

Lecture 1

Current Issues of Concern

- Global warming & Climate Change
- Species' extinction
- Soil degradatⁿ, loss of wetlands & agri land
- Ozone layer depletion
- Conc. of Toxics
- Depletⁿ & Degradatⁿ of Resources
- CO₂ emissions : Highest producer China
Highest producer (per capita) USA

Lecture 2

- water pollution
 - └ BOD : Biochemical Oxygen Demand
 - └ COD : Chemical Oxygen Demand.
- Human - Animal conflict : unchecked human expansion.
- Lake frothing (high phosphorus levels - shampoos, detergents)
- Indonesian Tsunami, 2004 effected :
 - Indonesia
 - Thailand
 - Myanmar → protected due to mangrove forest on coastline, same for Bangladesh
 - India
 - Sri Lanka
- Cutting of mangrove is remarkable in countries like Honduras, Vietnam etc
- 2018 2014, Ok was 1st Icelandic glacier to lose its status as glacier. & maybe in 200 years
- GHGs (CO₂, CH₄, NO_x etc) emitters
 - └ more like plateauing
 - └ NA & EU are decreasing
 - └ China
 - └ India

Lecture 3

- Sectors contri to GHGs :
 - 1. Energy - Major
 - 2. Agriculture - animal rearing is also included
 - 3. Industry - increasing
 - 4. Land use change & forestry - decreasing
- Energy - Electricity / Heat is the major contributor followed by Transportation & Construction.
- World energy growth - China → USA → India
- If concrete was a country, concrete would be third largest carbon emitter after China & USA. Internet would be 7th.

o China vs India

- From 1990 China had been developing much more rapidly than India.
- PPP (Purchasing Power Parity) : much less difference but still China > India
- wrt GHGs / person : USA > China > India

Air Pollution

- PM_{2.5} = Particulate matter <2.5 micron - it can enter our blood stream
- Hotspots : Northern India
Eastern Asia
Some parts of Africa
- 80% of 10 most polluted cities are in India.
- VOC = Volatile Organic Compounds

Xtra Read: The Anarchy - its a well researched book

Lecture 4

- > 90% deaths due to air pollution occur in low & middle income countries.

Growth of subsectors in Energy

- Oil & coal are relatively stagnant.
- Natural gas & renewables saw significant growth in 2018.
- EU has been pushing for renewables.
- It also depends on prevailing type of govt. as populist govt like in USA, Brazil tend to give in to public demand & has increased consumption of fossil fuels.
- 2019 June was hottest June on record.
- Difficulties in phasing out coal:
 - ↳ Increasing energy demands
 - ↳ Low cost of coal
 - ↳ Type of govt
 - ↳ Awareness & regulation
- At the rate of global warming, the land lost to increasing sea levels will be such that what was lost in few thousand years is going to be lost in few centuries.
- By 2050, 104 cities are going to witness temperatures no major city has experienced.
- Now we have one extreme event a week while before it was once every fortnight.
- Concerning problems in developed countries
 - ↳ Health
 - ↳ Poverty
 - ↳ Education
 - ↳ Environment
- One flight from London - Rome emits 234 kg CO₂ / person is more than CO₂ released per person in a year in middle - Africa.
- Similarly from London - Perth > citizen in India per year.

Lecture 5

- Aviation industry is one of the ^{fastest} growing polluters.
- International Civil Aviation Org (ICAO) is letting airlines buy carbon credits to offset emissions rather than reducing burned fuel.
- EU is pushing for more energy efficient housing planning
- Only handful sectors are planning for controlling climate change & govt aren't enforcing policies as they fear backlash.
- Leaving adaptation to local communities & orgs isn't gonna work if a national architecture for climate change isn't planned.
- Extinction of species is also common right now. As nearly half of 177 mammal species lost 80% of range.

Earth's Mass Extinctions

1. End-Ordovician - 443 mil yrs ago
2. Late-Devonian - 360 " "
3. Permian-Triassic - 250 " "
4. Triassic-Jurassic - 200 " "
5. Cretaceous-Tertiary - 65 " "

- Total biomass of human race accounts for just 0.01% life on Earth.
- Of all mammals on earth, 36% are human & 60% are livestock & 4% are wild mammals.
- Similarly 70% birds are in various poultry while 30% are wild.
- ∴ expansion of human civilization 83% wild mammals have been lost.

Lecture 6

- Cattle Rearing disadvantages
 - GHGs are released
 - Forests cut for land
 - Soy needed for feeding which also leads to deforestation
- Insects have 17x biomass of humans & their rate of extinction is 8x faster than mammals etc. They play a significant role in balancing nature.
- 80% of marine mammals, 50% plants & 15% fish are also lost due to human expansion.
- CO₂ also acidifies the sea as well as it absorbs H₂CO₃ & has other effects.
- South & central America has faced worst decline of biodiversity.
- 3/4 of earth is significantly affected by humans.
- Mining causes water pollution, Acidic Mine Drainage is absorbed or drained which later affects seas & oceans too.

Lecture 7

- What we can do?
 - ↳ reduce aviation
 - ↳ reduce energy use → GHGs ↓
 - ↳ AC at 29°C rather than 18°C 18°C
 - ↳ avoiding meat / dairy
 - ↳ using renewables
- Livestock Livestock uses 83% farmland but produces only 18% of calories & 37% of protein.
- Beef causes 105 kg GHGs / 100g while tofu causes 3.5 kg / 100g.
- Earth Overshoot Day falls on ~~1st~~ ^{this year} August 1st, marking the point at which "consumption" of resources exceeds the capacity of nature to regenerate.
- Air pollution
 - ↳ Modern pollution : outdoor air, chemicals ↑ ↗
 - ↳ Traditional pollution : indoor air, water ↓
- Our bodies have evolved to defend itself against infections, not pollution
- NO_x + VOC under sunlight produce O₃ which is highly toxic.
- NO_x is produced mainly by vehicles (majorly Diesel based vehicles)
- Clean air zones are the most effective way to cut NO_x but it's isn't a popular option in general crowd.

Lecture 8 and 9

- UNFCCC = UN Framework Convention on Climate Change
 - ↳ 197 parties
 - ↳ parent treaty of Paris Agreement 2015. → aim for 1.5°C b4 pre-industrial levels. → binding agreement < 2°C
 - ↳ NDC's Nationally Determined Contributions
 - ↳ India's NDC : 1. GHG emission intensity of GDP ↓ by 33% below 2005 levels b4 2030
 - 2. 40% power capacity → non-fossil fuels
 - 3. Additional carbon sink of 2.5 to 3 bri tonnes of CO₂ eqv.
 - ↳ COP (Conference of Parties) - Paris Agr 2015 was at COP21
- Is India on track : ↳ GHG emission ↓ by 24%
 - ↳ target of 450 GW by renewables - 100 GW achieved - on track for 500 GW. - renewable energy capacity ↑ by 2.5 x & solar by 13x
 - ↳ little progress on 3rd NDC
- Pre COP26 estimate > 2°C by 2100 , Post COP26 < 2°C by 2100
- China's targets : ↳ peak by 2030 → net zero by 2060 → GHG emission ↓ by 65%

- India's modified NDC : net zero by 2070
- COP26 :
 1. Emission cuts to be focussed on
 2. Coal to be phased down & not phased out
 3. Climate finance = 500 bn for adaptation rather than emission cuts.
- Even if we stop emissions effects aren't going to die down b4 150 yrs
Similarly for ozone hole it takes 20-30 yrs.
Thus for 1.5°C net zero by 2050 needed
- Even now investments in oil based companies isn't cutting down.
- Carbon Sequestration : Post combustion carbon capture & storage sequestration (CCS) can be done ie capturing CO_2 , compressing it, storing it to subsurface for sequestration centuries & then reusing it.
- Animal Husbandry needs to cut down & we can transfer to vegan based meat.
- Not all plantations are C-ve → only possible if we have a proper ecosystem.

→ Miyawaki Method : ~~SL~~ Soil preparation ~~SX~~ Purchase

• Miyawaki Method

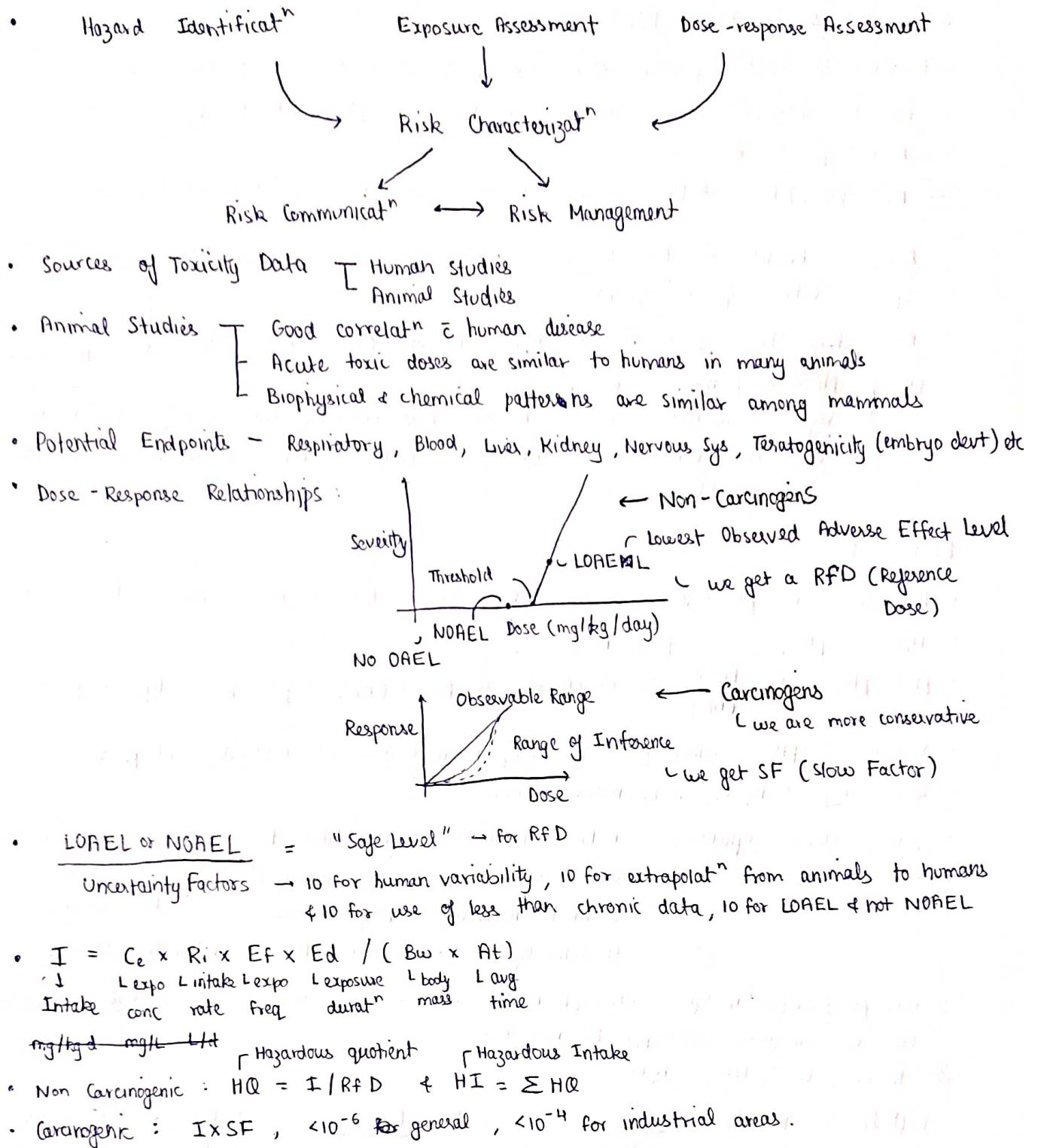
- L S1: Soil Preparation : A combi of perforators, water retainers, fertilizers & micro-org should be mixed to the soil
- L S2: Native species : Diverse plants for shrub layer, sub-tree layer, tree layer & canopy layer.
- L S3: Design a Forest : Random & dense
- L S4: Method of Plantation
- L S5: Tie plants to a stick : so that plants grow rapidly vertically.
- L S6: Maintaining

allow roots to grow quickly

L sludge from
water sewage plant
is also N-rich.

Lecture 10

- What is Risk ? Probability of adverse effects.
- Sometimes some sort of contamination can be later made more toxic by natural processes / degradation.
- Health - drinking water contaminated by vinyl chloride : Concentration
 - L Cancer Risk = Intake * Slope Factor (S.F.) = $f(C_e) * SF$
 - L anything $> 10^{-6}$ is unacceptable L depends on compound
- Some eg of risk estimated to ↑ chance of death by 10^{-6} in any year are smoking 1.4 cigarettes, spending 1 hr in coal mine, drinking 30 12-oz cans of soda (having saccharin)
- mere presence of toxic chemical is insufficient now as dosage matters
- Risk Assessment : Systematic characterization of potential adverse health effects due to exposure to hazardous agents.



Lecture 11 & 12

- O_2 enters surface water through mainly diffusion from atmosphere or photosynthesis by algae
- Equilibrium const $K = [C]^c [D]^d / [A]^a [B]^b \rightarrow aA + bB \rightleftharpoons cC + dD$
 - activity conc
 - activity not conc → but assume Ionic strength ↓, thus $\{ \cdot \} \approx [\cdot]$
- Phase = region w/ uniform chemical & physical prop (gas, liq, solid)
- Henry's Law = amt of gas dissolved ∝ partial pressure exerted by gas on liq surface, $H = \frac{C_g}{C_{aq}}$
 - other variants like P/C_{aq} also true.
- Higher H → more volatile
- Temp ↑, H ↑ (generally)
- $K_H = 1/H = C_{aq} / C_g$ when we define $\ln P$ in reverse direction

- $PV = nRT \rightarrow C = n/V = P/RT$
 - Dalton's Law : Total pressure of a mixture of gases is sum of partial pressures of gases.
 - If find DO in aerated water at 25°C in treatment plant, $K_H(\text{of O}_2, 25^\circ\text{C}) = 1.26 \times 10^{-3} \text{ M/atm}$
Partial pressure of $\text{O}_2 = 0.21 \text{ atm}$
 $\rightarrow K_H = [\text{O}_2]/P_{\text{O}_2} \Rightarrow [\text{O}_2] = 1.26 \times 10^{-3} \times 0.21 = 2.646 \times 10^{-4} \text{ M} = 8.467 \text{ mg/L}$
 - Rainwater droplets tend to absorb a lot of impurities as we assume many species estb a quick equilibrium.
 - After change from gas \rightarrow aq, if changes to acid/base it can effect pH
 - pH $\boxed{\text{pH of most mineral-bearing water is } 6.5 - 8.}$
 regulated in natural waters by acid-base rxns eg $\text{CaCO}_3 + \text{CO}_2 \rightarrow \text{Ca}^{2+} + 2\text{HCO}_3^-$, acids from volcanic activity (HCl, SO_2), biological rxns as equilibrium is estb very quickly.
- [imp variable in envt aspects. thus master variable]

Lecture 13

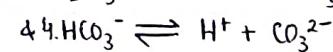
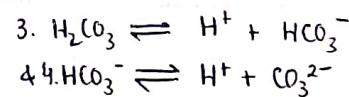
- $\text{HCl} + \text{H}_2\text{SO}_4$ has $\text{pK}_a \sim -3$ ie very strong acids but we have particular focus on H_2CO_3
- $\text{H}_2\text{CO}_3 \rightarrow \text{pK}_{a_1} = 6.3 \text{ & } \text{pK}_{a_2} = 10.3$
- $\text{pH} = \text{pK}_a + \log \frac{[\text{A}^-]}{[\text{HA}]}$ So at $\text{pH} = \text{pK}_a \Rightarrow [\text{A}^-] = [\text{HA}]$: good buffer. ($\text{pK}_a - 1, \text{pK}_a + 1$)
- Special \bar{c} pH = which species of a comp is more dominant wrt different pH value
- Acidity imposed by CO_2 is natural acidity
- Solving chemical equilibria :
 - List all chemical species likely to exist (cations, anions, neutral sp.)
 - List all independent chemical equations. $\boxed{\text{Chem equilibria}}$
 - Electro neutrality or charge balance $\boxed{\text{Mass balance}}$
 - Solve eqns : Often easier to calc H^+ & then others.

Q Calc pH of droplet in equi \bar{c} atmospheric CO_2 . Assume only carbonate sp. in water. Assume CO_2 conc in atm is 370 ppm by mole basis.

$\hookrightarrow \text{H}^+, \text{OH}^-, \text{CO}_3^{2-}, \text{HCO}_3^-$, H_2CO_3

$$1. [\text{H}^+] [\text{OH}^-] = K_w = 10^{-14} = \frac{[\text{H}^+] [\text{OH}^-]}{[\text{H}_2\text{O}]}$$

$$2. K_H = \frac{[\text{H}_2\text{CO}_3]}{P_{\text{CO}_2}}$$



5. Charge balance

we can neglect CO_3^{2-} as P_{CO_2} isn't very high

$$\text{So: } 2. [\text{H}_2\text{CO}_3] = K_H P_{\text{CO}_2} = 10^{-1.5} P_{\text{CO}_2}$$

$$3. \text{ } \text{ } \text{ } \text{ } K_{a_1} = \frac{[\text{H}^+] [\text{HCO}_3^-]}{[\text{H}_2\text{CO}_3]} \Rightarrow [\text{HCO}_3^-] = \frac{k_{a_1} \times K_H P_{\text{CO}_2}}{[\text{H}^+]} = \frac{10^{-7.8} P_{\text{CO}_2}}{[\text{H}^+]}$$

$$4. \text{Similarly } \text{ } \text{ } \text{ } \text{ } [\text{CO}_3^{2-}] = \frac{10^{-18.1} P_{\text{CO}_2}}{[\text{H}^+]} \quad r \approx 0$$

$$5. [\text{H}^+] = [\text{HCO}_3^-] + 2[\text{CO}_3^{2-}] + [\text{OH}^-] = \frac{10^{-7.8} P_{\text{CO}_2}}{[\text{H}^+]} + \frac{10^{-18.1} P_{\text{CO}_2} \times 2}{[\text{H}^+]} + \frac{10^{-14}}{[\text{H}^+]}$$

$$P_{\text{CO}_2} = 370 \times 10^{-6} \text{ atm} = 10^{-3.4} \text{ atm}$$

$$[\text{H}^+]^2 = 10^{-11.2} \Rightarrow [\text{H}^+] = 10^{-5.6} \text{ mol/L}$$

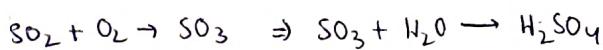
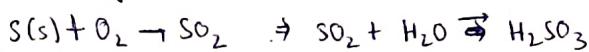
$$\text{pH} = 5.6$$

Lecture 14

- Also rise in atmospheric CO_2 conc doesn't change acidity of rainwater by significant amt as on $\Delta \text{pH} < 0.15$ but even a change of 0.5 in pH can adversely affect the marine life.
- pH of coke ≈ 3.56 as $\text{pP}_{\text{CO}_2} \approx 5 \text{ atm}$
- If pH of rainwater $< 5.7 \Rightarrow$ Acid Rain
- Effects of Acid Rain:
 - Acidification of surface water (kills aquatic ecosystem by releasing heavy metal ions from soil)
 - Damage to forests & vegetation
- Cross-boundary pollution : A large portion of SO_2 & NO_x travels due to surface winds.

Lecture 15

- Source of acid rain : coal contains 1-3% SO_2 normally



Q Find pH of acid rain when atm has 5 ppb SO_2 & 370 ppm CO_2 . $k_H(\text{SO}_2) = 10^{0.096} \text{ M/atm}$
 $k_{a_1} = 10^{-1.77}$, $k_{a_2} = 10^{-7.21}$. Assume SO_3 isn't formed.

L Relevant species : H^+ , OH^- , CO_3^{2-} , HCO_3^- , H_2CO_3 , SO_3^{2-} , HSO_3^- , SO_2

We can neglect HCO_3^- & CO_3^{2-} & $\text{SO}_3^{2-} \rightleftharpoons \text{H}^+ + \text{OH}^-$ as we expect $\text{pH} < 5$

$$\text{So: 1. } k_H \text{ P}_{\text{SO}_2} = [\text{SO}_2]_{\text{aq}} = 10^{0.096} \text{ P}_{\text{SO}_2}$$

$$2. k_{a_1} = [\text{H}^+] [\text{HSO}_3^-] / [\text{H}_2\text{SO}_3] \Rightarrow [\text{HSO}_3^-] = 10^{-1.674} \text{ P}_{\text{SO}_2} / [\text{H}^+]$$

$$3. [\text{H}^+] = [\text{HCO}_3^-] + 2[\text{CO}_3^{2-}] + [\text{HSO}_3^-] + 2[\text{SO}_3^{2-}] + [\text{OH}^-]$$

$$[\text{H}^+] = 10^{-9.87} / [\text{H}^+] \Rightarrow [\text{H}^+] = 10^{-4.98} \Rightarrow \text{pH} = 4.98$$

Small amt of SO_2 can be really toxic \uparrow , SO_3 & NO_x are even more toxic.

Soil is also affected during gpx due to acid rain due to mobilizatⁿ of diff ions in groundwater from minerals in topsoil & subsoil

Dissolutⁿ = process of forming dissolved comp from solid comp.

Q Rainwater falls on soil surface containing abundant amt of CaCO_3 . What will be pH.

$k_{sp}(\text{CaCO}_3) = 10^{-8.42}$. Assume instantaneous equi for dissolutⁿ, phase change & neutralizatⁿ.

L Rxns: 1. $\text{CO}_2(\text{g}) \rightleftharpoons \text{CO}_2(\text{aq}) \text{ i.e. H}_2\text{CO}_3$, $k_H = 10^{-1.5} \text{ M/atm}$

2. $\text{CO}_2(\text{aq}) \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$, $k_{a_1} = 10^{-6.3}$

3. $\text{HCO}_3^- \rightleftharpoons \text{H}^+ + \text{CO}_3^{2-}$, $k_{a_2} = 10^{-10.3}$

4. $\text{CaCO}_3 \rightleftharpoons \text{Ca}^{2+} + \text{CO}_3^{2-}$, $k_{sp} = 10^{-8.42}$

5. $2[\text{Ca}^{2+}] + [\text{H}^+] = [\text{HCO}_3^-] + 2[\text{CO}_3^{2-}] + [\text{OH}^-]$

Solving them, we get $\text{pH} = 8.21$ & $[\text{Ca}^{2+}] = 20 \text{ mg/L}$

This tells that after dissolutⁿ of CaCO_3 , carbonate adds to neutralizing capacity or alkalinity of water, \uparrow pH.

- Alkalinity is measure of acid neutralizing capacity of water (mainly due to HCO_3^- , CO_3^{2-} & OH^-)
ie Alkalinity (meq/L) = $[\text{HCO}_3^-] + 2 [\text{CO}_3^{2-}] + [\text{OH}^-] - [\text{H}^+]$
- (\rightarrow normality $[\cdot] \rightarrow$ molarity)
- Alkalinity of solⁿ does not change on bubbling CO_2 through water, as total charge is still 0.
- At pH 6/6.8, $[\text{H}^+] \approx [\text{OH}^-] + [\text{HCO}_3^-] \gg [\text{CO}_3^{2-}]$ so Alkalinity $\approx [\text{HCO}_3^-]$

Lecture 16

Q At equi. sample of water - pH = 10 has 32 mg/L of CO_3^{2-} . Find alkalinity

$[\text{OH}^-] = 10^{-4} \text{ M}$, $32 \text{ mg/L of } \text{CO}_3^{2-} = \frac{32 \times 10^{-3}}{60} = 0.53 \times 10^{-3} \text{ M} = 10^{-3.27} \text{ M}$

$\text{HCO}_3^- \leftrightarrow \text{H}^+ + \text{CO}_3^{2-}$, $K_{\text{a}} = 10^{-10.3} \Rightarrow [\text{HCO}_3^-] = 10^{-10} \times 10^{-3.27} / 10^{-10.3} = 10^{-2.97} \text{ M}$

Total Alkalinity (eq/L) = $10^{-2.97} + 2 \times 10^{-3.27} + 10^{-4} - 10^{-10} = 2.246 \times 10^{-3}$
 $= 2.2 \times 10^{-3} \text{ eq/L}$ $\text{M}_w \text{ of } \text{CaCO}_3 = 100 \text{ g}$ & is divalent, Alkalinity = $2.246 \times 10^{-3} \times 50 \text{ g of } \text{CaCO}_3 / \text{eq} = 112.3 \text{ mg/L}$

- Water Quality Parameters: second leading cause of death for < 5 yr olds.
- ↳ 5% deaths are due to diarrhoeal diseases which can be easily prevented
- ↳ Majority of deaths are somehow related to pollution (air, water etc)
- ↳ Diarrhoea is usually a symptom of infection in intestinal tract.
- ↳ „ is leading cause of malnutrition in < 5 year olds which affects their whole life.

Sources of Drinking Water

Groundwater	Surface Water
✓ 1. constant composition	✓ 1. variable composition
✓ 2. high mineral content	✓ 2. low mineral content
3. low turbidity	3. high turbidity
✓ 4. low or no D.O.	✓ 4. D.O. present (DO = Dissolved Oxygen)
5. low color	5. colored
6. High hardness	6. low hardness
7. High Fe, Mn	7. taste & odour
8. $\text{CO}_2 / \text{H}_2\text{S}$ maybe present	8. clay, silt, NOM

Pollution Loading

↳ Sources	<ul style="list-style-type: none"> Point Sources Non-pt Sources 	<ul style="list-style-type: none"> well defined origin, easily measured, relatively constant easy to treat & regulate diffused origin, more transient, often dependent on precipitation difficult to treat or regulate
		eg untreated sewage, agricultural, runoff etc



Lecture 17

- Typical Impurities in Water
 - ↳ Physical → suspended solids - due to Dissolved Solids (TDS) - how to measure
- Temperature - Taste & Odor
 - ↳ Chemical → what / due to measure by anions - cations - hardness - salinity - heavy metals (Hg, Pb, Cd etc)
 - ↳ Microbiological → due to measure by pathogens - biomass
 - ↳ Biochemical Instability → what due to BOD, COD - Natural Organic Matter - Total Organic C. ↓
Biochemical Oxygen Demand chemical Oxygen Demand

- A/C to 11th 5-year plan document to India (2007-12) 2.17 lakhs quality affected habitats & > 1/2 affected by excess iron, fluoride, salinity, nitrate & arsenic in this order.

- Approx 10 mil cases of diarrhoea

- Fluoride
 - Acceptable limit = 1 mg/L & permissible limit = 1.5 mg/L

- Excess can cause fluorosis i.e. fluoroapatite forms in bones decreasing the mechanical competence causing abnormal str & poor quality
 - Low levels - reduces dental caries & stabilize skeletal sys.

- Conductivity is ↑ in Rajasthan (due to low precipitatⁿ) & east coast as farmers take out more groundwater, ocean water seeps in.

- This ↑ chloride levels & salinity & most crops are not salinity tolerant.

- Nitrates & Nitrates easily seep to groundwater & pollute it.

- Excess levels can cause "blue-baby" syndrome in infants which is a fatal blood disorder (reductⁿ of oxygen carrying capacity)

Lecture 18 & 19

- Arsenic is carcinogenic & can also cause acute toxicity.

- Acceptable limit = 0.01 mg/L & permissible = 0.05 mg/L

- As(III) is less soluble & thus immobile while As(V) is soluble & thus mobile

- Over-exploitatⁿ of underground water causes geochemical leaching of arsenic (through rocks) into the groundwater

- most toxic subs found in groundwater

- ingestⁿ at > 10 µg/L for long time causes severe disorders, commonly starts by pigmentatⁿ then skin lesions, keratosis & often cancer & death.

- Typical Water Quality Parameters:

1. Turbidity (suspended Solids)
2. Total Dissolved Solids (TDS)
3. Hardness (Ca^{2+} & Mg^{2+})
4. Dissolved Oxygen (DO)
5. BOD (Biochemical Oxygen Demand)
6. COD (Chemical Oxygen Demand)
7. Total / fecal coliform
8. Nitrogen & Phosphorous

- Suspended Solids
 - Natural Waters : 1. Hazard to aquatic life (induces anaerobic zone)
2. Siltatⁿ - Reduces reservoir capacity
 - Wastewaters : 1. Measure of pollution strength
2. Designing of Sludge Treatment Facilities in WWTPs
3. Estimate of Active biomass
 - Drinking water : 1. turbidity is used rather than TSS
2. pathogens thrive on surface of suspended solids
 - Volatile (Organic : Algae, bacteria) or Inert/fixed (inorganic : clay etc)
 - 0 = clear groundwater, 300 mg/L = sewage etc

- TDS :
 - 1. ~~0.880~~ Summatⁿ /o all ions
 - 2. 0-50 = ideal drink^g water, freshwater = <1500 mg/L, saline = >5000mg/L & sea water 30-34 g/L
 - 3. Removal
 - Dissolved : Reverse Osmosis, Precipitatⁿ, Oxidatⁿ
 - Colloids : Ultra Nano filtratⁿ
 - Suspension : Coagulatⁿ - Flocculatⁿ - Settling

- Hardness :
 - 1. Sum of all polyvalent cations but practically the amt /o Ca^{2+} & Mg^{2+} .
 - 2. It is divided into CO_3^{2-} & HCO_3^{2-} hardness.
 - 3. 100 - 150 mg/L as CaCO_3 is moderate hardness.
 - 4. Carbonate Hardness - temp hardness bcs can be removed by boiling
 - 5. Non carbonate " permanent hardness
 NCH associated w/ Cl^- , NO_3^- & SO_4^{2-}
 - 6. $\text{NCH} = \text{TH} - \text{CH}$
 - 7. If alkalinity $\geq \text{TH}$, $\text{NCH} = 0$
- DO :
 - 1. critical to sustain aquatic ecosystem including fish.
 - 2. 4-5 ppm of DO is min amt that will support a large, diverse fish populatⁿ. 9 ppm is good fishing spots. Yamuna has 0.
 - 3. If below 1-2 ppm \rightarrow large fish kills
- Oxygen Demand :
 - 1. Sewage also exerts an oxygen demand to oxidize into CO_2 , H_2O etc
 - 2. BOD, COD, ThOD give an indicatⁿ of organic content in water.
 - 3. BOD : amt of oxygen consumed by micro-orgs to convert all biodegradable org matter to CO_2 , H_2O & NH_3
 - 4. COD : amt of strong oxidant needed to convert subs to CO_2 , H_2O & NH_3 .
 - 5. ThOD : theoretical amt of oxygen req to convert material to CO_2 , H_2O + in N-contain^g cases, NH_3 .



Lecture 20

- Simple BOD Measurement :
 - Initial DO - Final DO = Oxygen demand in that amt of time
 - Time is usually taken as 5 days at 20°C or 3 days at 27°C, put in dark in an incubator.
↳ avoid photosynthesis etc
- BOD Test :
 - It employs a bacterial seed to catalyze oxidatⁿ to 300 mL full strength or diluted wastewater.
 - $\Delta BOD_t = DO_i - DO_f$
 - DO ↑ Time

Nitrogenous BOD
Carbonaceous BOD
 - $\text{NH}_4^+ + \text{O}_2 \rightarrow \text{NO}_3^- + \text{NO}_2^- \text{ etc}$
 ↳ Nitrificatⁿ can occur if nitrify^g org are present
 ↳ Nitrificatⁿ starts after 5-8 days after start to BOD incubatⁿ period
 ↳ DO-t curve if N absent
 - Nitrificatⁿ inhibitors are added to prevent measurement to NBOD during BOD test.

Q DO is 8 mg/L & 0 mg/L after 5 days. BOD?

↳ BOD = 6 mg/L

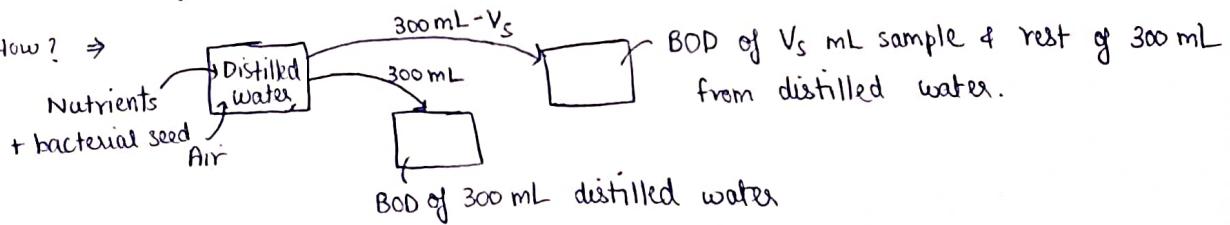
• Most of the time BOD > 6 mg/L, eg for typical sewage it is ~~approx~~ 200 mg/L

Q DO is 8 mg/L & 0 after 5 days. BOD?

↳ We can't as DO is limited

• At DO < 2 mg/L, micro-org can't thrive so BOD isn't accurate, thus we dilute

↳ How? ⇒



↳ Here $300 \text{ mL} = V_b$, $BOD = \frac{DO_i - DO_f}{V_s / V_b}$ } Not to remember

P

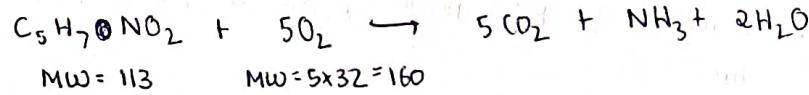
↳ $V_m BOD_m = V_s BOD_s + V_b BOD_b$: Fundamental approach

↓ + ↓
Mixture Sample Dilutⁿ water

- COD Test :
 - Measured in terms of $K_2Cr_2O_7$ reduced during 2 hr of reflux in a medium of boiling 50% H_2SO_4 in presence of Ag_2SO_4 catalyst.
 - Doesn't distinguish b/w bio-degradable & non-bio-degradable org matter.
Thus $COD \geq BOD$
 - It also ignores nitrogenous oxygen demand.



Q 1 mg/L glutarimide ($C_5H_7NO_2$) is completely oxidized. Find ThOD, COD, BOD, BOD₅, Total Organic Carbon (TOC)



1. ThOD = $160/113 = 1.42 \text{ mg O}_2/\text{mg } C_5H_7NO_2 = 1.42 \text{ mg/l}$

2. COD = $1.42 \text{ mg O}_2/\text{mg ()}$

3. BOD_{ult} = COD

4. $BOD_5 = 0.68 BOD_{ult} = 0.97 \text{ mg O}_2/\text{mg l}$

5. TOC = $5 \times 12 / 113 = 0.53 \text{ mg TOC / mg l}$

Lecture 21

• How can we estimate BOD from a BOD test? Using mass balance & other processes etc. as matter follows laws of physics.

• Mass Balance: 1. Choose control volume
2. Select subs for which budget is to be made (as react^{ns} are specific, eg S_0/SO_2)
3. Consider all import & exports (add sources, subtract sinks)

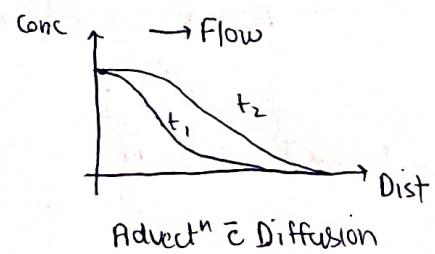
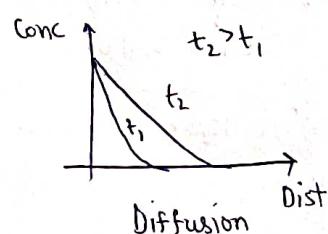
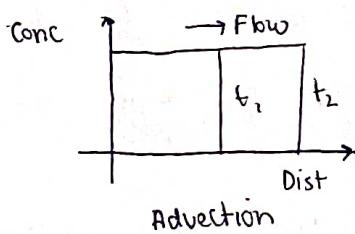
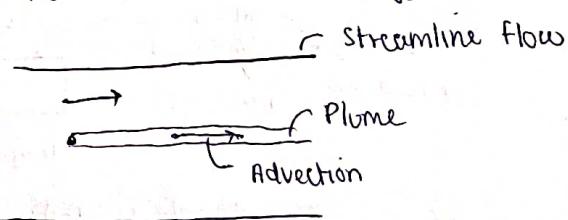
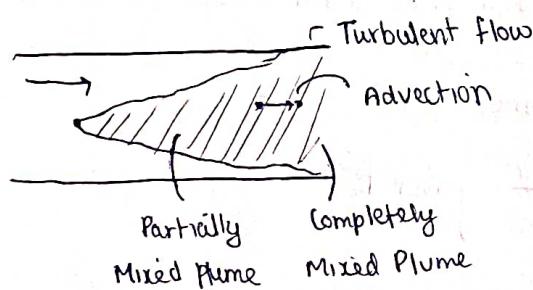
• Rate of Accumulatⁿ = Rate of Input - Rate of Output

• Adveⁿ: Transfer of matter by the flow of fluid, eg a unmanned boat in a river flows away due to water currents.

• Diffusion occurs whenever there is conc. gradient

• In streamline flows, the diffusion is slower compared to turbulent diffusion.
↳ molecular diffusion

Eg: scent diffuses faster if fan is on, no net air current but diffusion is faster.



• $\frac{\partial M}{\partial t} = \sum \text{mass in} - \sum \text{mass out} \pm S_{\text{Sources/Sinks}}$

• $\frac{dC}{dt} + \nabla \cdot \bar{J} = \pm S$
 \downarrow
 Conc Flux (mass / area time)

$$J_{\text{advection}} = uC \quad J_{\text{diffusion}} = -D \nabla C$$

↓
speed of flow ↓
Diff coeff

$$\frac{dC}{dt} + \nabla(uC) = D \nabla^2 C \pm S$$

(neglected as $u > >$)

$$\frac{dC}{dt} + \nabla(uC) = r_f - r_L$$

(rate of loss)
(rate of formation)

$$\text{Consider flow only along } x\text{-dir, } \frac{dC}{dt} + u \frac{dC}{dx} = r_f - r_L$$

$$\frac{V \frac{dC}{dt}}{dt} = Q_{in} C_{in} - Q_{out} C_{out} + V(r_f - r_L)$$

(V/t) (V/t)

Lecture 22

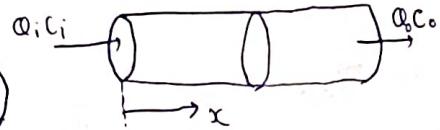
- Batch Reactor : To model closed systems

$$\hookrightarrow \frac{V \frac{dC}{dt}}{dt} = V(r_f - r_L) \Rightarrow \frac{dC}{dt} = r_f - r_L \quad \text{as } Q_{in} C_{in} = Q_{out} C_{out} = 0$$

- Plug flow reactor : Since C isn't const inside reactor

$$\hookrightarrow \frac{dC}{dt} + \frac{u dC}{dx} = r_f - r_L \quad \left(\text{Also } \theta = \frac{x_{\text{dist}}}{u} = \text{Hydraulic Retention Time} \right)$$

(gives an idea about time spent in reactor)

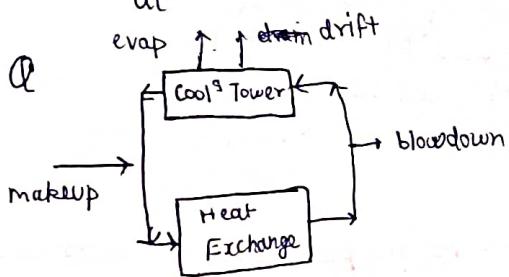


$$\hookrightarrow \frac{dC}{dt} + \frac{dC}{dx} = r_f - r_L$$

$$\text{At steady state } \frac{dC}{dt} = r_f - r_L$$

- CSTR or CMFR : Conti Stirred Tank Reactor or Conti Mixed Flow Reactor

$$\hookrightarrow \frac{dC}{dt} \rightarrow 0, 0 = Q_i C_i - Q_o C_o + V(r_f - r_L)$$



water is lost as evap & drift. So water is added in makeup & removed in blowdown. Assume same TDS in drift, recirculation & blowdown.

Rest of ques in video.

$$\sim i) Q_m = Q_e + Q_d + Q_b, Q_b = 0.002 - 0.0001 - 0.001 = 9 \times 10^{-4} \text{ m}^3/\text{s}$$

$$\text{Also } Q_m C_m = Q_e C_e + Q_d C_d + Q_b C_b$$

$$C_b = Q_m C_m / (Q_d + Q_b) = 1000 \text{ mg/L}$$

$$ii) Q_{m,\min} = Q_e + Q_d = 1.1 \times 10^{-3} \text{ m}^3/\text{s}, C_r = 5500 \text{ mg/L}$$

Thus we need a blowdown to maintain C_r .

- C, N, P in excess → cause algal bloom → when N, P, C is low → algae dies → micro-org biodegrade it → increases BOD.

Q Derive steady state P conc of lake:

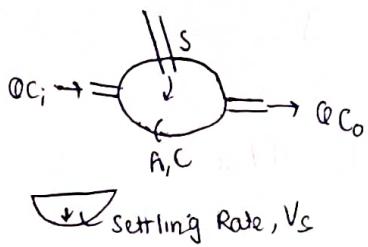
~ Batch \times , PFR $\times \rightarrow$ CSTR

$$\frac{V \frac{dC}{dt}}{dt} = Q_i C_i - Q_o C_o + S - V_s A C$$

(at steady state)

$$Q(C_i - C_o) + S - V_s A C = 0$$

$$\therefore \text{CSTR, } C_o = C, \quad Q C_i = V_s A C - S + Q C, \quad C = (S + Q C_i) / (V_s A + Q)$$



Lecture 23

- $aA + bB \rightarrow \text{Products}, \quad r = k [A]^a [B]^b$ generally

Q Sample of TMDD was taken after 30 min & show $[TMDD] = 2 \text{ mg/L}$

Find θ for 1mg/L from 10 mg/L in steady state. Assume TMDD is removed as $r_L = k_1 C_{\text{tmdd}}$

~ Batch $\rightarrow \frac{V \frac{dC}{dt}}{dt} = V(r_f - r_L), \quad \frac{dC}{dt} = -r_L = -k_1 C, \quad C_t = C_0 e^{-k_1 t}$

$$C_{30}/C_0 = e^{-k_1 \cdot 30 \text{ min}}, \quad 2/10 = e^{-k_1 \cdot 30 \text{ min}}, \quad k_1 = 0.0536 \text{ min}^{-1}$$

PFR $\rightarrow \frac{dc}{dt} + u \frac{dc}{dx} = r_f - r_L, \quad \frac{dc}{dt} = -k_1 C, \quad C_0 = C_0 e^{-k_1 \theta}$

$$\theta = 42.9 \text{ min}$$

$$\text{CSTR} \rightarrow \frac{V \frac{dC}{dt}}{dt} = Q_i C_i - Q_o C_o + V(r_f - r_L) = Q(C_i - C_o) + V(0 - kC), \quad \theta = V/Q$$

$$V/kC = Q(C_i - C_o), \quad V/Q = \theta = (C_i - C_o)/kC = (C_0 - C)/kC, \quad \theta = 168 \text{ min}$$

- Modeling BOD Decay: 1. Control volume is BOD bottle

2. Apply mass balance as batch

$$3. \quad \frac{d(VC)}{dt} = 0 - 0 + V(0 - r_i)$$

L conc of org at time t, thus represented as L_t

$$\frac{dL_t}{dt} = -k L_t \Rightarrow L_t = L_0 e^{-kt}$$

$$4. \quad \text{BOD} = L_0 - L_t = L_0 (1 - e^{-kt}), \quad \text{also BOD}_{ult} = L_0$$

L_{ultimate}

Lecture 24

Eg $\text{BOD}_5 = 102 \text{ mg/L} + \text{BOD}_{20}$ (corresponds to BOD_{ult}) = 158 mg/L. What is pseudo first order rate const.

$$\sim \text{BOD}_t = L_0 (1 - e^{-kt}), \quad k = -\ln (1 - \text{BOD}_t/L_0) / t = -\ln (1 - 102/158) / 5 \text{ day}$$

$$k = 0.21 \text{ day}^{-1}$$

- As temp \uparrow , metabolism of micro-org \uparrow , thus rate const of degradation also \uparrow .

- Empirical Engg's approach, $k_T = k_{20} \theta^{T-20}$, $\theta = 1.135$ if $T \in (4^\circ\text{C}, 20^\circ\text{C})$ } Based on
 $\theta = 1.056$ if $T \in (20^\circ\text{C}, 30^\circ\text{C})$ } observations

Q Rate const for degradation, k , was determined to be 0.2 days^{-1} at 20°C .

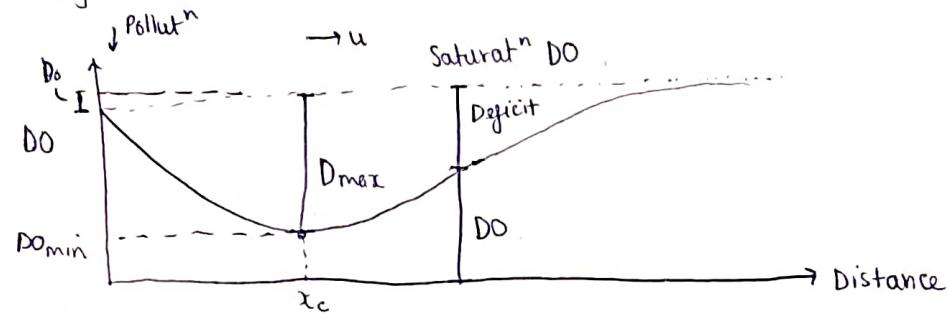
Find it for 25°C & 10°C

$$\sim k_T = 0.2 \theta^{T-20}, \quad k_{25} = 0.26 \text{ day}^{-1}, \quad k_{10} = 0.056 \text{ day}^{-1}$$

$$\theta = 1.056$$

$$\theta = 1.135$$

↳ From 20°C - 25°C , metabolism is high & not that diff but at 10°C $k \ll$, thus degradation is much slower.



PFR in last 3 min to be seen