WATER TREATMENT

SKAA 2912

COAGULATION

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INTRODUCTION

- Surface waters containing both organic and inorganic particles – colloidal particles and dissolved organic constituents
  - Particulate constituents contributing to colour and turbidity
  - Possess a very large surface area to volume
  - At pH level above 4.0, their surface are generally negatively charged

<table>
<tr><th>ORGANIC</th><th>INORGANIC</th></tr>
<tr><td>Decay living organisms (e.g. humic acids) and microorganisms (e.g. viruses, bacteria, protozoan, algae)</td><td rowspan="2">Caused by natural erosion processes (e.g. silt, clay, mineral oxides)</td></tr>
<tr><td>Dissolved organic matter is often identified as natural organic matter (NOM)</td></tr>
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INTRODUCTION

- Objective:
  - **To form particles large enough to be removed**
  - **To destabilize particles and enable them to become attached to other particles**
  - **To create flocculant particles**
- What is coagulation?
  - A process of adding chemical into the water that cause a reduction of the forces tending to keep particles apart.

INTRODUCTION

- Design of coagulants need to consider
  - Coagulant **type** and **concentration**
  - **Mixing intensity** and **method** used to disperse chemicals into the water for **destabilization**

- Mechanism used to achieve particulate destabilization
  - Adsorption and charge neutralization
  - Adsorption and interparticle bridging
  - Precipitation and enmeshment

ADSORPTION AND CHARGE NEUTRALIZATION

- Particulates in natural waters are **negatively charged**.
- Mechanism:

Adsorb oppositely charged ions or polymers

- Three main categories:
  - Hydrolyzed metal salts
  - Pre-hydrolyzed metal salts
  - Cationic polymers

  (Hydrolyzed and pre-hydrolyzed metal salts: Involve aluminium and iron ions)

  Can only cover partial of the particle surface at optimum dosage. Therefore, they are normally coupled with inorganic coagulants for effective particle bridging

CAUTION

Too much of coagulants – particles become positive charge → become stable once again

ADSORPTION AND INTERPARTICLE BRIDGING

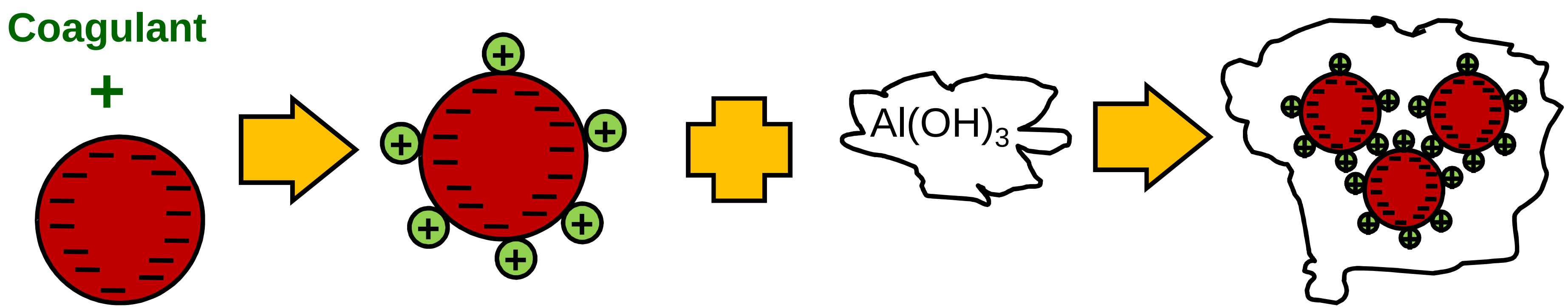
- Mechanism:

  Adsorption of polymer chains on particle surfaces is a result of

  – coulombic (charge-charge) interactions
  – dipole interaction
  – hydrogen bonding
  – van der Waals forces

PRECIPITATION AND ENMESHMENT

- Also known as "sweep floc"
- Coagulant form insoluble precipitate and particulate matter is entrapped in the precipitate



COAGULANTS

- Commonly used:-
  - Alum ($Al_2(SO_4)_3.14H_2O$)
  - Ferric chloride ($FeCl_3$)
  - Ferric sulfate ($Fe_2(SO_4)_3$)

  } Hydrolyzed metal salts

  - Polyaluminium chloride → Prehydrolyzed metal salts
  - Cationic polymers (polyacrylamide + cationic monomer)

- Factors affecting coagulation process:-
  - Coagulant dosage
  - pH
  - Turbidity
  - Alkalinity
  - Natural organic matter
  - Temperature
  - Mixing

COAGULANTS

- Action of alum and iron salts

Addition of alum and iron salts into water,

$$Al_2(SO_4)_3 \Leftrightarrow 2Al^{3+} + 3SO_4^{2-}$$

$$FeCl_3 \Leftrightarrow Fe^{3+} + 3Cl^-$$

$$Fe_2(SO_4)_3 \Leftrightarrow 2Fe^{3+} + 3SO_4^{2-}$$

The ions then react with water to form metal hydroxide precipitates

$$Al^{3+} + 3H_2O \Leftrightarrow Al(OH)_3 + 3H^+$$

$$Fe^{3+} + 3H_2O \Leftrightarrow Fe(OH)_3 + 3H^+$$

$$Al_2(SO_4)_3.14H_2O \rightarrow 2Al(OH)_3 + 6H^+ + 3SO_4^{2-} + 8H_2O$$

$$FeCl_3 + 3H_2O \rightarrow Fe(OH)_3 + 3H^+ + 3Cl^-$$

$$Fe_2(SO_4)_3 \cdot 9H_2O \rightarrow Fe(OH)_3 + 6H^+ + 3SO_4^{2-} + 3H_2O$$

The dissociated species of SO_4^{2-} and Cl^- lowers the pH of the solution and consume alkalinity (acts as buffer to stabilize pH in water)

COAGULANTS

- Action of alum and iron salts
  - Addition of alkalinity (e.g. **caustic soda (NaOH), lime ($Ca(OH)_2$) or soda ash (Na_2CO_3)**) is needed if natural alkalinity is insufficient to buffer the pH
  - **1 eq/L of alum or ferric will consume 1 eq/L of alkalinity**
  - Commonly used: NaOH → easy to handle and uses in small dosage

$$Al_2(SO_4)_3.14H_2O + 6NaOH \rightarrow 2Al(OH)_3 + 3Na_2SO_4 + 14H_2O$$

$$Al_2(SO_4)_3.14H_2O + 3Ca(OH)_2 \rightarrow 2Al(OH)_3 + 3CaSO_4 + 14H_2O$$

COAGULANTS

Example:

The concentration of the supplied stock alum ($Al_2(SO_4)_3.14H_2O$) is 645 g/L and the alum dose applied to a water treatment plant with a capacity of 43, 200 m^3/day is 30 mg/L, calculate

a. the chemical feed rate in L/min
b. the alkalinity consumed (expressed as mg/L as $CaCO_3$)
c. the amount of precipitate produced in mg/L and kg/day
d. the amount of NaOH to be added to counteract the consumption of alkalinity by alum

COAGULANTS

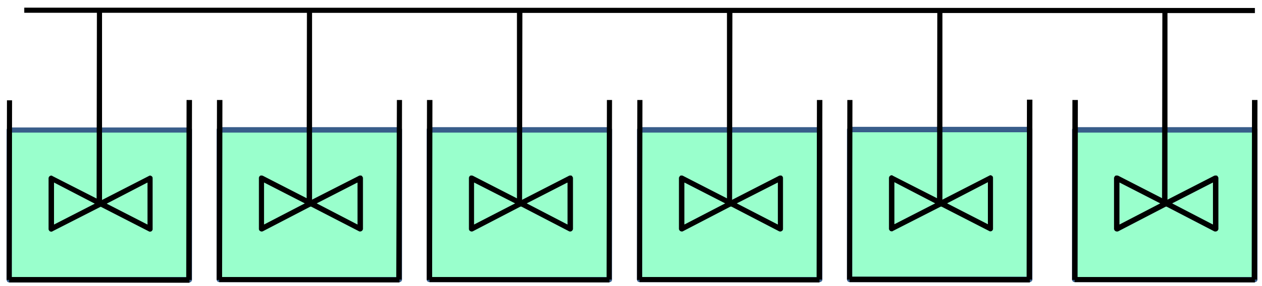
- Guidance on the use of coagulants

Water Quality Parameter	Al^{3+}	Fe^{3+}
Turbidity	Sweep-floc is required for low turbidity water	
Alkalinity	High alkalinity – pH adjustment for optimum coagulation is difficult Insufficient alkalinity – form soluble Al^{3+} resulting in post-flocculation in downstream processes	The impact of Fe^{3+} is less than Al^{3+}
pH	Optimum pH: 5.5 - 7.7 Higher pH can cause algae growth which can affect the coagulant dose	Optimum pH: 5 – 8.5
Natural organic matter	Control coagulant dosage Decrease in pH increase NOM removal	
Temperature	Affect solubility of products Floc formed in colder water tends to be weaker	

JAR TEST

- Act as a screening aid – impossible to predict the performance of a coagulation process due to the reactions that occurred upon the addition of alum
- Useful to review:
  - The operating regions for the alum and iron
  - Interactions with other constituents in water
  - To determine the typical/optimum dosages
  - The importance of initial blending when using metal salts
  - To determine the quality of coagulant used in water treatment plant
- Test is repeated with every significant change of raw water quality

JAR TEST



- Raw water sample are filled into 4-6 beakers
- Each beaker possesses different coagulant concentration
- Mix rapidly for 30 to 60 seconds
- Mix slowly for 15 minutes
- Stop mixing and let flocs settle.
- Determine the optimum dosage by observing the removal of
  - **Turbidity or suspended solids**
  - **Natural organic matter (UV_{254}, Dissolved organic carbon)**
  - **Residual dissolved coagulation concentrations Fe^{3+} or Al^{3+}**
  - **Sludge volume that is produced**
- To determine the optimum pH, repeat step 5 but vary the pH in each beaker

JAR TEST

Example

A water treatment plant treats 43200 m^3 of water in a day. Based on Jar Test, the optimum dosage obtained when 50 mL of 1g/L is added into 2 L of water. Find

i. the amount of alum required (kg) in a month
ii. the flow rate of the alum solution (m^3/day).

TYPES OF MIXER

- Purpose:

  To provide a **uniform dispersion of coagulant chemical** throughout the influent water

- Types:
  - Mechanical method (flume mixer)
  - Hydraulic method (flash mixer)

REFERENCES

- Crittenden, J.C., Trussell, R.R., Hand, D.W., Howe, K.J., T chobanoglous, G. (2012). *Water Treatment: Principles and Design*, 3rd Edition, USA: John Wiley & Sons.