EWCE-332
Environmental Engineering
Sessional Credit 1.5

Department of Environmental, Water Resources, and Coastal Engineering

Chemical Coagulation (Alum Coagulation)

Colloidal Particles in Surface Water

- Colloidal particles in surface water cause **turbidity** and **color** in water.

- Colloidal particles that cause color and turbidity are difficult to separate from water because –
  - ✓ the particles will not **settle by gravity** and
  - ✓ are so small that they pass through the pores of most common **filtration media**.

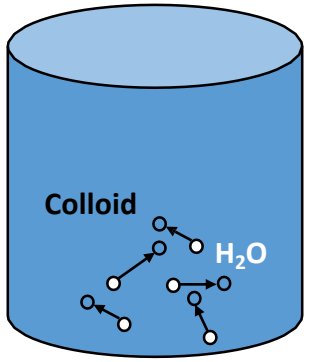
Colloidal Particles in Surface Water

Various sizes of particles in raw water

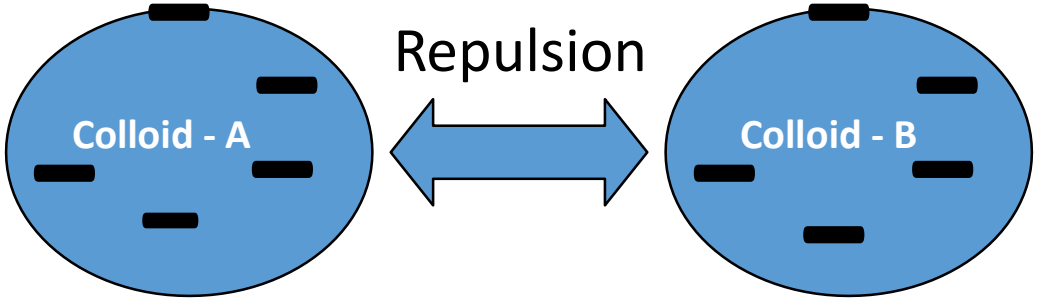
Particle diameter (mm)	Type	Settling velocity
10	Pebble	0.73 m/s
1	Course sand	0.23 m/s
0.1	Fine sand	0.6 m/min
0.01	Silt	8.6 m/d
0.0001 (10 micron)	Large colloids	0.3 m/y
0.000001 (1 nano)	Small colloids	3 m/million y

Gravity settling

Colloid Stability



- ✓ Colloids have a net negative surface charge
- ✓ Electrostatic force prevents them from agglomeration



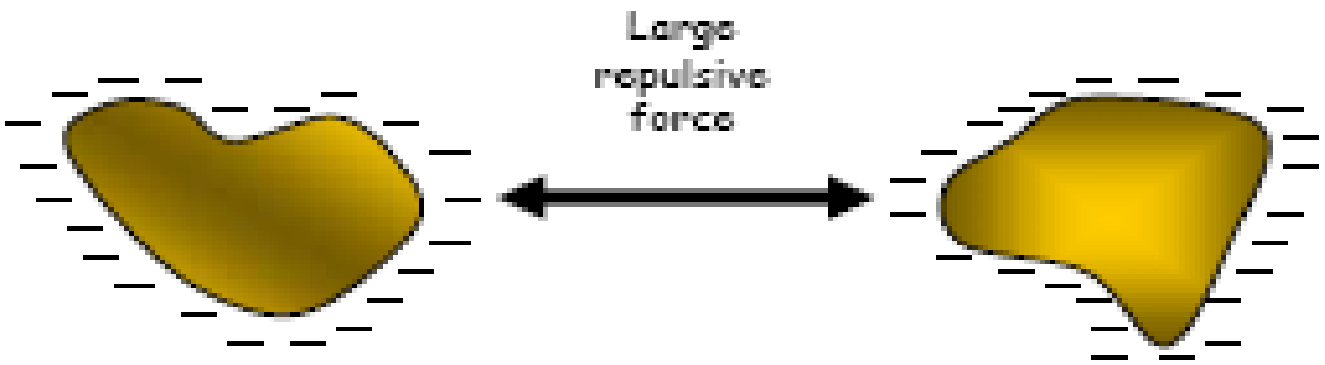
- ✓ Brownian motion keeps the colloids in suspension
- ✓ Impossible to remove colloids by gravity settling

Colloidal Interaction

- There are two major forces acting on colloids:

1) electrostatic repulsion

(simply, negative colloids repel other negatively charged colloids)



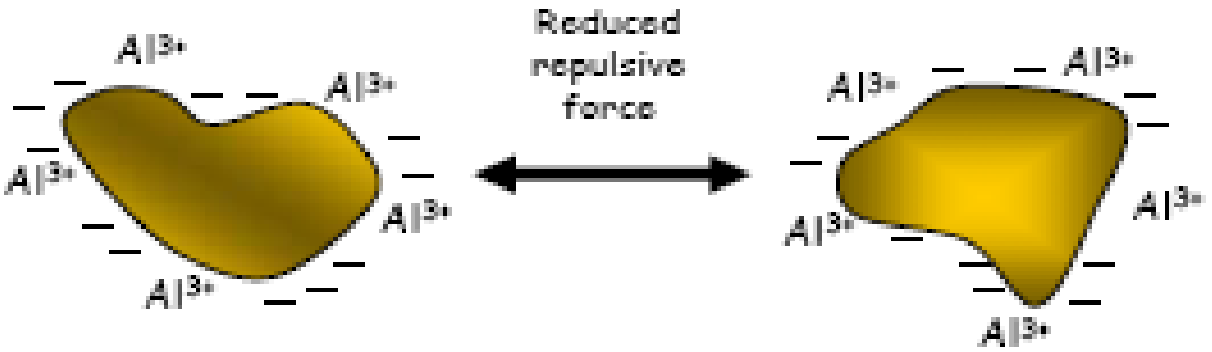
2) intermolecular, or van der Waals, attraction.

Coagulation

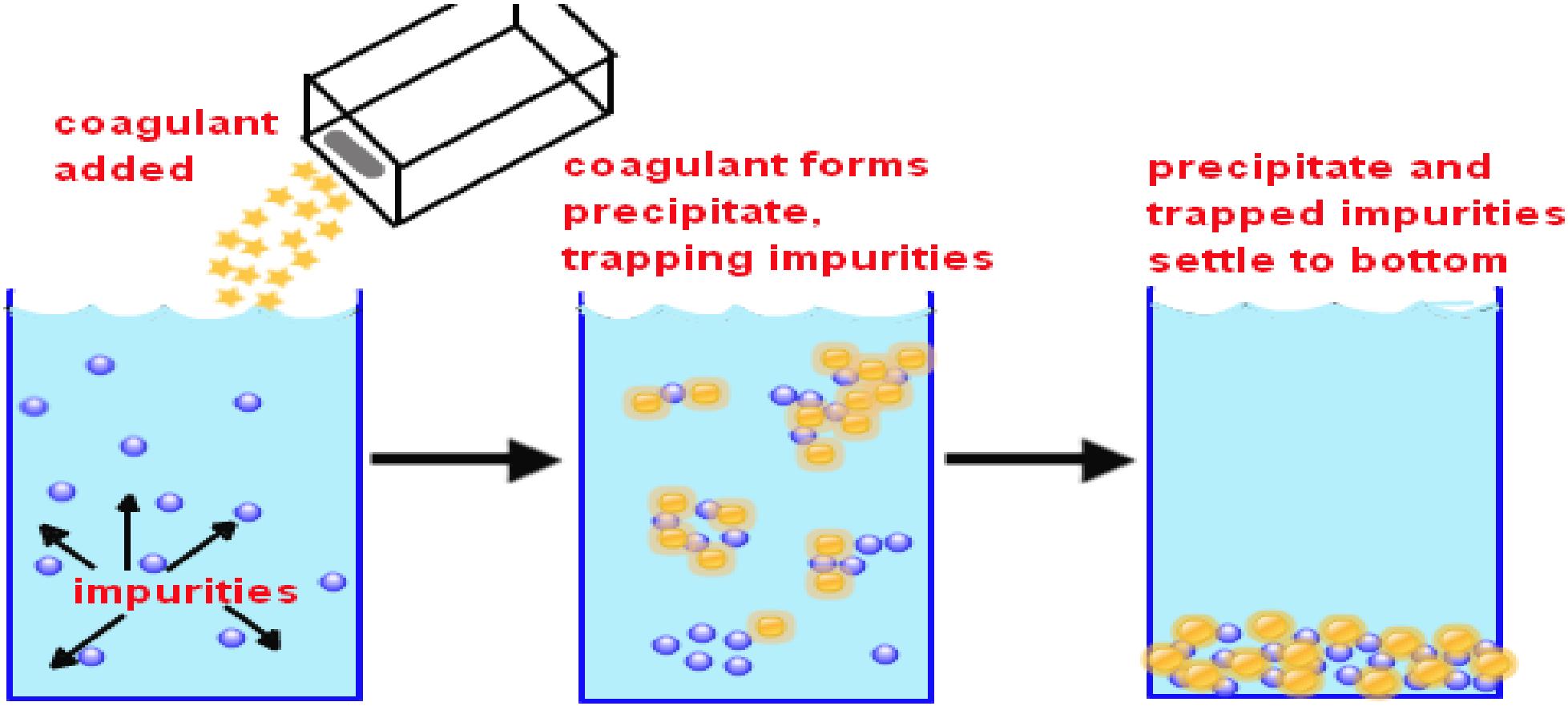
- In order to be removed, the individual colloids must aggregate and grow in size so that they can settle by gravity.
- Chemical agents are used to promote colloid aggregation by destroying the forces that stabilize colloidal particles.
- The process of destroying the stabilizing forces and causing aggregation of colloids is referred to as chemical coagulation.
- Coagulation involves reduction of electrical forces of repulsion and promotion of “chemical type” interaction between colloids.

Charge Reduction

- Coagulants can be used to reduce the electrostatic repulsive forces
- The electrostatic repulsion reduced by the addition of countercharged ions [Al^{3+}]



Chemical Coagulation of Colloidal Particles

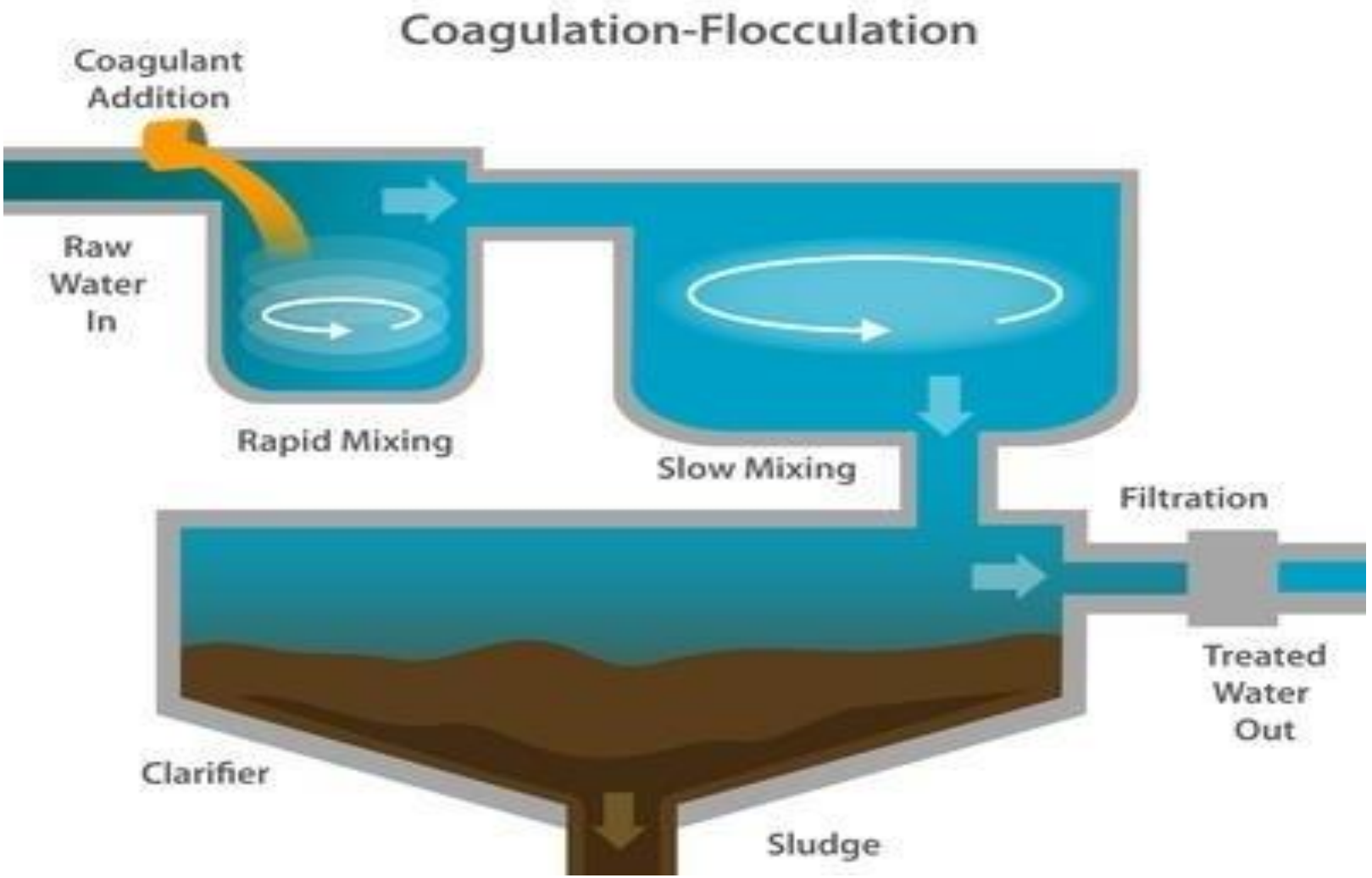


Coagulation and Flocculation

- **Coagulation** is a process used to neutralise charges and thus forming a mass large enough to settle or be trapped in the filter.

- **Flocculation** is gentle stirring or agitation to encourage the particles thus formed to agglomerate into masses large enough to settle or be filtered from solution.

Coagulation and Flocculation



Coagulant

- **Typical Coagulants**

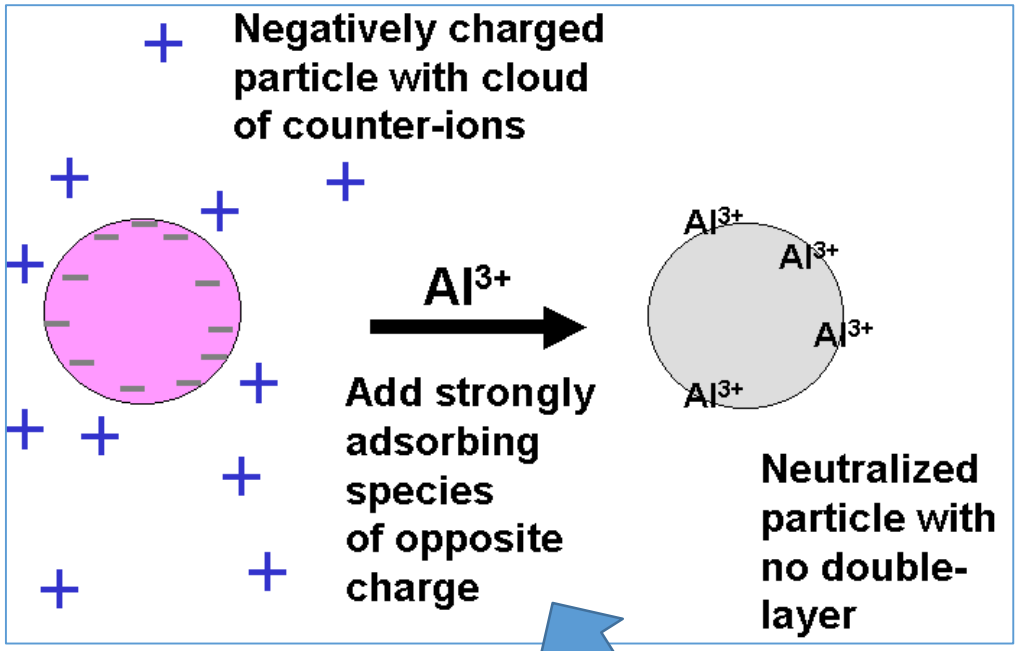
Aluminum sulfate: $Al_2(SO_4)_3.14H_2O$

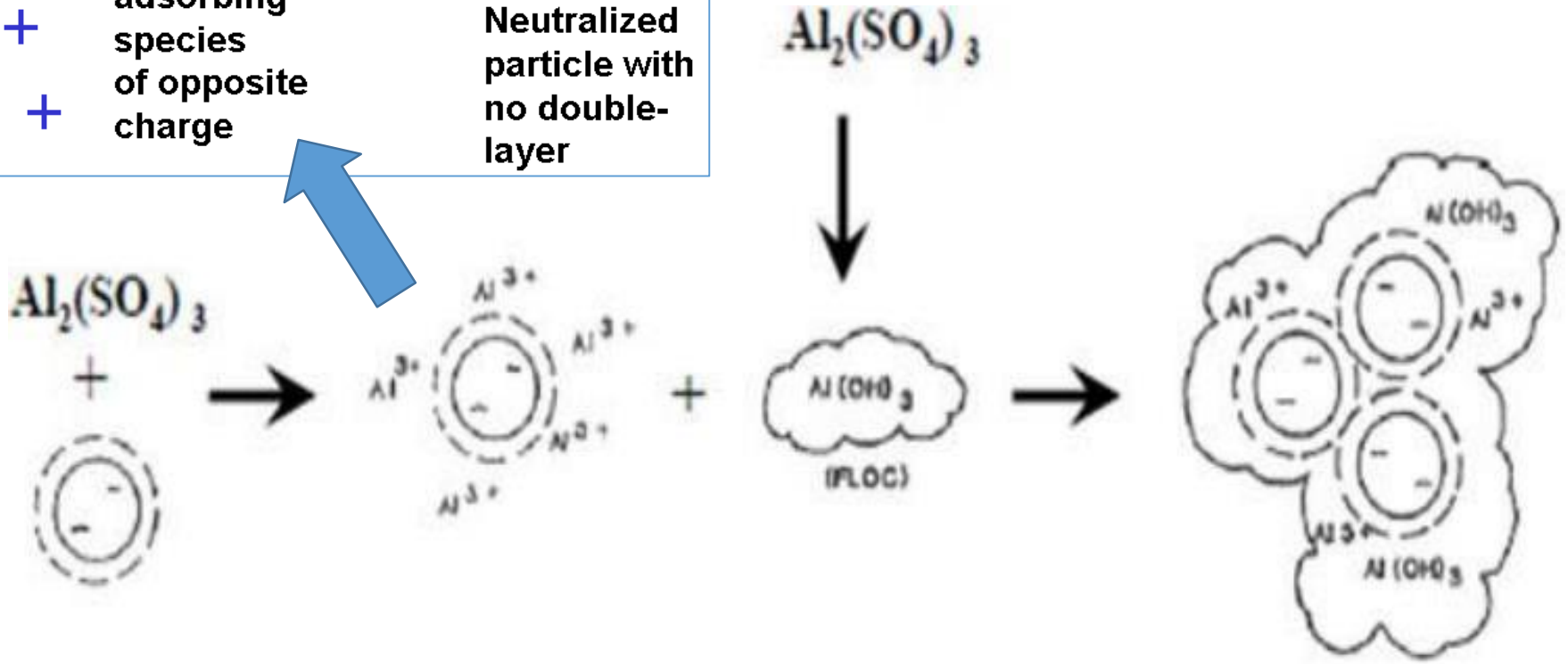
Iron salt- Ferric sulfate: $Fe_2(SO_4)_3$

Iron salt- Ferric chloride: Fe_2Cl_3

Poly aluminum chloride (PAC): $Al_2(OH)_3Cl_3$

Coagulant – Alum (Aluminum sulfate)





colloids are enmeshed

Coagulant – Alum (Aluminum Sulfate)

- The common metal salt alum (aluminum sulfate) is a good coagulant for water containing appreciable organic matter.

- The chemical formula used for commercial alum is $Al_2(SO_4)_3,14H_2O$.

- Once dissolved in water, aluminum forms hydroxo-complexes and solids [e.g., $Al(OH)_3(s)$, $Al(OH)^{2+}$, $Al(OH)_2^{+}$, $Al(OH)_4^{-}$;and as a result pH of water is lowered, especially if alkalinity of water is low.

- Theoretically, each mg/l of alum consume approximately 0.50 mg/l (as $CaCO_3$) of alkalinity.

Coagulant – Alum (Aluminum Sulfate)

- The common metal salt alum (aluminum sulfate) is a good coagulant for water containing appreciable organic matter.

- The chemical formula used for commercial alum is $Al_2(SO_4)_3,14H_2O$.

- Once dissolved in water, aluminum forms hydroxo-complexes and solids [e.g., $Al(OH)_3(s)$, $Al(OH)^{2+}$, $Al(OH)_2^{+}$, $Al(OH)_4^{-}$;and as a result pH of water is lowered, especially if alkalinity of water is low.

- Theoretically, each mg/l of alum consume approximately 0.50 mg/l (as $CaCO_3$) of alkalinity.

Chemical Reaction

$$Al_2(SO_4)_3.14H_2O\ (alum) = 2Al^{3+} + 3SO_4^{2-}$$

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

$$Al^{3+} + 3H_2O = Al(OH)^{2+} + H^+$$

$$Al^{3+} + 3H_2O = Al(OH)_2^{+} + 2\ H^+$$

$$Al^{3+} + 3H_2O = Al(OH)_4^{-} + H^+$$

Chemical Reaction

1 mole of alum consumes 6 moles of bicarbonate (HCO_3^-)

Represents major alkalinity

$$Al_2(SO_4)_3 \cdot 14H_2O + 6HCO_3^- \Leftrightarrow 2Al(OH)_3 \cdot 3H_2O(s) + 6CO_2 + 8H_2O + 3SO_4^{2-}$$

If alkalinity is not enough, pH will reduce greatly

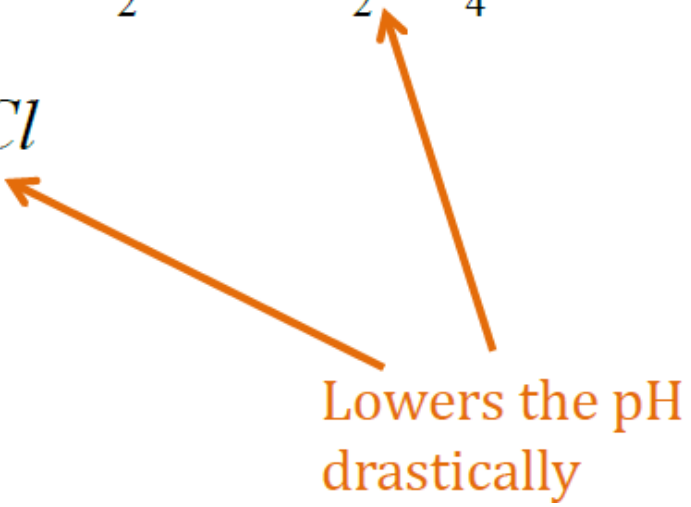
Lime or sodium carbonate may be needed to neutralize the acid.

Chemical Reaction

- **If sufficient Alkalinity is not present**

$$Al_2(SO_4)_3 \cdot 14H_2O \Leftrightarrow 2Al(OH)_3 \cdot 3H_2O(s) + 2H_2O + 3H_2SO_4$$

$$FeCl_3 + 3H_2O \Leftrightarrow Fe(OH)_3 \cdot 3H_2O(s) + 3HCl$$



Environmental Significance of Coagulation

- Removal of **turbidity** and **color** from water and wastewater.
- Coagulation with alum and ferric chloride or ferric sulfate is also widely used for removal of **heavy metal ions** (e.g., lead, arsenic) from water.
- In this process heavy metal ions are primarily removed by **adsorption** (and **subsequent precipitation**) onto coagulated floes of metal (either aluminum or iron) hydroxides.
- Coagulation with alum and ferric chloride/sulfate have been successfully used for **removal of arsenic** from water.

Lab Procedure of Coagulation

REAGENTS

(1) Standard Alum solution

APPARATUS

(1) 6 Paddle Floc Stirrer (for Jar Test)

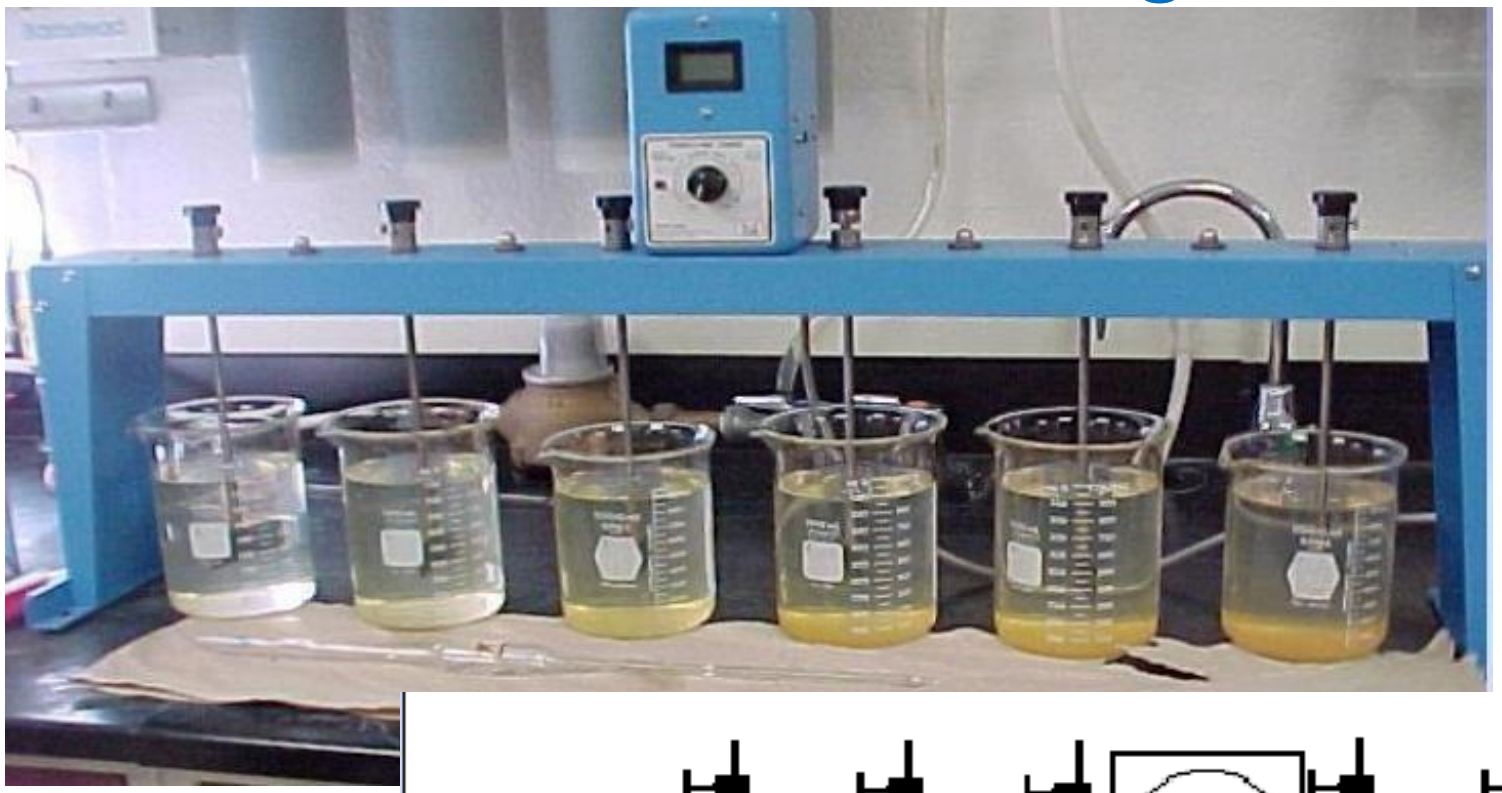
(2) pH meter (for pH measurement)

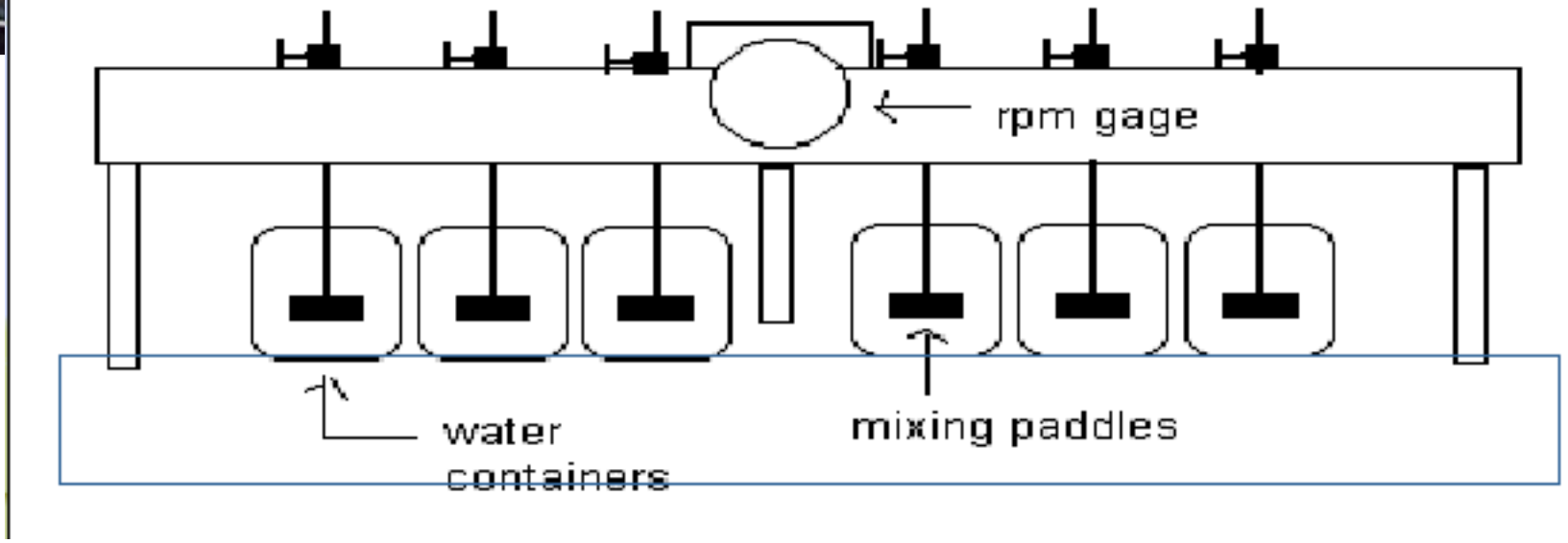
(3) Turbidity meter (for turbidity measurement)

(4) Spectrophotometer (for color measurement)

(5) Glass beakers (1000 ml; 6 nos.)

Lab Procedure of Coagulation – Jar Test





Lab Procedure of Coagulation – Steps in Jar Test

- Fill six 1000 ml beakers each with 500 ml water to be treated.
- Add required coagulant (standard alum solution) to each beaker.
- Mix the samples in the beaker with the help of the stirring device. Subject the samples to one minute of **rapid mixing** followed by 15 minutes of **slow mixing**
- Allow the flocs to settle down for about 15 minutes.
- Observe the characteristics of the flocs and the settling rates.

Lab Procedure of Coagulation – Steps in Jar Test

- Collect the supernatant from each beaker and measure **pH, color and turbidity of each**.

- Plot **pH versus alum dose** in a graph paper and observe effect of alum dose on pH.

- Plot **color versus alum dose** in a graph paper and observe effect of alum dose on color.

- Plot **turbidity versus the coagulant (alum) dose** in a graph paper. The coagulant dose with the lowest residual turbidity will be the optimum coagulant dose. Hence, determine optimum dose of alum from this plot.

Lab Procedure of Coagulation – Optimum Alum Dose and pH

