WATER TREATMENT

SKAA 2912

WATER QUALITY PARAMETERS
(CHEMICAL – NUTRIENTS, HARDNESS, ALKALINITY)

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NUTRIENTS

- Carbon, Nitrogen and Phosphorus are crucial elements needed by animal and plants to live
- C – from CO_2, degradation of organic compounds
- N,P – limiting factors

NUTRIENTS

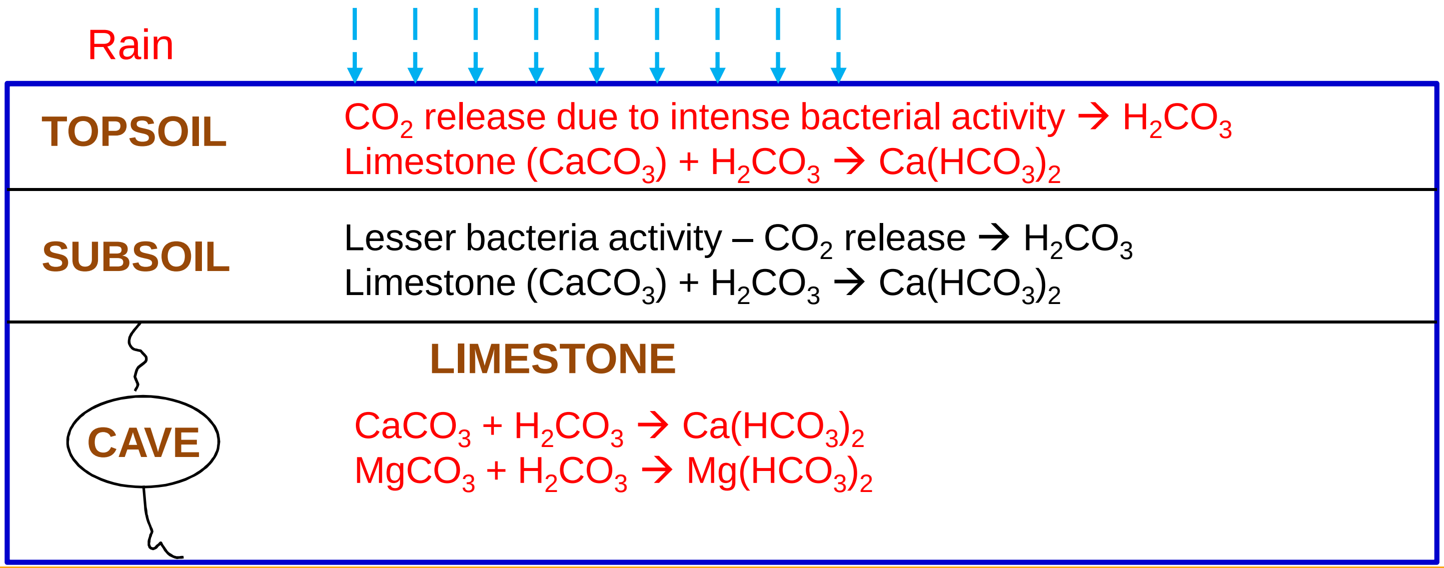
- Nitrogen (N)
  - Present in the form of ammonia or ammonium found in complex mixture of organic compounds such as proteins, amino acids and amino sugars
  - Sources:
    - Element for protein, chlorophyll and biological compounds
    - Decomposition to a simple compound
      Protein → Amino acid → NH_3 → NO_2^- → NO_3^-
    - Animals and human wastes, chemicals (fertilizers)
  - Effects:
    - Poisoning in human and animal babies (baby blue syndrome – insufficient of oxygen in the blood due to the substitution of NO_3^- & NO_2^- in the blood vessel)
    - Excessive algae and aquatic plants breeding
    - Potential formation of nitrosamines and nitrosamides that can cause cancer in various tissue. However, these formation can be inhibited by the consumption of Vitamin C.
  - MCL: Total nitrate-N and nitrite-N <10 mg/L

NUTRIENTS

- Phosphorus (P)
  - An essential requirement for the growth of algae and other biological organisms
  - In the form of orthophosphates (PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^{-}$, H_3PO_4), condensed phosphate and organic phosphate
  - Sources:
    - Readily present in soil
    - Fertilizers
    - Human wastes (organic phosphates)
    - Domestic wastes (element in detergent)
  - Effects:
    - Algae blooms
    - > 0.2 mg/L – interfere the coagulation process in water treatment plant

HARDNESS

- Definition: A measure of “multivalent” cations in water such as Ca^{2+}, Mg^{2+}, Fe^{2+} and Mn^{3+}
- Due to Ca^{2+} and Mg^{2+} in water and is expressed as an equivalent concentration as calcium carbonate (Total Hardness = $Ca^{2+} + Mg^{2+}$)
- Source:
  - Dissolved from rocks and soils (natural mineral on earth) due to bacterial activity (release as CO_2)



HARDNESS

- Effects:
  - Excessive soap usage
  - Precipitate formation in hardware:

    Affect cleaning (e.g. laundry (rough and scratchy clothes), dishwashing (spots on glasses and dishes), shower (film build up on bathtub, faucets, sink; sticky and dull feeling on hair))
  - Precipitate formation in pipe

    ↑ Temperature & pH : Hard water build up scales in pipe and cause low water pressure
  - Water taste bitter ($CaCO_3$)

    Contribution of other ions to water hardness is always < 1 mg/L – insignificant

HARDNESS

- Characterization of water hardness
  - Soft water: < 75 mg/L $CaCO_3$
  - Moderately hard water: 75-150 mg/L $CaCO_3$
  - Hard water: 150-300 mg/L $CaCO_3$
  - Very hard water: >300 mg/L $CaCO_3$
- Types of water hardness

  (Total Hardness = Carbonate Hardness + Non-carbonate Hardness)
  - Carbonate hardness
  - Non-carbonate hardness

HARDNESS

Example:

Calcium	=	29.0	mg/L
Magnesium	=	16.4	mg/L
Sodium	=	23.0	mg/L
Potassium	=	17.5	mg/L
Bicarbonate (as HCO_3^-)	=	171.0	mg/L
Sulphate	=	36.0	mg/L
Chloride	=	24.0	mg/L

a) Convert the above concentrations from mg/L to meq/L,
b) What is the hypothetical combination?
c) Find the water hardness in terms of mg/L as $CaCO_3$

ALKALINITY

- Definition:
  - The measure of ions in water to neutralize acid
  - A measure of its capability to neutralize acid
  - The quantity of strong acid required to titrate the solution to pH near 4.7
- In natural water, alkalinity is due to the salts of weak acids (bicarbonate (HCO_3^-), carbonate (CO_3^{2-}) and hydroxide (OH^-) ions)
- Sources:
  - Mineral dissolved in water and air
  - Human activities such as detergent (in wastewater), fertilizers, pesticides, etc
- Effects:
  - Non-pleasant taste
  - Reaction between alkaline constituent and cation (positive ion) produces precipitation in pipe

ALKALINITY

- In water hardness section, we learnt that
  - Bacteria activity release CO_2 which dissolved in water as carbonic acid, H_2CO_3 (pH 4.7)

pKa 6.35: H_2CO_3 and HCO_3^- are at equilibrium

$$H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$$

$$K_1 = \frac{[H^+][HCO_3^-]}{[H_2CO_3]}$$

pKa 10.33: HCO3- and CO_3^{2-} are at equilibrium

$$HCO_3^- \Leftrightarrow H^+ + CO_3^{2-}$$

$$K_2 = \frac{[H^+][CO_3^{2-}]}{[HCO_3^-]}$$

ALKALINITY

- The specific concentration of each species can be computed when each fraction of the species is determined

$$C_T = [H_2CO_3] + [HCO_3^-] + [CO_3^{2-}]$$

$$\alpha_{H_2CO_3} = \alpha_0 = \frac{[H_2CO_3]}{C_T} = \frac{[H^+]^2}{[H^+]^2 + K_1[H^+] + K_1K_2}$$

$$\alpha_{HCO_3^-} = \alpha_1 = \frac{[HCO_3^-]}{C_T} = \frac{[H^+]K_1}{[H^+]^2 + K_1[H^+] + K_1K_2}$$

$$\alpha_{CO_3^{2-}} = \alpha_2 = \frac{[CO_3^{2-}]}{C_T} = \frac{K_1K_2}{[H^+]^2 + K_1[H^+] + K_1K_2}$$

ALKALINITY

- We know that,
  - Alkalinity is the amount of strong acid needed to titrate the solution to pH near 4.7
  - Major alkalinity constituents include HCO_3^-, CO_3^{2-} and OH^-
  - For acids & bases, one equivalent is one mole of H^+
  - Therefore,

$$[\text{ALK}]\ \text{meq/L} = [HCO_3^-] + 2[CO_3^{2-}] + [OH^-] - [H^+]$$

ALKALINITY

- The concentration of carbonate and bicarbonate ions can be calculated if the pH and total alkalinity is known.

$$[\mathrm{ALK}]\,\mathrm{meq/L} = [\mathrm{HCO_3^-}] + 2[\mathrm{CO_3^{2-}}] + [\mathrm{OH^-}] - [\mathrm{H^+}]$$

$$K_2 = \frac{[\mathrm{H^+}][\mathrm{CO_3^{2-}}]}{[\mathrm{HCO_3^-}]}$$

$$\mathrm{H_2O} \Leftrightarrow \mathrm{H^+} + \mathrm{OH^-}$$

$$K_w = [\mathrm{H^+}][\mathrm{OH^-}] = 10^{-14} \;@\; 25^\circ\mathrm{C}$$

$$[\mathrm{HCO_3^-}] = \frac{\left([\mathrm{ALK}] - \frac{K_w}{[\mathrm{H^+}]} + [\mathrm{H^+}]\right)}{\left(1 + \frac{2K_2}{[\mathrm{H^+}]}\right)}$$

$$[CO_3^{2-}] = \frac{\left([ALK] - \frac{K_w}{[H^+]} + [H^+]\right)}{\left(1 + \frac{[H^+]}{2K_2}\right)}$$

ALKALINITY

- The concentration of carbonate and bicarbonate ions can be calculated if the pH and total alkalinity is known.

$$[\mathrm{ALK}]\,\mathrm{meq/L} = [\mathrm{HCO_3^-}] + 2[\mathrm{CO_3^{2-}}] + [\mathrm{OH^-}] - [\mathrm{H^+}]$$

$$[\mathrm{HCO_3^-}] = C_T\alpha_1 \qquad [\mathrm{CO_3^{2-}}] = C_T\alpha_2$$

$$[\mathrm{ALK}]\,\mathrm{meq/L} = C_T(\alpha_1 + 2\alpha_2) + \left(\frac{K_w}{[\mathrm{H^+}]}\right) - [\mathrm{H^+}]$$

ALKALINITY VS HARDNESS

- When alkalinity < total hardness

  Carbonate hardness (mg/L) = alkalinity (mg/L)

- When alkalinity ≥ total hardness

  Carbonate hardness (in mg/L) = total hardness (in mg/L)

REFERENCES

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