharmaceuticals)

No chlorine by-products (THMs)

Membrane Spectrum

Process	Pore size	Removes
MF	0.1–10 μm	Suspended soli
UF	0.01–0.1 μm	Bacteria, viruse
NF	1–10 nm	Divalent ions
RO	0.1–1 nm	All dissolved io

Activated Carbon

Removes organic compounds, taste/odour, chlorine from water by adsorption. Surface area 500–1500 m^2/g

Wastewater Reuse & Recycling

Categories of Reuse

Agricultural: Treated wastewater for irrigation (largest reuse globally)

Industrial: Cooling water, process water

Municipal non-potable: Toilet flushing, street cleaning, firefighting

Groundwater recharge: Indirect potable reuse via aquifer

Direct potable reuse: Advanced treated water into drinking supply (emerging)

Zero Liquid Discharge (ZLD):
All wastewater treated and recycled within facility; no effluent discharged

- Mandatory for textile, pharma, tannery in India (CPCB norms)
- Uses evaporators, crystallizers, RO in sequence

Rain Water Harvesting:
Collect roof/surface runoff
Recharge groundwater table

Mandatory in several Indian states for buildings >100 m^2

Water Pollution: Sources & Effects

Source	Pollutants	Effects
Domestic sewage	BOD organics, pathogens, N, P	O depletion, disease, eutrophication
Industrial effluent	Heavy metals, acids, solvents	Toxicity to aquatic life, bioaccumulation
Agricultural runoff	Pesticides, fertilizers (N, P)	Eutrophication, algal blooms, nitrate in groundwater
Thermal power plants	Heated water	Thermal pollution — reduces DO, kills fish
Oil spills	Petroleum hydrocarbons	Coats birds/fish, smothers benthic organisms
Mining	Acid mine drainage (H SO , Fe^{2})	Acidification, heavy metal contamination
Plastic waste	Microplastics	Accumulate in food chain, hormone disruption

Eutrophication: Excess N, P → algal bloom → algae die → BOD rises → DO falls → fish kills (dead zone)

Mid-Point Summary: Unit 7

Covered So Far

- ✓ Water quality parameters (physical & chemical)
- ✓ DO, BOD, COD definitions & significance
- ✓ Hardness: types, units, interconversion
- ✓ Hardness numericals (ppm, °F, °Cl)
- ✓ Lime-soda process (all reactions)
- ✓ Zeolite process + regeneration
- ✓ Ion exchange (demineralization)
- ✓ Reverse osmosis + desalination

Still To Come

- PYQ short & 7-mark questions
- More hardness + lime-soda numericals
- Boiler scale numericals
- Fluoride in water (health effects)
- Groundwater contamination
- Exam tips & common errors
- Revision flash points
- Mind map
- Unit summary + course wrap-up

Fluoride in Drinking Water

Fluoride & Health

Optimal: 0.6–1.5 mg/L
Prevents dental caries (tooth decay)

Defluoridation needed when:
>1.5 mg/L (WHO limit)
>1.5 mg/L causes **dental fluorosis** (mottled enamel)
>4 mg/L causes **skeletal fluorosis** (bone deformity)

India context: Fluoride belt in Rajasthan, Gujarat, AP; 20+ states affected

Defluoridation Methods:

- **Nalgonda technique:** Alum + lime → floc adsorbs F ; low cost, widely used in India
- **Activated alumina (AA):** F adsorbed on Al O ; regenerated with NaOH + H SO
- **RO:** Removes >95% fluoride
- **Ion exchange:** Anion resin removes F

Fluoridation: In low-F areas,

NaF/H SiF added to reach 1 mg/L

Groundwater Contamination

Major Contaminants

Natural: Arsenic (West Bengal, Bangladesh), Fluoride, Iron, Nitrate from soil

Industrial: Heavy metals (Pb, Cd, Cr, Hg), petroleum hydrocarbons, solvents (TCE, PCE)

Agricultural: Nitrate (NO_3^-), pesticides, herbicides

Urban: Leaking sewers, landfill leachate, road salt

Arsenic in Groundwater:
Reductive mobilisation: FeOOH dissolved under anaerobic conditions releases adsorbed As
India limit: 0.01 mg/L (WHO)

Nitrate Health Effects:
$>$45 mg/L $\rightarrow$ methemoglobinemia (blue baby syndrome) in infants
$NO_3^- \rightarrow NO_2^-$ binds Hb, reduces O_2 carrying capacity

Remediation:

Pump-and-treat, permeable reactive barriers, phytoremediation, monitored natural attenuation

BOD and COD: Numericals

Worked Examples

Q1. A wastewater sample has initial DO = 9 mg/L. After 5-day incubation at 20°C, DO = 2 mg/L. Find BOD_5.
$BOD_5 = \textit{Initial DO} - \textit{Final DO} = 9 - 2 = \mathbf{7\ mg/L}$

Q2. 0.4 g $K_2Cr_2O_7$ is used to oxidize organics in 250 mL sample. Calculate COD.
MW $K_2Cr_2O_7$ = 294 g/mol; equivalent weight = 294/6 = 49

$$\text{Equivalents} = \frac{0.4}{49} = 8.16 \times 10^{-3}\ \text{eq}$$

O_2 equivalent wt = 8 g/eq

$$\text{COD} = \frac{8.16 \times 10^{-3} \times 8}{0.250} = \mathbf{0.261\ g/L = 261\ mg/L}$$

Q3. BOD/COD ratio = 0.35. Is biodegradation treatment suitable?
*Ratio < 0.4 → **not suitable**; industrial/physico-chemical treatment preferred*

PYQ: Short Answer Questions (2 marks) — Set 1

Q. Define hardness of water.
Inability of water to produce lather with soap due to dissolved Ca^{2+} and Mg^{2+} salts of bicarbonates, chlorides and sulphates.

Q. Distinguish temporary and permanent hardness.
Temporary: due to bicarbonates; removed by boiling. Permanent: due to chlorides/sulphates; cannot be removed by boiling.

Q. Define BOD.
Amount of O_2 (mg/L) consumed by microorganisms to biodegrade organic matter at $20^{\circ}C$ over 5 days. High BOD = highly polluted.

Q. What is scale in boiler? Why harmful?
Hard deposit ($CaSO_4$, $CaCO_3$) on inner boiler walls. Bad heat conductor → overheating → metal weakening → explosion risk + fuel waste.

Q. What is reverse osmosis?
Water forced through semi-permeable membrane under pressure > osmotic pressure. Removes all dissolved ions, bacteria.

Q. What is zeolite process?
Uses $Na_2Al_2Si_2O_8 \cdot xH_2O$ to exchange Na^{+} for Ca^{2+}/Mg^{2+}. Regenerated with NaCl.

PYQ: Short Answer Questions (2 marks) — Set 2

Q. What is caustic embrittlement?
Cracking of boiler steel at stressed joints due to concentrated NaOH in crevices. Prevented by adding Na_2SO_4 (ratio $>$ 2.5:1 vs NaOH).

Q. What is priming and foaming?
Priming: carryover of water droplets with steam. Foaming: stable foam on boiler water surface due to dissolved organics/oils.

Q. State principle of ion-exchange softening.
Cation resin (R-H) exchanges H^+ for Ca^{2+}/Mg^{2+}; anion resin (R-OH) exchanges OH^- for Cl^-/SO_4^{2-}. Combined $=$ demineralized water.

Q. What is coagulation and flocculation?
Coagulation: alum $Al_2(SO_4)_3$ hydrolyses to $Al(OH)_3$ gel, neutralizes colloidal charges. Flocculation: gentle stirring aggregates particles into flocs for settling.

Q. Define COD. How does it differ from BOD?
O_2 equivalent of all oxidizable matter (by $K_2Cr_2O_7$). COD $\geq$ BOD always; includes non-biodegradable organics.

Q. What is breakpoint chlorination?
Dose of Cl_2 at which all NH_3 is oxidized to N_2 and free Cl_2 residual begins to appear.

PYQ: 7-Mark — Lime-Soda Process

Explain lime-soda process with all reactions (7 marks)

Principle: Lime [$Ca(OH)_2$] + soda ash [Na_2CO_3] precipitate hardness ions as $CaCO_3$ and $Mg(OH)_2$.

Reactions:

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + 2H_2O$$
$$Mg(HCO_3)_2 + 2Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + Mg(OH)_2 \downarrow + 2H_2O$$
$$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 \downarrow + Na_2SO_4$$
$$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 \downarrow + 2NaCl$$
$$MgSO_4 + Ca(OH)_2 \rightarrow Mg(OH)_2 \downarrow + CaSO_4$$
$$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 \downarrow + Na_2SO_4$$
$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 \downarrow + H_2O$$

Process: Cold (50–80 ppm residual) or hot ($<$15 ppm). Sludge removed by sedimentation + filtration. Advantages: cheap, removes turbidity, Fe, CO_2. Disadvantage: sludge disposal.

PYQ: 7-Mark — Municipal Drinking Water Treatment

Describe municipal drinking water treatment with flowchart (7 marks)

Screening	Screens remove large debris from river intake
Sedimentation	Plain settling; removes heavy suspended particles
Coagulation	Alum added; $Al(OH)_3$ gel precipitates colloids; pH adjusted with lime
Flocculation	Gentle stirring; flocs grow and settle in clarifier
Sand filtration	Slow or rapid sand filter removes fine particles and bacteria
Disinfection	Cl_2 (0.2–0.5 mg/L residual), ozone, or UV; kills pathogens
pH correction	Lime/CO_2 adjustment to 6.5–8.5
Fluoridation	NaF added if $F^- < 0.6$ mg/L
Distribution	Pumped to overhead tanks and supply network

BIS/WHO limits: pH 6.5–8.5; TDS <500; Hardness <200; Cl_2 residual 0.2 mg/L; Coliform = 0/100 mL

PYQ: 7-Mark — Sewage Treatment

Describe sewage treatment (primary, secondary, tertiary) (7 marks)

Primary (Physical): Screening → Grit chamber → Primary sedimentation tank
Removes 30–40% BOD, 60% SS; produces primary sludge

Secondary (Biological):
Trickling filter: Wastewater trickled over stone/plastic media with biofilm; aerobic oxidation; BOD removal 80–90%
Activated sludge: Aeration tank; microbes consume organics; secondary clarifier; sludge recycled; BOD removal 90–95%

Tertiary: Sand filtration, activated carbon, nutrient removal (N, P), disinfection, RO
Final effluent meets standards for river discharge or reuse

Sludge treatment: Anaerobic digestion → biogas (60–70% CH_4) + biosolids (fertilizer)

CPCB effluent standards: BOD $<$10 mg/L; SS $<$20 mg/L; pH 6.5–9.0

Numerical: Boiler Scale and Zeolite

Worked Examples

Q1. A boiler uses water with hardness 200 ppm. 50,000 litres used per day. Find mass of $CaCO_3$ scale formed.

$200\ ppm = 200\ mg/L$

$Scale/day = 200 \times 10^{-3}\ g/L \times 50{,}000\ L = \mathbf{10{,}000\ g} = \mathbf{10\ kg/day}$

Q2. Water contains $CaCl_2 = 222$ mg/L, $MgCl_2 = 190$ mg/L. Zeolite exchange capacity = 85 g $CaCO_3$/kg. Find zeolite needed for 10,000 L.

Hardness ($CaCl_2$): $\frac{222 \times 100}{111} = 200$ ppm; Hardness ($MgCl_2$): $\frac{190 \times 100}{95} = 200$ ppm

Total = 400 ppm; $CaCO_3$ equiv $= 400 \times 10^{-3} \times 10{,}000 = 4000$ g

Zeolite $= \frac{4000}{85} \times 1000 = \mathbf{47.06\ kg}$

Common Exam Errors & Tips

Common Mistakes

- Forgetting $CaCO_3$ equivalent in ppm formula
- Confusing bicarbonates = temporary with chlorides/sulphates = permanent
- Zeolite regenerated by NaCl, not Na_2CO_3
- Mg salts need **two** separate lime-soda reactions
- COD $\geq$ BOD always; never vice versa
- Free CO_2 needs lime in lime-soda process (often forgotten)

Exam Strategy

- Write MW and formula before each numerical step
- Separate each salt in hardness calculations
- Simple flowchart earns diagram marks (5/7-mark Q)
- Memorise all 7 lime-soda reactions
- 2-mark = definition + 1 example = full marks
- Show balanced equations with product states ($\downarrow$, $\uparrow$)
- BOD/COD ratio indicates treatment method choice

Industrial Water: Cooling Systems

Cooling Water Problems

Scale: $CaCO_3$, $CaSO_4$ in heat exchangers

Corrosion: Dissolved O_2, CO_2, microbiological activity

Biofouling: Algae, bacteria (*Legionella* in cooling towers)

Treatments:
Scale inhibitors: polyphosphates, HEDP
Corrosion inhibitors: molybdates, benzotriazole
Biocides: Cl_2, isothiazolone, glutaraldehyde

Cycles of Concentration (CoC):

$$\text{CoC} = \frac{\text{TDS in recirculating water}}{\text{TDS in makeup water}}$$

Higher CoC $\rightarrow$ less makeup water (better efficiency), but higher scaling risk. Typical: 3–5 cycles.

Blowdown: Fraction of recirculating water purged to control TDS buildup.

***Legionella* control:** Residual biocide; periodic hyperchlorination; storage temperatures $>60^\circ$C

Comprehensive Hardness Numerical

Full Classification Example

Problem: Water contains: $Ca(HCO_3)_2 = 16.2$ mg/L; $Mg(HCO_3)_2 = 14.6$ mg/L; $CaSO_4 = 13.6$ mg/L; $MgCl_2 = 9.5$ mg/L. Find temporary, permanent and total hardness in ppm and °F.

Salt	MW	mg/L	Hardness (ppm)
$Ca(HCO_3)_2$	162	16.2	$\frac{16.2\times100}{162} = 10$ (Temp)
$Mg(HCO_3)_2$	146	14.6	$\frac{14.6\times100}{146} = 10$ (Temp)
$CaSO_4$	136	13.6	$\frac{13.6\times100}{136} = 10$ (Perm)
$MgCl_2$	95	9.5	$\frac{9.5\times100}{95} = 10$ (Perm)

Temporary = 10+10 = **20 ppm = 2°F** Permanent = 10+10 = **20 ppm = 2°F**
Total hardness = **40 ppm = 4°F**

Water Conservation & Environmental Regulations

Conservation Strategies

Domestic: Low-flow fixtures, rainwater harvesting, greywater reuse

Agricultural: Drip irrigation (50% less water vs flood), soil moisture monitoring

Industrial: Recirculation cooling, ZLD, water audits

India schemes: Jal Jeevan Mission (piped water to rural households); Atal Bhujal Yojana (groundwater management)

Indian Regulations

Water Act, 1974: Prevention & Control of Pollution

EP Act, 1986: Environment Protection

IS 10500:2012: BIS drinking water standard

CPCB effluent norms:

pH: 6.5–9.0
BOD: $<$30 mg/L (river discharge)
SS: $<$100 mg/L
Oil & grease: $<$10 mg/L
ZLD mandatory: textile, pharma, tannery

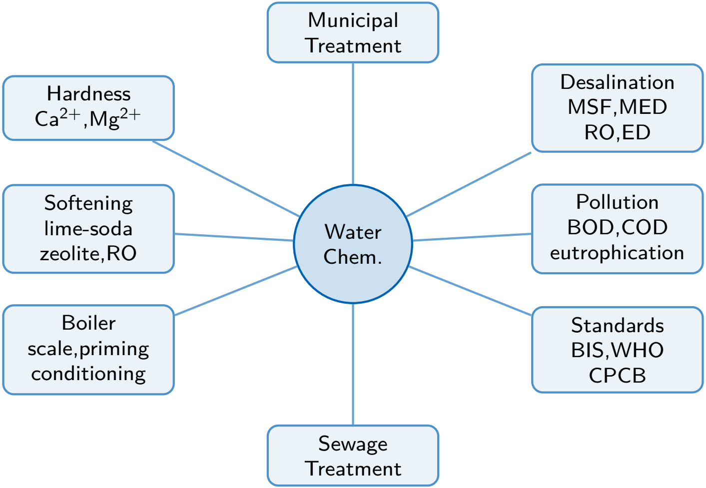
Revision Flash Points: Unit 7

- Hardness ppm = (mg/L × 100) / MW of salt as $CaCO_3$
- 1 ppm = 0.1°F = 0.07°Cl = 0.056°d
- Temporary hardness = bicarbonate salts; removed by boiling
- Lime-soda: $Ca(OH)_2$ removes temporary; Na_2CO_3 removes permanent Ca; both needed for Mg salts
- Zeolite regenerated by 10% NaCl; cannot remove turbidity
- Ion exchange → demineralized (DM) water for boiler feed
- RO: pressure > osmotic pressure; removes all dissolved ions
- Boiler troubles: scale, priming, foaming, caustic embrittlement, corrosion
- Scale: $CaSO_4$ hardest; poor heat transfer → explosion risk
- N_2H_4 removes O_2 without adding TDS (high-pressure boilers)
- BOD_5 at 20°C; BOD/COD < 0.4 → biological treatment unsuitable
- Breakpoint Cl_2: all NH_3 oxidized; free Cl_2 appears
- BIS: pH 6.5–8.5; TDS <500; hardness <200; F^- 0.6–1.5 mg/L
- Dental fluorosis >1.5 mg/L; skeletal fluorosis >4 mg/L
- Defluoridation: Nalgonda technique or activated alumina
- Sewage: primary (physical) → secondary (biological) → tertiary
- Anaerobic digestion of sludge → biogas (60–70% CH_4)
- Eutrophication: excess N, P → algal bloom → DO depletion → dead zone
- ZLD mandatory for textile/pharma/tannery in India

Key Data & Reactions for Exam

Item	Value / Reaction
Hardness units	1 ppm $= 0.1^\circ$F $= 0.07^\circ$Cl
Hardness formula	$\frac{mg/L \times 100}{MW}$ as $CaCO_3$ equivalent
BOD (clean water)	<1 mg/L; polluted river 5–10; sewage 200–500
DO (clean water)	8–9 mg/L; fish survive >4 mg/L
Municipal Cl_2 residual	0.2–0.5 mg/L
Zeolite formula	$Na_2Al_2Si_2O_8 \cdot xH_2O$ (Na_2Ze)
Zeolite regeneration	$CaZe + 2NaCl \rightarrow Na_2Ze + CaCl_2$
Internal conditioning	$3CaSO_4 + 2Na_3PO_4 \rightarrow Ca_3(PO_4)_2 \downarrow + 3Na_2SO_4$
O_2 scavenger	$N_2H_4 + O_2 \rightarrow N_2 + 2H_2O$
Caustic embrittlement	$Na_2SO_4 : NaOH$ ratio > 2.5
Coagulation	$Al_2(SO_4)_3 + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 \downarrow + 3CaSO_4 + 6CO_2$

Unit 7: Concept Mind Map



Hardness Numericals: Practice Set

Practice Problems

Q1. Find hardness in ppm: $CaCl_2$ = 111 mg/L; $MgSO_4$ = 60 mg/L.
$CaCl_2$: $\frac{111\times100}{111} = 100$ *ppm*; $MgSO_4$: $\frac{60\times100}{120} = 50$ *ppm*; *Total* = ***150 ppm***

Q2. Convert 150 ppm to °F and °Cl.
$^\circ F = 150/10 = \mathbf{15^\circ F}$; $^\circ Cl = 150/14.3 = \mathbf{10.5^\circ Cl}$

Q3. Water: $Ca(HCO_3)_2$ = 81 mg/L; $MgSO_4$ = 72 mg/L; $CaCl_2$ = 55.5 mg/L.
Find temporary and permanent hardness.
Temp: $Ca(HCO_3)_2$ *only* $= \frac{81\times100}{162} = 50$ *ppm*
Perm: $MgSO_4$: $\frac{72\times100}{120} = 60$; $CaCl_2$: $\frac{55.5\times100}{111} = 50$; *Total perm* = ***110 ppm***
Total= ***160 ppm = 16° F***

Numerical: Lime and Soda Required

Lime-Soda Requirement Calculation

Problem: Calculate lime [$Ca(OH)_2$] and soda [Na_2CO_3] required to treat 1 litre of water containing: $Ca(HCO_3)_2$ = 32.4 mg/L; $MgCl_2$ = 19 mg/L; $MgSO_4$ = 24 mg/L.

MW: $Ca(HCO_3)_2$=162; $MgCl_2$=95; $MgSO_4$=120; $Ca(OH)_2$=74; Na_2CO_3=106

Lime required:

For $Ca(HCO_3)_2$: $\frac{32.4}{162} \times 74 = 14.8$ mg/L

For $MgCl_2$ (2 moles lime): $\frac{19}{95} \times 2 \times 74 = 29.6$ mg/L

For $MgSO_4$ (2 moles lime): $\frac{24}{120} \times 2 \times 74 = 29.6$ mg/L

Total lime = 74.0 mg/L

Soda required:

$MgCl_2$ produces $CaCl_2$: $\frac{19}{95} \times 106 = 21.2$ mg/L

$MgSO_4$ produces $CaSO_4$: $\frac{24}{120} \times 106 = 21.2$ mg/L

Total soda = 42.4 mg/L

Key Parameters in Sewage Treatment

Parameter	Typical Sewage	After Treatment
BOD	200–300 mg/L	<10 mg/L (tertiary)
COD	300–600 mg/L	<50 mg/L
SS	150–300 mg/L	<20 mg/L
Total N	30–50 mg/L	<10 mg/L
Total P	5–15 mg/L	<1 mg/L
pH	7 (neutral)	6.5–9.0
DO	≈0	>6 mg/L (after aeration)
Coliforms	10^6–10^9/100 mL	0 (after disinfection)

Treatment Efficiency

Primary: 30–40% BOD removal; Secondary: 85–95% BOD removal; Tertiary: >99% BOD removal

RO and Membrane Processes: Summary

Reverse Osmosis in Detail

Osmosis: Solvent flows from dilute to concentrated solution through semi-permeable membrane.

Osmotic pressure: $\Pi = iCRT$ (van't Hoff)

RO: Applied pressure $> \Pi$ forces water through membrane, leaving ions behind.

Seawater $\Pi \approx 27$ bar; operating pressure 50–80 bar
Brackish water: 10–20 bar

Membrane: Thin-film composite (TFC) polyamide; pore $\approx$ 0.1–1 nm
Recovery: 40–85% of feed water recovered

RO Applications:

- Seawater desalination (SWRO)
- Brackish water treatment
- Boiler feed water production
- Industrial pure water
- Pharmaceutical grade water
- Domestic RO systems

R.O. Rejects (brine):
Must be disposed carefully; high TDS brine disposal is an environmental challenge for inland plants.

Pre-treatment for RO:

Coagulation $\rightarrow$ filtration $\rightarrow$ cartridge filter $\rightarrow$ antiscalant dosing $\rightarrow$ RO

Water, Sustainability & Global Perspective

Global Water Facts

Total global water: 1.386 billion km^3
Freshwater: 2.5% only
Accessible freshwater: $<$1%

2.2 billion people lack safe drinking water (UN, 2022)
4.2 billion lack adequate sanitation

UN SDG 6: Clean water and sanitation for all by 2030

India annual per capita water availability dropping from 5177 m^3 (1951) to $\approx$1486 m^3 (2021)

Indian Water Challenges:

- Groundwater over-extraction (Punjab, Rajasthan, UP)
- River pollution (Ganga, Yamuna)
- Industrial effluents in water bodies
- Arsenic and fluoride in groundwater
- Urban water supply infrastructure gaps

Green Chemistry Approach:

Water-less processes, solvent recycling, minimizing industrial water footprint, eco-friendly effluent treatment technologies

Electrodialysis (ED) & Advanced Desalination

Electrodialysis Principle

DC voltage applied across a stack of alternating cation-exchange membranes (CEM) and anion-exchange membranes (AEM).

Cations move toward cathode through CEM; anions move toward anode through AEM.

Result: dilute and concentrate compartments alternate in stack.

Best for: Brackish water (1000–5000 ppm TDS)
EDR: Electrodialysis Reversal — polarity periodically reversed to prevent fouling

Desalination Technology Comparison

Method	Energy	Best for	Sca
MSF	High	Seawater	Lar
MED	Medium	Seawater	Lar
SWRO	Low	Seawater	All
BWRO	Very low	Brackish	All
ED/EDR	Low	Brackish	Sm me

Water Quality Monitoring & Testing

Laboratory Tests

EDTA titration: Total hardness measurement
$Ca^{2+} + Mg^{2+}$ titrated with 0.01 M EDTA; indicator EBT (wine red $\rightarrow$ blue at endpoint)

Winkler method: DO measurement
$MnSO_4 + KI + H_2SO_4$; I_2 liberated titrated with $Na_2S_2O_3$

Permanganate method: COD (quick estimate)

Dichromate method: Accurate COD
BOD apparatus: DO bottle, 5-day incubation, 20°C dark

Online/Field Monitoring:

- pH meter, conductivity meter, turbidimeter
- DO probe (polarographic or optical)
- TDS meter (conductivity-based)
- Fluoride ISE (ion-selective electrode)
- Spectrophotometer: nitrate, phosphate, chromium
- TOC analyser (Total Organic Carbon)

Real-time monitoring: SCADA systems monitor treatment plant parameters online; alarms for out-of-spec conditions

Microbiological Water Quality

Indicator Organisms

Total Coliforms: Normal inhabitant of gut of warm-blooded animals; indicates fecal contamination risk. Limit: 0/100 mL (drinking water)

E. coli: Specific indicator of fecal contamination; Limit: 0/100 mL

Heterotrophic Plate Count (HPC): General bacterial count; Limit $<$100 CFU/mL

Why coliforms? Easy to detect, survive longer than pathogens, correlate with pathogen presence

Detection Methods

MPN method (Most Probable Number): Multiple tube fermentation; statistical estimate of coliforms per 100 mL

Membrane filtration: 100 mL filtered; incubated on selective media; colonies counted

Rapid methods: Colilert (enzyme substrate), flow cytometry

Presumptive $\rightarrow$ **Confirmed** $\rightarrow$ **Completed** test sequence

PYQ: Short Answer Questions — Set 3

Q. Define dissolved oxygen (DO). What is its significance?
O_2 dissolved in water; determined by Winkler method. Clean natural water: 8–9 mg/L. DO $<$ 4 mg/L: aquatic life stressed. DO $=$ 0: anaerobic (septic) conditions.

Q. What is the significance of BOD/COD ratio?
Ratio indicates biodegradability. $>$0.6: easily biodegradable; 0.4–0.6: biodegradable; $<$0.4: biologically resistant; need chemical/physical treatment.

Q. What is eutrophication?
Excess N and P in water body $\rightarrow$ algal bloom $\rightarrow$ algae die $\rightarrow$ microbial decomposition raises BOD $\rightarrow$ O_2 depletion $\rightarrow$ fish kills (hypoxic/anoxic

Q. What is sedimentation? How is it enhanced?
Settling of suspended particles under gravity. Enhanced by coagulation (alum) and flocculation (gentle stirring) to form larger, faster-settling flocs.

Q. Define TDS. What does high TDS indicate?
Total Dissolved Solids $=$ all dissolved inorganic and organic matter. Measured by evaporation or conductivity. High TDS indicates contamination, industrial effluent, or excessive hardness. Limit: 500 mg/L (BIS).

Q. What is the Nalgonda technique?
Defluoridation: alum $+$ lime added $\rightarrow$ $Al(OH)_3$ floc adsorbs F^- $\rightarrow$ floc settled and filtered. Low-cost, widely used in rural India.

PYQ: 7-Mark — Boiler Troubles & Prevention

Explain boiler troubles and their prevention (7 marks)

Trouble	Cause	Prevention
Scale	$CaSO_4$, $CaCO_3$, $CaSiO_3$ deposits	Na_3PO_4/calgon; blowdown; DM water
Priming	High dissolved/suspended solids; rapid boiling	Slow heating; blowdown; baffle plates
Foaming	Oil, grease, organic matter in water	Remove oils; add anti-foam agents
Caustic embrittlement	NaOH conc. in crevices at stressed joints	Add Na_2SO_4 (ratio $>$2.5:1); use riveted boilers $\rightarrow$ welded construction
O_2 corrosion	Dissolved O_2 in feed water	Deaeration $+$ N_2H_4 or Na_2SO_3
CO_2 corrosion	Dissolved CO_2 from bicarbonate decomposition	Add cyclohexylamine or morpholine (neutralising amines)

External treatment: Ion exchange/RO for DM water. **Internal conditioning:** Chemicals added to boiler feed water to control residual impurities.

Complete Hardness Removal Methods: Summary

Method	Removes	Residual	Sludge	Best Use
Boiling	Temporary only	Moderate	$CaCO_3$	Domestic, small scale
Lime-soda (cold)	All types	50–80 ppm	Yes, large	Municipal, industrial
Lime-soda (hot)	All types	$<$15 ppm	Yes	Industrial
Zeolite	All types	$\approx$0	No	Industrial, domestic
Ion exchange (mixed)	All ions	$\approx$0	No	Boiler feed, lab, pharma
RO	All ions	$\approx$0	Brine	Desalination, DM water
Nanofiltration	Divalent ions	Low	Small	Partial softening

Key deciding factors

Scale: Municipal $\rightarrow$ lime-soda; Industrial softening $\rightarrow$ zeolite; Boiler feed (zero hardness required) $\rightarrow$ ion exchange or RO; Desalination $\rightarrow$ SWRO.

Numericals: Osmotic Pressure & Practical Problems

Problems

Q1. Water with 5000 mg/L NaCl. Approximate osmotic pressure? (MW NaCl = 58.5; T = 25°C; $i = 2$)

$C = \dfrac{5}{58.5} = 0.0855$ mol/L; $\Pi = iCRT = 2 \times 0.0855 \times 0.0831 \times 298 =$ **4.23** bar

Q2. An RO unit has 40% recovery and feed flow 100 L/h. What is product and reject flow?

$Product = 40\% \times 100 = 40\ L/h; \quad Reject\ (brine) = \mathbf{60}\ L/h$

Q3. BOD test: 10 mL sample diluted to 300 mL. Initial DO = 9 mg/L; final DO = 3 mg/L. Find BOD.

DO consumed = $9 - 3 = 6$ mg/L (in 300 mL)

Actual BOD = $6 \times \dfrac{300}{10} =$ **180 mg/L**

Unit 7 Exam Strategy & High-Value Topics

Guaranteed 7-Mark Topics

- Lime-soda process (all reactions + advantages)
- Zeolite process (reactions + regeneration)
- Boiler troubles and prevention (full table)
- Municipal drinking water treatment (flowchart)
- Sewage treatment (primary + secondary + tertiary)
- Reverse osmosis (principle + applications)

High-Value Numericals

- Hardness in ppm (all salts given, classify temp/perm)
- Convert ppm to °F and °Cl
- Lime and soda required for a water sample
- Zeolite volume/NaCl for regeneration
- BOD from DO readings
- Scale formed per day from hardness data

Weightage: ≈**15%** of DI01000071 final paper. Expect 1–2 numericals, 2–3 short definitions, and 1 descriptive (process flowchart or boiler troubles).

Engineering Chemistry DI01000071: Complete!

All Units Covered

- ✓ **Unit 1:** Atomic Structure, Bonding & Solutions
- ✓ **Unit 2:** Electrochemistry (EMF, batteries, corrosion)
- ✓ **Unit 3:** Corrosion (types, factors, protection)
- ✓ **Unit 4:** Fuels (classification, calorific values, numericals)
- ✓ **Unit 5:** Lubricants (properties, testing, viscosity)
- ✓ **Unit 6:** Polymers (types, synthesis, properties)
- ✓ **Unit 7:** Water Chemistry (hardness, treatment, boiler)

Exam Preparation Checklist

- ☐ Revise all formulas and key reactions (flashcards)
- ☐ Practice 5+ numericals per unit
- ☐ Draw all process flowcharts from memory
- ☐ Write short definitions for every bold term
- ☐ Attempt 3–4 PYQs without notes
- ☐ Review common errors slide per unit
- ☐ Revise unit mind maps 1 day before exam

Engineering Chemistry

DI01000071

"Water is the driving force of all nature."

— Leonardo da Vinci

Milav Dabgar
Lecturer, Department of Electronics & Communication Engineering
Government Polytechnic Palanpur

All 7 Units Complete ✓