

L-17
Coagulation and Flocculation
Part-I

Environmental Engineering-I



Content

Part-I

- Coagulation, Types of Coagulant,

Part-II

- dosing, rapid mixing, Flocculation-design parameters.



Purpose

- The primary purpose of the coagulation/flocculation process is the removal of turbidity from the water.
- **Turbidity is a cloudy appearance of water caused by small particles suspended therein.**
- Water with little or no turbidity will be clear.
- Water with a high turbidity can be very difficult to properly disinfect.



No Turbidity



80 NTU

Why coagulation and flocculation?

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

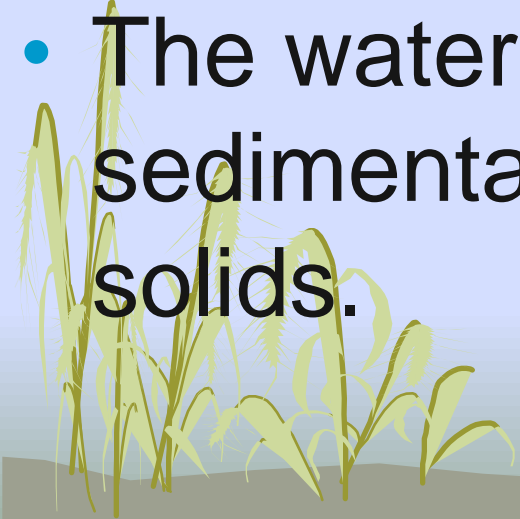
Colloids – so small in size: gravity settling not possible

Coagulant aided sedimentation required to remove following impurities

1. Miscellaneous fragments of animal and vegetable matter
2. plankton mainly phytoplankton (microscopic plants).
3. Finely divided colloidal matter and clay.
4. Organic colouring matter partly in solution and partly in colloidal form.
5. Bacteria and viruses in small extent
6. Complex mixture of organic compounds

Coagulation-Flocculation

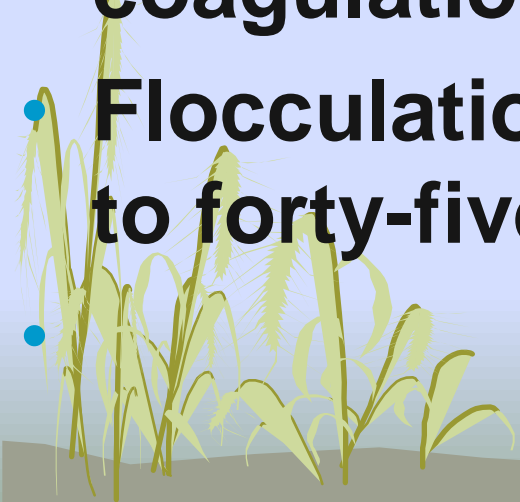
- In conventional coagulation-flocculation-sedimentation, a **coagulant is added to the source water to create an attraction among the suspended particles.**
- **The mixture is slowly stirred to induce particles to clump together into “flocs.”**
- The water is then moved into a quiet sedimentation basin to settle out the **solids.**



- In the **flash mixer**, coagulant chemicals are added to the water and the **water is mixed quickly and violently**.
- The purpose of flash mixing is to evenly **distribute the chemicals through the water**.
- Flash mixing typically lasts a minute or **less**. **If the water is mixed for less than thirty seconds, then the chemicals will not be properly mixed into the water.**
- However, if the water is mixed for more than sixty seconds, then the mixer blades will shear the newly forming floc back into small particles.



- After flash mixing, coagulation occurs. During **coagulation**, the coagulant chemicals neutralize the electrical charges of the fine particles in the water, allowing the particles to come closer together and form large clumps.
- The final step is **flocculation**. During flocculation, a **process of gentle mixing brings the fine particles formed by coagulation into contact with each other.**
- **Flocculation typically lasts for about thirty to forty-five minutes.**



To summarize,

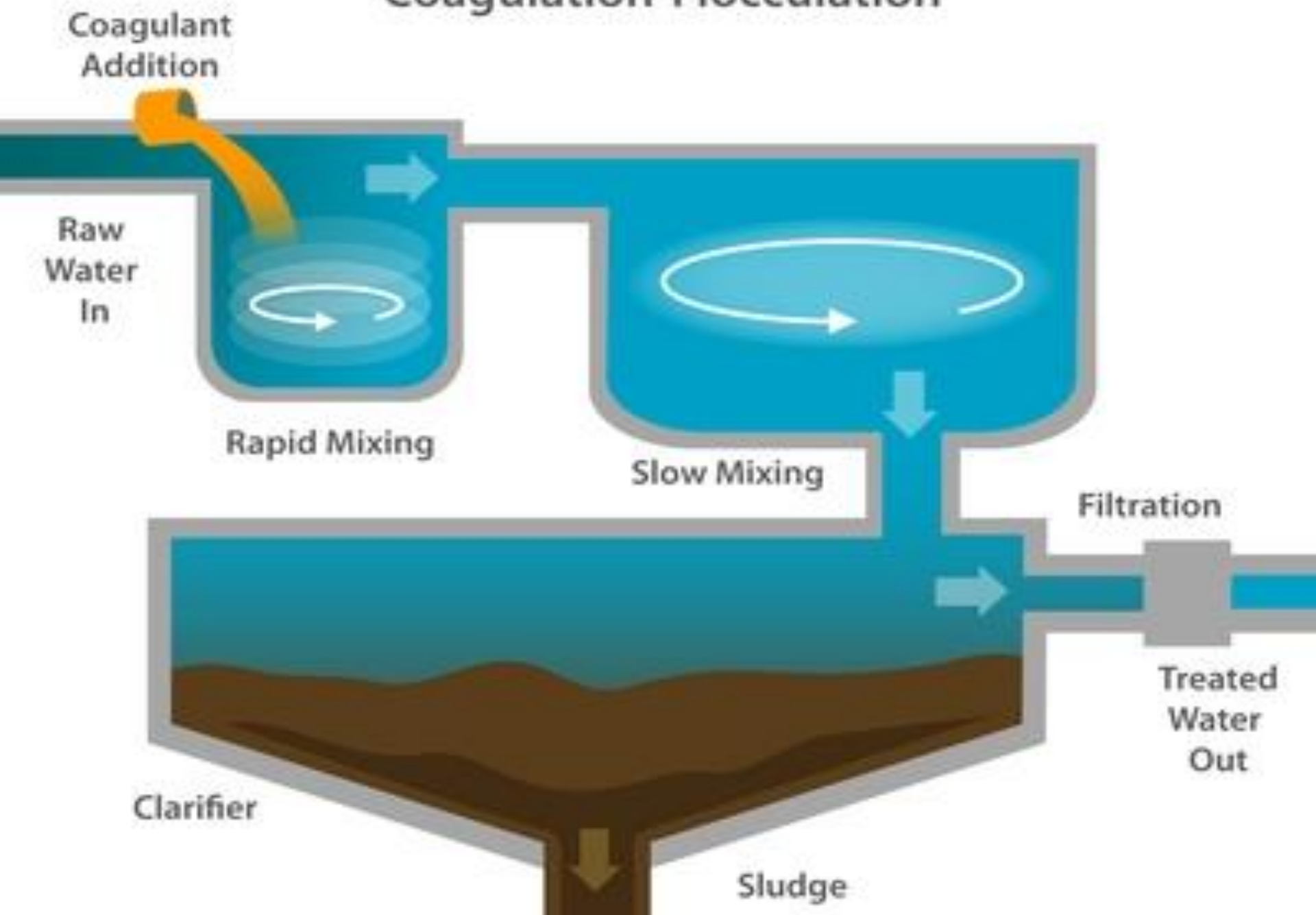
- **Coagulation Is**

- The addition and rapid mixing of coagulants
- The destabilization of colloidal and fine particles
- The initial aggregation of destabilized particles

- **Flocculation Is**

- The gentle agitation to aggregate destabilized particles to form rapid-settling floc

Coagulation-Flocculation



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THEORY OF COAGULATION



Coagulation & Flocculation : Colloidal Characteristics

Classification of colloidal solids in water acc. to their affinity for water

Hydrophilic Colloids

Have an affinity for water due to existence of water soluble groups (e.g. amino, carboxyl, sulfonic, hydroxyl etc.) on the colloidal surface

These groups promote hydration and cause a water film to collect and surround the hydrophilic colloid

Examples: proteins, soaps, synthetic detergents

Hydrophobic Colloids

Have little affinity for water

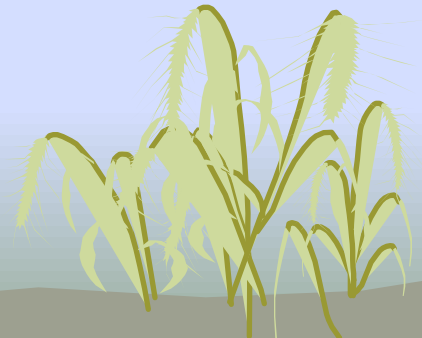
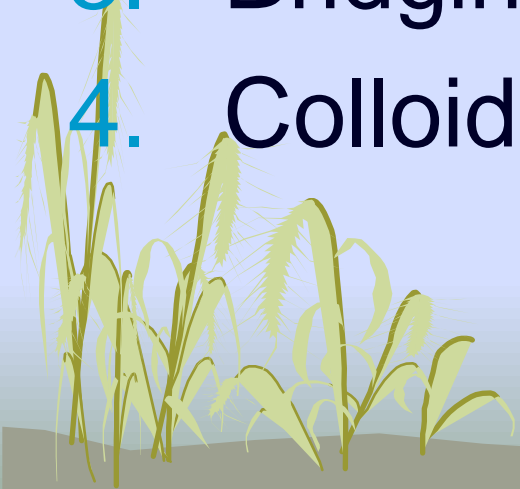
They do not have any significant water film or water of hydration

Examples: inorganic colloids (e.g., clay, metal)

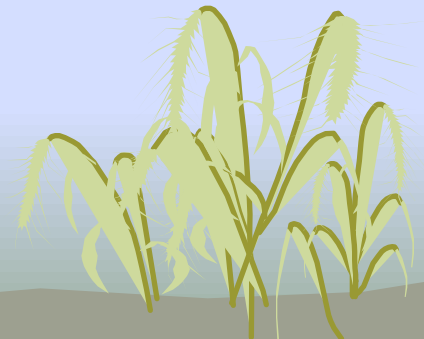
Destabilization of colloidal particles takes place by following ways

Coagulation and flocculation can be caused by any of the following:

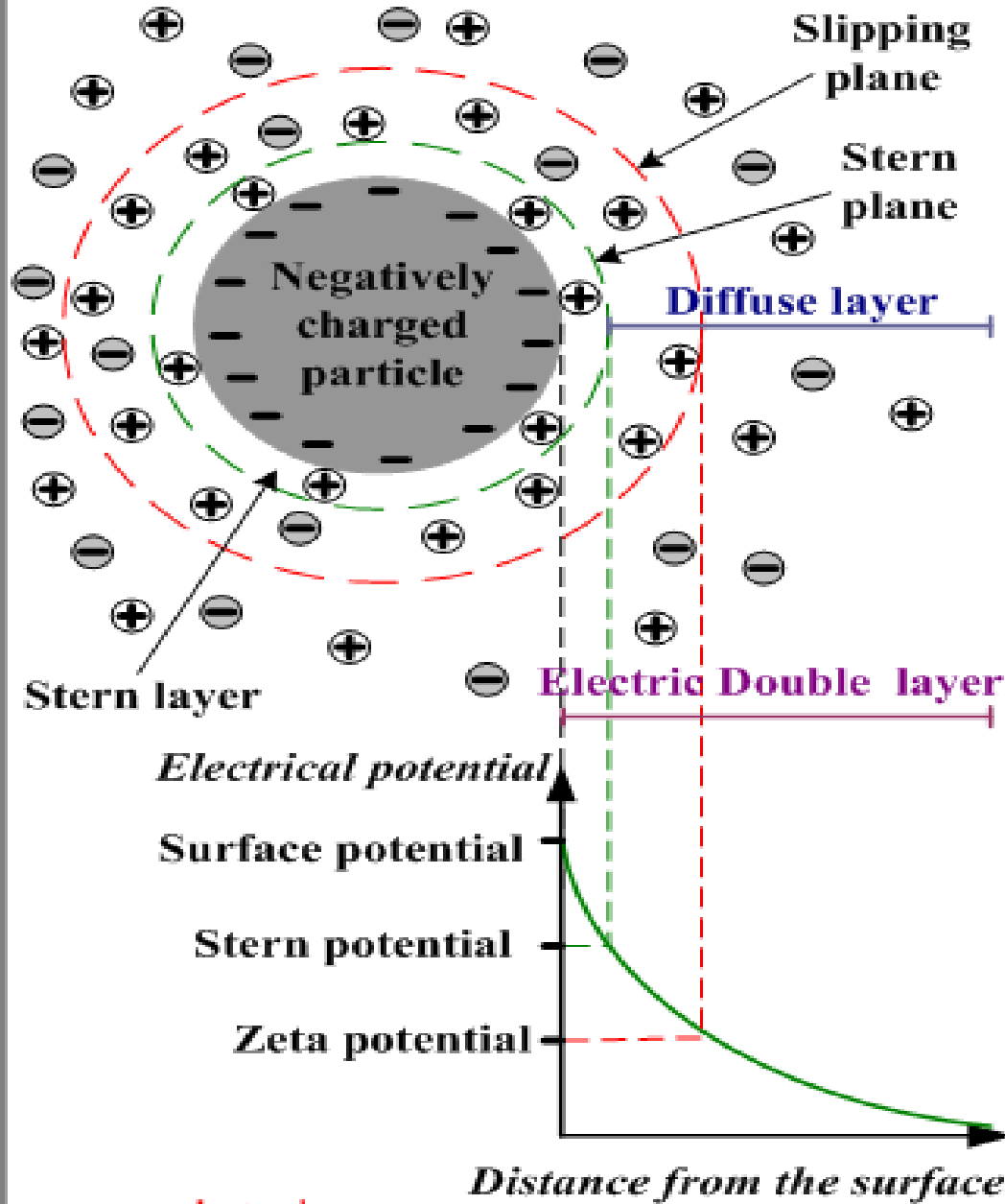
1. Double layer compression
2. Charge neutralization
3. Bridging
4. Colloid entrapment



1. DOUBLE LAYER COMPRESSION THEORY



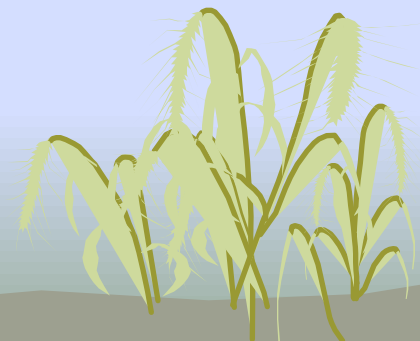
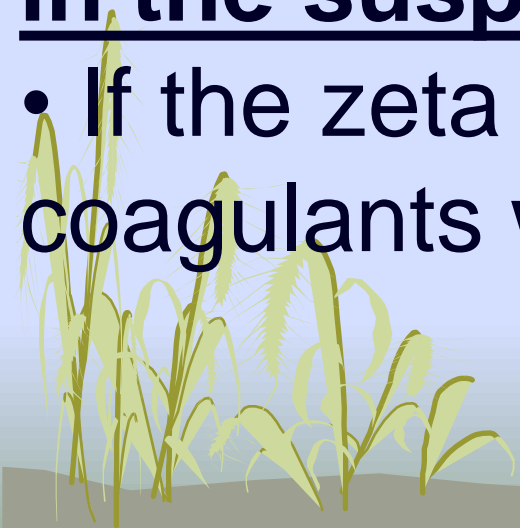
Electric Double Layer



An Electric Double Layer consists of three parts:

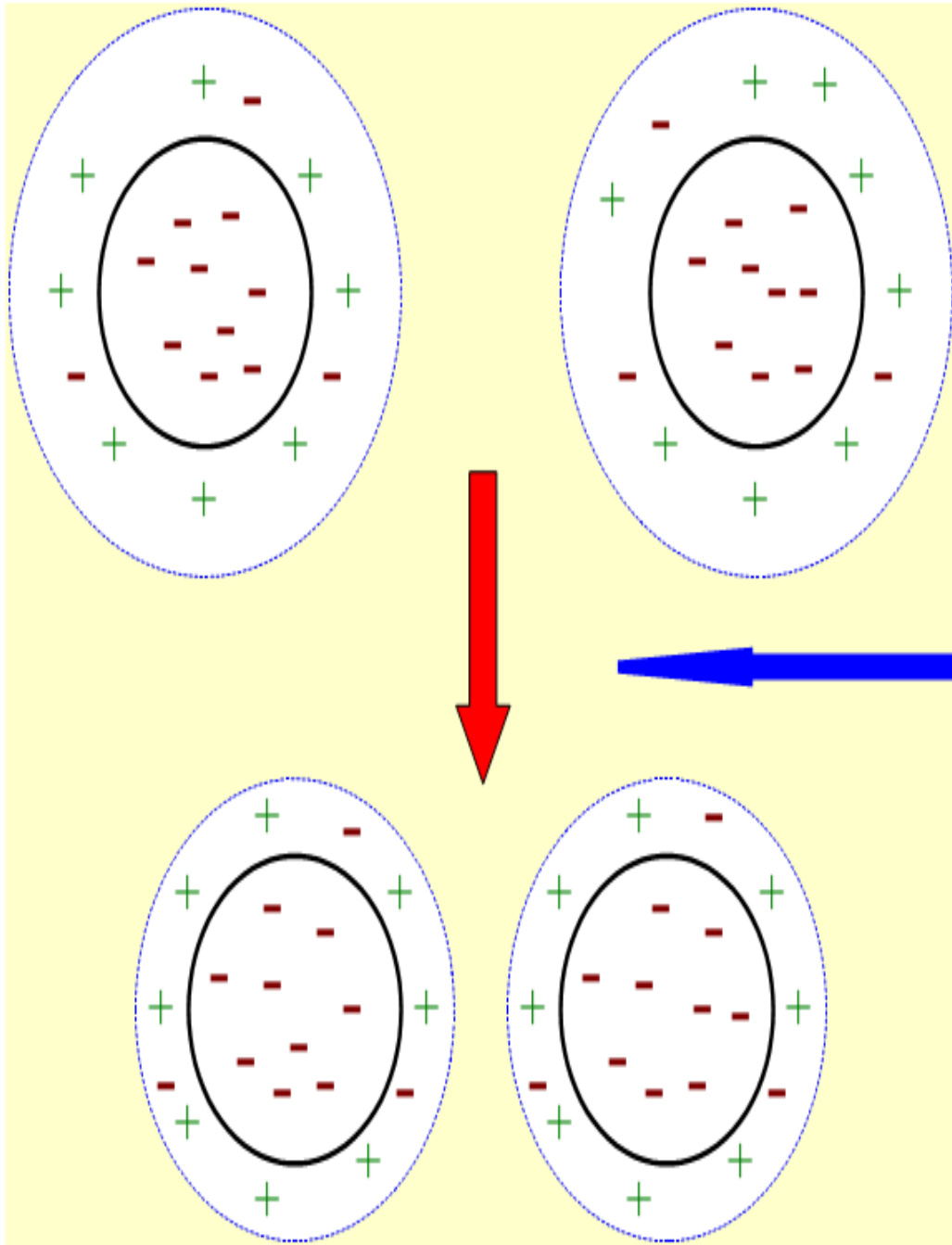
- **Surface charge** - charged ions (commonly negative) adsorbed on the particle surface.
- **Stern layer** - counter ions (charged opposite to the surface charge) attracted to the particle surface and closely attached to it by the electrostatic force.
- **Diffuse layer** - a film of the dispersion medium (solvent) adjacent to the particle. Diffuse layer contains free ions with a higher concentration of the counter ions. The ions of the diffuse layer are affected by the electrostatic force of the charged particle.

- The amount of coagulant which should be added to the water will depend on the **zeta potential, a measurement of the magnitude of electrical charge surrounding the colloidal particles.**
- **The zeta potential as the amount of repulsive force which keeps the particles in the suspension.**
- If the zeta potential is large, then more coagulants will be needed.



- When coagulants (Electrolytes) are added into the water it changes ionic concentration.
- Which compresses double layer and weakens repulsive forces.
- The basic goal of coagulation is to reduce the net repulsive force.

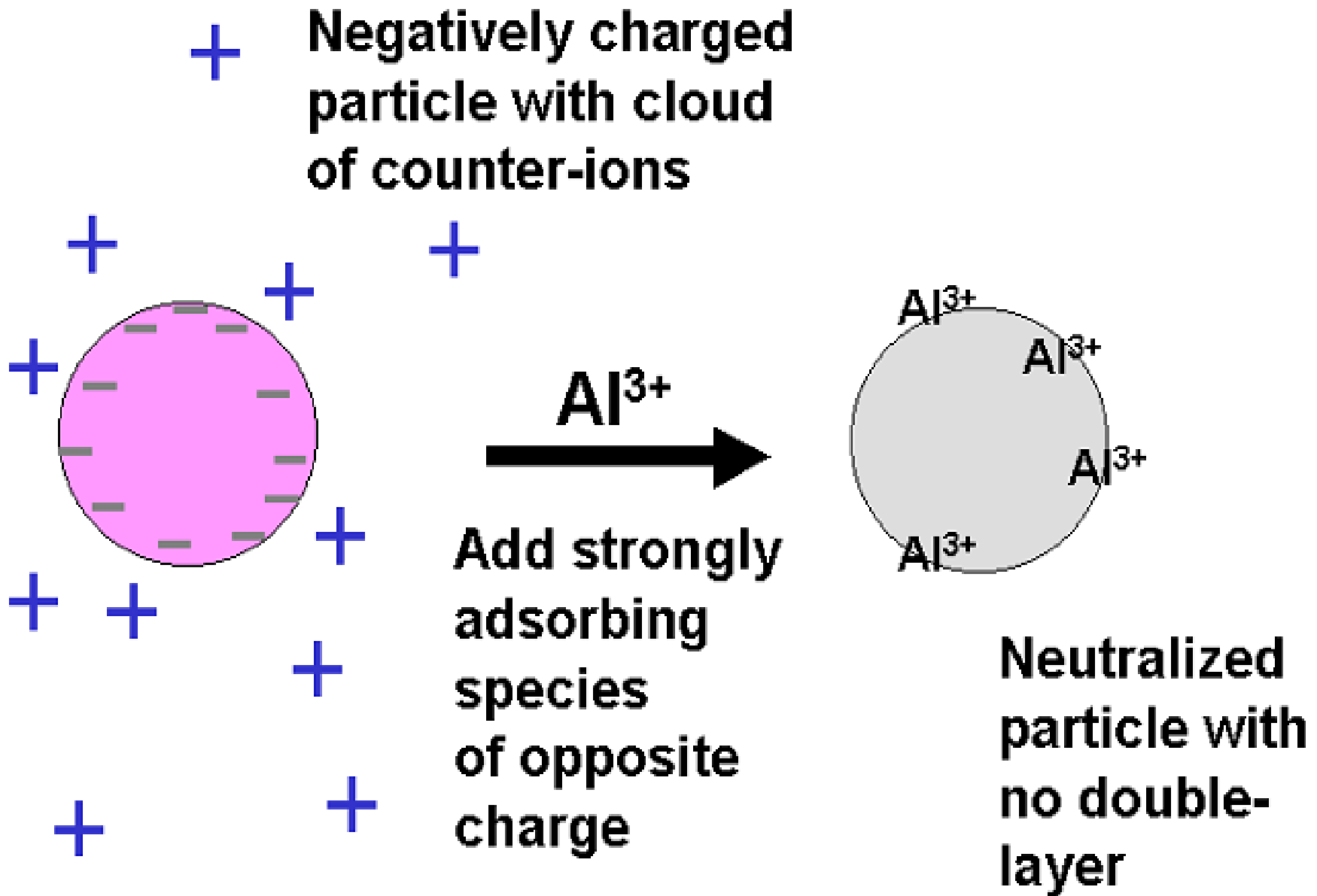




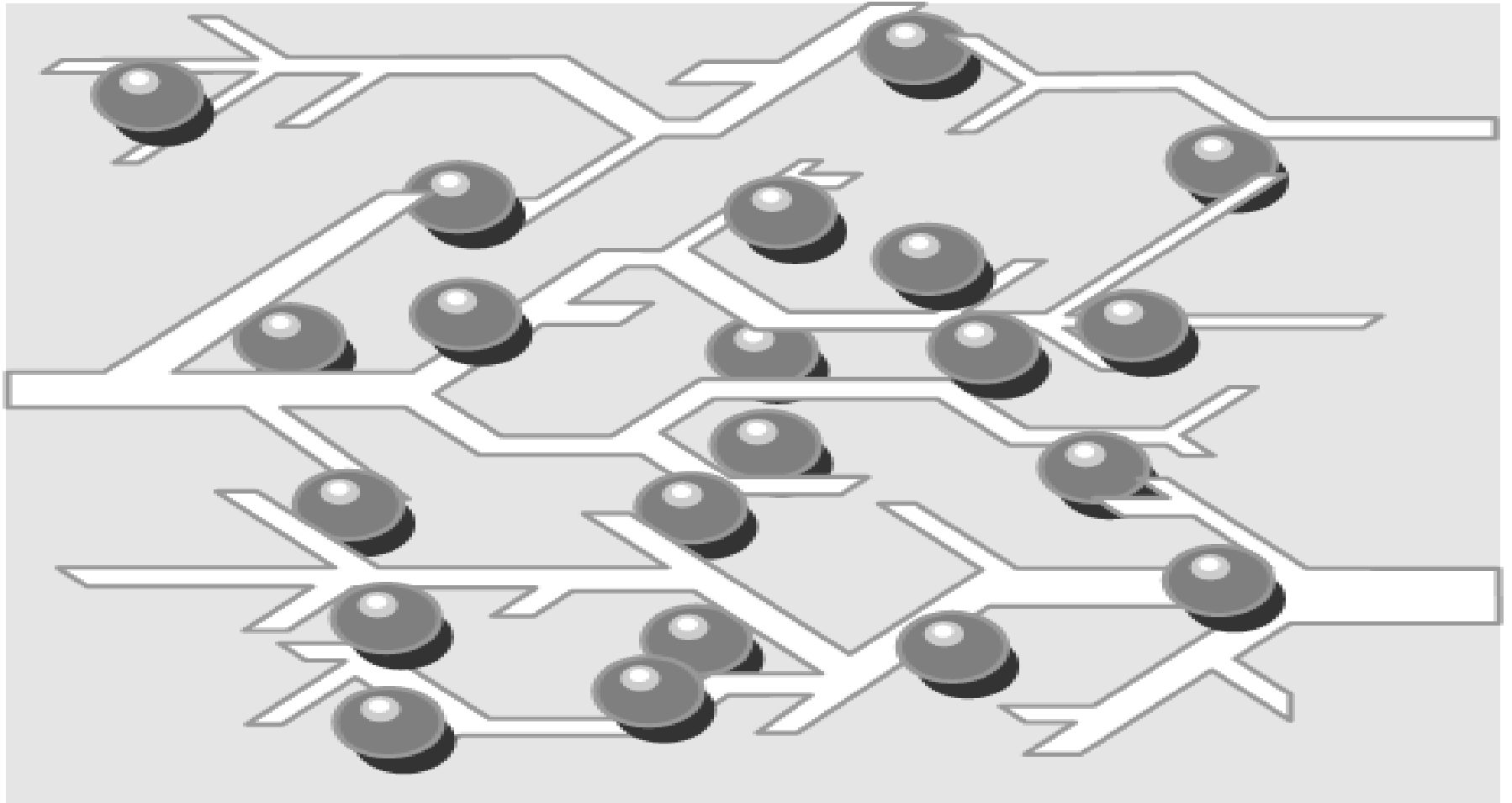
Double layer
gets
compressed
after addition of
coagulant

**coagulant
(electrolyte)**

2. Charge Neutralization



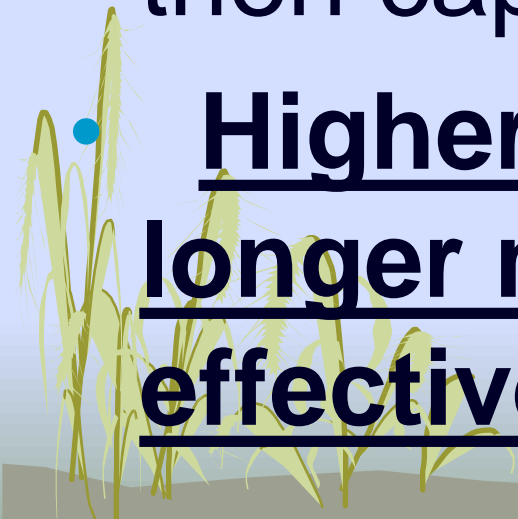
3. Bridging



Bridging

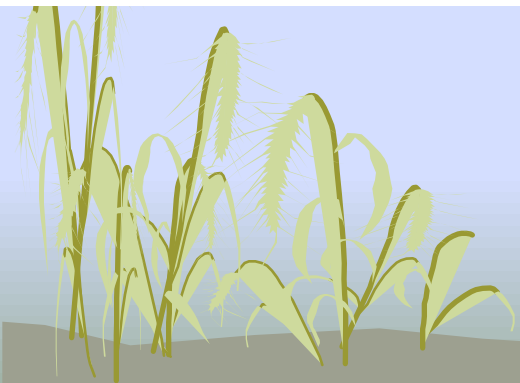
Each polymer chain attaches to many colloids.

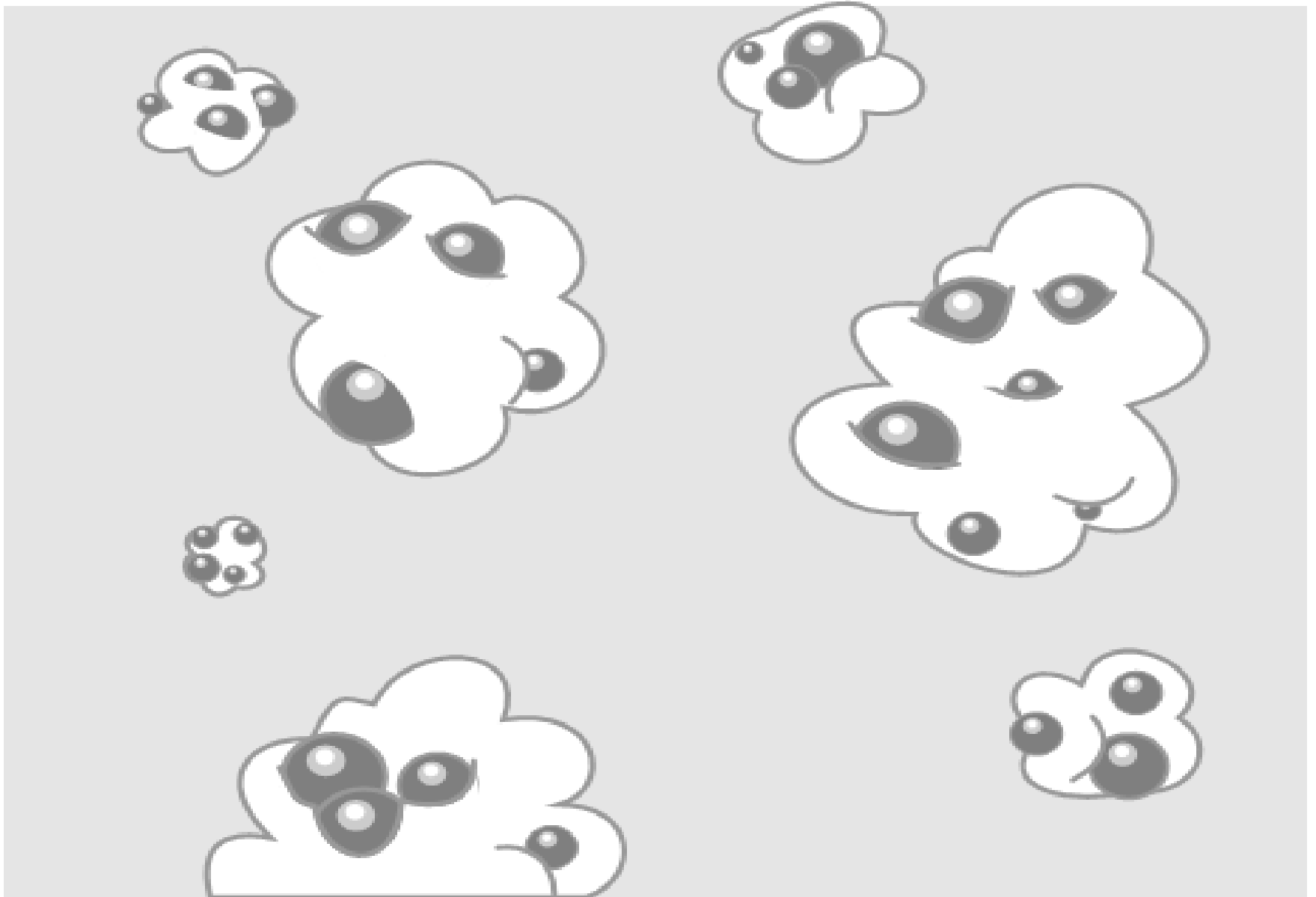
- Bridging occurs when a coagulant forms threads or fibers which attach to several colloids, capturing and binding them together.
- Inorganic primary coagulants and organic polyelectrolytes both have then capability of bridging.
- Higher molecular weights mean longer molecules and more effective bridging.



4. Colloidal entrapment

Sufficient amount of coagulants ($\text{Al}_2(\text{SO}_4)_3$, FeCl_3 , MgCO_3 and $\text{Ca}(\text{OH})_2$) can generate rapid precipitates ($\text{Al}(\text{OH})_3$, $\text{Fe}(\text{OH})_3$, $\text{Mg}(\text{OH})_2$ and CaCO_3) and colloids may become enmeshed in these. (Also called *Sweep floc* coagulation)



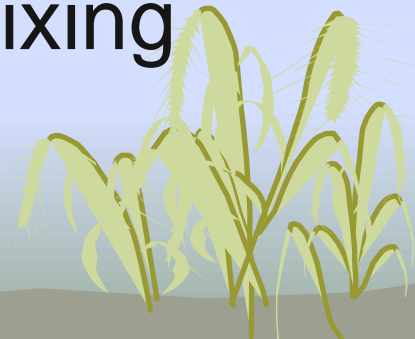
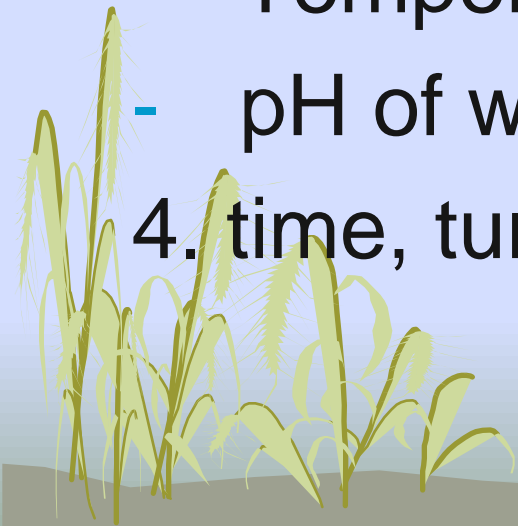


Sweep Flocc

Colloids become enmeshed in the growing precipitate.

Factors affecting coagulation

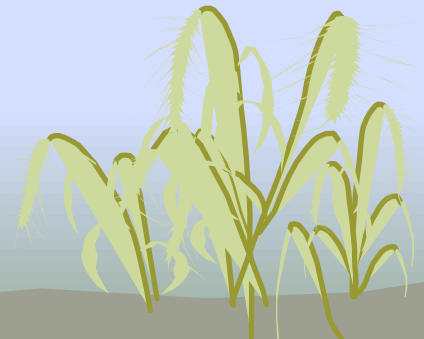
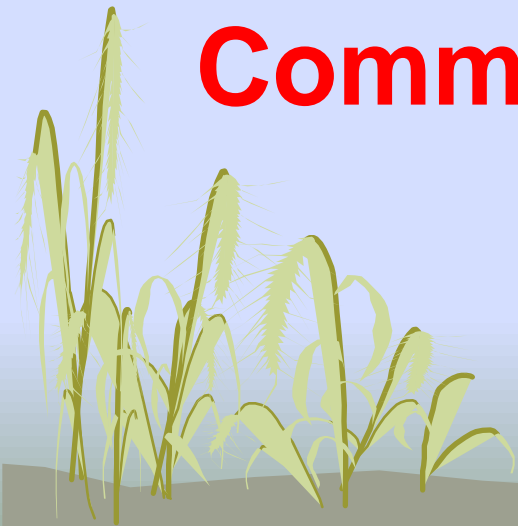
1. Types of coagulant
2. Quantity or dose of coagulant
3. Characteristics of water such as
 - Type and quantity of suspended matter
 - Temperature of water
 - pH of water
4. time, turbulence and method of mixing



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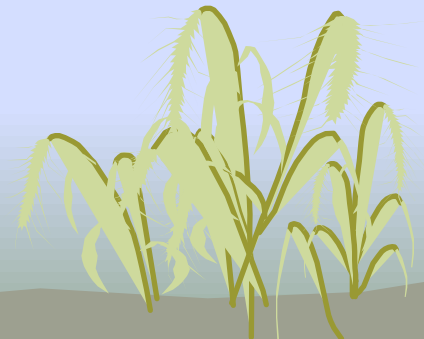
Jar Test and

Common coagulants



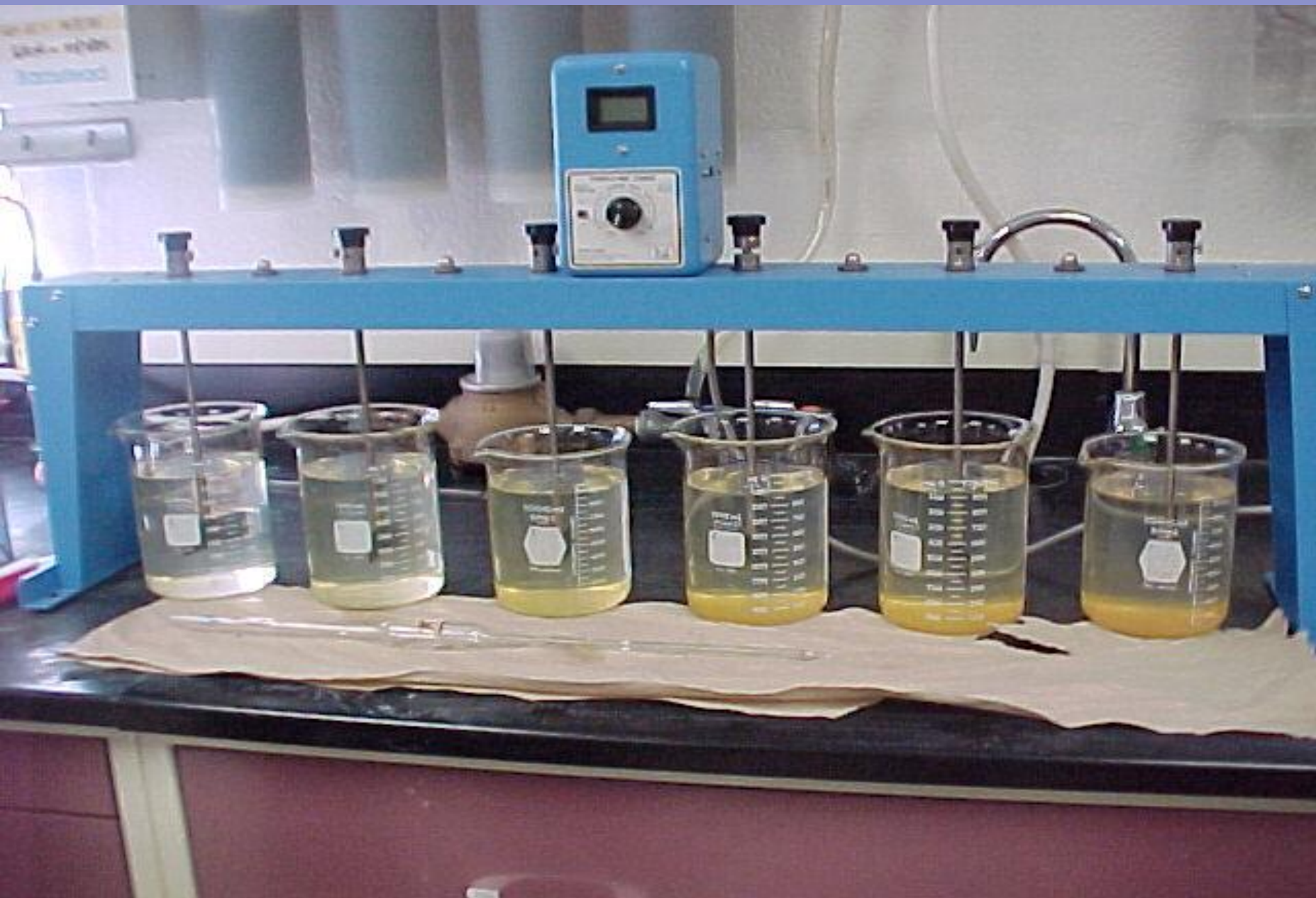
A jar test simulates the coagulation and flocculation processes in batch mode

JAR TEST



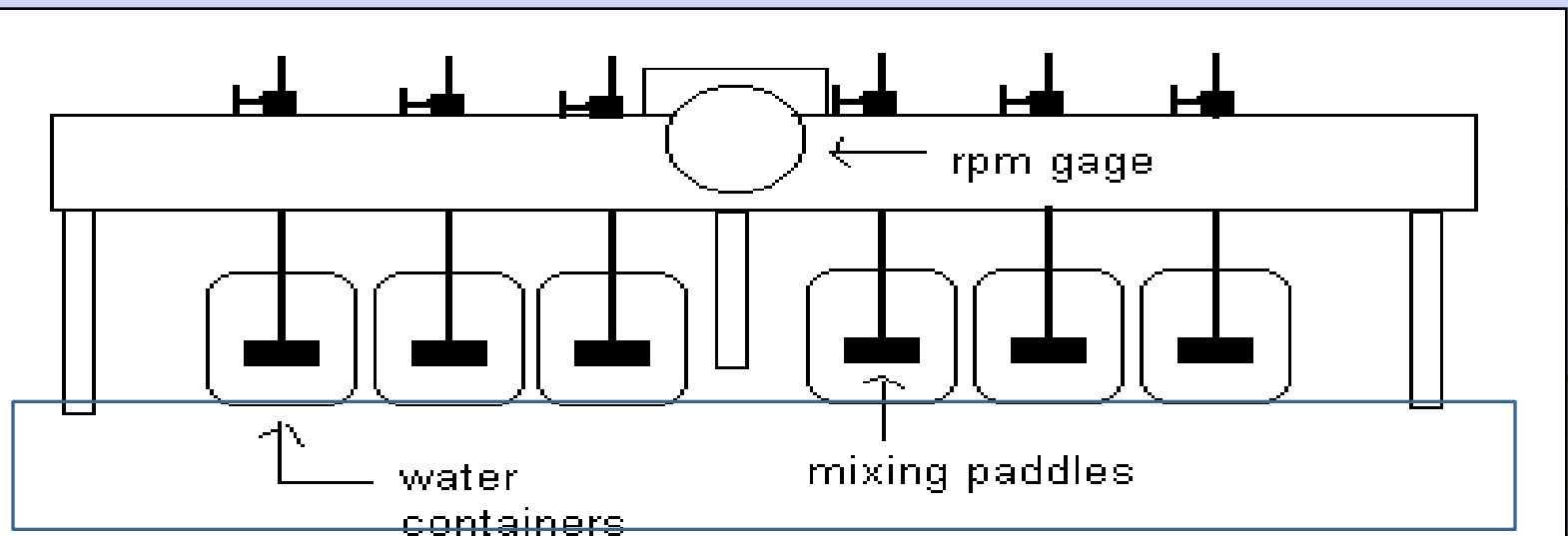
STEPS

- ❑ Fill the jars with raw water sample (500 or 1000 mL) – usually 6 jars
- ❑ This time adjust pH of all jars at optimum (@ 7) while mixing using H_2SO_4 or NaOH/lime
- ❑ Add different doses of the selected coagulant (alum or iron) to each jar (Coagulant dose: 0 to 50 mg/Lit-interval of 10 mg/Lit)
- ❑ Rapid mix each jar at 100 to 150 rpm for 1 minute. The rapid mix helps to disperse the coagulant throughout each container
- ❑ Reduce the stirring speed to 25 to 30 rpm for 25 to 30 mins

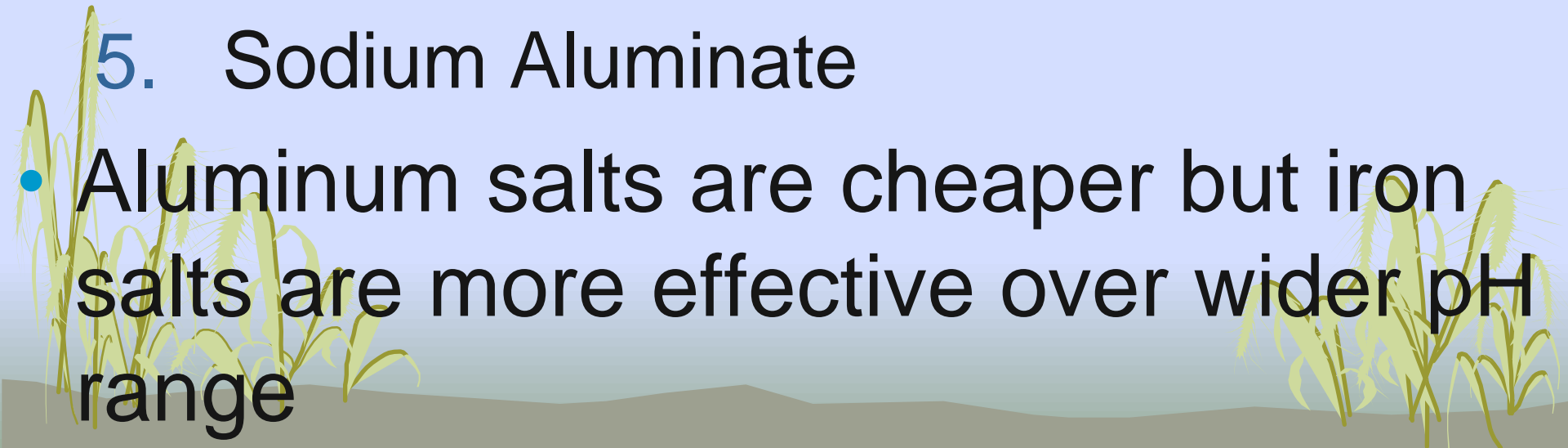


- Turn off the mixers and allow flocs to settle for 30 to 45 mins
- Then measure the final residual turbidity in each jar
- Plot residual turbidity against coagulant dose

The coagulant dose with the lowest residual turbidity will be the optimum coagulant dose

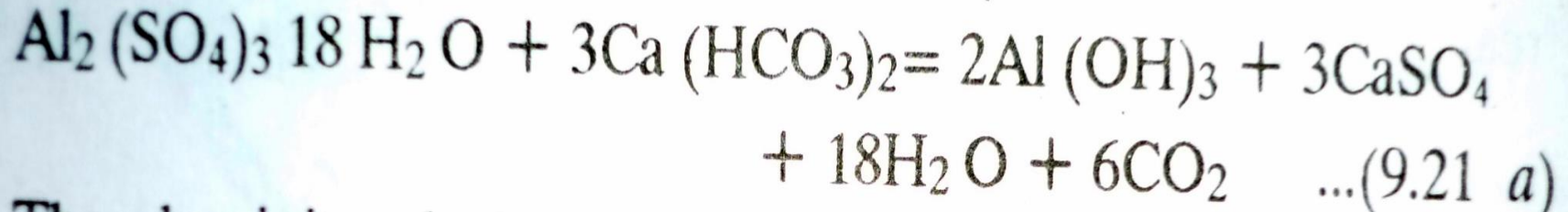


Coagulants

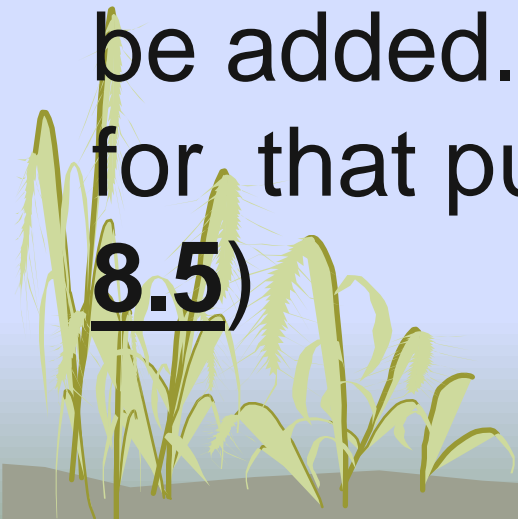
- Mainly aluminum and iron salts
 1. Aluminum sulfate
 2. Chlorinated copperas
 3. Ferrous sulfate and lime
 4. Magnesium carbonate and lime
 5. Sodium Aluminate
 - Aluminum salts are cheaper but iron salts are more effective over wider pH range
- 

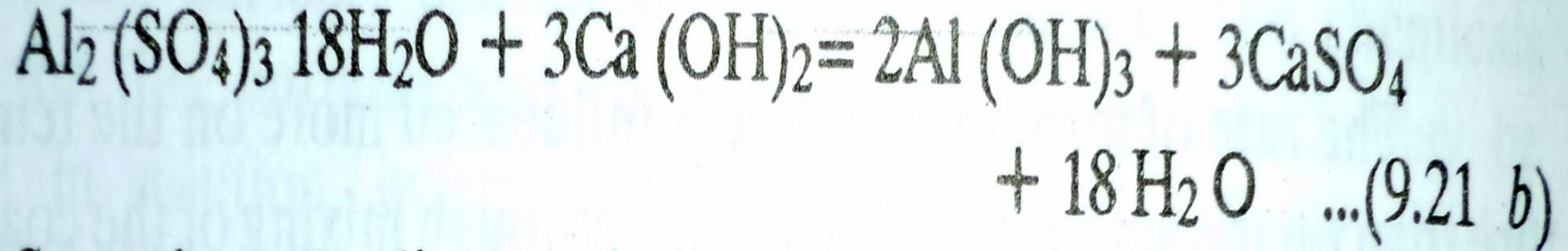
1. Aluminum Sulfate or Alum

- To produce the hydroxide floc, enough alkalinity should present in the water

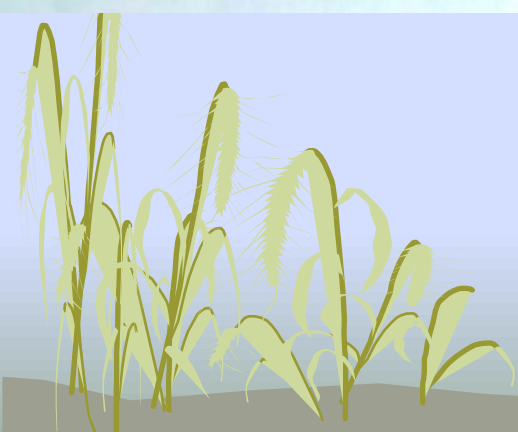
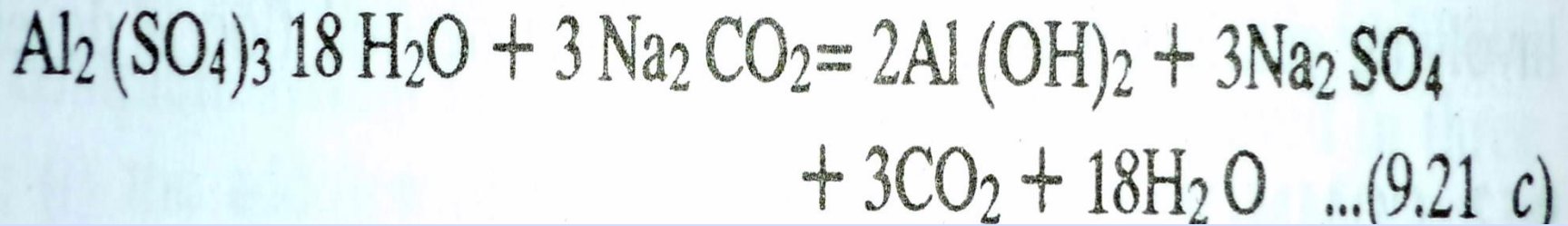


- If alkalinity is not enough, then it should be added. Usually hydrated lime is used for that purpose (***optimum pH is 6.5 – 8.5***)





Sometimes, sodium carbonate, known as *soda ash*, is added to form alkalinity. The resulting reaction is :



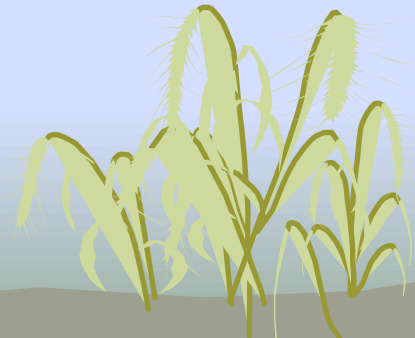
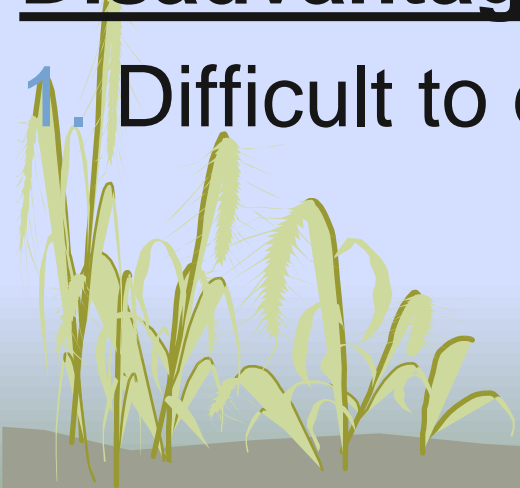
- Under normal circumstances Dose of Alum varies from 10 to 30 mg/lit of water.

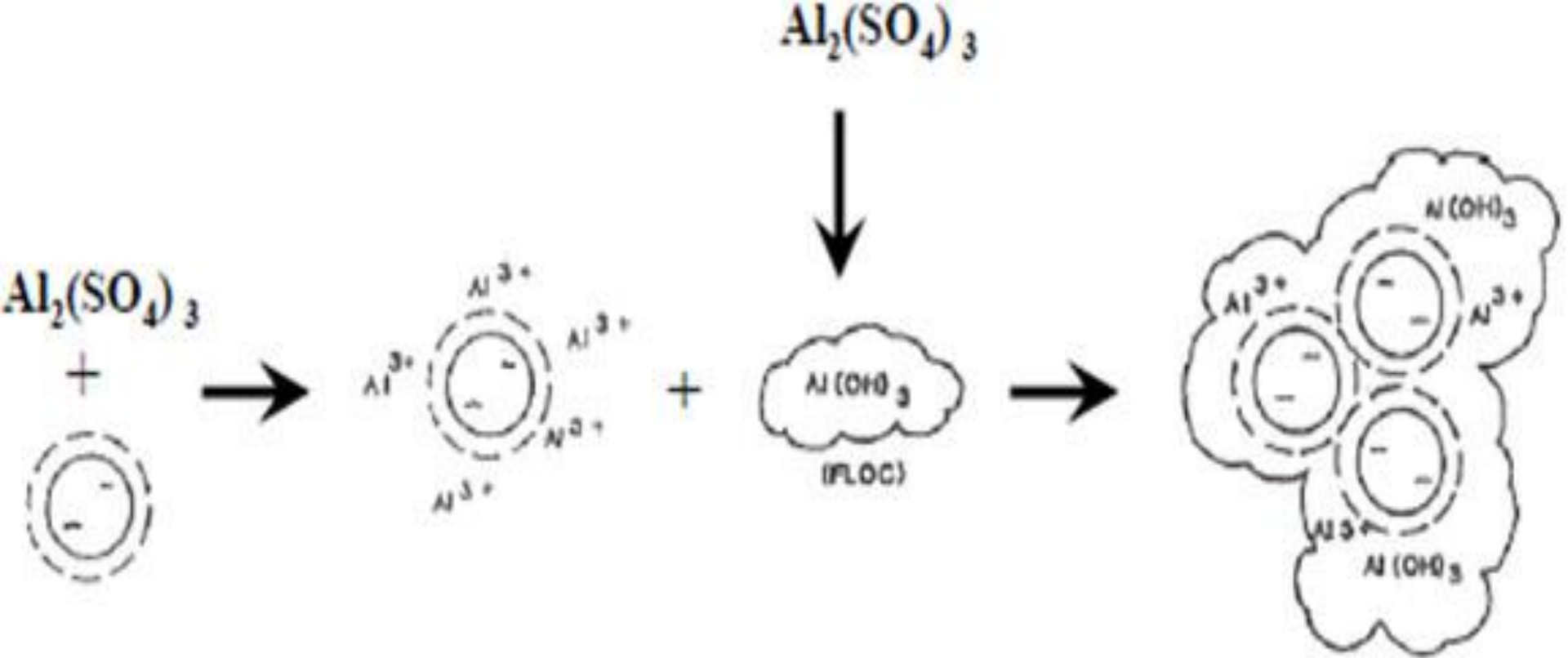
Advantages

1. Alum reduces taste and odour
2. Cheap
3. Easily available
4. Soluble in water

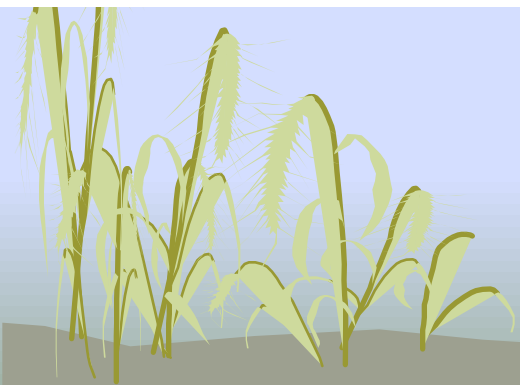
Disadvantages

1. Difficult to dewater the sludge



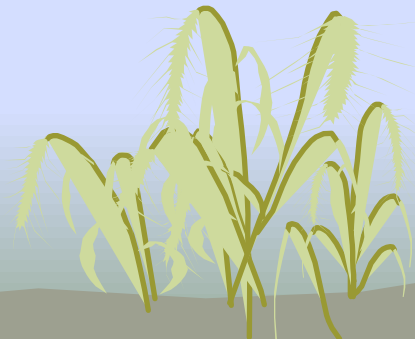


**colloids are
enmeshed**



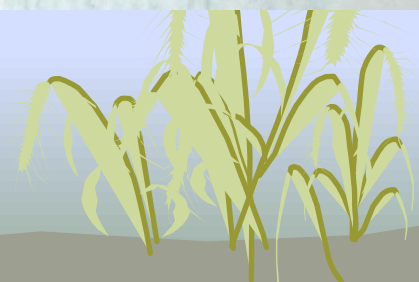
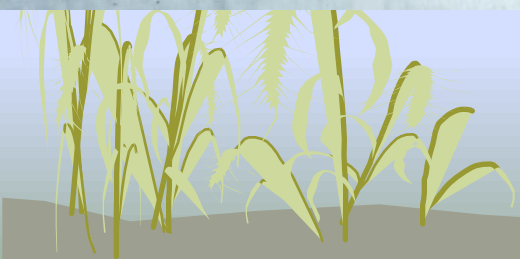
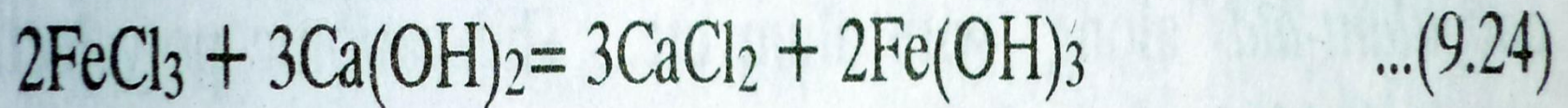
2. Ferrous Sulfate (Chlorinated Copperas)

- The optimum pH range is 3.5 to 6.5
- At higher pH i.e. 9.5 it removes manganese
- More expensive than alum
- Effective in colour removal.
- Low solubility in water



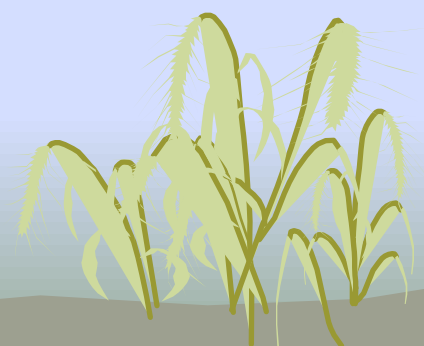
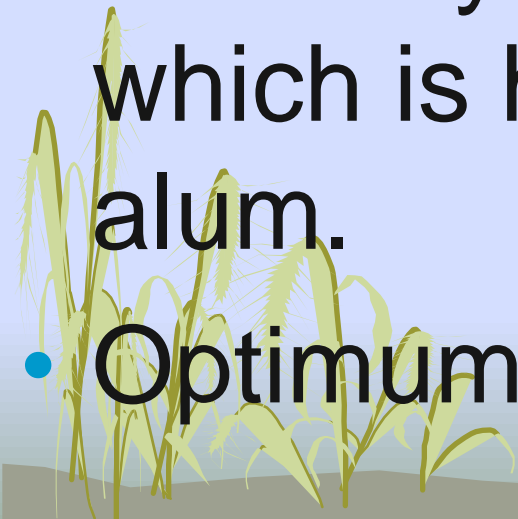


The ferric sulphate and ferric chloride, produced instantaneously, are called *chlorinated copperas*. Both of these are immediately available for the formation of ferric hydroxide floc; the resulting reactions are :



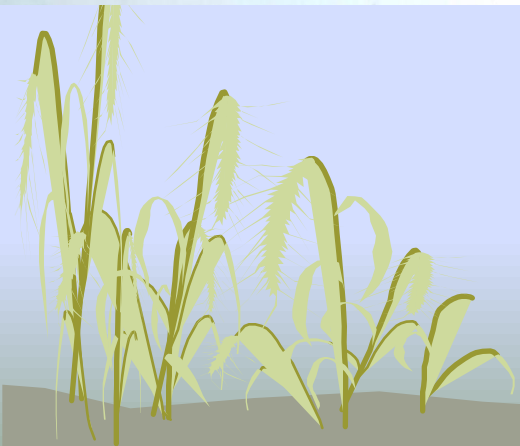
3. Ferrous Sulfate and lime

- Ferrous sulphate can react with natural calcium bicarbonate alkalinity in water, but its slow process.
- Hence Lime is added in water.
- Ferric hydroxide is gelatinous floc, which is heavier than floc formed by alum.
- Optimum pH range is below 7



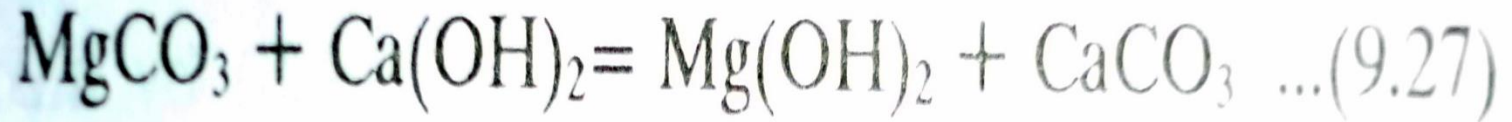


The ferrous hydroxide $\text{Fe}(\text{OH})_2$ thus formed, though an efficient floc, is soon oxidized by dissolved oxygen in water, and ferric hydroxide is formed :

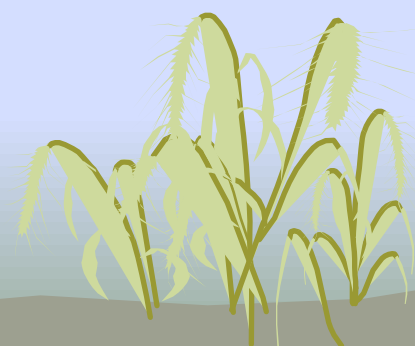
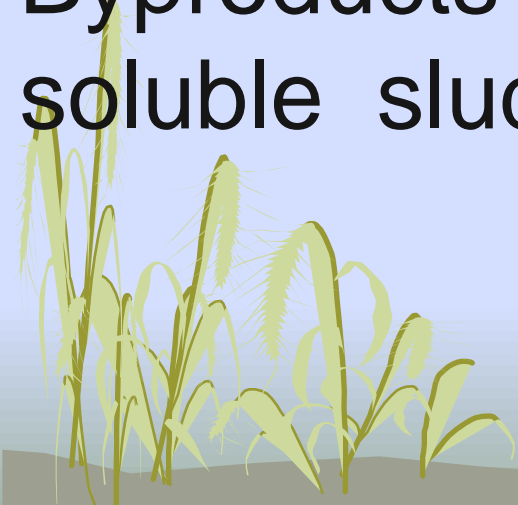


4. Magnesium carbonate and lime

When magnesium carbonate and lime are dissolved in magnesium hydroxide and calcium carbonate are formed as

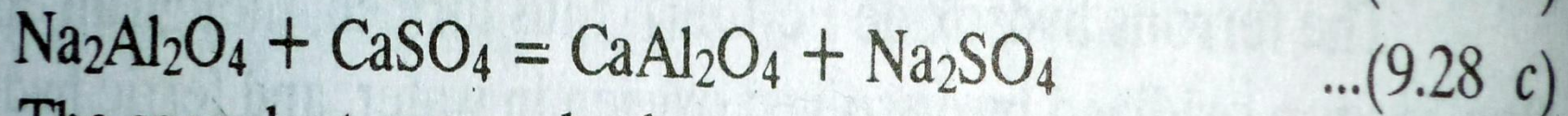
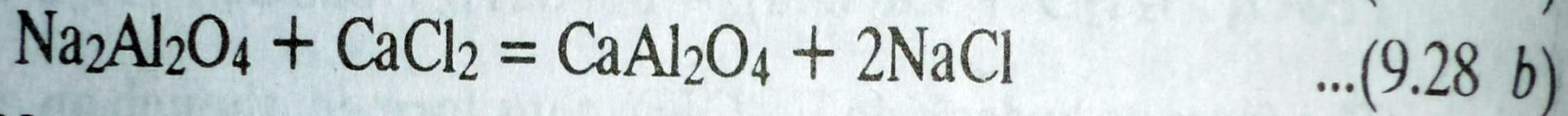
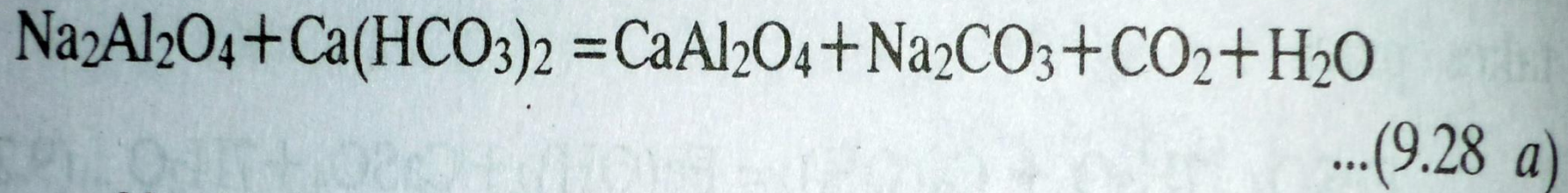


Byproducts of above reaction forms soluble sludge, so not commonly used



5. Sodium Aluminate

Sodium aluminate $\text{Na}_2\text{Al}_2\text{O}_4$ is alkaline in reaction and is used very much less often than alum because of its cost. It reacts with the salts of calcium and magnesium, as under :



The coagulant remove both temporary and permanent hardness, and is effective for a pH range of 6 to 8.50 naturally available in water.

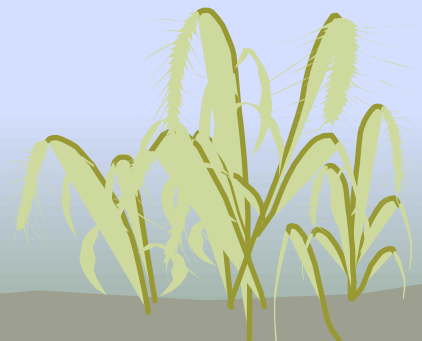
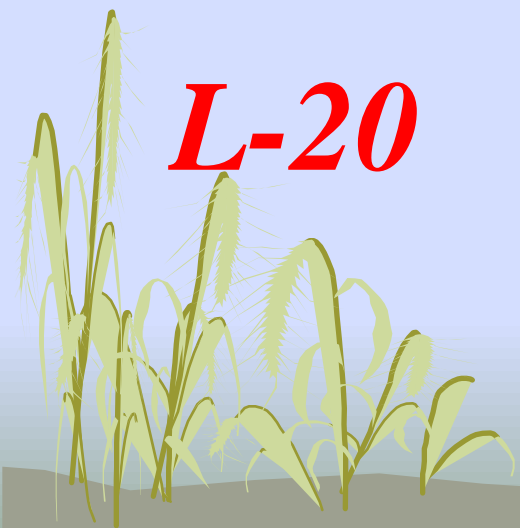
Comparison of Alum and Iron salt

1. Iron salts forms heavy floc as compared to alum, hence more Solids are removed
2. time of reaction and floc formation is less for iron salts, hence 't' reduces.
3. Iron salts can work efficiently over wider pH range
4. Iron salts can remove taste and odour.
5. Less mud ball formation as compared to alum



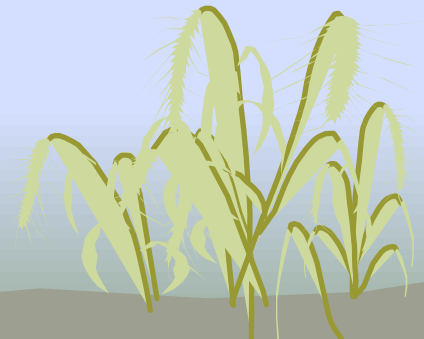
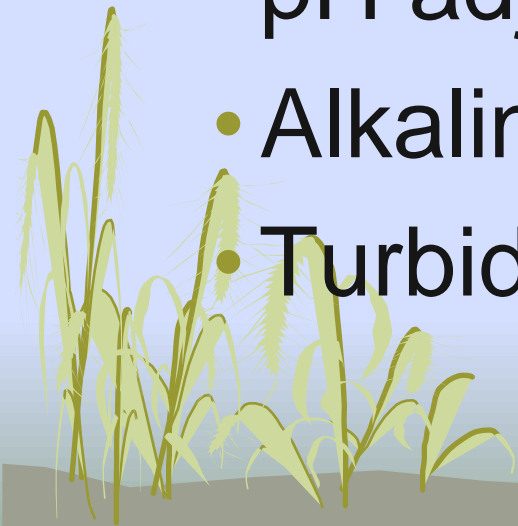
6. Under some cases iron salts are more economical.
7. Iron salts cause staining and promotes growth of iron bacteria.
8. Iron salts make water more corrosive as compared to alum
9. Handling of iron salts requires skill.
10. More CO_2 is formed so water becomes corrosive.
11. Alum Coagulation may not be proper if K or Na are present in water

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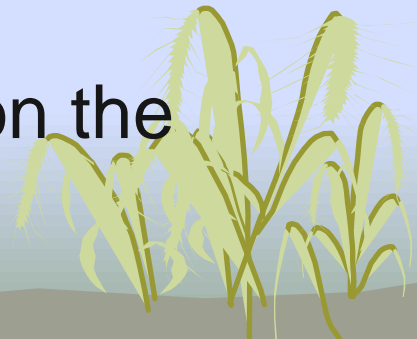
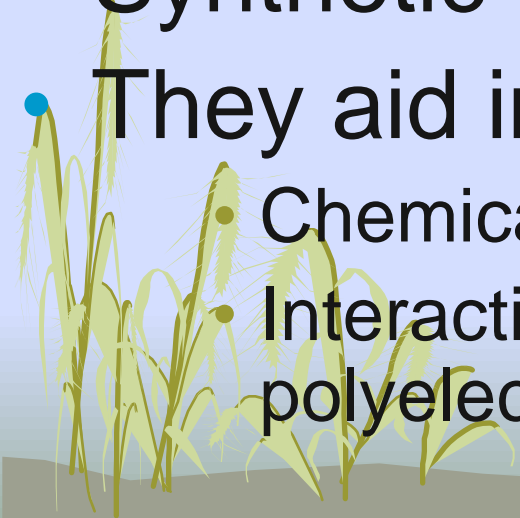
Coagulant Aids

- Are used to produce quick-forming, dense and rapid-settling flocs
 - Polyelectrolytes
 - pH adjustment
 - Alkalinity addition
 - Turbidity addition



Polyelectrolytes

- Anionic (-vely charged)
- Cationic (+vely charged)
- Polyampholites (both +vely and –vely charged groups)
- Natural such as starch
- Synthetic (more common in coagulation)
- They aid in coagulation by:
 - Chemical bridging
 - Interaction between reactive groups on the polyelectrolyte and the floc



Flocculation

Polymer



+

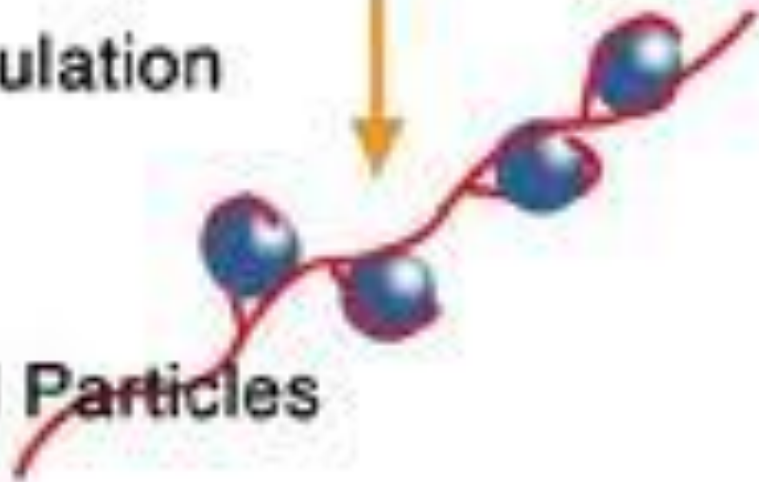
Suspended Particles



Flocculation

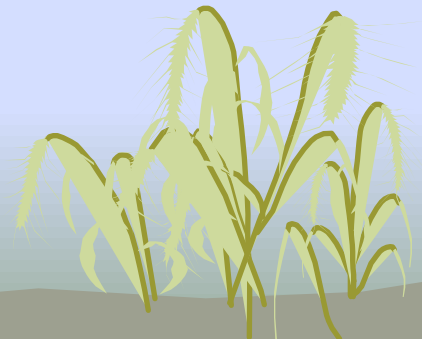
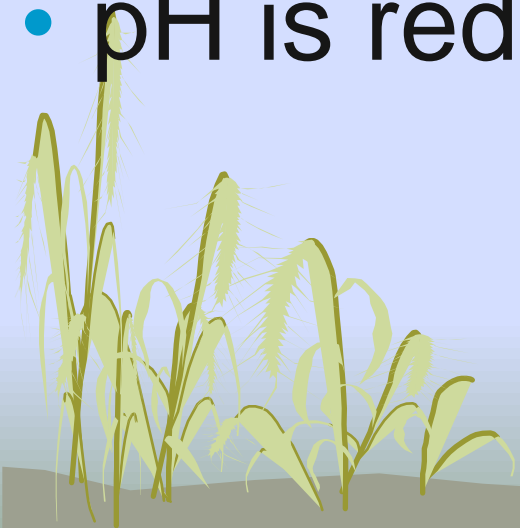


Agglomerated Particles



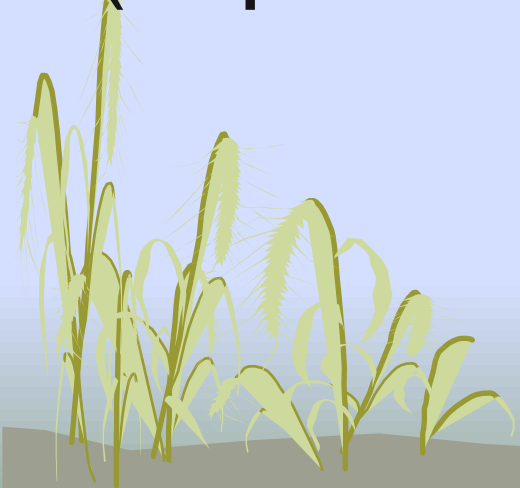
pH Adjustment

- Is used if pH of water to be treated is not within the optimum pH of the coagulant
- pH is increased using lime
- pH is reduced using sulfuric acid



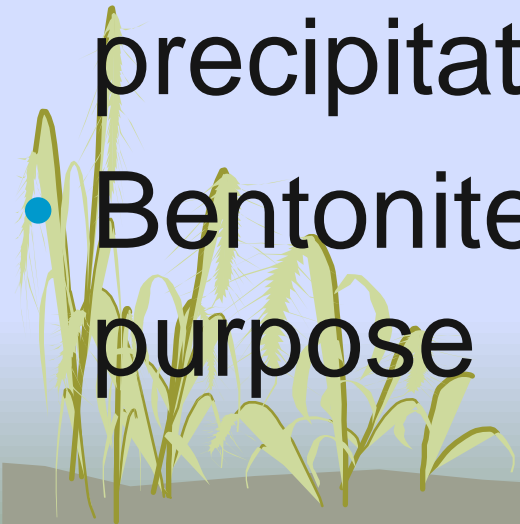
Alkalinity Addition

- Is used when natural alkalinity is not enough to produce good floc
- Hydrated or slaked lime is used
- Soda ash (Na_2CO_3) is also used (expensive)



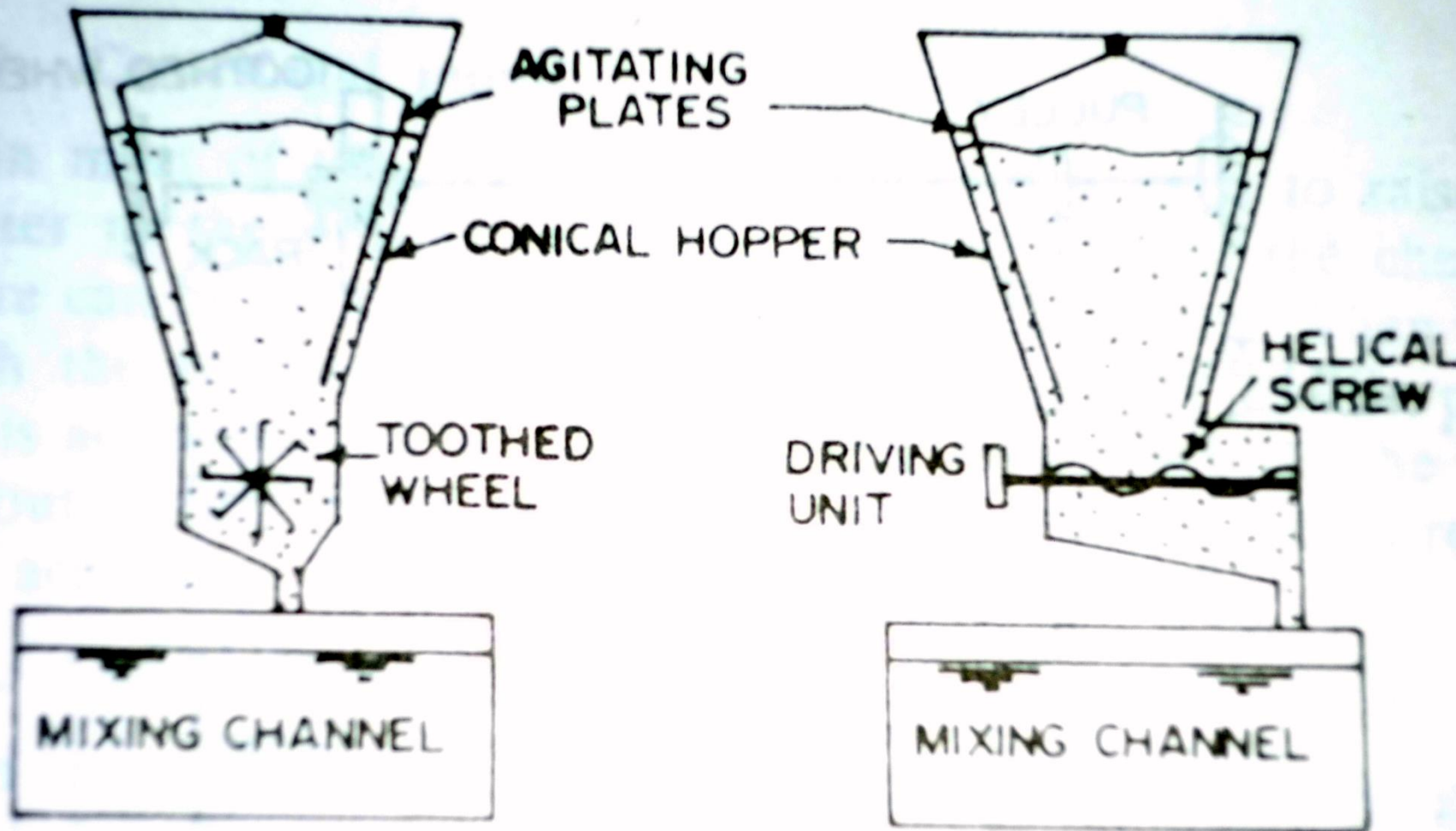
Turbidity Addition

- Is used to provide sufficient particulate concentration to achieve rapid coagulation through sufficient inter-particle collision
- Is done by recycling chemically precipitated sludge
- Bentonite Clays are also used for that purpose



Method of feeding coagulants

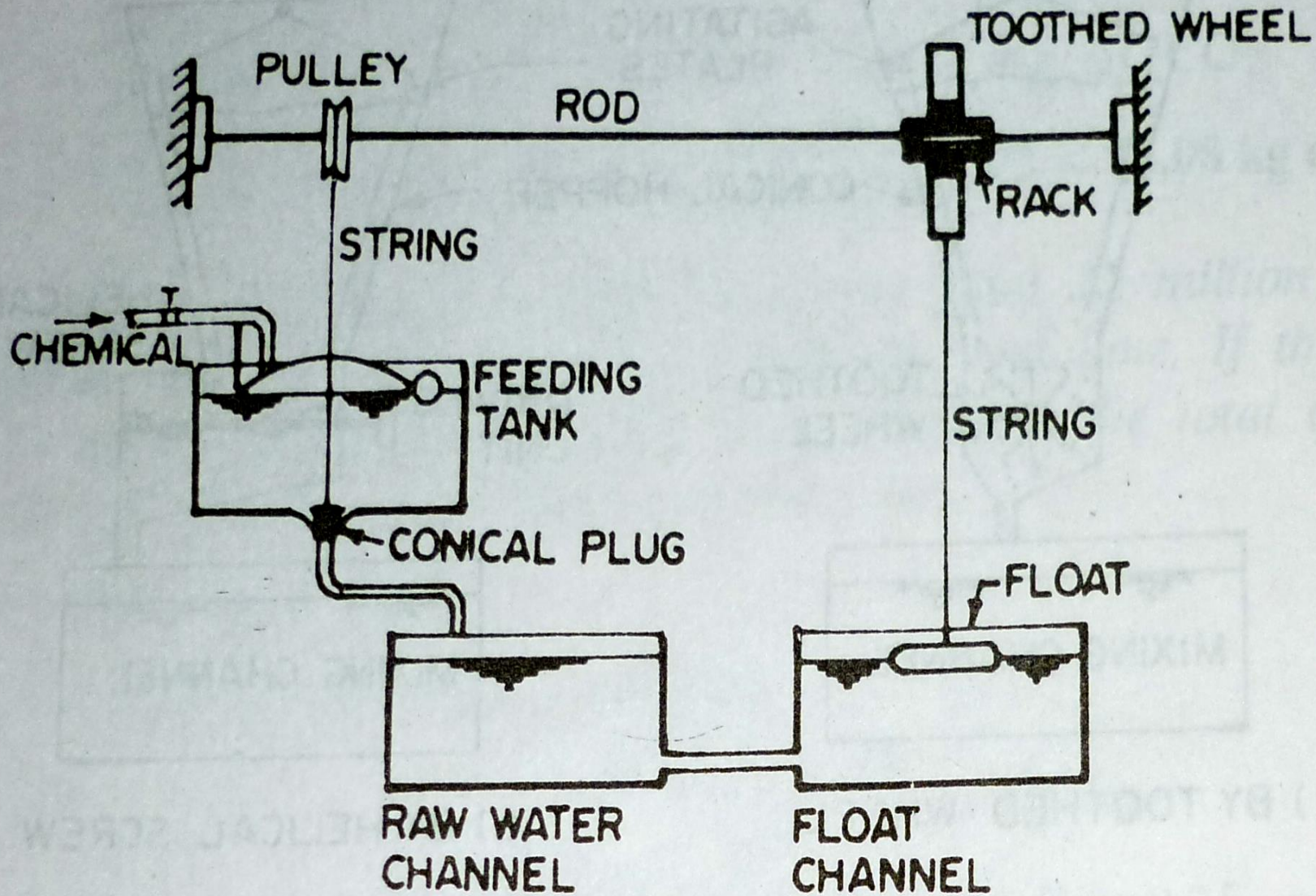
1. Dry feeding



(a) BY TOOTHED WHEEL

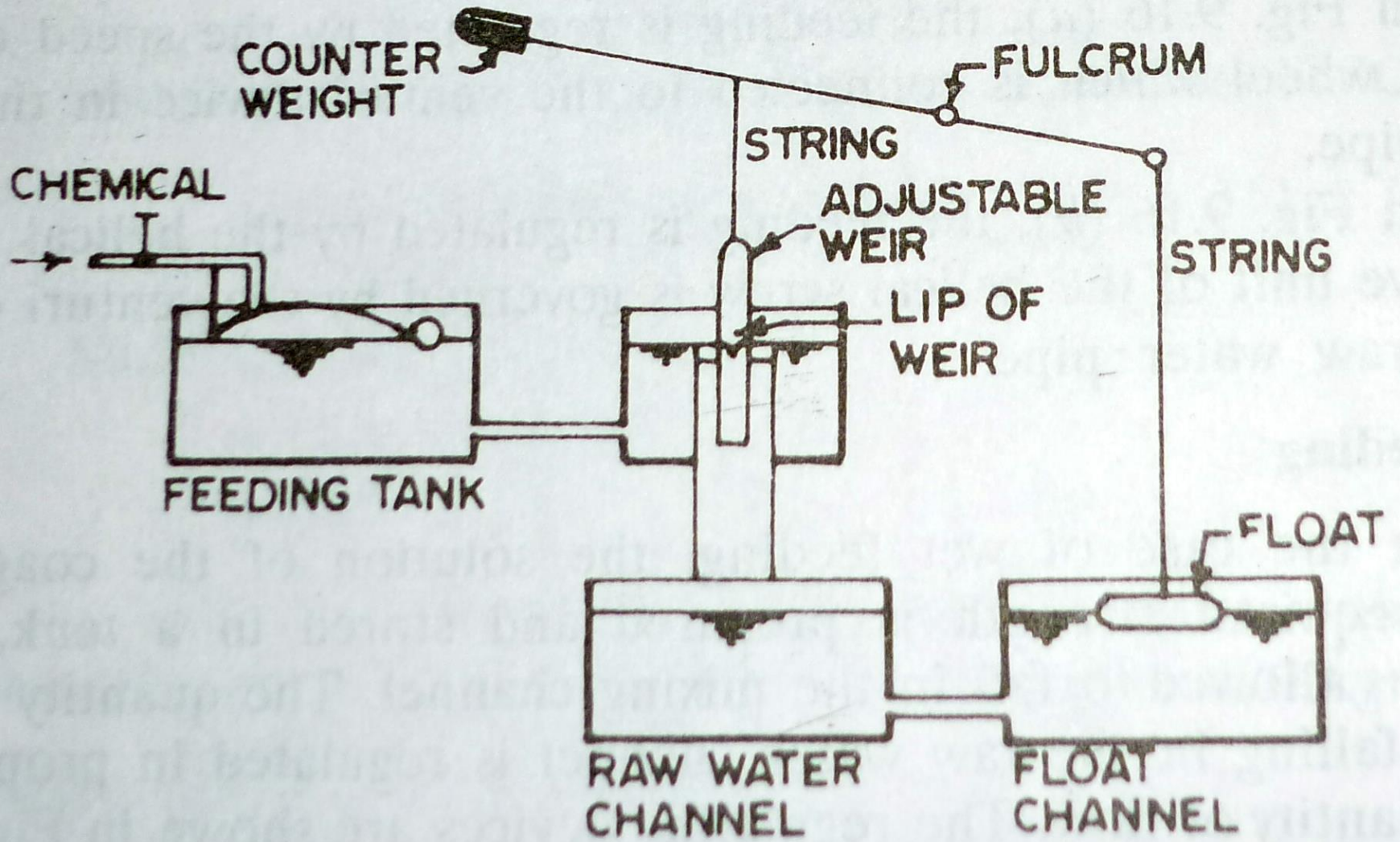
(b) BY HELICAL SCREW

2. Wet feeding

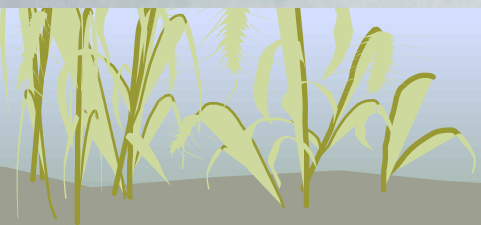


(a) WET FEEDING BY CONICAL PLUG

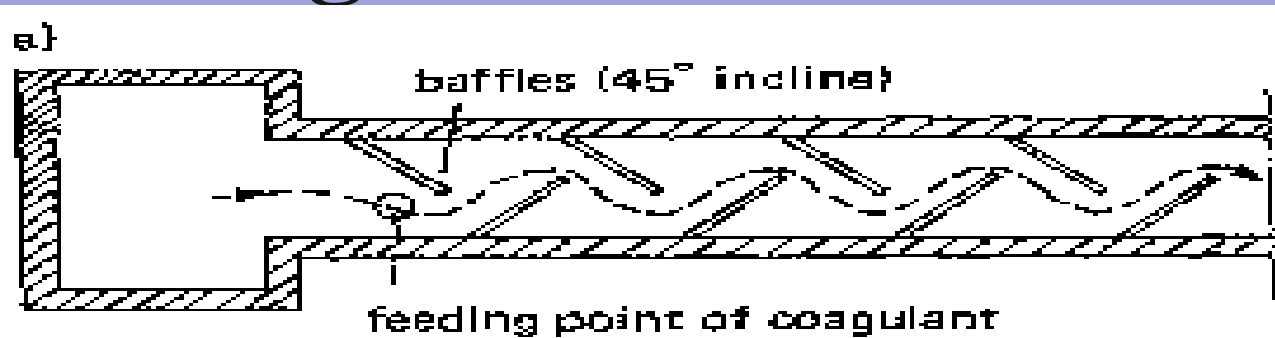




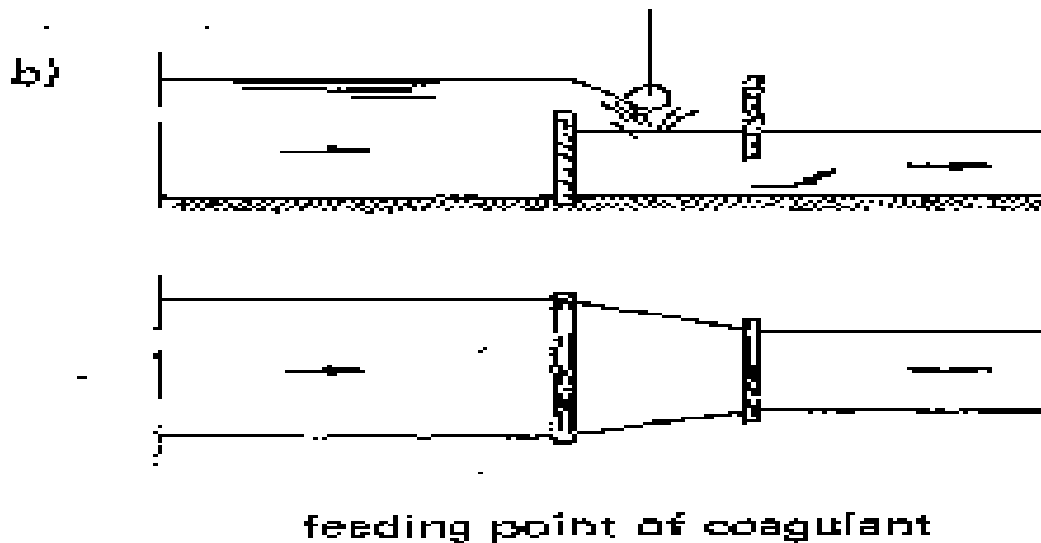
(b) WET FEEDING BY ADJUSTABLE WEIR



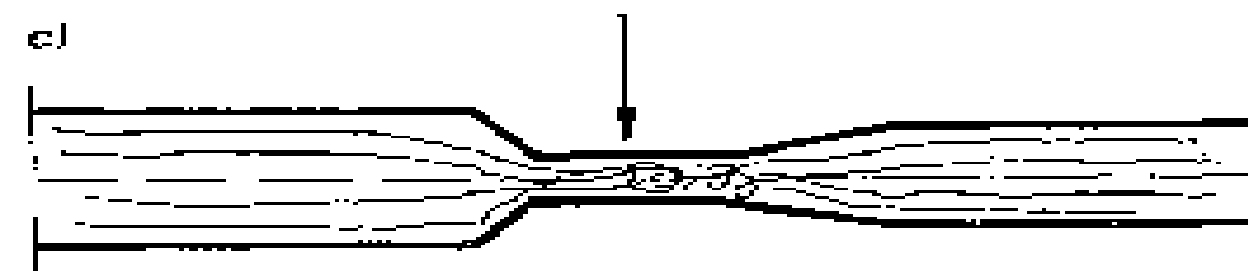
Mixing devices: Hydraulic mixing in water flow



a. Channel with baffles



b. Overflow weir



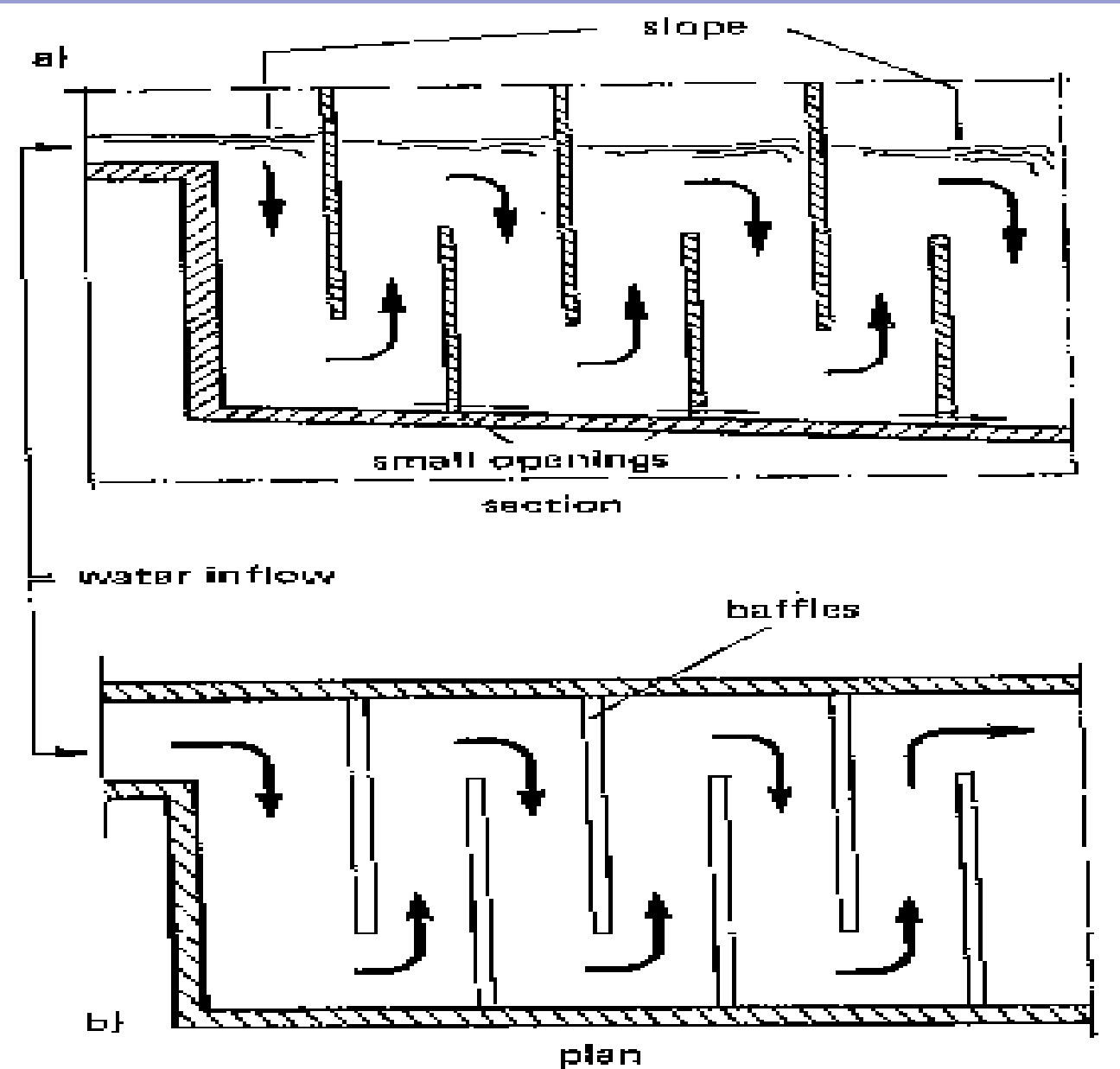
c. Hydraulic jump mixing







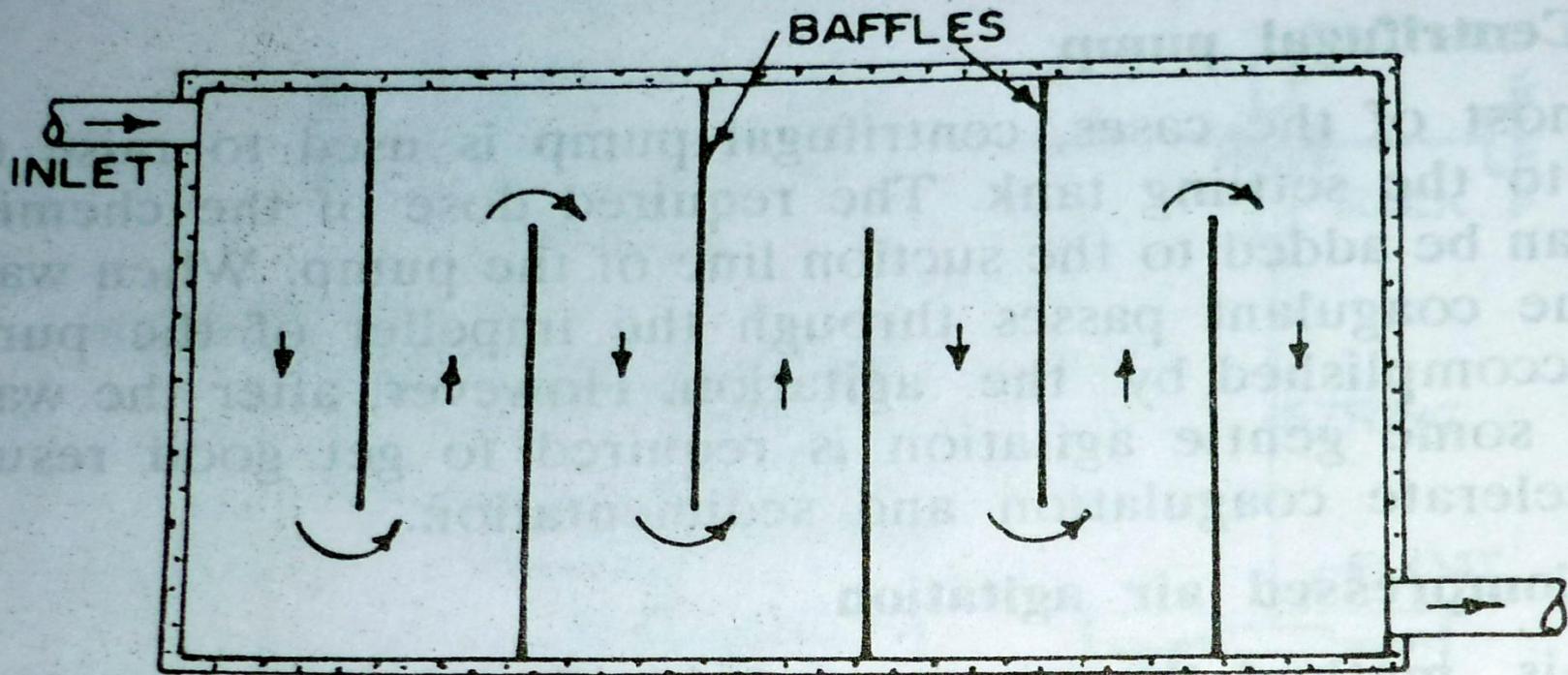
Mixing devices : Hydraulic mixing in flocculation tank



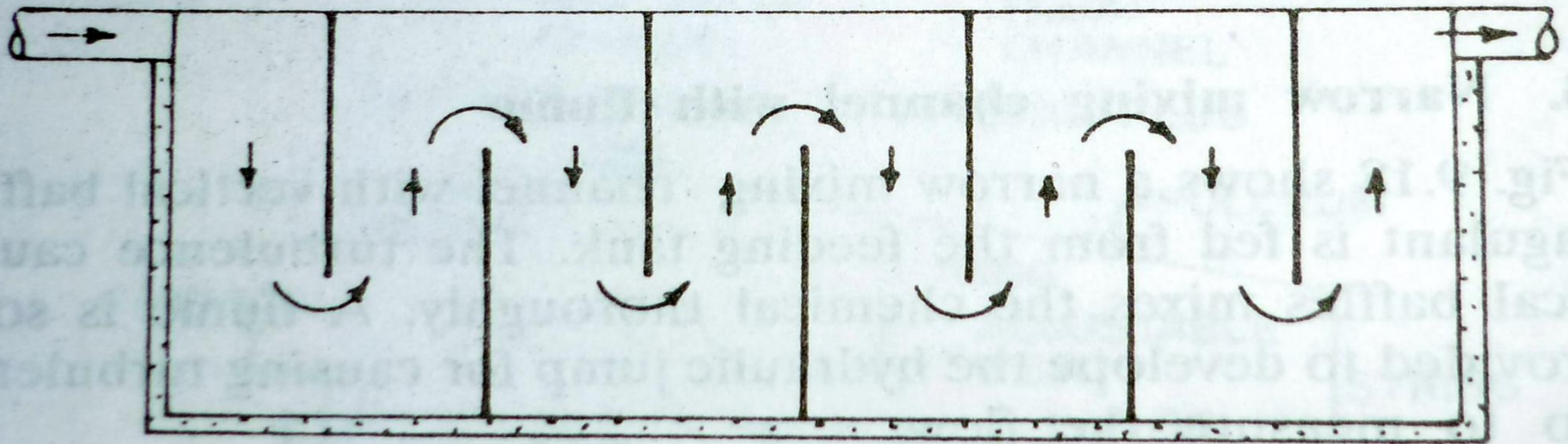
- **A. Vertical flow**

- **B. Horizontal flow**





(a) 'ROUND THE END' TYPE



(b) 'OVER AND UNDER' TYPE

- ***Horizontally baffled tank***

The water flows horizontally.

The baffle walls help to create turbulence and thus facilitate mixing

- ***Vertically baffled tank***

The water flows vertically.

The baffle walls help to create turbulence and thus facilitate mixing





Flash mixer

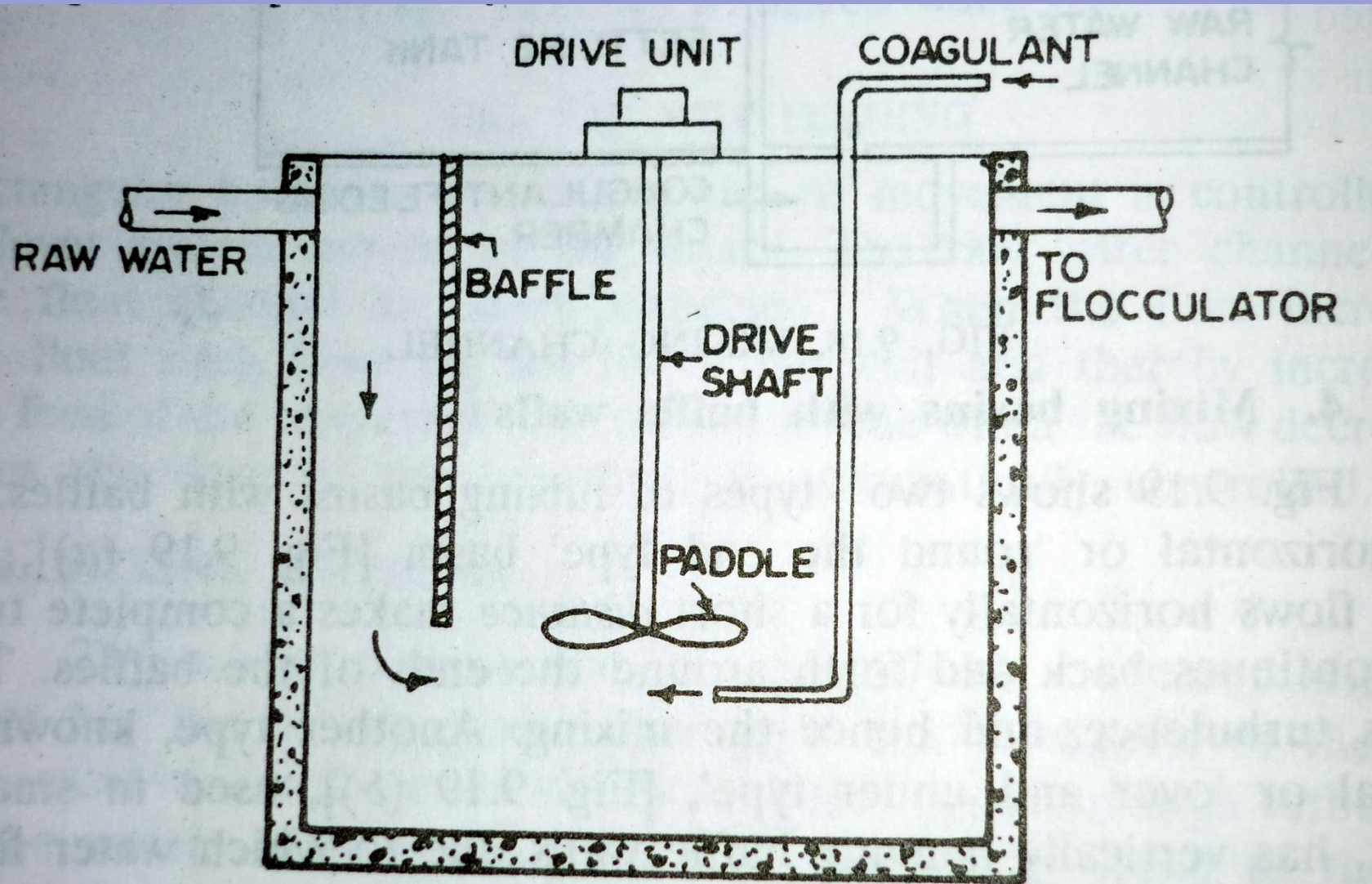
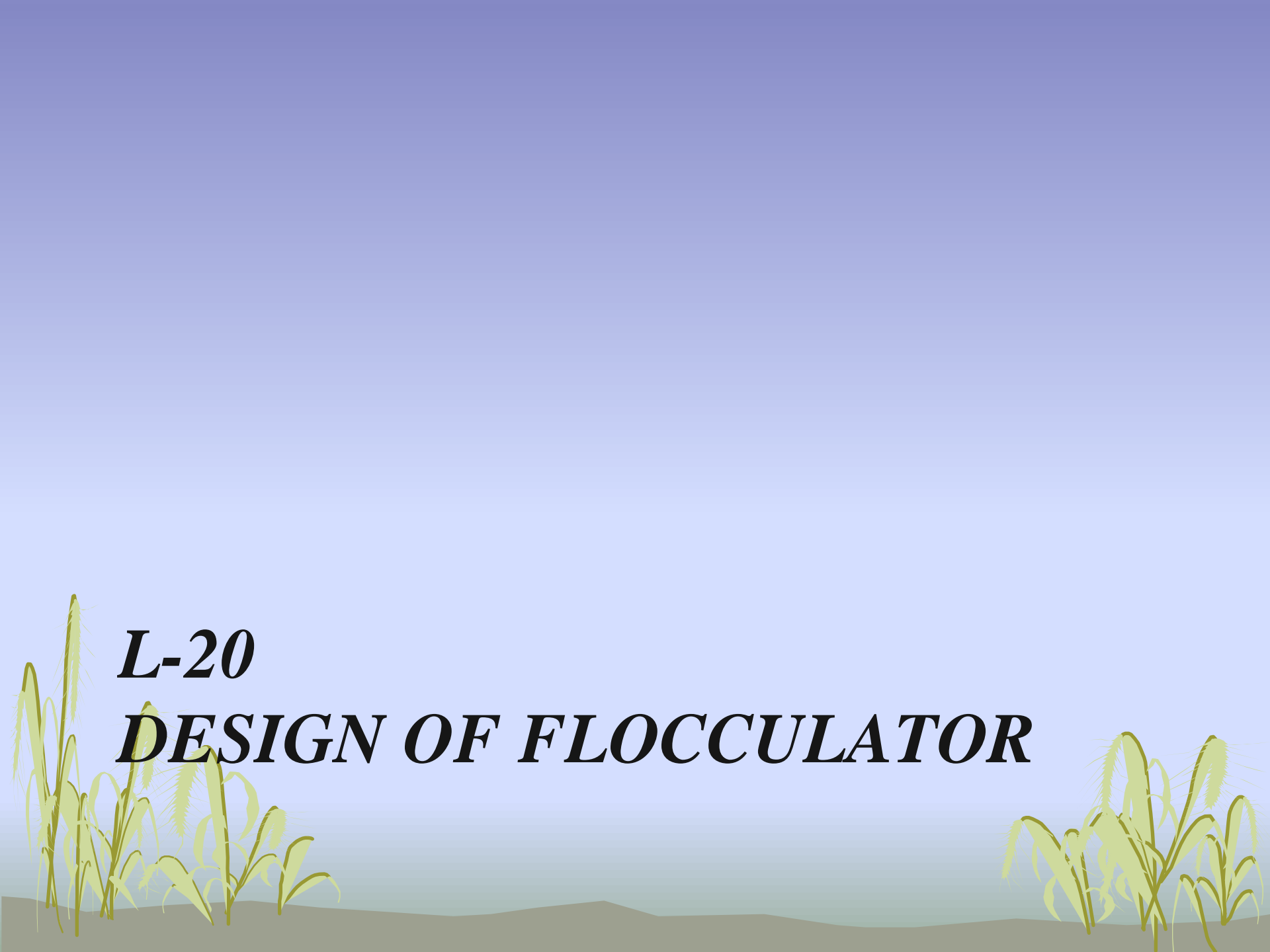


FIG. 9.20. FLASH MIXER

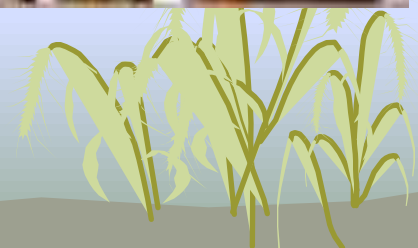
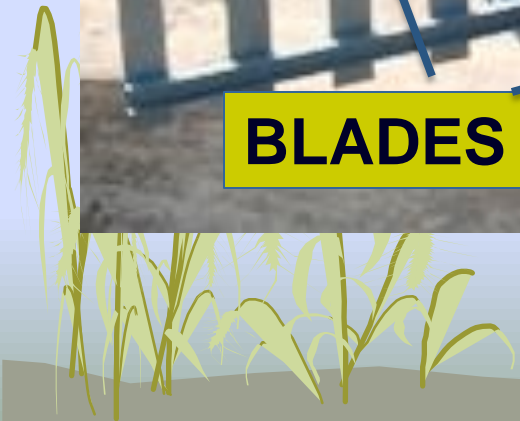




L-20

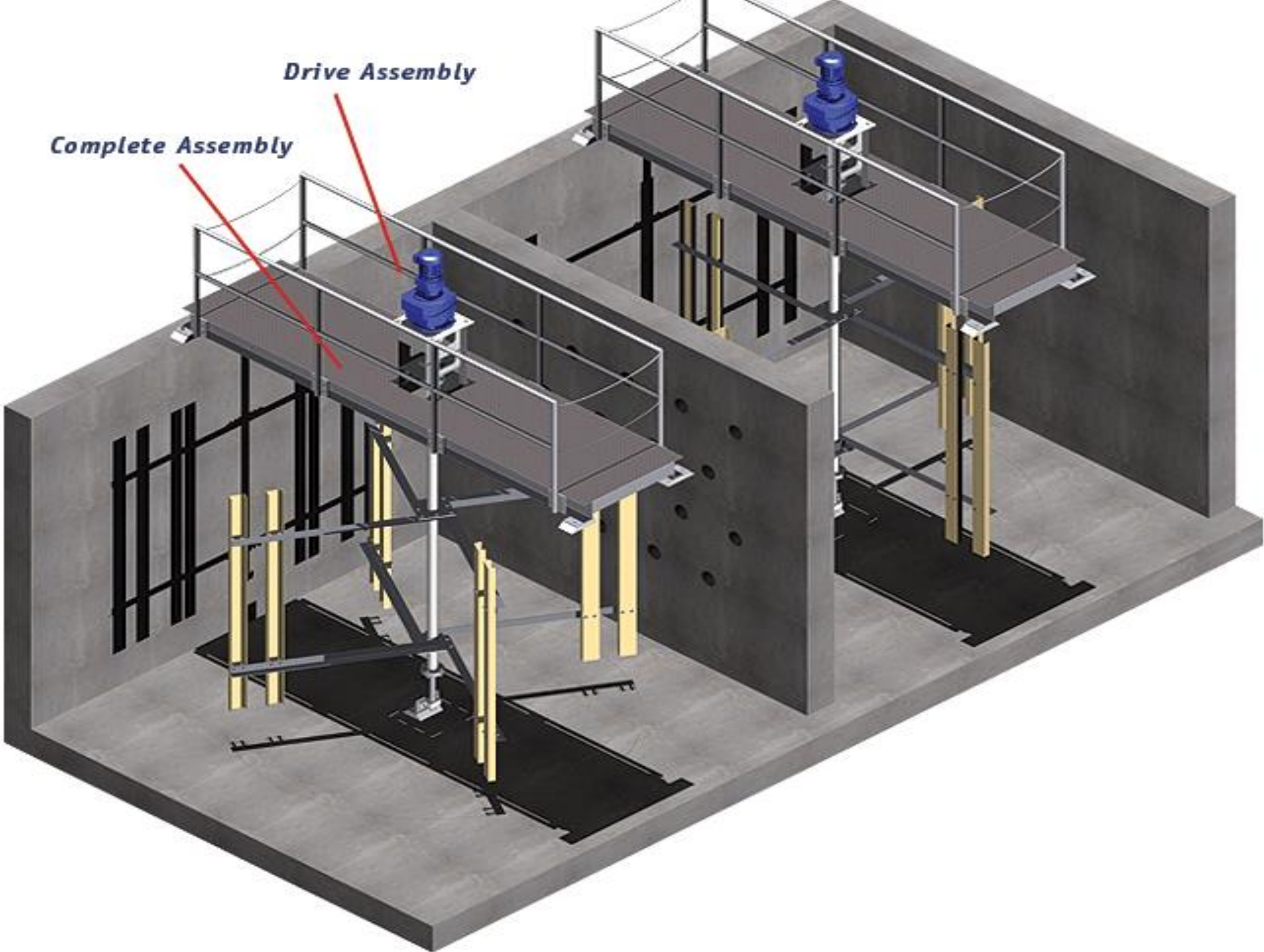
DESIGN OF FLOCCULATOR

Vertical shaft flocculator

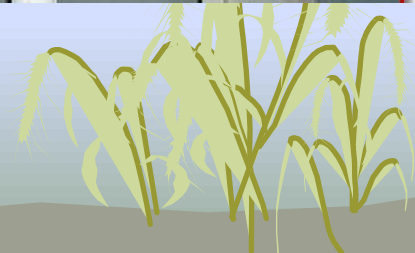


Drive Assembly

Complete Assembly

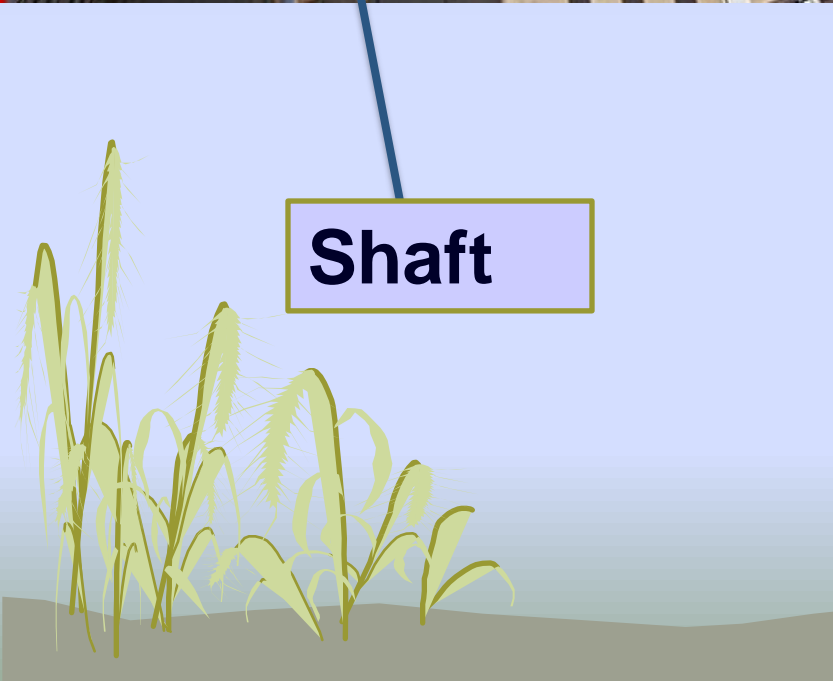


Horizontal shaft flocculator





Plank

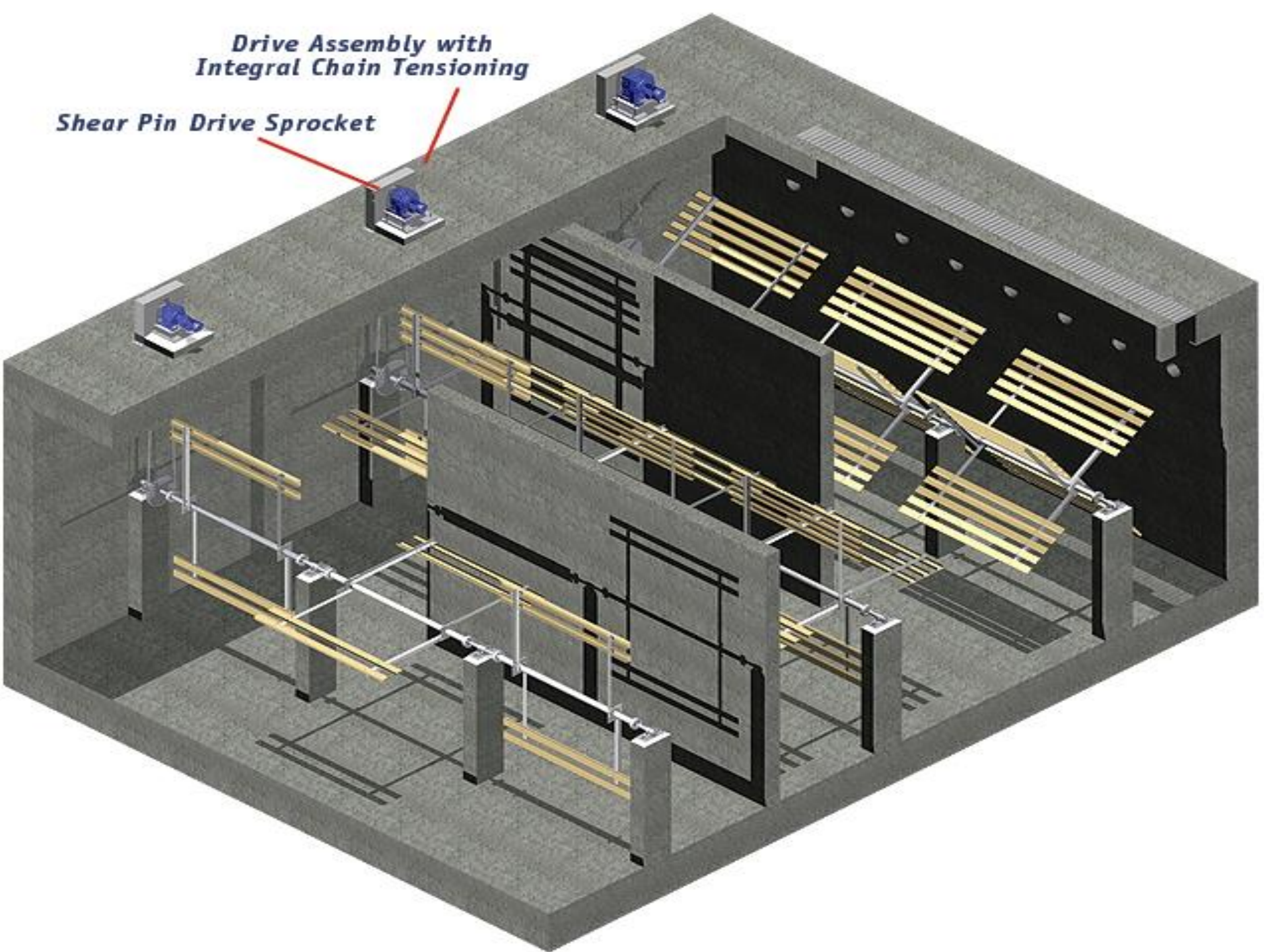


Shaft

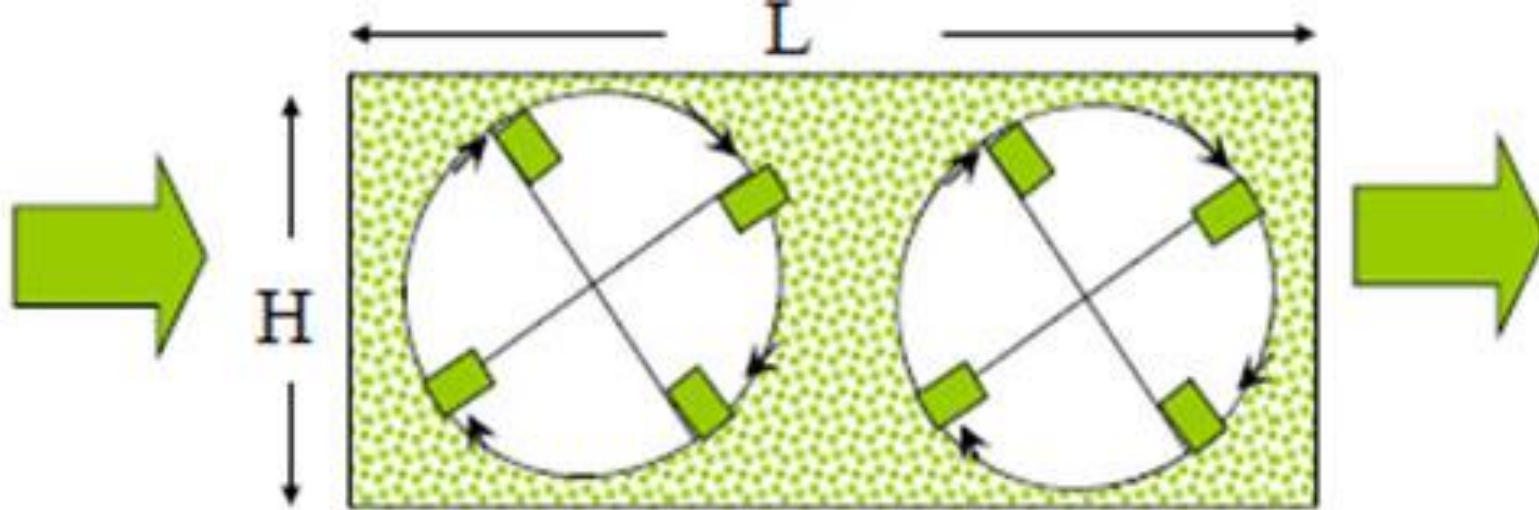


*Drive Assembly with
Integral Chain Tensioning*

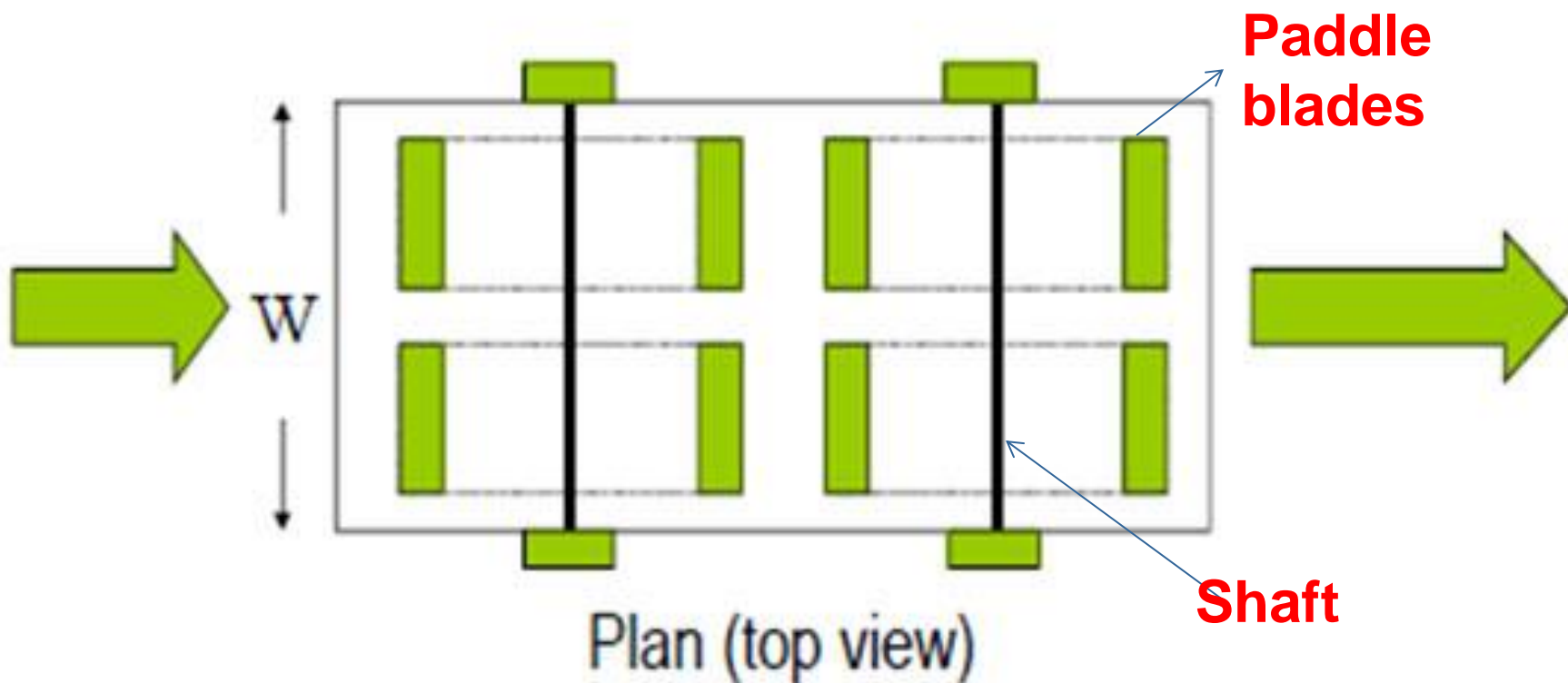
Shear Pin Drive Sprocket



Transverse paddle



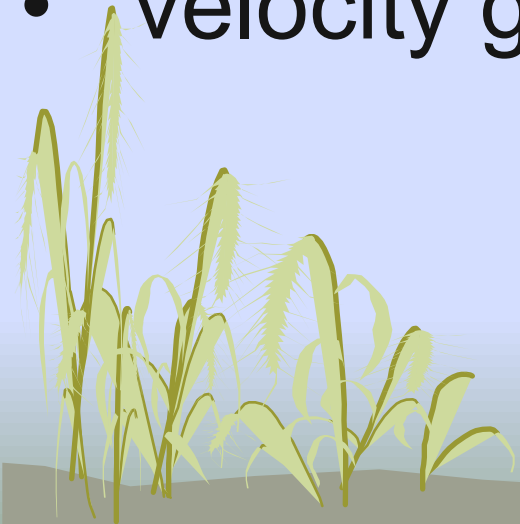
Cross flow Flocculator (sectional view)



Plan (top view)

Paddle blade flocculator

- The Main design parameters of flocculator units are:
 - mixing time, t
 - volume of flocculator V ,
 - velocity gradient, G



Velocity Gradient

Difference in velocities of two particles, divided by the distance between their paths. It is a measure of relative velocity of two particles of fluid at a distance.

$$G = \left| \frac{V_B - V_A}{L} \right|, \text{ s}^{-1}$$

Therefore the velocity gradient can be expressed in terms of power as:

$$G = \left(\frac{P}{V\mu} \right)^{1/2}$$

Where:	G	=velocity gradient	10 to 75 1/s
	P	=power input, W	
	V	=volume of water in flocculator, m ³	
	μ	=dynamic viscosity, N.s/m ² or kg/m.s	
	g	=9.81m/s ²	

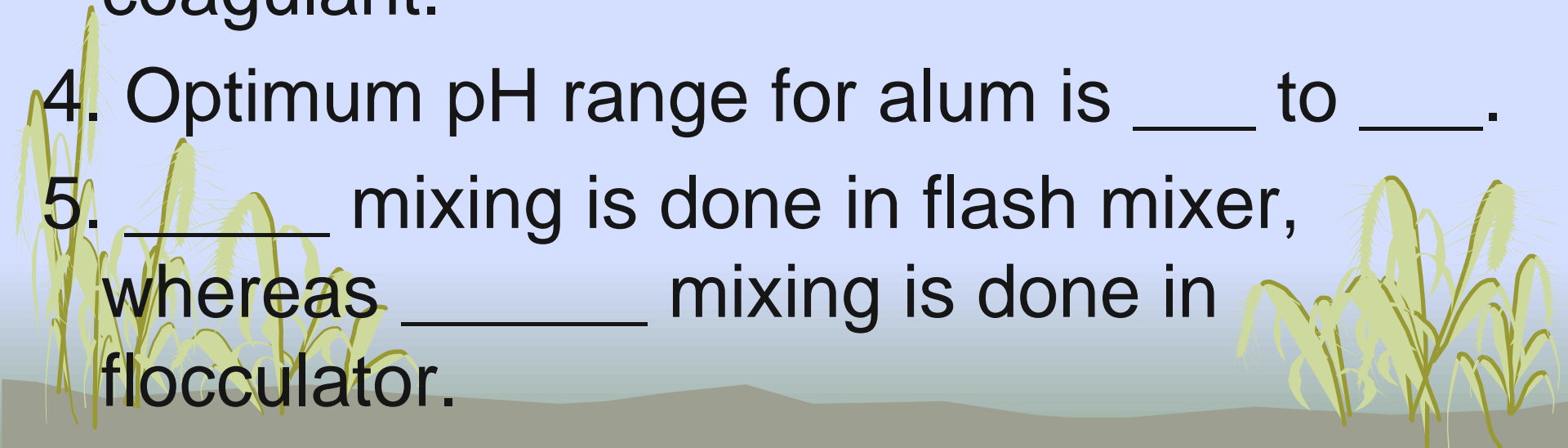
High velocity gradient promotes rapid flocculation, and too ^{Low} velocity gradients can result in fragile flocs, which get torn apart.

Design criteria for flocculator

1. Depth of tank = 3 to 4.5 m (some times 5)
2. Detention time 10 to 40 min (30 min)
3. Velocity of flow = 0.2 to 0.8 m/s (0.4 m/s)
4. Total area of paddles = 10 to 25 % of c/s area
5. Peripheral velocity of blades = (Should be less than 1 m/s) 0.2 to 0.6 m/s
6. Velocity gradient $G = 10$ to 75 s^{-1}
7. $G.t$ factor = 10^4 to 10^5
8. Power consumption = 10 to 36 KW/mld

9. Outlet flow velocity = 0.15 to 0.25 m/s
10. $C_D = 1.8$ for flat blades
11. Distance between paddle edge and side of basin = 15 to 40 cm
12. $K=0.25$
13. Relative velocity is 75% of paddle velocity
i.e. $v_r = 0.75 \times v_p$
14. Area of paddles = length of blades x width x no. of blades in that compartment
i.e. $A_p = l_b \times w \times n$
15. Distance between two paddles in same compartment (in plan) = about 1m

Objective Questions

1. For design of flocculator G value shall be in the range of ____ to ____ 1/s.
 2. Relative velocity shall be assumed as ____% of paddle velocity.
 3. _____ is commonly used as coagulant.
 4. Optimum pH range for alum is ____ to ____.
 5. _____ mixing is done in flash mixer, whereas _____ mixing is done in flocculator.
- 

Theory Questions

1. Explain theory of coagulation.
2. Write detailed note on 'design of flocculator'.
3. List out coagulants used in water treatment and explain any one with the help of chemical reactions.
4. What are coagulant aids?
5. Compare Alum and iron salts as coagulants.

