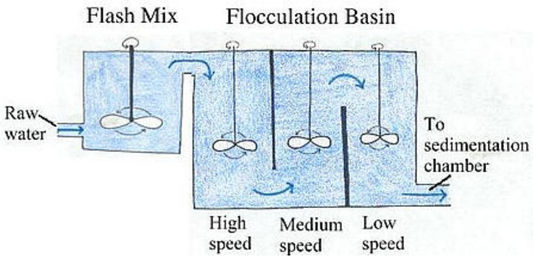
CE 370

Coagulation and Flocculation

Part 2

Rapid Mixing and Flocculation

- Rapid mixing is used to:
  - Disperse chemicals uniformly throughout the mixing basin
  - Allow adequate contact between the coagulant and particles
  - Microflocs are produced
- Flocculation is used to:
  - Agglomerate microflocs to larger ones



Devices

- Agitation in rapid mixing and flocculation is performed by:
  - Mechanical agitators (most common)
  - Pneumatic agitators
  - Baffled basins

Design

- The degree of mixing is based on the power provided, which is measured by the velocity gradient:

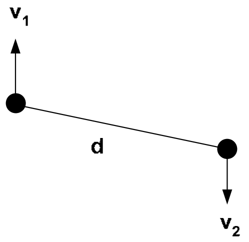
$$G = \sqrt{\frac{W}{\mu}} = \sqrt{\frac{P}{\mu V}}$$

  - G = velocity gradient, sec^{-1}
  - W = power imparted per unit volume of basin, N-m/s-m^3
  - P = power imparted, N-m/s
  - V = basin volume, m^3
  - μ = absolute viscosity of water (μ=0.00131 N-s/m^2)

Velocity Gradient

- The velocity gradient of two fluid particles that are 0.05ft apart with a relative velocity of 0.2fps is equal to:

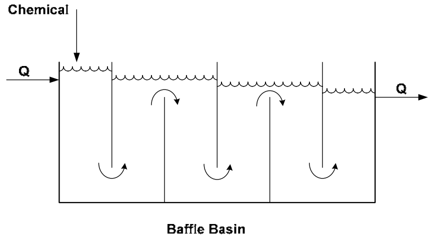
2fps/0.05ft = 40fps/ft



Design

- The velocity gradient for baffle basins is:

$$G = \sqrt{\frac{\gamma h_L}{\mu T}}$$



- γ = specific weight of water
- h_L = head loss due to friction and turbulence
- T = detention time

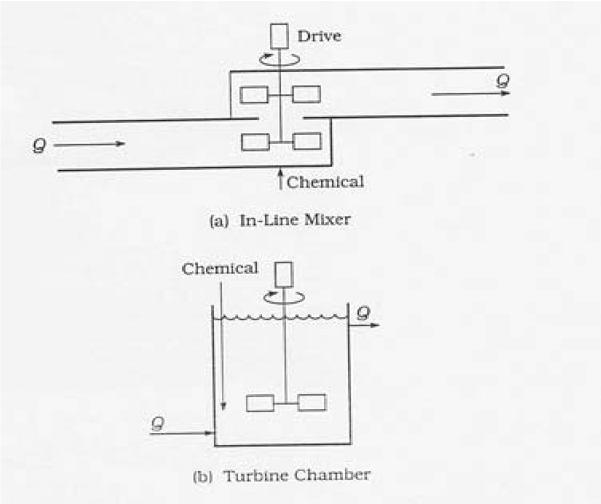
Velocity Gradient

- The rate of particle collision $\propto$ G
- Shear force $\propto$ G
- Total number of particle collisions $\propto$ GT

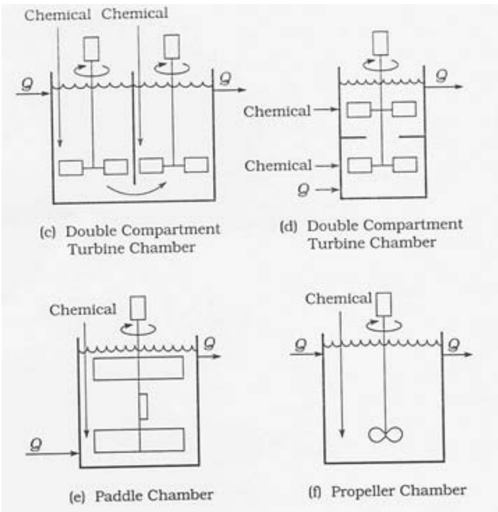
Rapid Mixing

- Mixing devices
- Detention time
- Types of impellers

Mixing Devices



Mixing Devices



Mixing Devices

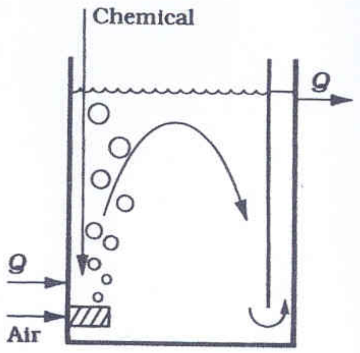


FIGURE 8.16 *Pneumatic Rapid Mixing*

Detention Time

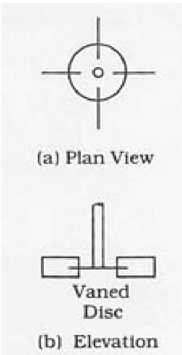
Typical detention times and velocity gradients for rapid mixing basins are given in the table below:

T (Seconds)	G (fps/f or sec^{-1}; mps/m of s^{-1})
20	1000
30	900
40	790
50	700

Rotary Mixing

- Rotary mixing devices can be
  - Turbines
  - Paddle impellers
  - propellers

Turbine Impellers



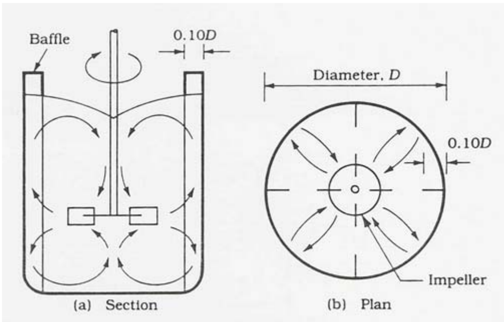
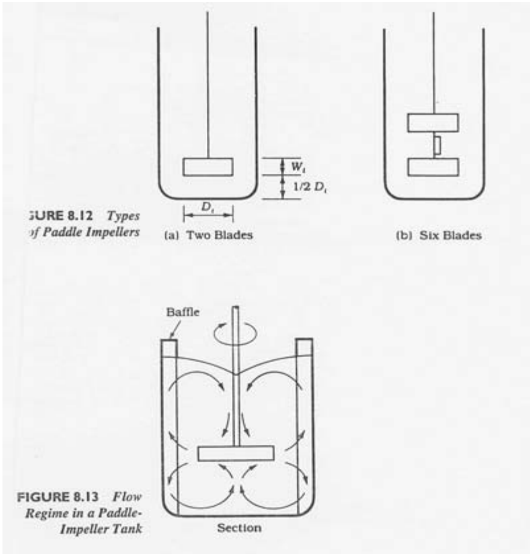


FIGURE 8.11 *Flow Regime in a Turbine-Impeller Tank*

Paddle Impeller



URE 8.12 *Types f Paddle Impellers*

FIGURE 8.13 *Flow Regime in a Paddle-Impeller Tank*

Propeller Impeller

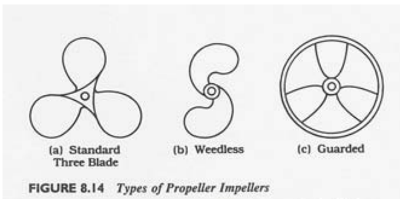


FIGURE 8.14 *Types of Propeller Impellers*

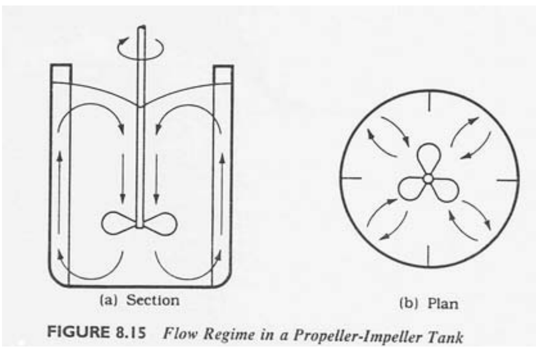


FIGURE 8.15 *Flow Regime in a Propeller-Impeller Tank*

Impeller Design

The power imparted to the liquid by various impellers is given by:

For turbulent flow ($N_{Re} > 10{,}000$) in a baffled tank:

$$P = K_T\, n^3\, D^5_i\, \rho$$

Where:

- P = power, ft-lb/sec (N-m/s)
- K_T = impeller constant for turbulent flow
- n = rotational speed, rps
- D_i = impeller diameter, ft (m)
- ρ = density of the liquid, $\rho = \gamma/g$
- γ = specific weight of the liquid, lb/ft^3
- g = gravity, 32.17 ft/sec^2 (9.81 m/s^2)

For unbaffled tanks the power imparted is 75% of the baffled tanks

Impeller Design

For laminar flow ($N_{Re} <$ 10 to 20) in a baffled or unbaffled tank:

$$P = K_L\, n^2\, D^3_i\, \mu$$

Where:

- P = power, ft-lb/sec (N-m/s)
- K_L = impeller constant for laminar flow flow
- n = rotational speed, rps
- D_i = impeller diameter, ft (m)
- μ = absolute viscosity, lb-force-sec/ft^2 (N-s/m^2)

Reynolds number for impellers is given by:

$N_{Re} = D^2_i\, n\, \rho / \mu$

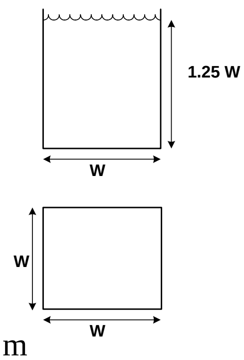
Table 8.2 gives values for K_T and K_L for baffled tanks

Example – Rapid Mixing

A square rapid-mixing basin, with a depth of water equal to 1.25 times the width, is to be designed for a flow of 7570 m3/d. The velocity gradient is to be 790 mps/m, the detention time is 40 seconds, the operating temperature is 10° C, and the turbine shaft speed is 100 rpm. Determine:

- The basin dimensions
- The power required

Solution



Find the volume of the basin,

V = Q / t

$$V = \frac{7570 m^3}{1440 \min} \times \frac{\min}{60 \sec} \times 40 \sec = 3.5 m^3$$

The dimensions are

(W)(W)(1.25W) = 3.50 m^3

W = 1.41 m

The depth of the basin, H = (1.25)(1.41 m) = 1.76 m

Use W = 1.41 m; H = 1.76

Using the velocity gradient equation

$$P = \mu G^2 V = (0.0013 N - s/m^2)(790/\sec)^2(3.5 m^3) = 2863 N - m/s$$

Flocculation

➢ Agitation is provided by:
  - Mechanical agitation (most common) OR
  - Pneumatic agitation

➢ Mechanical agitation is provided using:
  - Paddle wheels (most common)
  - Turbines
  - Propellers

Rapid Mixing and Flocculation

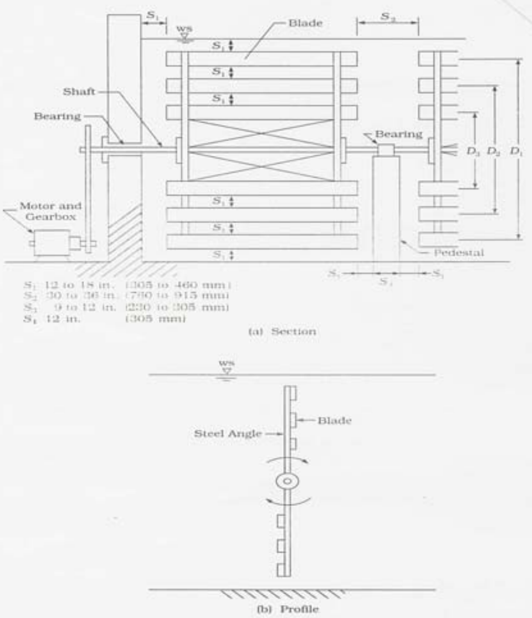
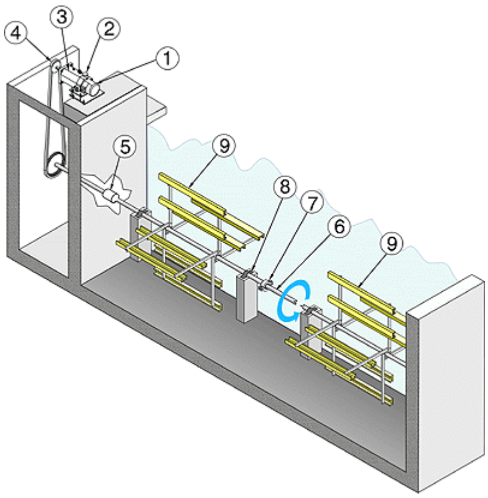


FIGURE 8.18 *Horizontal-Shaft Flocculation Paddle Wheels*



Flocculation

- Complete flocculation depends on:
  - The relative ease and rate of by which the small microfloc aggregate into large floc particles
  - Number of particle collisions
- OR in other words, it depends on:
  - Floc characteristics
  - G (if G is too high, large floc will not be formed)
  - GT (gives indication on the number of collisions)
- Fragile flocs require low G values (<5/sec)
- High-strength flocs require high G values (≈10/sec)

Flocculation Basins

- Designed to provide tapered flocculation [decreasing G values (high 50 to low 20 to lower 10/sec)]
- Horizontal and vertical shafts are used to mount the paddle wheel
- Flocculation basins are composed of minimum 3 compartments to:
  - Minimize short circuiting
  - Facilitate tapered flocculation

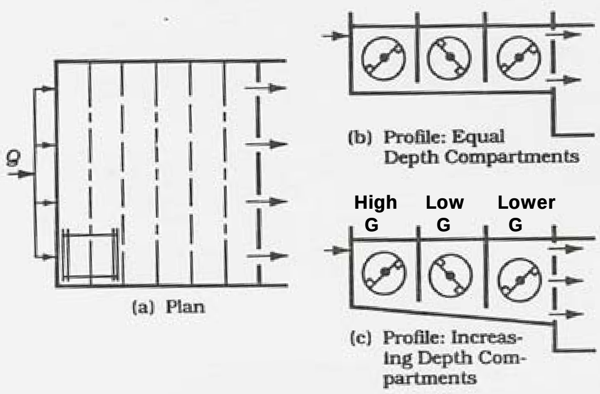


FIGURE 8.19 *Horizontal-Shaft Paddle-Wheel Flocculator (Cross-Flow Pattern)*

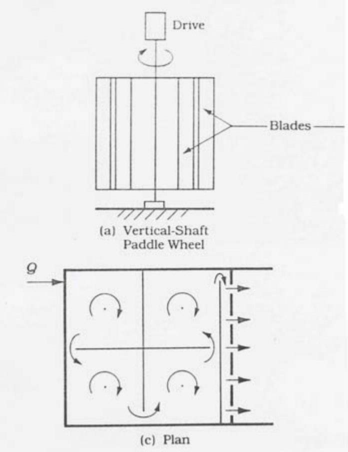


FIGURE 8.21 *Vertical-Shaft Paddle-Wheel Flocculator*

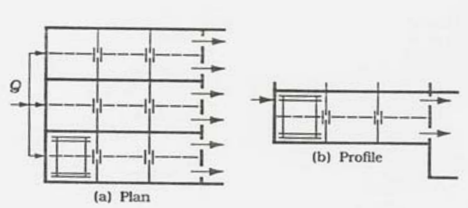


FIGURE 8.20 *Horizontal-Shaft Paddle-Wheel Flocculator (Axial-Flow Pattern)*

Flocculation Basins

- For cross-flow, tapered flocculation can be provided by:
  - Varying the paddle size
  - Varying the number of paddles
  - Varying the diameter of the paddle wheels
  - Varying the rotational speed of the various shafts
- For axial-flow, tapered flocculation can be provided by:
  - Varying the paddle size
  - Varying the number of paddles

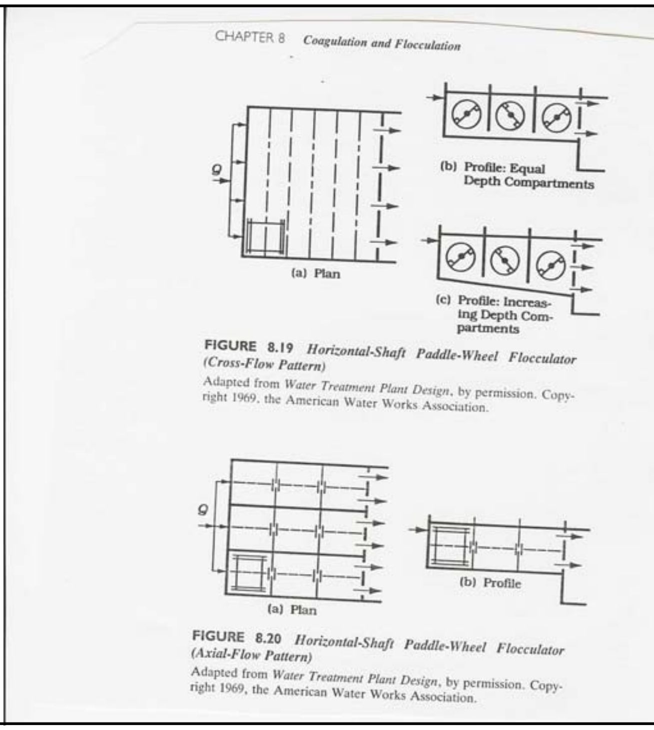


FIGURE 8.19 *Horizontal-Shaft Paddle-Wheel Flocculator (Cross-Flow Pattern)*
Adapted from *Water Treatment Plant Design*, by permission. Copyright 1969, the American Water Works Association.

FIGURE 8.20 *Horizontal-Shaft Paddle-Wheel Flocculator (Axial-Flow Pattern)*
Adapted from *Water Treatment Plant Design*, by permission. Copyright 1969, the American Water Works Association.

Paddle Wheels Design

The power imparted by paddle wheels is given by the following:

$$P = C_D A \rho \frac{v^3}{2} = C_D A \frac{\gamma}{g} \frac{v^3}{2}$$

Where:

- C_D = Coefficient of drag
- A = Paddle area, ft^2 (m^2)
- ρ = density of the liquid, $\rho = \gamma/g$
- v = Velocity of the paddle relative to water, fps (mps)
- g = gravity, 32.17 ft/sec2 (9.81 m/s2)

Table 8.3 gives values for drag coefficient.

Example on Flocculation

A cross-flow, horizontal shaft, paddle wheel flocculation basin is to be designed for a flow of 25,000m^3/d, a mean velocity gradient of 26.7/sec (at 10° C), and a detention time of 45 minutes. The GT value should be from 50,000 to 100,000. Tapered flocculation is to be provided, and the three compartments of equal depth in series are to be used. The G values determined from laboratory tests for the three compartments are G1 = 50/sec, G2 = 20/sec, and G3 = 10/sec. These give an average G value of 26.7/sec. The compartments are to be separated by slotted, redwood baffle fences, and the floor of the basin is level. The basin should be 1.5 m in width to adjoin the settling tank. Determine:

1. **The GT value**
2. **The basin dimensions**
3. **The power to be imparted to the water in each compartment**

Example on Flocculation

Solution

The GT value = (26.7/sec)(45 min)(60 sec/min) = 72,100

Since GT value is between 50,000 and 100,000, the detention time is satisfactory.

Basin volume, V = (flow) × (detention time) = (25,000 m^3/d)(45 min)(hr/60 min) = 781 m^3

Profile area = (volume / width) = (781 m^3 / 15 m) = 52.1 m^2

Assume compartments are square in profile, and x is the compartment width and depth.

Thus, (3x)(x) = 52.1 x^2 = 17.37 x = 4.17 m 3x = 3(4.17) = 12.51m

Then, **width = depth = 4.17 m**

length = 12.51 m

volume = (4.17)(12.51)(15.0) = 783 m^3

The Power, P = $\mu G^2 V$ (at 10° C, μ = 0.00131 N-s/m^2)

P (for first compartment) = (0.00131 N-s/m^2)($50^2/s^2$)(783 m^3/3) = 855 N-m/s = 855 J/s = 855 W

P (for second compartment) = (0.00131)(20^2)(783/3) = 137 W

P (for third compartment) = (0.00131)(10^2)(783/3) = 34.2 W

Coagulation & Flocculation in Wastewater Treatment

- The same aluminum and iron salts are used in wastewater
- Wastewater requires higher dosages (≥ 300 mg/l) and coagulates faster than surface water
- Beside coagulation, lime and iron salts remove phosphorous
- Coagulant aids include polyelectrolytes, addition of turbidity and lime addition

Coagulation & Flocculation in Wastewater Treatment

- Rapid-mixing basins have detention time of 1 to 2 minutes (due to high SS and large coagulant dosage)
- Velocity gradients in rapid-mixing basins are about 300/sec, which are lower than those for water (due to nature of organic solid)
- GT and T are lower than those used with water

Coagulation & Flocculation in Wastewater Treatment

- For alum and iron salts
  - T is typically 15 to 30 min
  - G is typically 20 to 75/sec
  - GT is typically 10,000 to 100,000
- For lime
  - T is typically 1 to 2 min in rapid-mixing basins
  - T is typically 5 to 10 min in flocculation basins
  - G is typically ≥ 100/sec