Lecture 2: Coagulation and Flocculation

Water Treatment Technology

Water Resources Engineering
Civil Engineering
ENGC 6305

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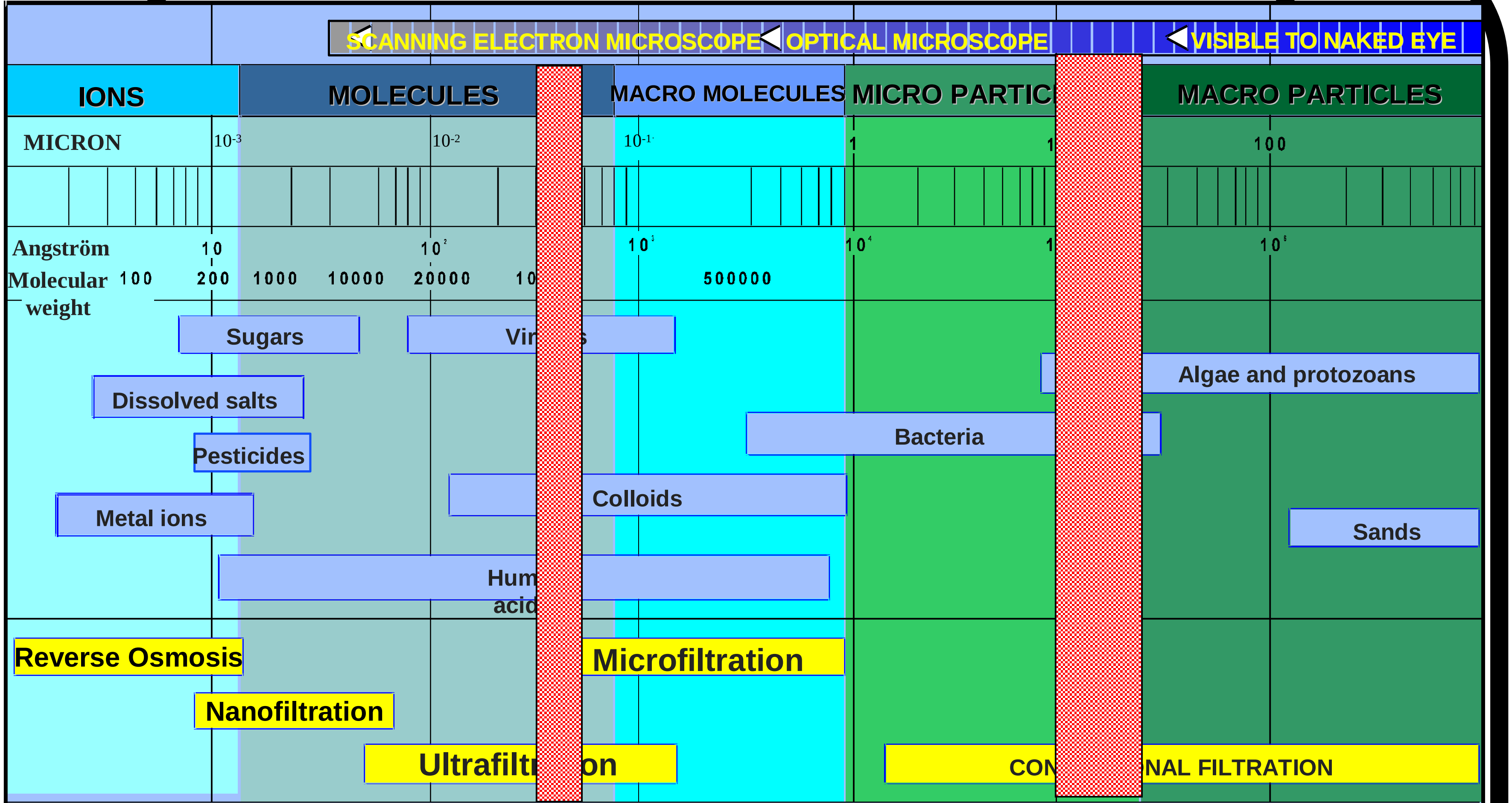
Coagulation and flocculation

1. Definitions:

- Coagulation and flocculation are two consecutive process (i.e. occur one after the other) that are used to remove colloidal particles from water.
- Colloids are very small particles (turbidity and color causing particles) that can not be removed neither by sedimentation (due to their light weight) nor by filtration. Examples of colloids: soil particles, bacteria, viruses and color causing materials. These colloids are stable in solution and theoretically will stay there for ever unless an action is done to destabilize them. Coagulation and flocculation are the two processes used for this destabilization.

Particles Spectrum



Note : 1 Angström = 10^{-10} meter = 10^{-4} micron

Figure 2.1

Coagulation and flocculation

2. Colloidal Stability

- Colloids are very Small particles (0.01 to 1 μm)
- Most naturally occurring particles in water are negatively charged. Since like charges repel, these small particles, or colloids, will remain suspended almost indefinitely.
- A fixed layer of positive ions (counterions) is attracted to the negatively charged colloids by electrostatic attraction. This layer is called stern layer or fixed layer. This layer is surrounded by a movable diffuse layer of counterions but with a lower concentration than that in the fixed layer. The two layers form what is called the **double layer theory**.
- The surface between the two layers is called the shear surface. When the colloid moves the fixed layer moves with it.
- The positive charge attached to the colloid in the stern layer is not enough to neutralize the negative charge of the colloid. So there is a net electrical potential around the colloid as shown in the Figure 2.2.
- The Electrical potential at the shear surface is called the Zeta potential which is a measure of the repulsive force of the colloid to other colloids having the same charge.

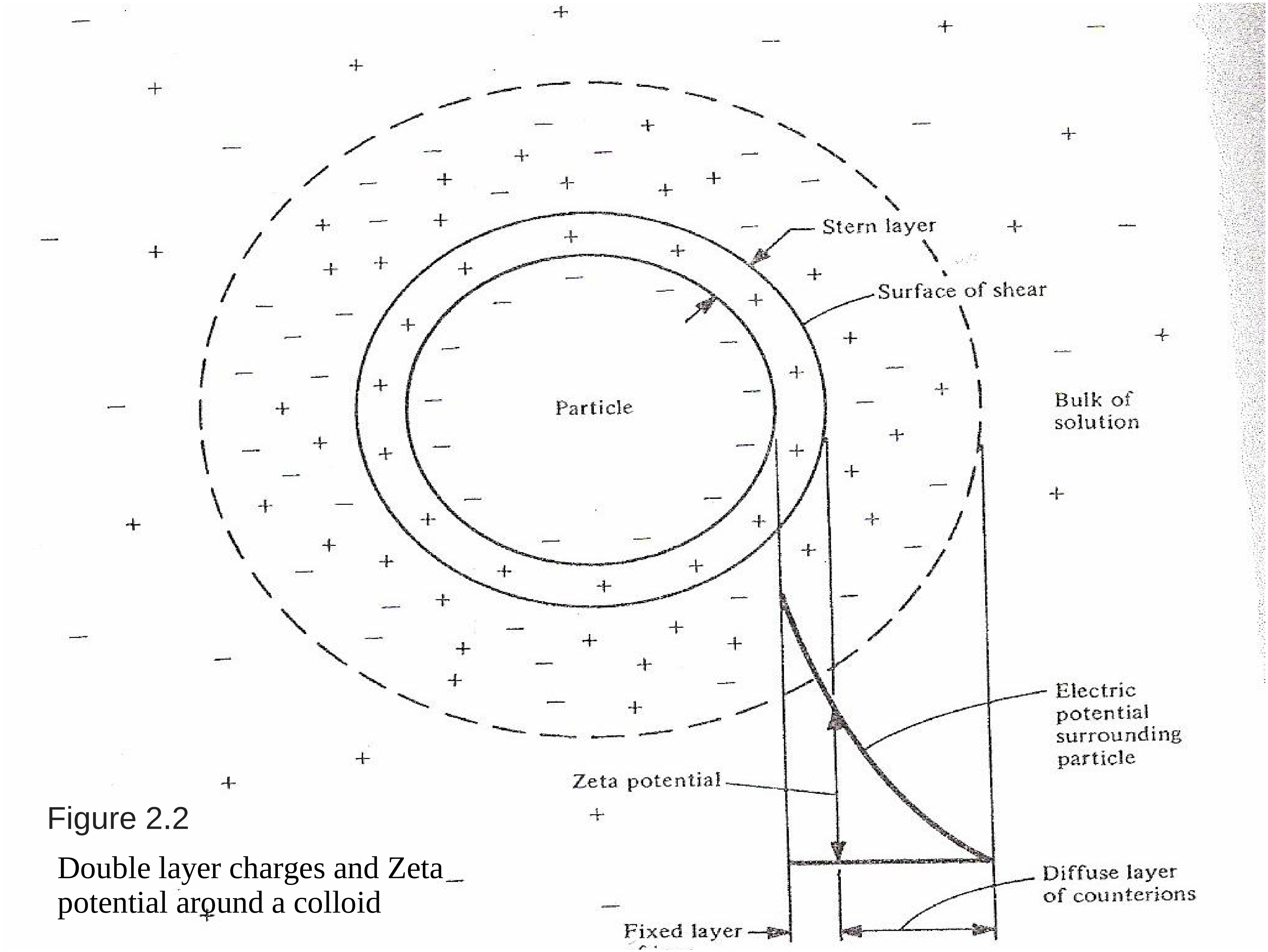


Figure 2.2

Double layer charges and Zeta potential around a colloid

Coagulation and flocculation

- There are two major forces acting on colloids:

1) Electrostatic repulsion

negative colloids repel other negatively charged colloids

2) Intermolecular, or van der Waals, attraction.

Figures 2.3 : Illustrates these two main forces.

For a stable colloid the net energy is repulsive.

Figures 2.4 (a): A stable suspension of particles where forces of repulsion exceed the forces of attraction

Coagulation and flocculation

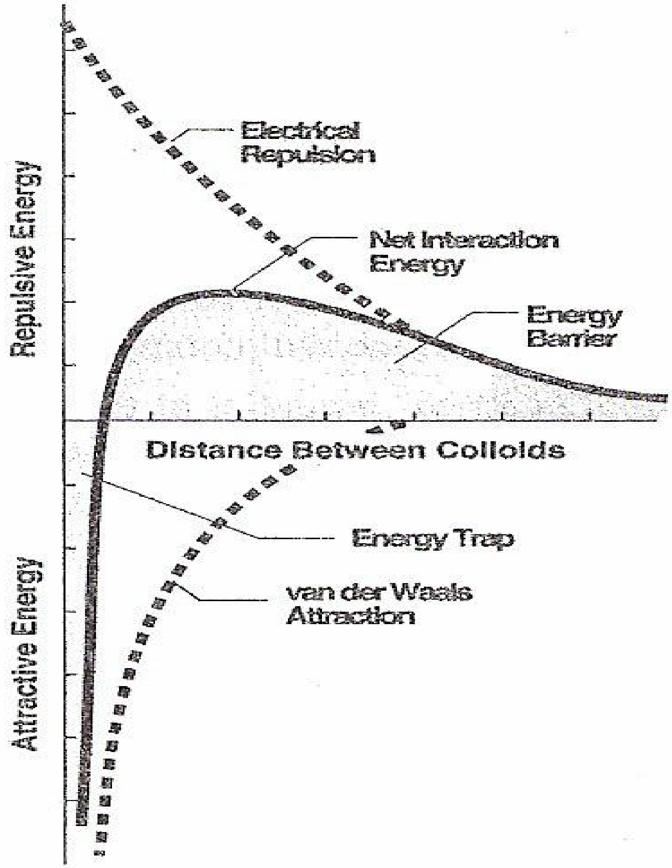


Figure 2.3

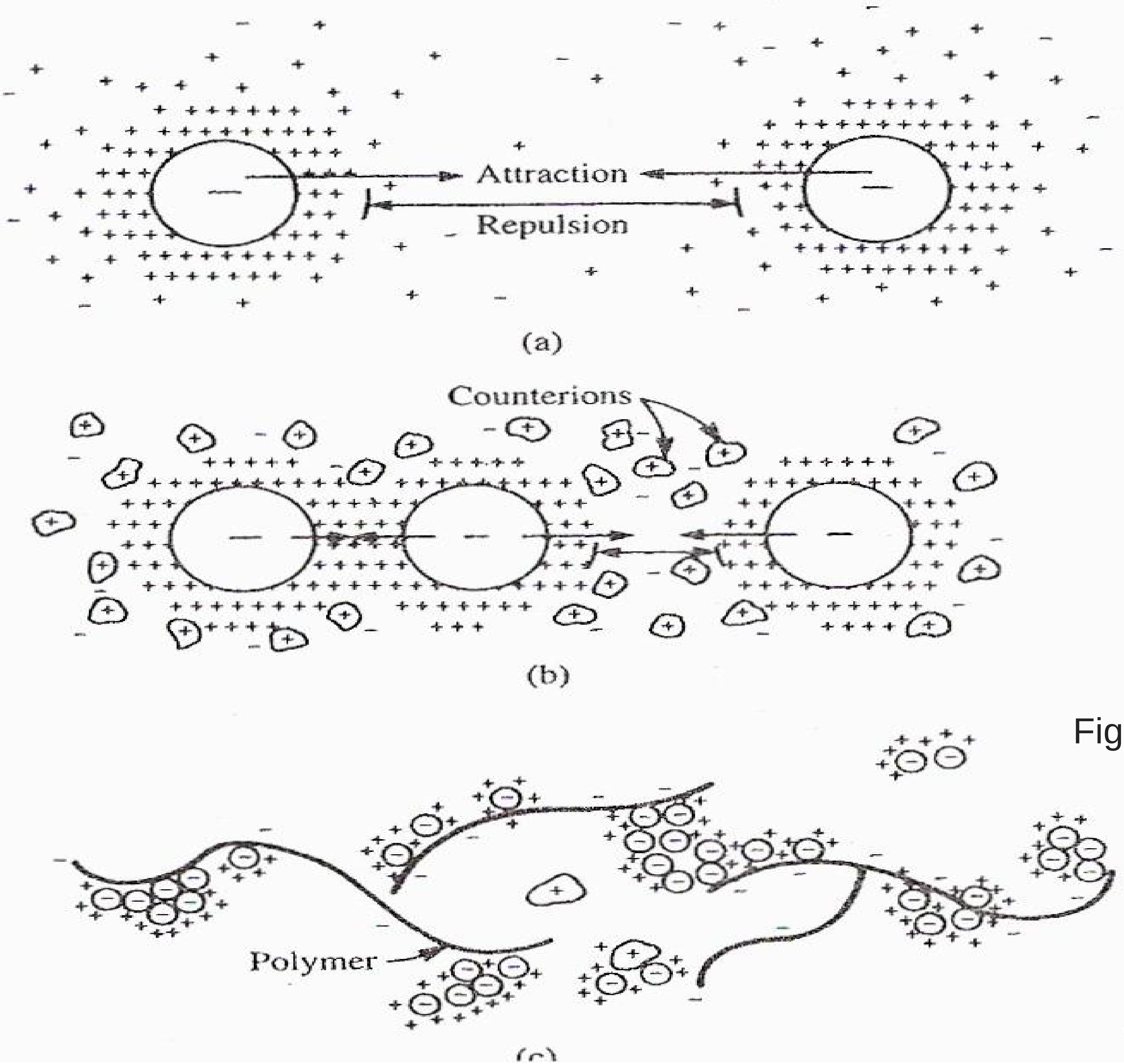


Figure 2.4

Coagulation and flocculation

3. Coagulation (Colloidal Destabilization)

- It is the process of destabilization the colloids by adding chemicals (Coagulants) with a counter charge to neutralize the charge carried by the colloids. This will reduce the repelling force and gives the opportunity for the attractive forces to prevail and allow the particles and make them ready to agglomerate and form bigger particles.

See Figure 2.4 (b): Destabilization caused by counterions of a coagulant which neutralize the negative ion of the colloid.

4. Flocculation (Forming Flocs)

After destabilization (i.e. **Coagulation)**, particles will be ready to a tract and agglomerate and form **flocs**. But this agglomeration is slow and they need help to accelerate this agglomeration.

This help is called **Flocculation** **“**which is the slow stirring or gentle agitation to aggregate the destabilized particles and form a rapid settling floc”. This gentle mixing increases the collisions between the particles and help them to agglomerate. Notice that rapid mixing will destroy the flocs, that's why we need gentle mixing.

We will discus flocculation later in this lecture. Lets now return back to Coagulation.

Coagulation and flocculation

Coagulation

Flocculation/Sedimentation

Coagulation and flocculation

5. Coagulants:

The chemicals added to water to destabilize colloids are called Coagulants. The most common Coagulants used in water treatment are:

- Aluminum Sulfate (Alum): $Al_2(SO_4)_3 \cdot 14H_2O$
- Ferric Chloride : $FeCl_3 \cdot xH_2O$
- Ferric sulfate : $Fe_2(SO_4)_3 \cdot xH_2O$

Two key properties of Coagulants

- Should be nontoxic: health concern
- Trivalent ions: most efficient compared to mono and divalent.

Coagulation and flocculation

6. Coagulation chemistry:

If Alum is used the following reactions occur:

- $Al_2(SO_4)_3 \cdot 14H_2O \leftrightarrow 2Al^{3+} + 3SO_4^{2-} + 14H_2O$
- $2Al^{3+}$ + colloids ↔ neutralize surface charge
- $2Al^{3+} + 6HCO_3^- \leftrightarrow 2Al(OH)_3(s) + 6CO_2$
- If insufficient bicarbonate is available:

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

- Optimum pH: 5.5 to 6.5
- Operating pH: 5 to 8

Coagulation and flocculation

7. Factors affecting Coagulation

The two main factors affecting the coagulation process are:

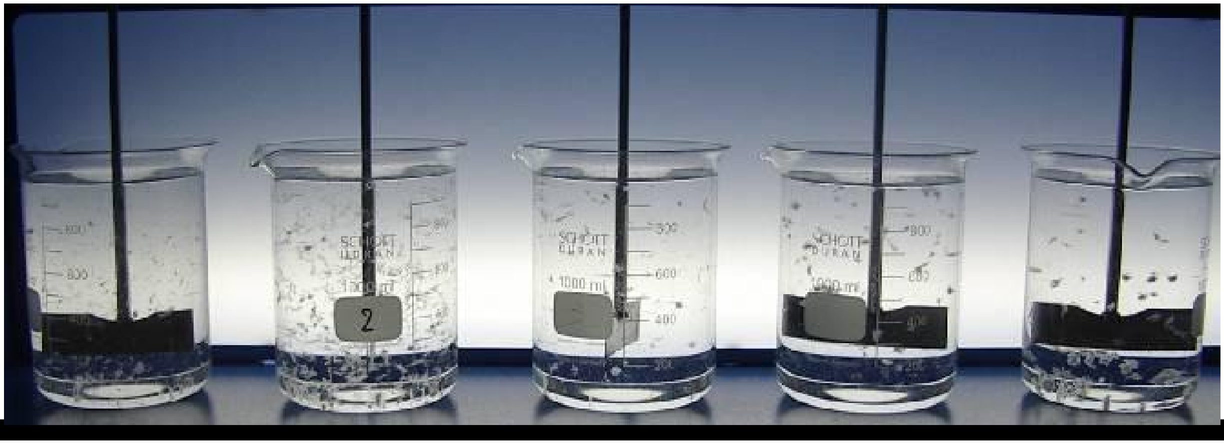
- Coagulant dosage
- pH of the water

The optimum dosage and optimum pH are determined by laboratory test called the Jar Test. the Jar test consists of six beakers filled with the water to be treated and then each is mixed and flocculated uniformly. A test is often conducted by first dosing each jar with the same value of coagulant and varying the pH of each jar. The test can then be repeated by holding the pH constant and varying the coagulant dosage.

See Figures 2.5 , 2.6 and 2.7.

Jar Test

Figure 2.5



Optimum pH for coagulation

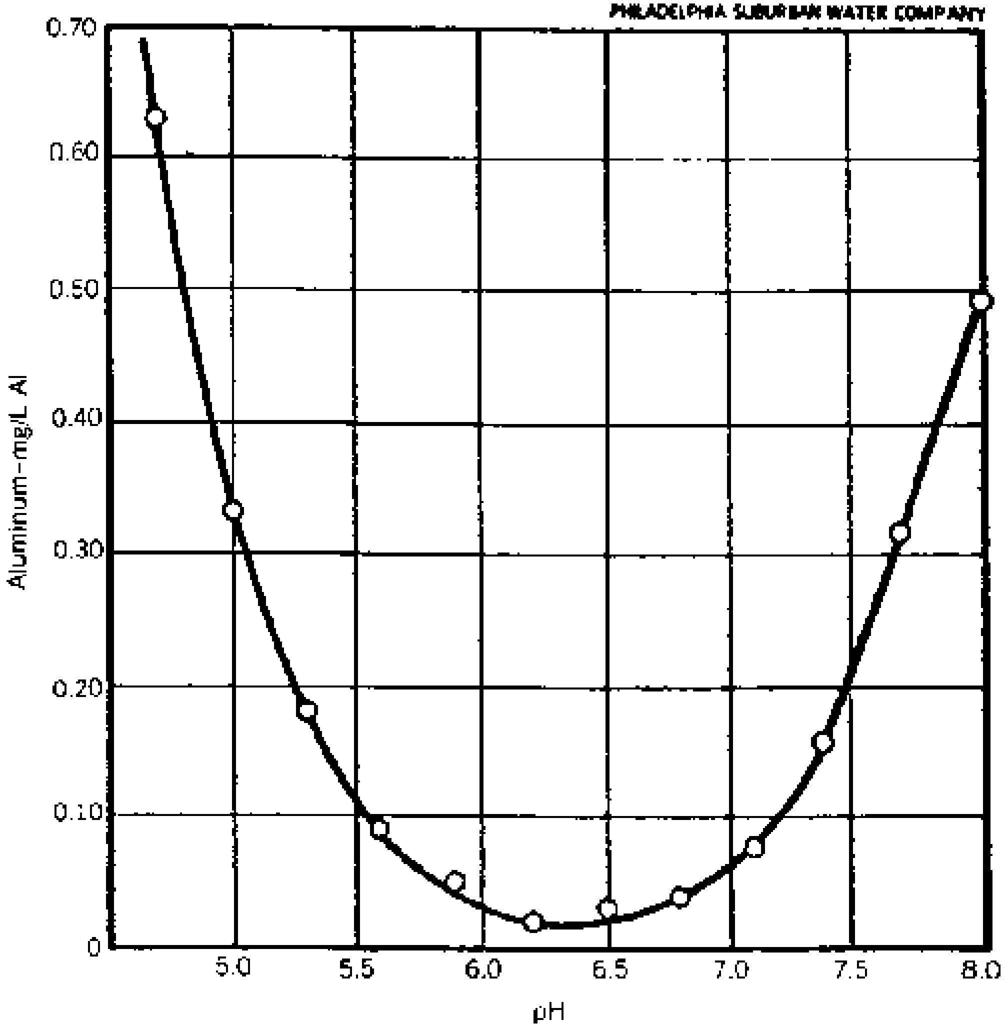


Figure 2.6

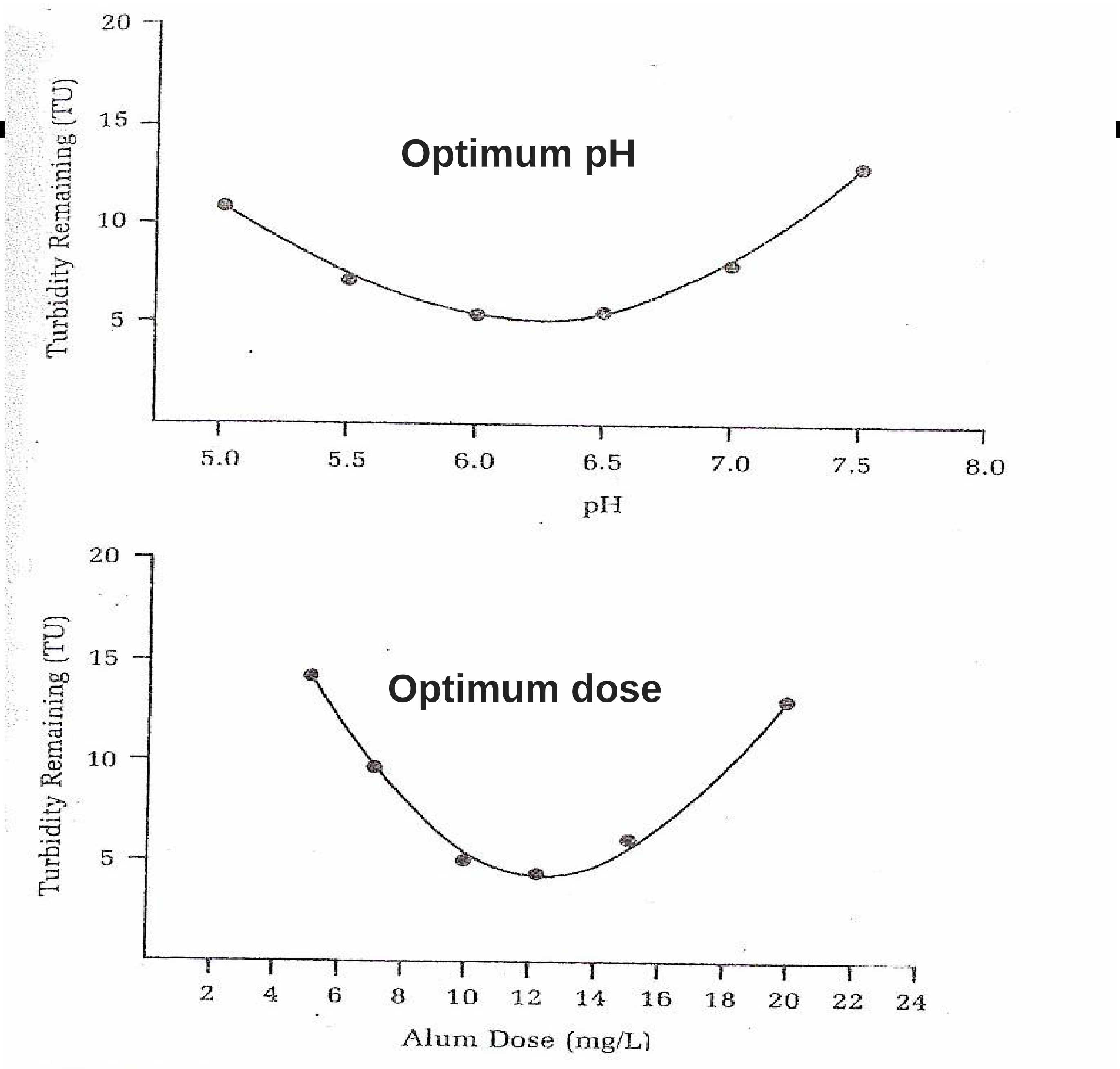


Figure 2.7 Optimum pH and optimum dose from the jar test

Coagulation and flocculation

8. Coagulation aids

Coagulation aids are chemicals that are added to inhance the coagulation process. Some examples of these chemicals are:

- **pH adjusters:**

  Alkalis : lime [$Ca(OH)_2$] or Soda Ash [Na_2CO_3)] to lower the pH

  Acids : Sulfuric acid [H_2SO_4] to raise the pH

- **Inter-particle bridging aids**

  Polymers: long chained carbon compounds of high molecular weight that join flocs together and forms a shape that looks like a bridge connecting many flock.

- **Weight adding aids**

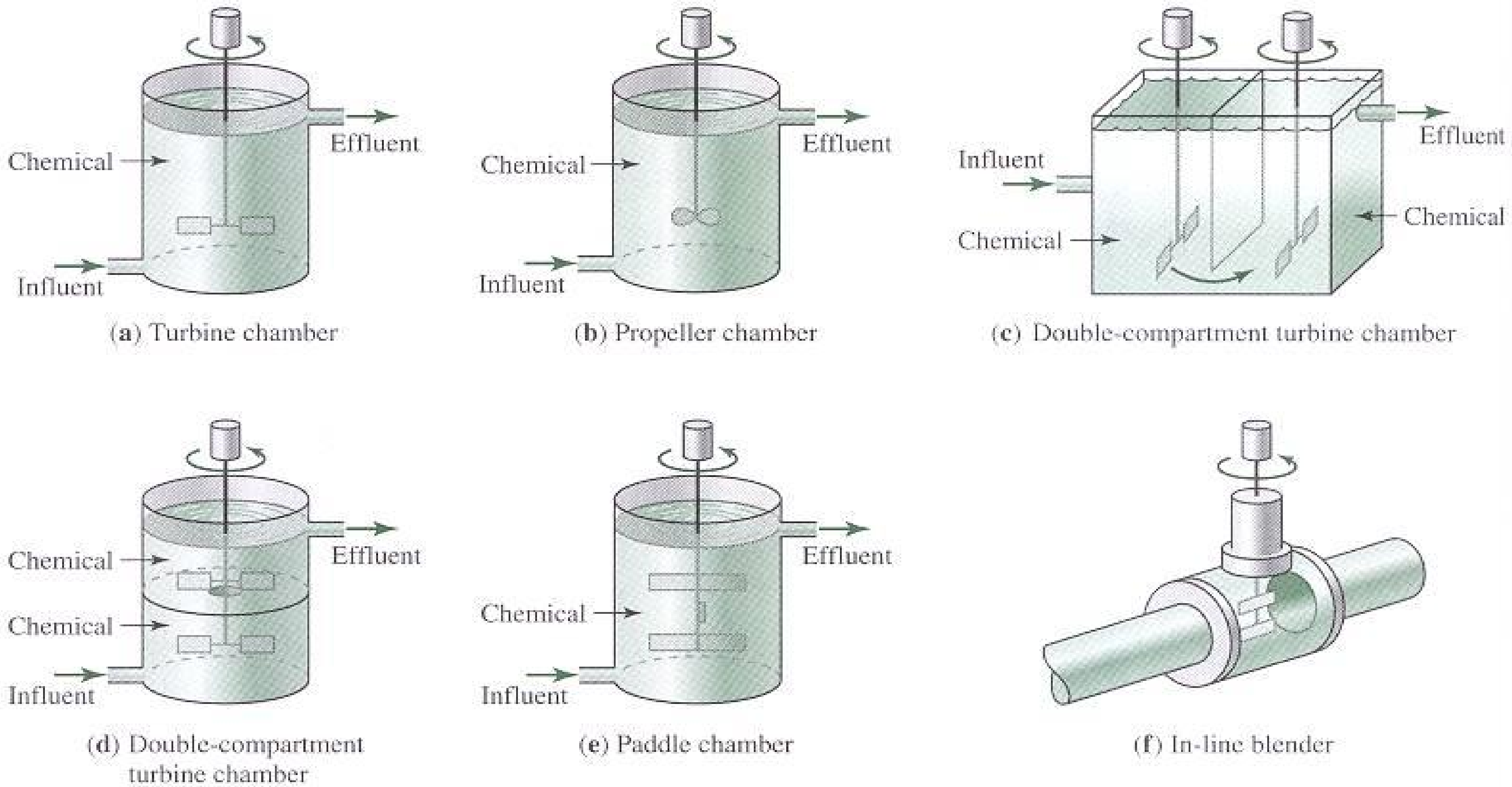
  activated silica and clay. They are both negatively charged and attracted to the positive coagulant ions and help in increasing the weight of the flocs.

Coagulation and flocculation

9. Coagulation and Rapid Mixing:

- When coagulants are added to water in treatment plants, they need to be mixed and dispersed instantly. The Coagulation reaction takes place in very low time less than 1 second.
- Coagulation occurs in a rapid mixing tank such as those shown in Figure 2.8.
- Rapid mixing may also be achieved using hydraulic jump mixing as shown in Figures 2.9 and 2.10.
- See also Figures 2.10,2.11 and 2.12

Rapid Mixing Tanks



(a) Turbine chamber (b) Propeller chamber (c) Double-compartment turbine chamber

(d) Double-compartment turbine chamber (e) Paddle chamber (f) In-line blender

Figure 2.8

Hydraulic Jump Mixer

Figure 2.9

Hydraulic Jump Mixer

Figure 2.10

Impeller Mixer

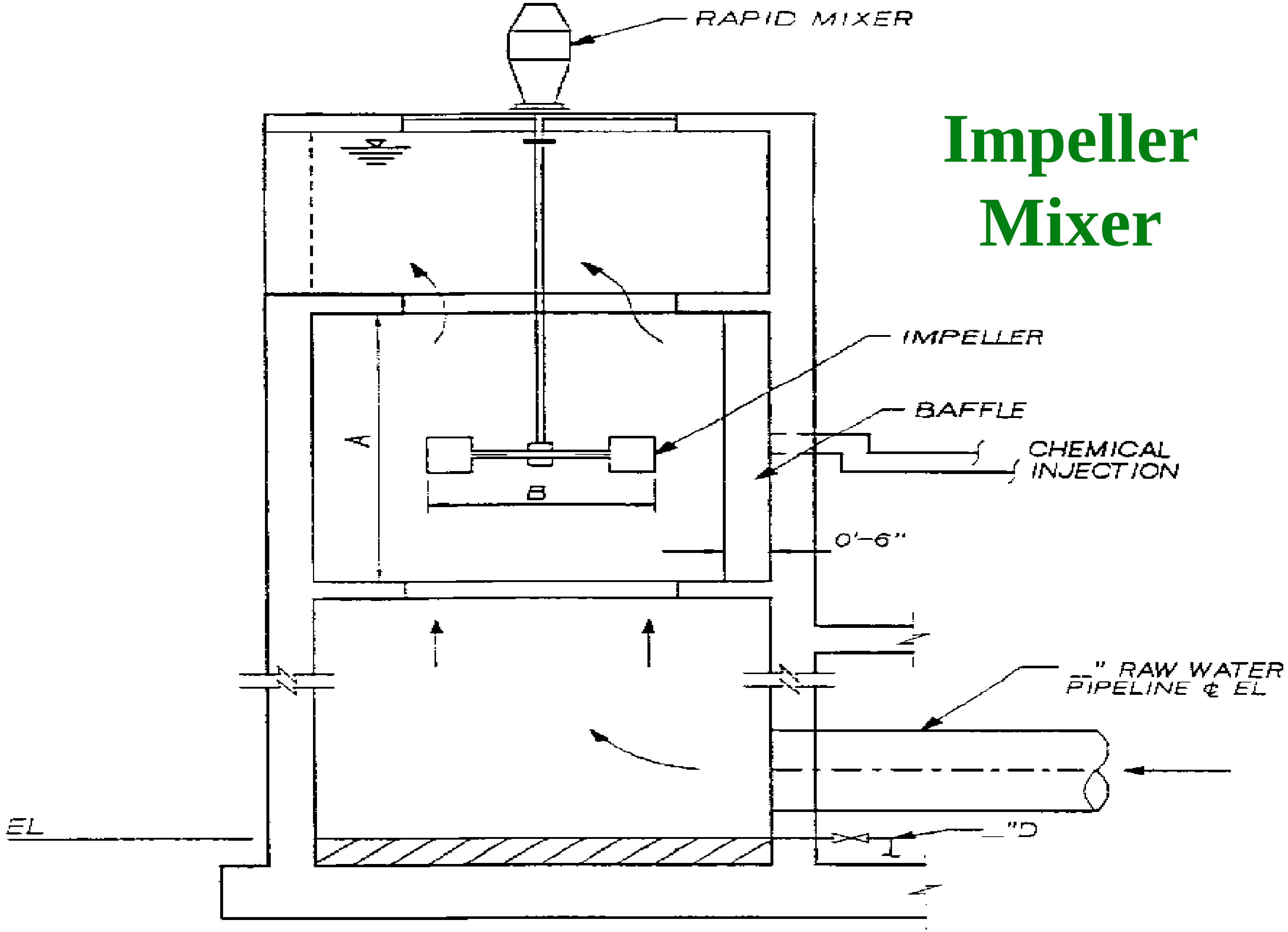


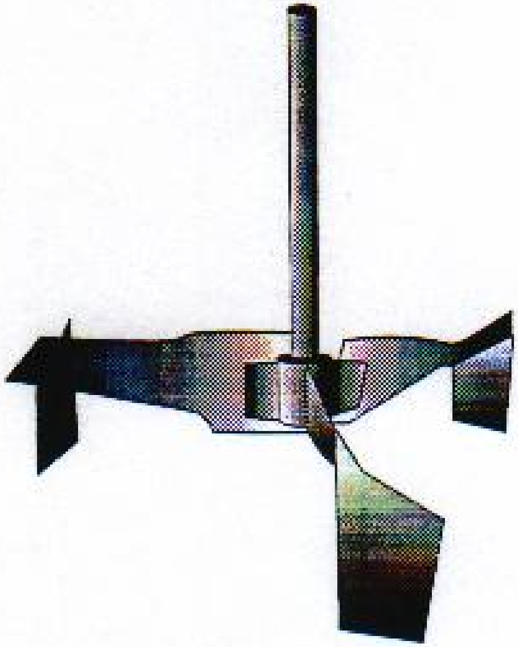
Figure 2.11

Mechanical Flash Mixer

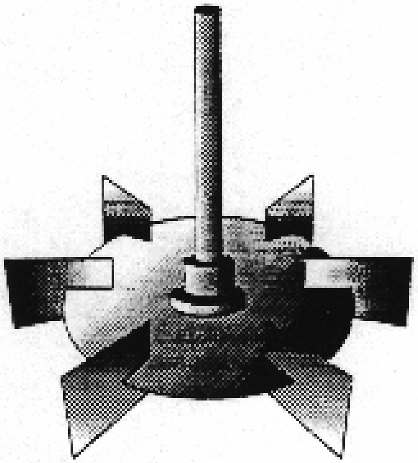
Figure 2.12

Propeller (axial)

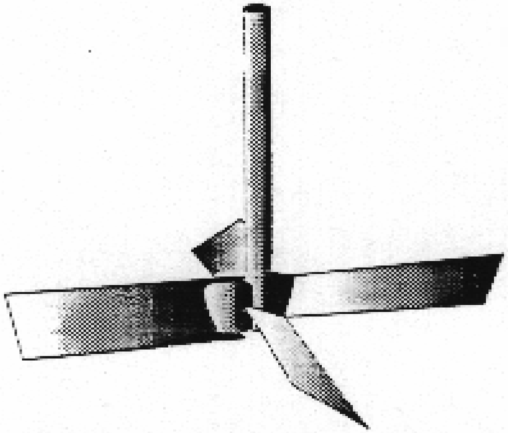
Propeller (axial)



Foil with Stabilizing Fins (axial)



Disk (Rushton) Turbine (Radial)



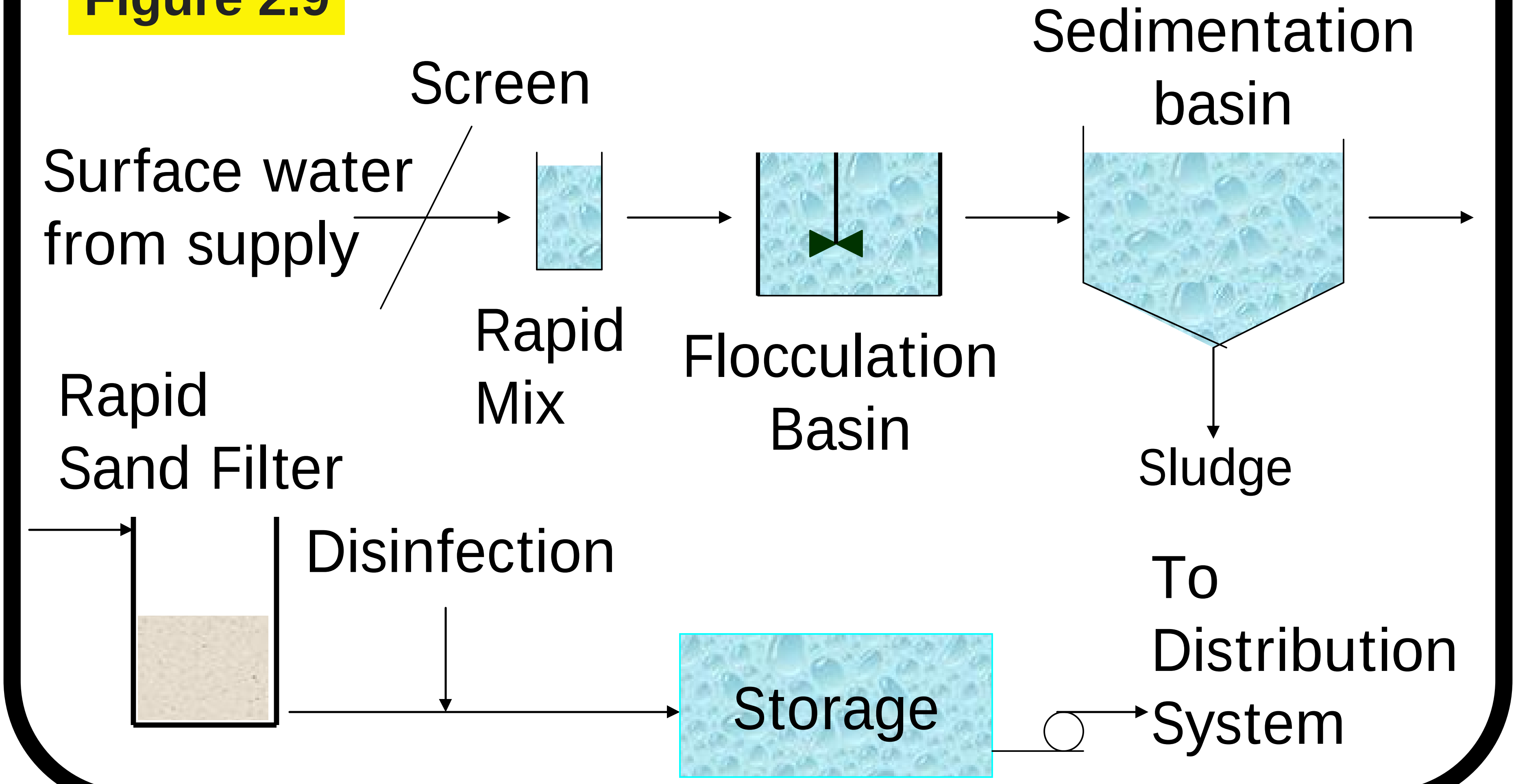
Pitched Blade Turbine (axial)

Various Impeller Shapes

Figure 2.13

Coagulation and flocculation

Figure 2.9



Sedimentation basin

Screen

Surface water from supply

Rapid Mix

Flocculation Basin

Sludge

Rapid Sand Filter

Disinfection

Storage

To Distribution System

Coagulation and flocculation

10. Flocculation (Forming Flocs)

-After destabilization (i.e. **Coagulation)**, particles will be ready to a tract and agglomerate and form **flocs**. But this agglomeration is slow and they need help to accelerate this agglomeration.

- This help is called **Flocculation** **“**which is the slow stirring or gentle agitation to aggregate the destabilized particles and form a rapid settling floc”. This gentle mixing increases the collisions between the particles and help them to agglomerate. Notice that rapid mixing will destroy the flocs, that's why we need gentle mixing.

- Flocculation occurs in a tank called a Flocculator or Flocculation Basin equipped with a method for Slow Mixing. The most common types of Flocculators are shown in the following slides.

Flocculator Types

11. Flocculator Types

A. Mechanical Mixing Flocculators

-Vertical shaft with impeller (turbine or propeller type blades)

-Paddle type with either horizontal or vertical shafts

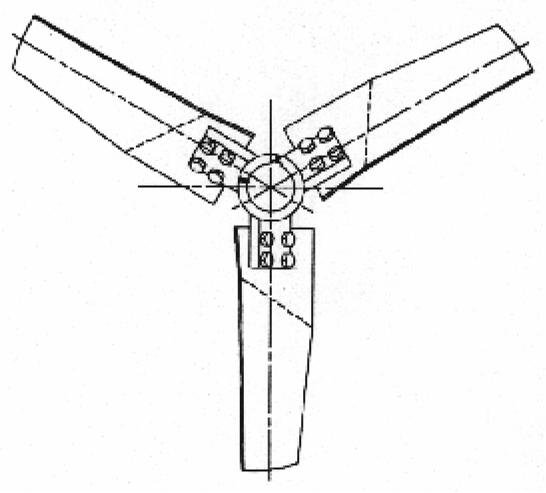
- Walking Beam Flocculator

B. Hydraulic Mixing Baffled Channels Flocculators

-Horizontal baffled channels

-Vertically baffled channel

Vertical Impeller Flocculator



Hydrofoil impeller

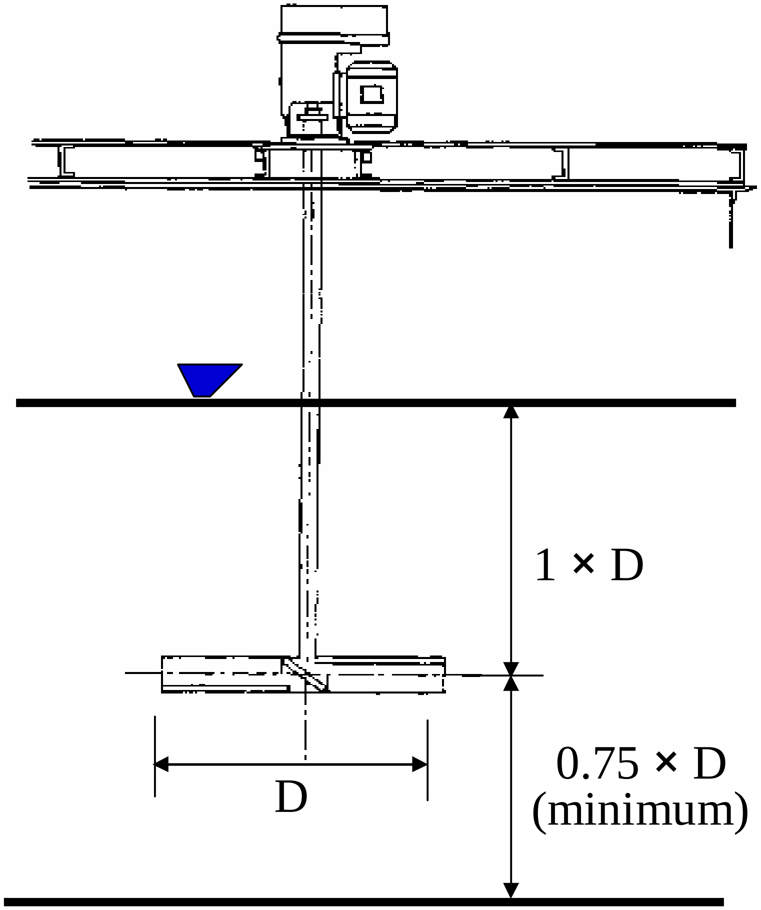


Figure 2.10

Vertical Impeller Flocculators

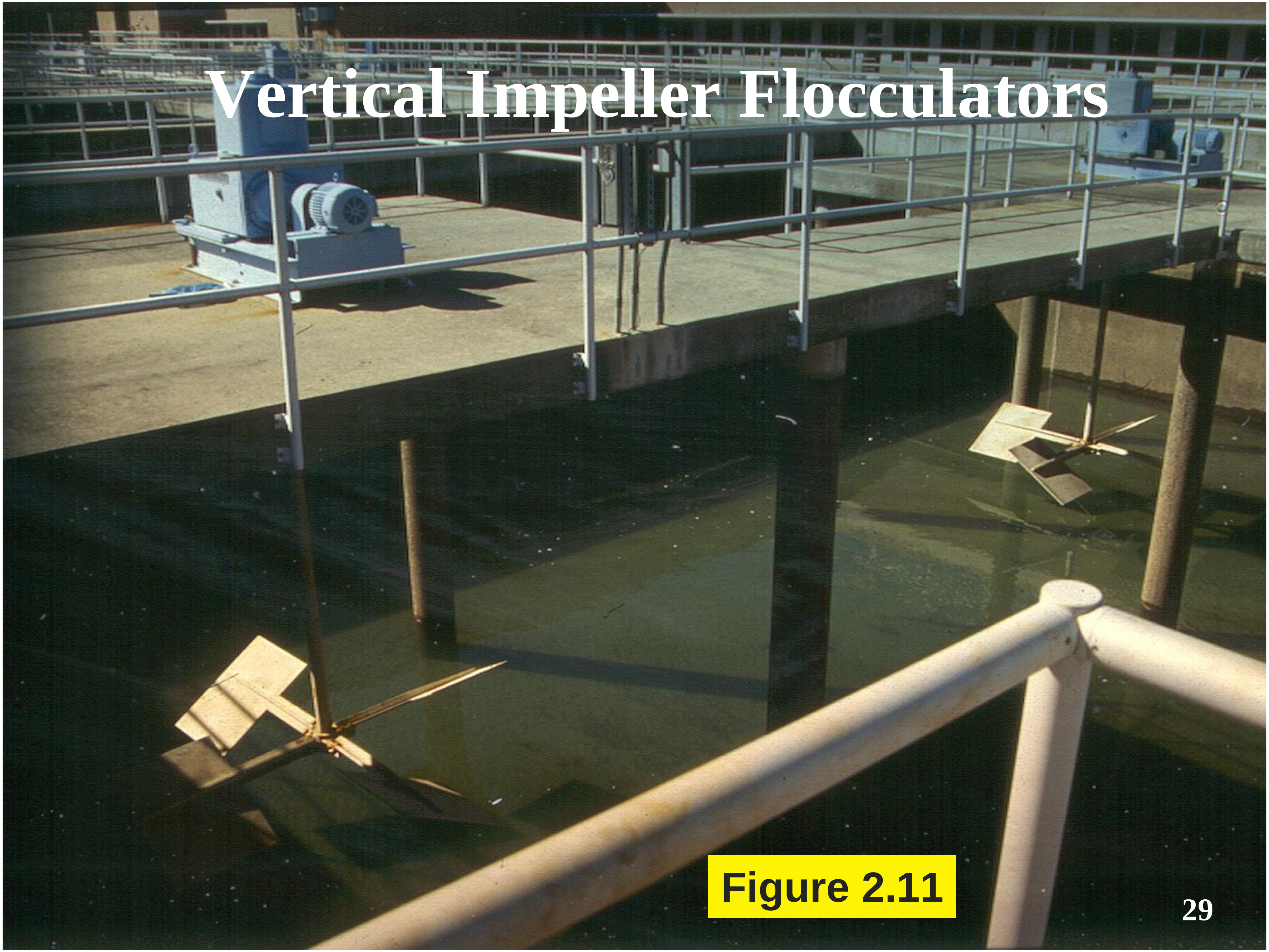


Figure 2.11

Vertical Shaft Paddle Flocculator

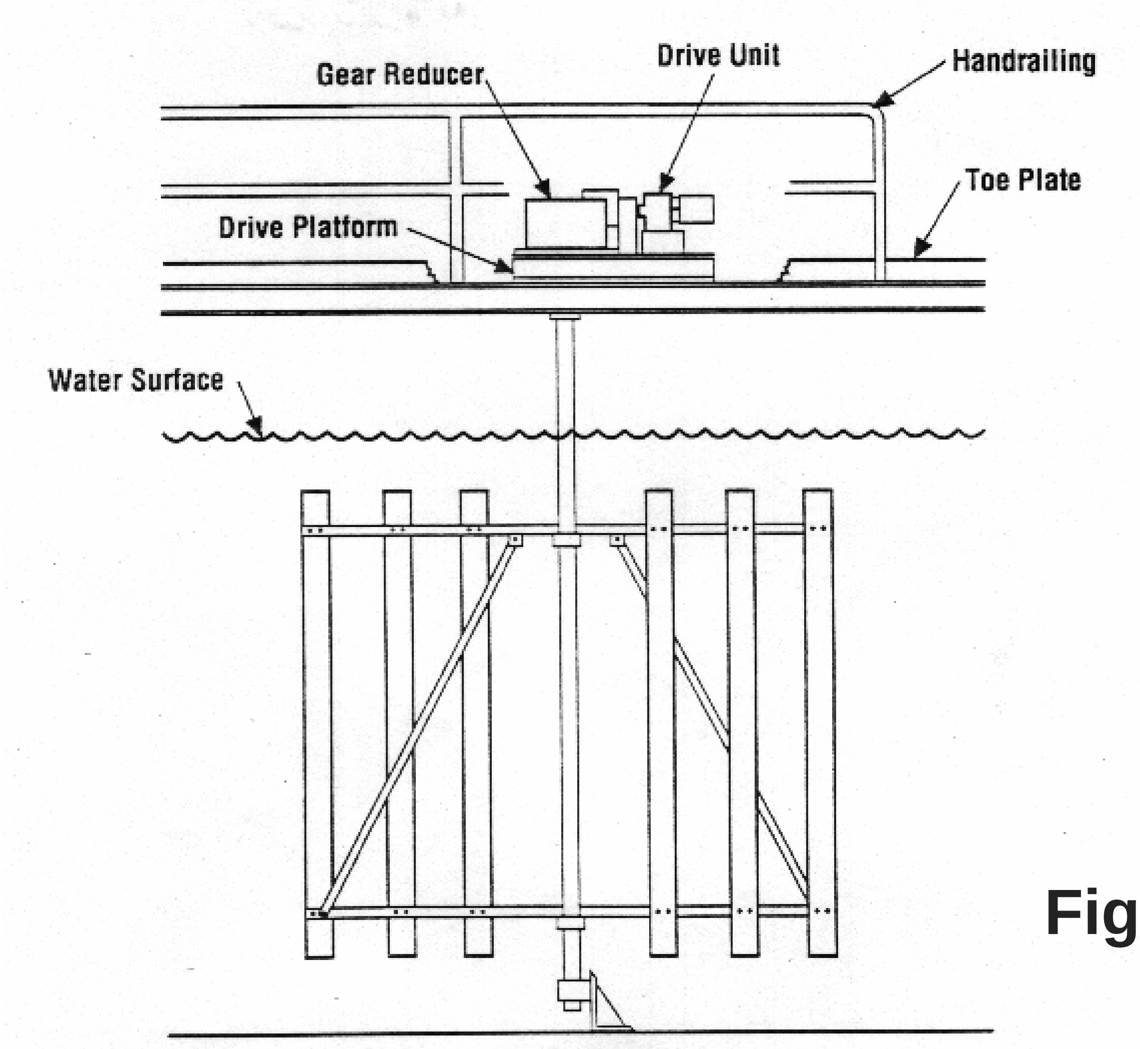
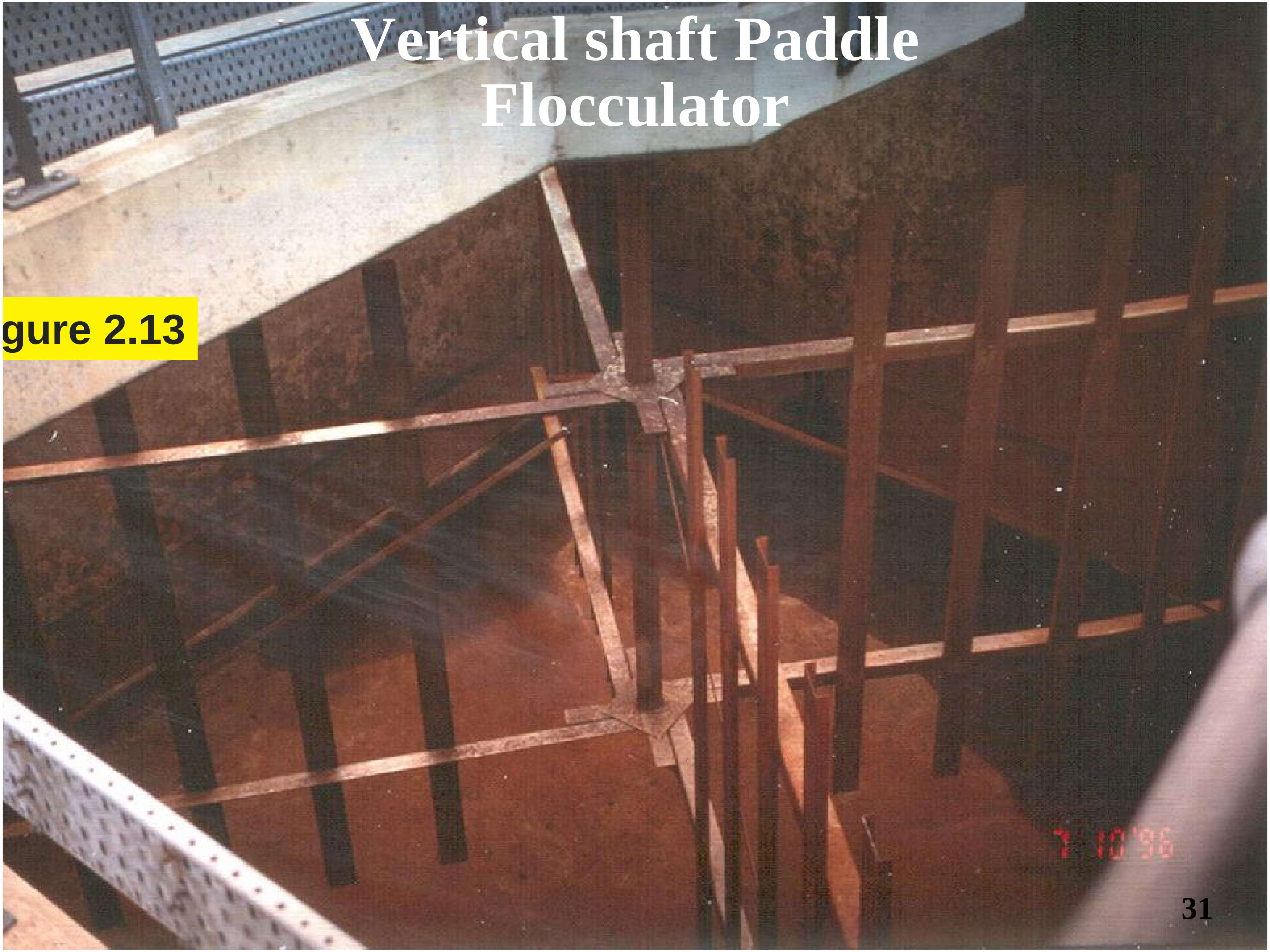


Figure 2.12

Vertical shaft Paddle Flocculator



gure 2.13

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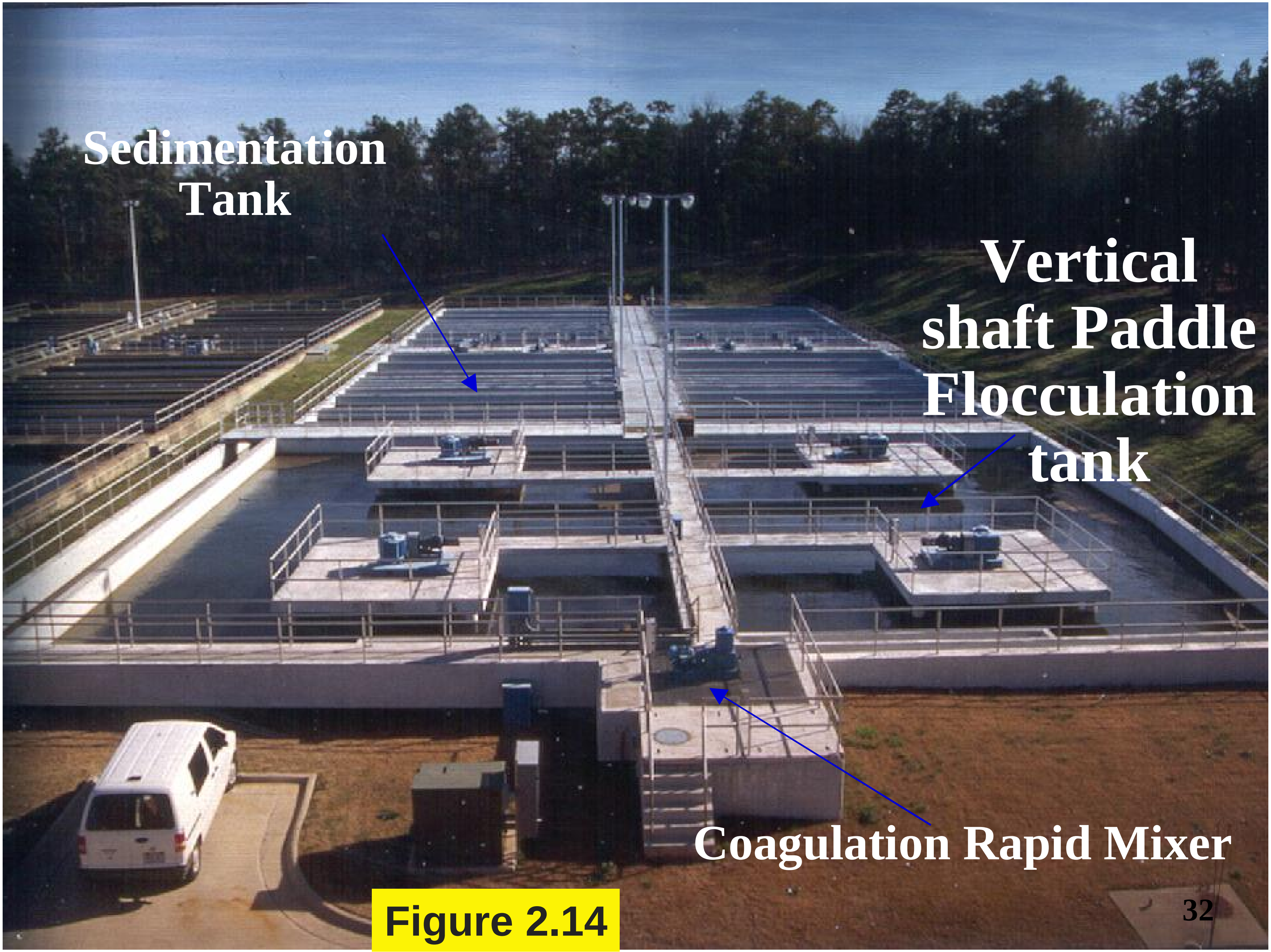

Sedimentation Tank

Vertical shaft Paddle Flocculation tank

Coagulation Rapid Mixer

Figure 2.14

Horizontal Paddle Flocculator

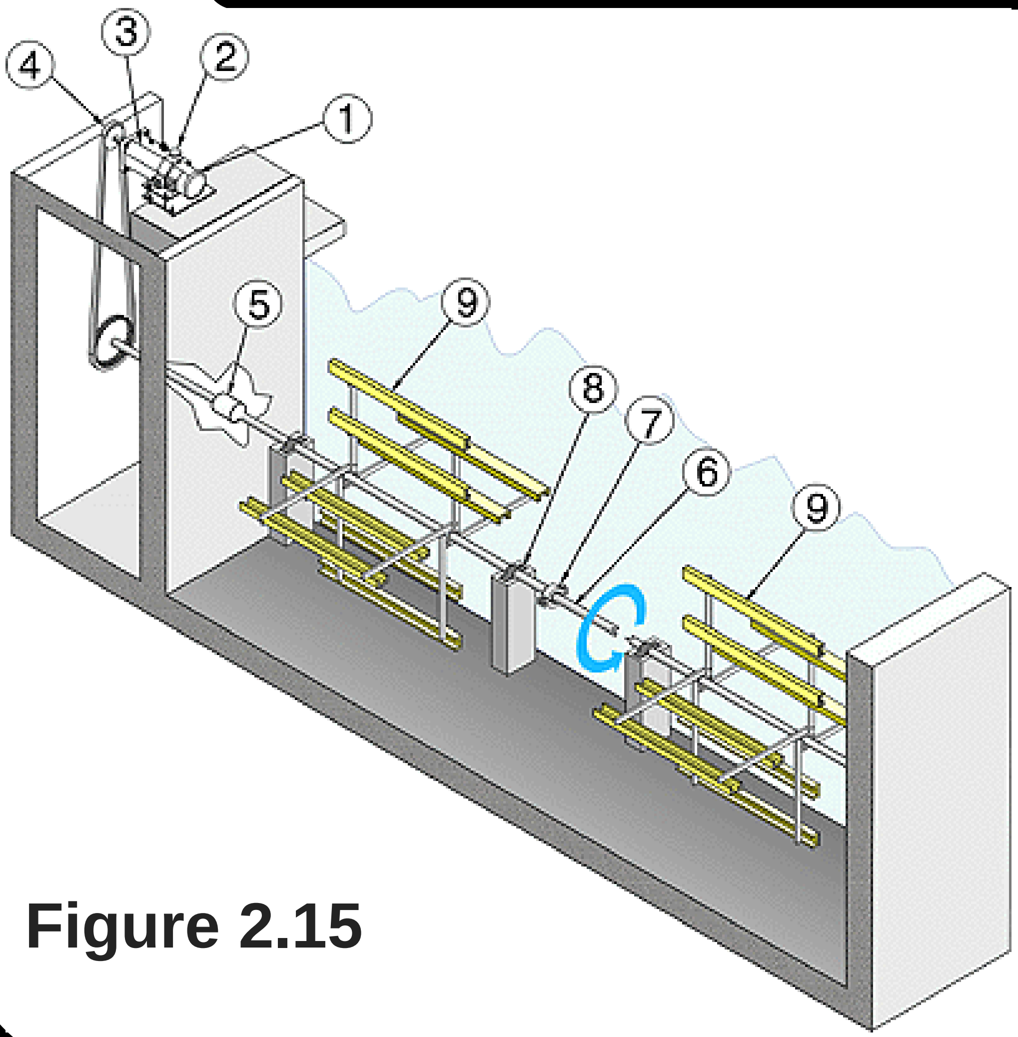

Figure 2.15

1. Drive motor
2. Variable speed drice
3. Gear reducer
4. Chain & sprocket power transfer
5. Stuffing box
6. Flocculator line shafting
7. Shasft connections
8. Bearings
9. Paddle reel assemblies

Horizontal Paddle Flocculator

FIGURE 9–7

Paddle flocculator.

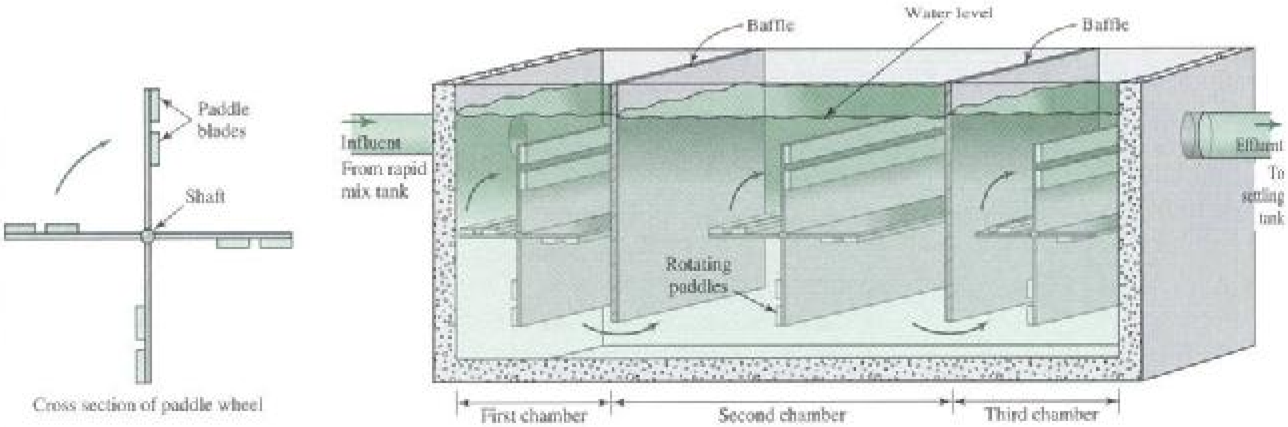

FIGURE 9–8

Baffled chamber flocculator.

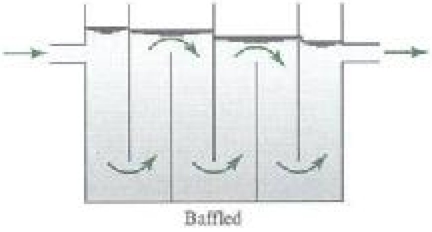

Figure 2.16

Walking Beam Flocculator

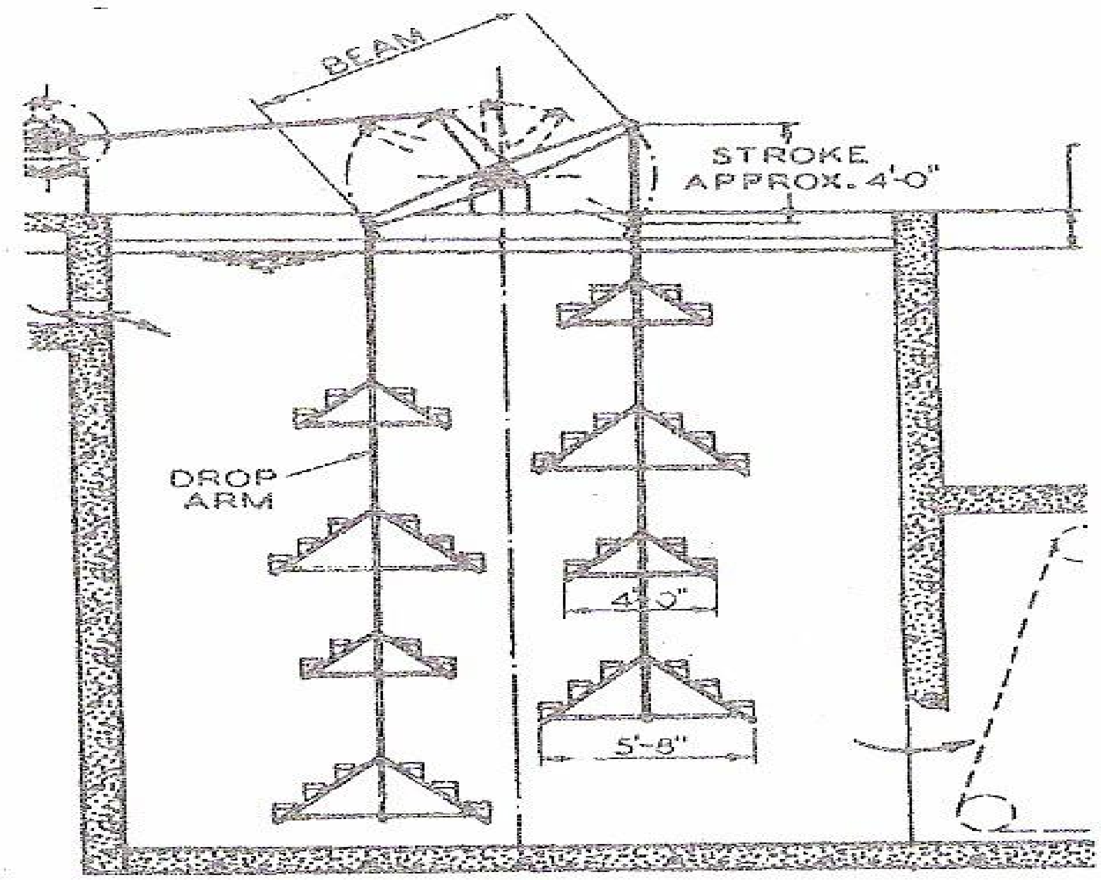

Figure 2.17

Walking Beam Flocculator

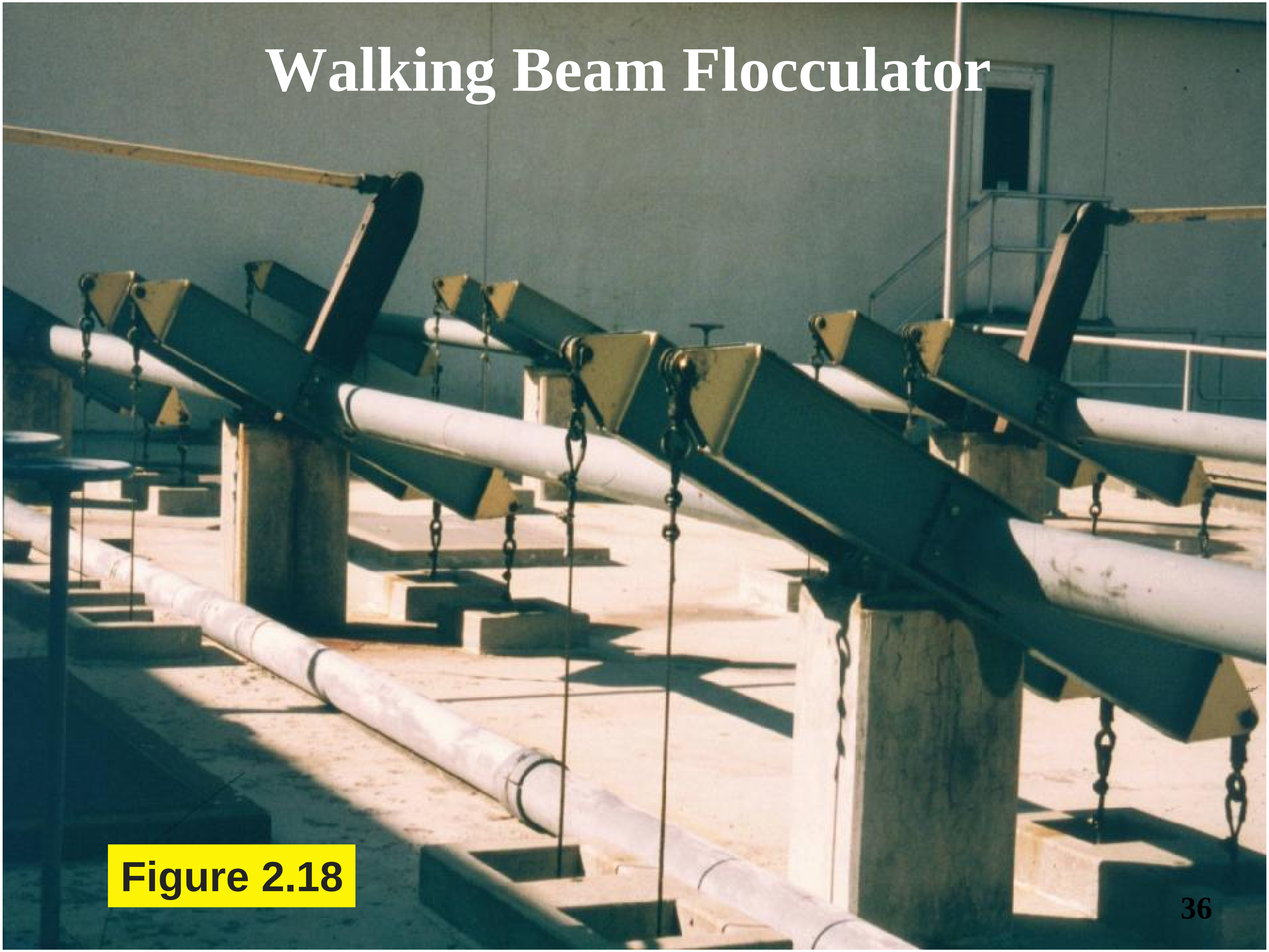

Figure 2.18

Walking Beam Flocculator

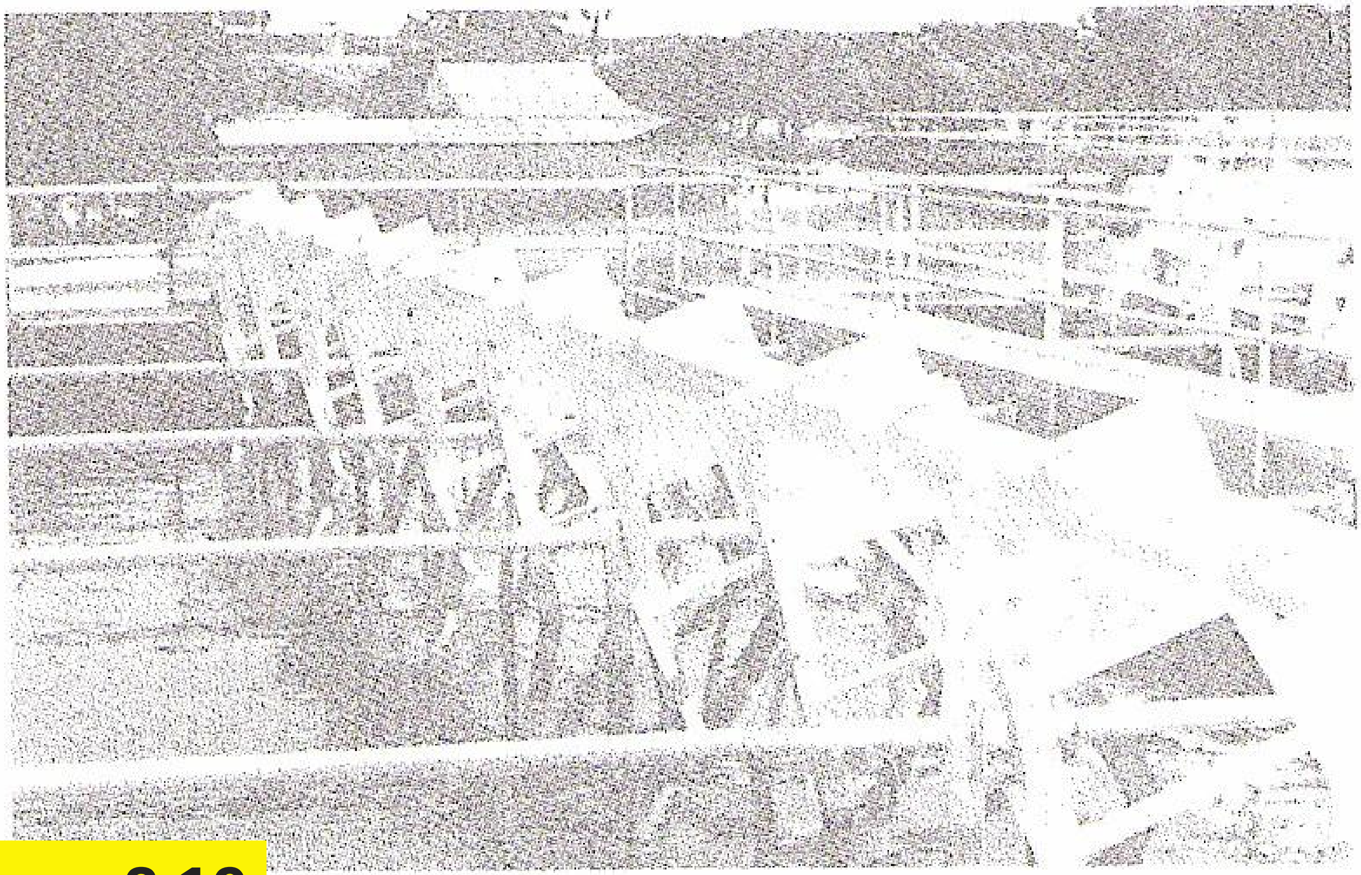

Figure 2.19

Horizontal Baffled Flocculator

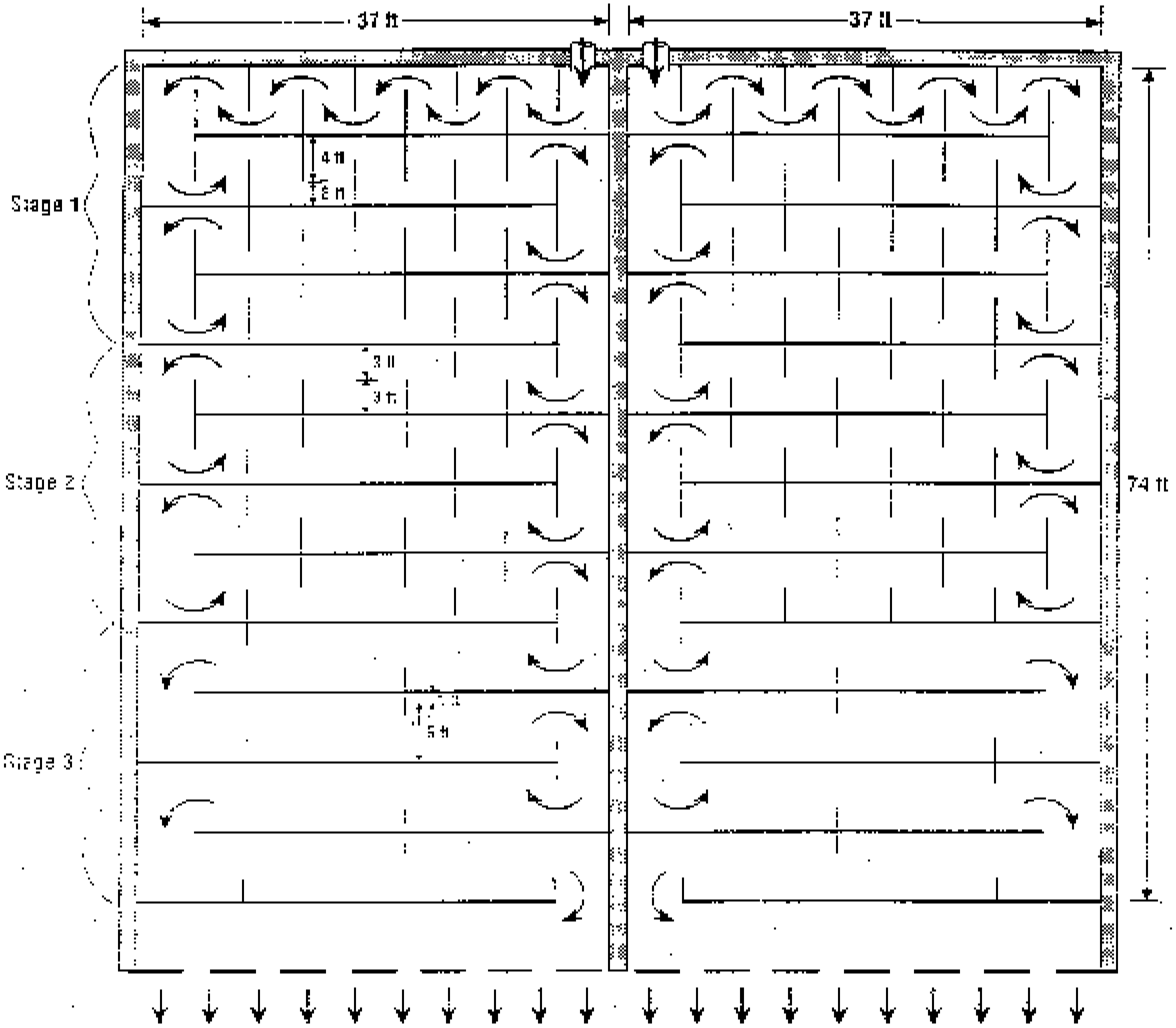

Figure 2.20

Vertical Baffled Flocculator

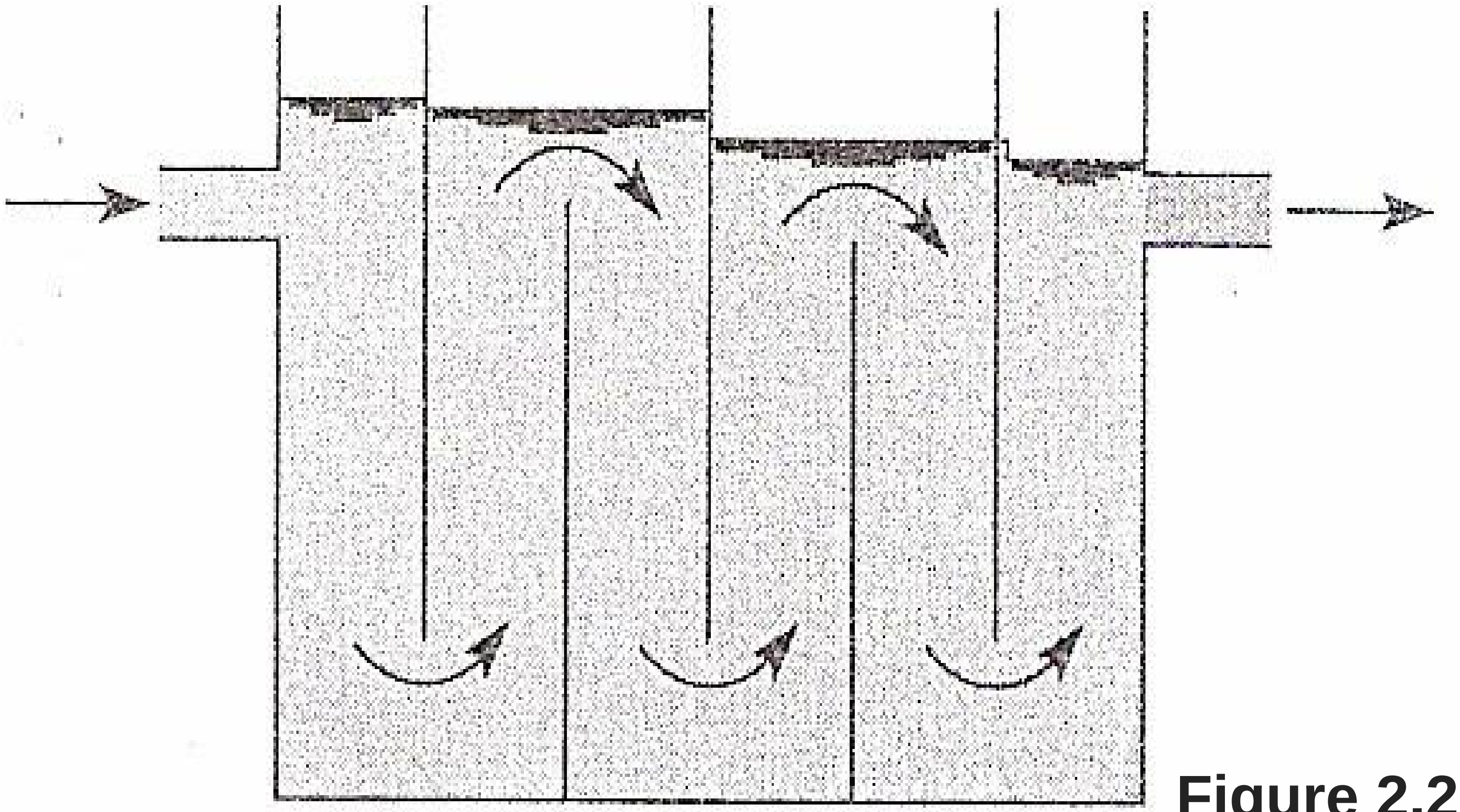

Figure 2.21

Figure 2.22

Horizontal Flocculators

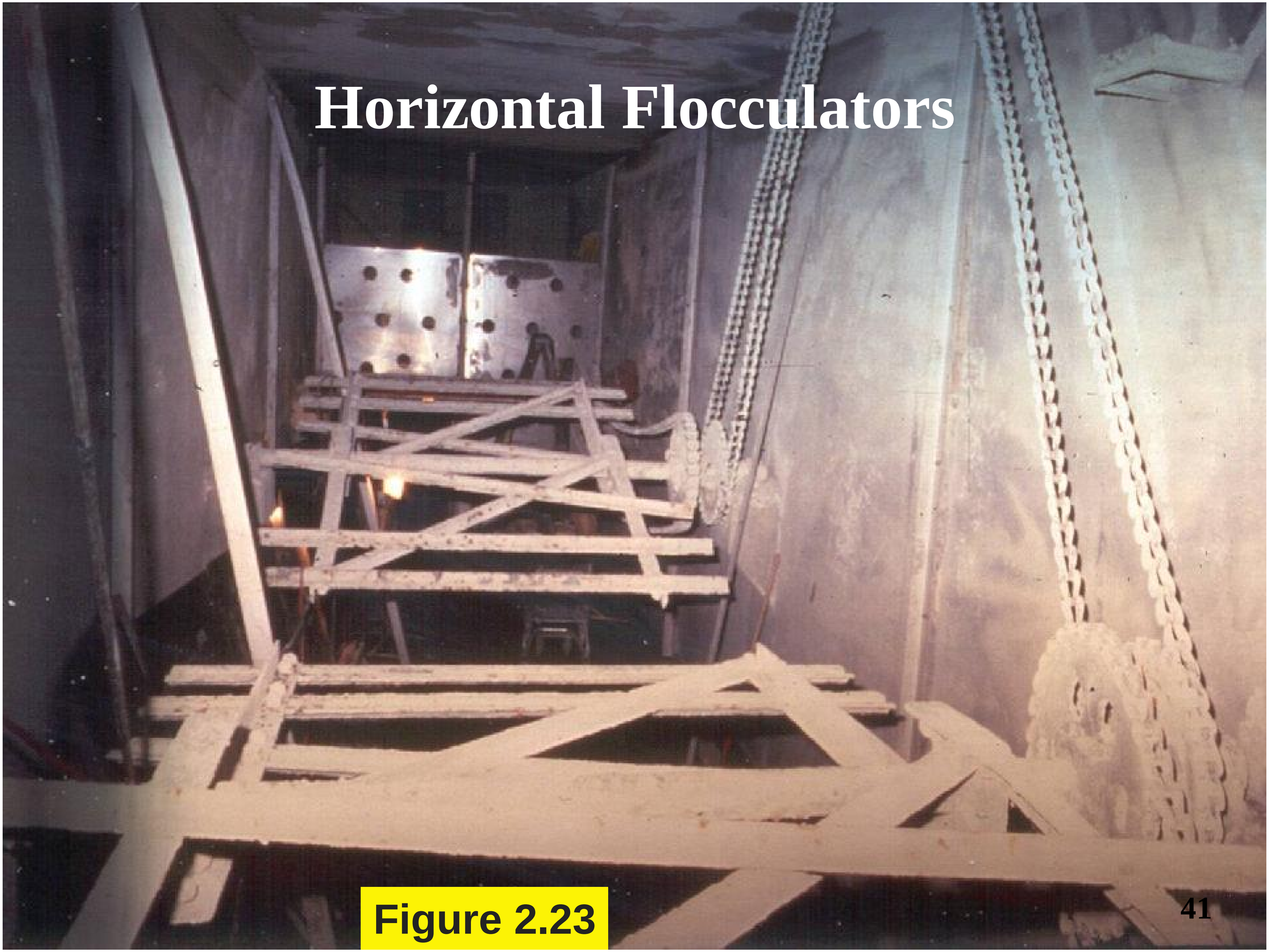

Figure 2.23

Flocculator

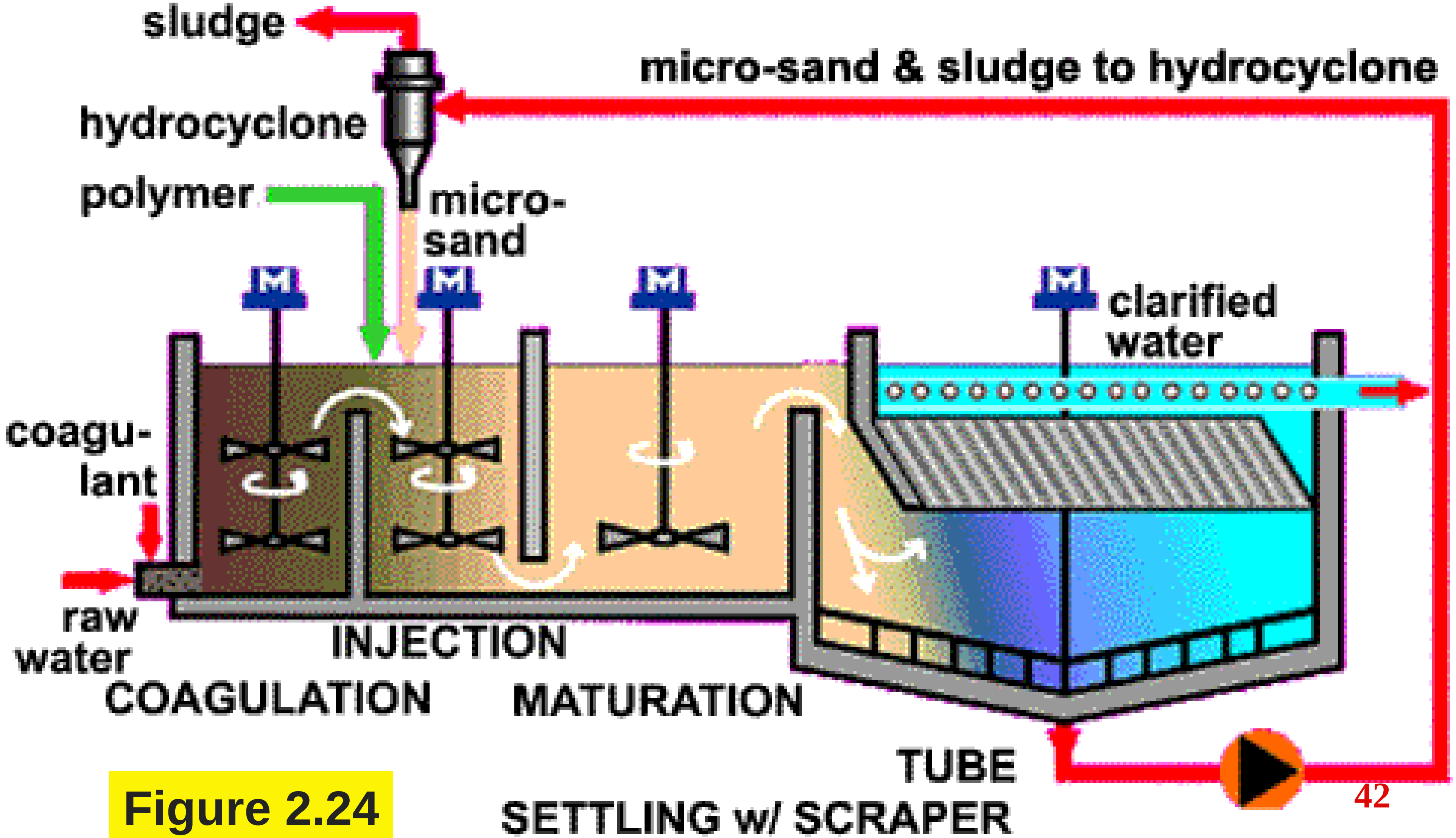

Figure 2.24