ENVE 301
Environmental Engineering Unit Operations

Chapter: 6
Mixing

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Mixing

Common Applications:

→Mixing of coagulant chemicals (COAGULATION)

→Flocculation

→Addition of chlorine for disinfection

→Biological treatment

3 phenomena contribute to mixing:

1. Molecular diffusion → is due to thermally induced Brownian motion and is not significant compared to other 2 phenomena.

2. Eddy current (generated as a result of velocity gradient)

3. Non-uniform flow

} are functions of the degree of turbulence in the basin.

The degree of mixing $\propto$ Magnitude of eddy currents or formed within the liquid turbulence

Velocity Gradient (G)

Rate of particulate collision $\propto$ G

Therefore;
G must be sufficient to furnish the desired rate of particulate collisions.

G ↑ shear force ↑

$$G = \sqrt{\frac{P}{\mu \forall}}$$

↓

1/sec

P = Power dissipated ,W (Nm/sec)

μ = Dynamic viscosity, ($Nsec/m^2$)

V = Volume to which the power is applied, (m^3)

Example:

Two water particles moving 1m/sec relative to each other at a distance 0,1m would have

$$G = \frac{1m / \sec}{0.1m} = 10 \sec^{-1}$$

Velocity gradient ⟶ measure of the relative velocity of two particles of fluid and distance between.

MIXERS

Hydraulic Mixing Devices

- Venturi sections
- Hydraulic jumps
- Parshall flume
- Weirs
- Baffled mixing chambers

Mechanical Mixing Devices

- Propeller mixer
- Turbine mixer
- Paddle mixer

Pneumatic Mixers

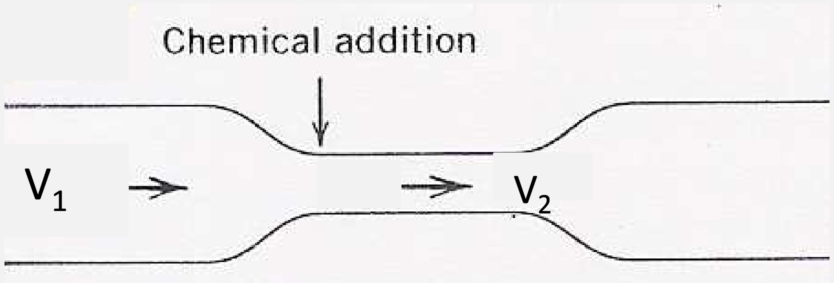
- Air diffusers

Hydraulic Mixers

- The degree of turbulence is measured by the loss in head.
- Dependent on flow
- Power dissipation in a hydraulic device= $\rho g Q \Delta h_L$

  (h_L ↓ Headloss)

Hydraulic Mixers (continue)



Venturi section for chemical addition

Ref: Droste, 1997, John Wiley & Sons, Inc.

$$h_L = C_d \frac{V_2^2}{2g}$$

A) Venturi Sections

→ The reduced pressure in the throat of the section aspirates the chemical feed solution into flow.

→ Turbulence generated in the throat.

→ As the flow jet expands upon exiting the throat → Mixing.

B) Hydraulic Jumps

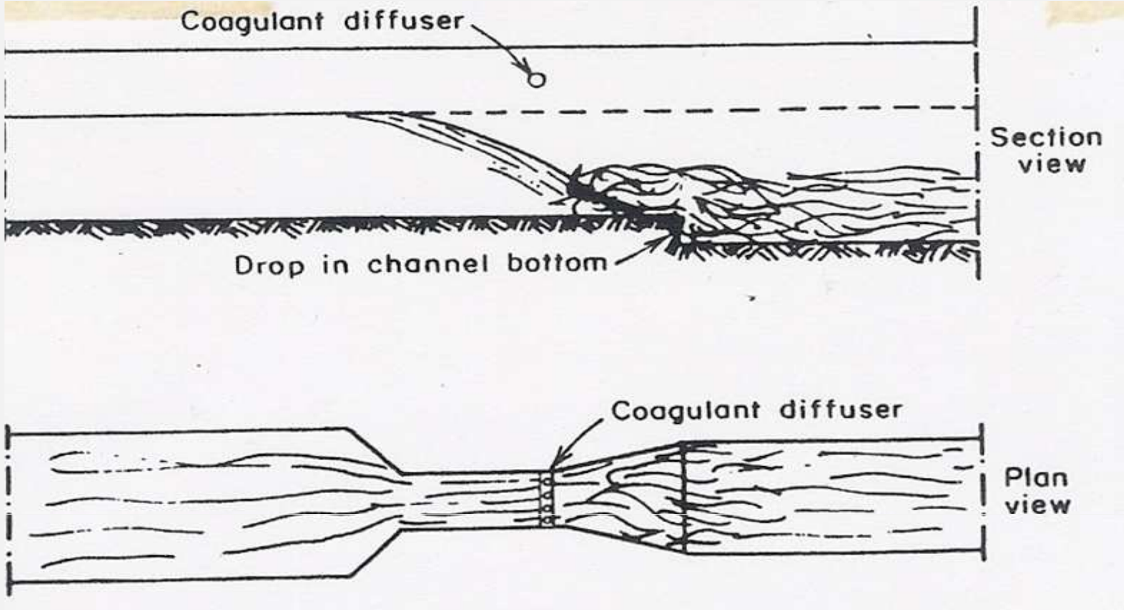


Figure 5.1. Hydraulic jump mixer. *Source:* Adapted from IRC, 1981b.

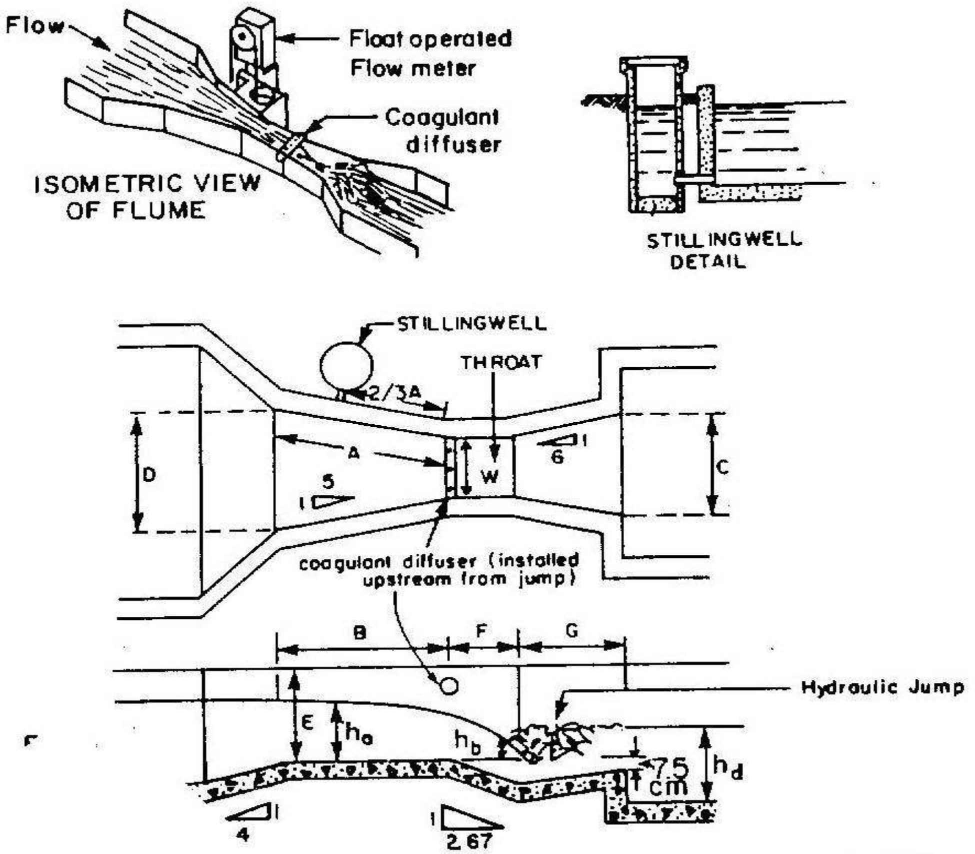
Ref: Schulz & Okun, 1984, John Wiley & Sons

→ A chute followed by a channel, with or without a drop in the elevation of channel floor.

Chute ⟶ Creates supercritical flow.

Turbulence generated in the jump ⟶ Provide suitable mixing.

C) Parshall Flume

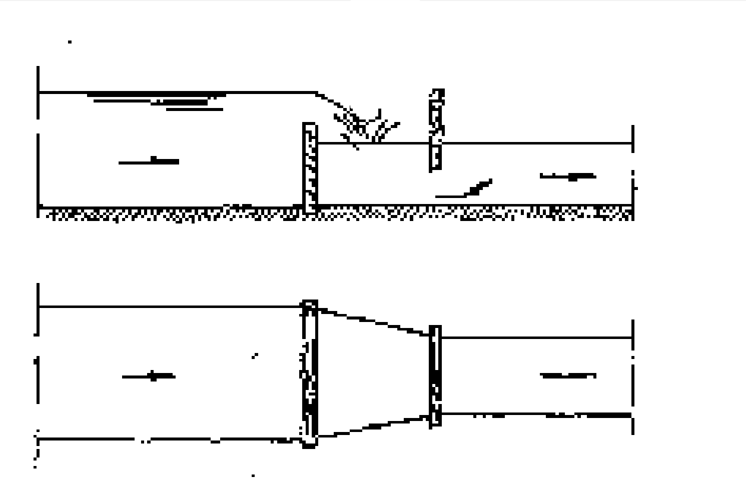


ıme rapid mixer. *Source:* Adapted from Okun and Ponghis, 1975.

Ref: Schulz & Okun, 1984, John Wiley & Sons

→ Effective rapid mixer when a hydraulic jump is incorparated immediately downstream of flume.

D) Weirs



The sudden drop in the hydraulic level over the weir induces the turbulence in water for mixing.

Chemicals are added over weir with the help of diffusers.

The vertical fall of water the weir → at least 0.1m to ensure sufficient turbulence

The height of the coagulant diffuser over the weir → at least 0.3m to penetrate the nappe thickness

E) Baffled Mixing Chambers

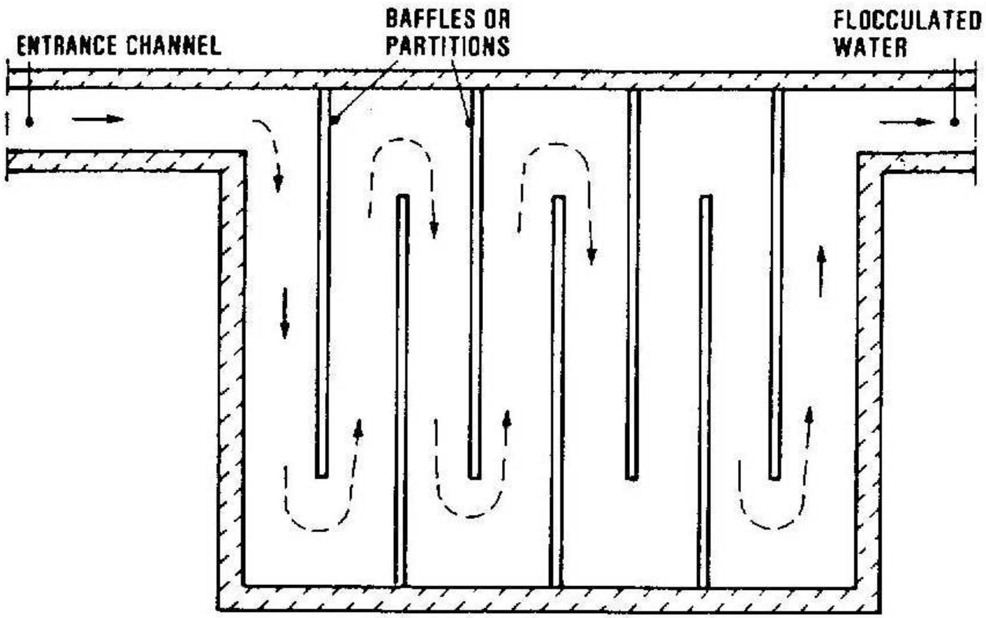


Figure 6.2. Horizontal-flow baffled channel flocculator (plan). *Source:* IRC, 1981b.

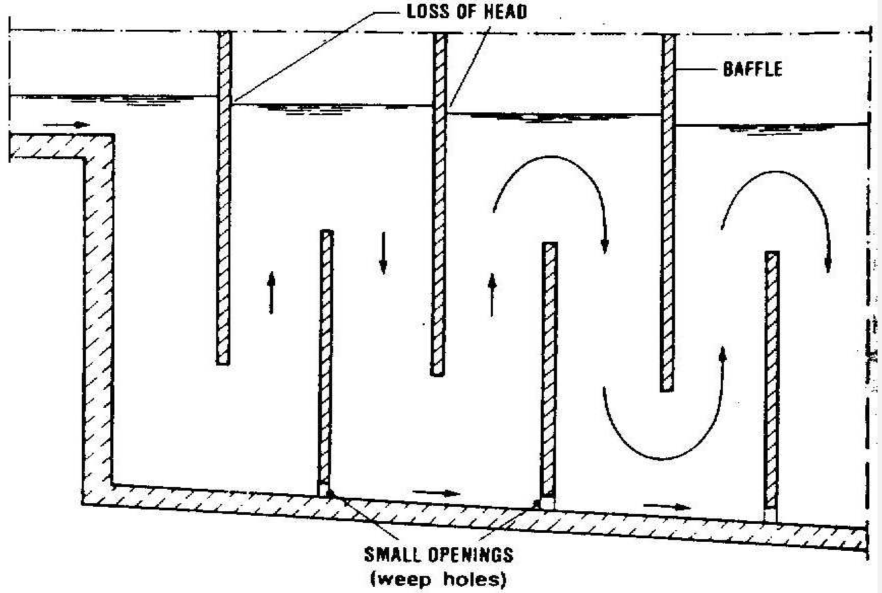


Figure 6.3. Vertical-flow baffled channel flocculator (cross-section). *Source:* IRC, 1981b.

Ref: Schulz & Okun, 1984, John Wiley & Sons

Mixing is accomplished by reversing the flow of water through channels formed.

a) Around-the-end (horizontal flow) baffles
b) Over-and-under (vertical flow) baffles

F) Static Mixers

contain internal vanes or orifice plates
that bring about sudden changes
in the velocity pattern

→are identified by their lack of moving parts

→mixing occurs in a plug-flow regime

→the longer the mixing element

the better the mixing

however headloss increases

Mixing time is quite short
typically less than 1 sec.

FLUID MECHANICS

Angled vanes promote turbulance

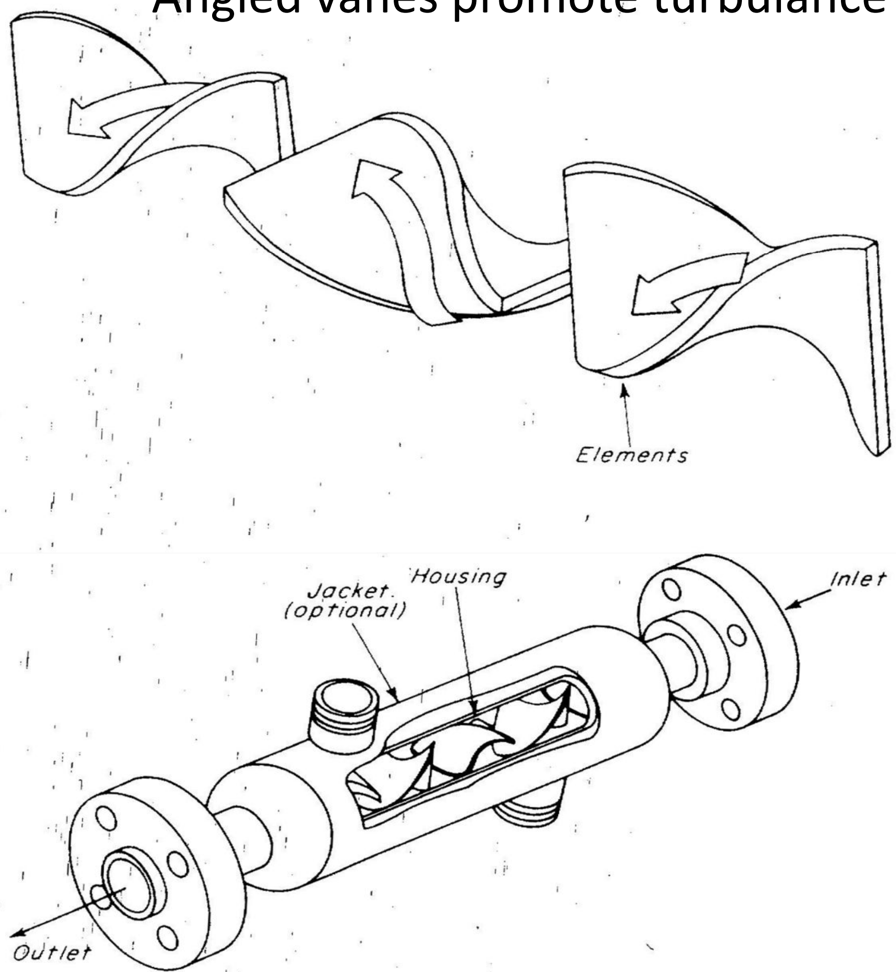


FIGURE 9-19
Static mixer unit. [*STATIC MIXER is a registered Trademark © of Kenics Corporation, N. Andover, Mass.*]

In-line Mixers → similar to static mixers
but contain a rotating mixing element to enhance the mixing.

Mechanical Mixing Devices

Turbine and Propeller Mixers

Reynolds number for impellers $R_e = \dfrac{D^2 n \rho}{\mu}$

D = diameter of impeller , m

n = rev/sec

ρ = density of liquid , kg/m^3

μ = dynamic viscosity Ns/m^2

R = reynolds number (unitless)

Reynolds number : $Re < 10$ ⟶ laminar

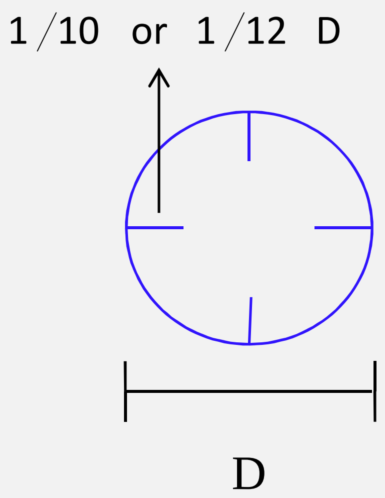
$Re > 1000$ ⟶ turbulent

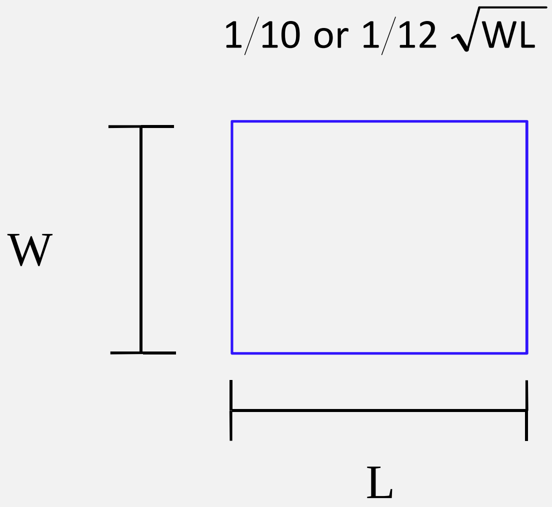
Vortexing :

→ Liquid to be mixed rotates with the impeller

→ Reduction in the difference between the fluid velocity and the impeller velocity (effectiveness of mixing decreases)

<u>In circular or rectangular tanks the usual method used to limit vortexing</u>.
To install 4 or more vertical baffles extending approximately 1/10th the diameter out from the wall.





Power imparted in an unbaffled tank = 1/6 of the power imparted in the same tank with baffles

Power imparted in an unbaffled square tank = 75% of the power imparted in a baffled square or a baffled circular tank.

Power in a baffled vertical square tank } Power in a baffled vertical circular tank having D=width of square tank

In small tanks (to prevent vortexing):

→Mounting the impeller off-center

→Mounting the impeller at angle with verticle

→Mounting the impeller to the side of basins at angle

Turbine or propeller mixers are usually constructed with a vertical shaft driven by a speed reducer and electric motor.

Types of Impellers :

1. Radial flow impellers

   Generally have flat or curved blades located parallel to the axis of shaft.

2. Axial flow impellers

   Make an angle of less than 90^{o} with drive shaft.

Turbine and Propeller Mixers (continue)

Laminar flow

for Re<10

Developed by Rushton

$$P = k \mu n^2 D^3$$

- P: Power (watt)
- k: Impeller constant
- μ: Dynamic viscosity $\frac{Ns}{m^2}$
- n: Revolutions per second rev/sec
- D: Diameter of impeller (m)

Power imparted in either **baffled** or **unbaffled** tank

Turbine and Propeller Mixers (continue)

Turbulent flow
(for Re>10000)

$$P = k \rho n^3 D^5$$

Power (watt) $\frac{Nm}{sec}$

Impeller constant

Density kg/m^3

Revolutions per second rev/sec

Diameter of impeller (m)

Power imparted in a <u>baffled</u> tank

Turbine and Propeller Mixers (continue)

Ref: Metcalf Eddy,1991 , McGraw Hill

TABLE 6-7
Values of *k* for mixing power requirements [16]

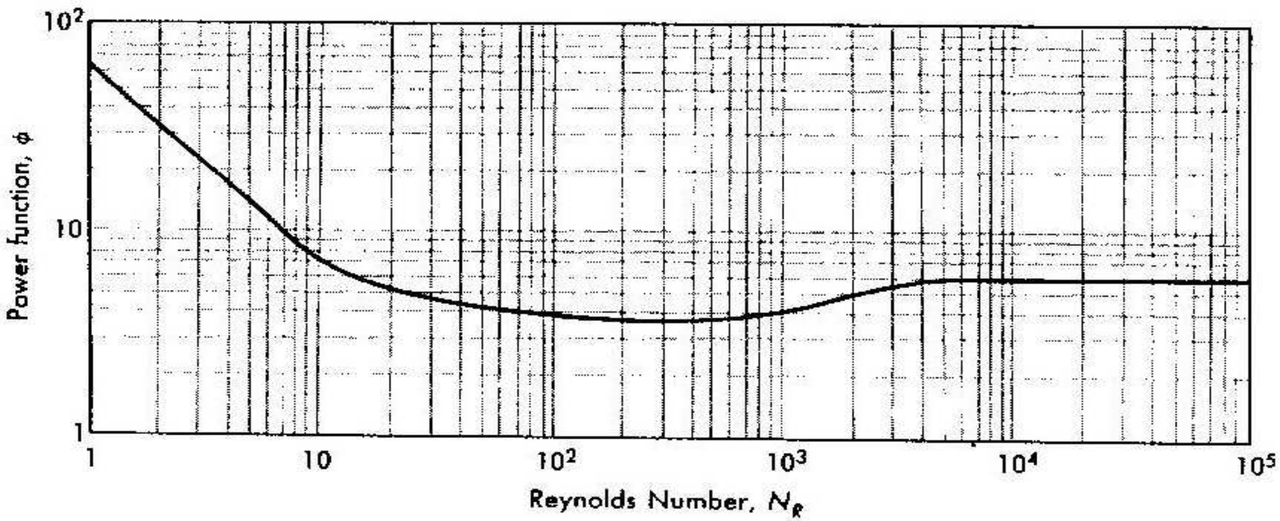
Impeller	Laminar range, Eq. 6-5	Turbulent range, Eq. 6-6
Propeller, square pitch, 3 blades	41.0	0.32
Propeller, pitch of two, 3 blades	43.5	1.00
Turbine, 6 flat blades	71.0	6.30
Turbine, 6 curved blades	70.0	4.80
Fan turbine, 6 blades	70.0	1.65
Turbine, 6 arrowhead blades	71.0	4.00
Flat paddle, 6 blades	36.5	1.70
Shrouded turbine, 2 curved blades	97.5	1.08
Shrouded turbine with stator (no baffles)	172.5	1.12

Table 2.2. Values of Constants K_L and K_T in Eqs. (**2.12**) **and** (2.13) for Baffled Tanks Having Four Baffles at **Tank** Wall, with Width Equal to 10 Percent of the Tank Diameter

Ref: Reynolds/Richards 2nd Edition, 1982

Type of Impeller	K_L	K_T
Propeller, pitch of 1, 3 blades	41.0	0.32
Propeller, pitch of 2, 3 blades	43.5	1.00
Turbine, 4 flat blades, vaned disc	71.0	6.30
Turbine, 6 flat blades, vaned disc	71.0	6.30
Turbine, 6 curved blades	70.0	4.80
Fan turbine, 6 blades at 45°	70.0	1.65
Shrouded turbine, 6 curved blades	97.5	1.08
Shrouded turbine, with stator, no baffles	172.5	1.12
Flat paddles, 2 blades (single paddle), $D_i/W_i = 4$	43.0	2.25
Flat paddles, 2 blades, $D_i/W_i = 6$	36.5	1.60
Flat paddles, 2 blades, $D_i/W_i = 8$	33.0	1.15
Flat paddles, 4 blades, $D_i/W_i = 6$	49.0	2.75
Flat paddles, 6 blades, $D_i/W_i = 6$	71.0	3.82

From: (1) "Mixing of Liquids in Chemical Processing" by J. H. Rushton. In *Industrial and Engineering Chemistry* 44, no. 2 (December 1952): **2931**, copyright 1952, American Chemical Society; and (2) "Mixing—Present Theory and Practice" by J. H. Rushton and J. Y. Oldshue. In *Chemical Engineering Progress* 46, no. 4 (April 1953): 161. Reprinted by permission.



Ref: Tchobanoglous and Scroeder, 1985, Addison-Wesley Publishing Company

FIGURE 12.9

Mixing power function curve for standard tank configuration shown in Fig. 12.8.

Source: Adapted from Ref. [12.23].

Power imparted in an <u>unbaffled tank</u> (valid for laminar and turbulent flow)

$\phi =$ Power function dimensionless = $\frac{P}{\rho N^3 D^5}$

$\phi = k R_e^p$

k= constant of an impeller $\propto$ tank geometry

P= -1 (for laminar)

P= 0 (for turbulent)

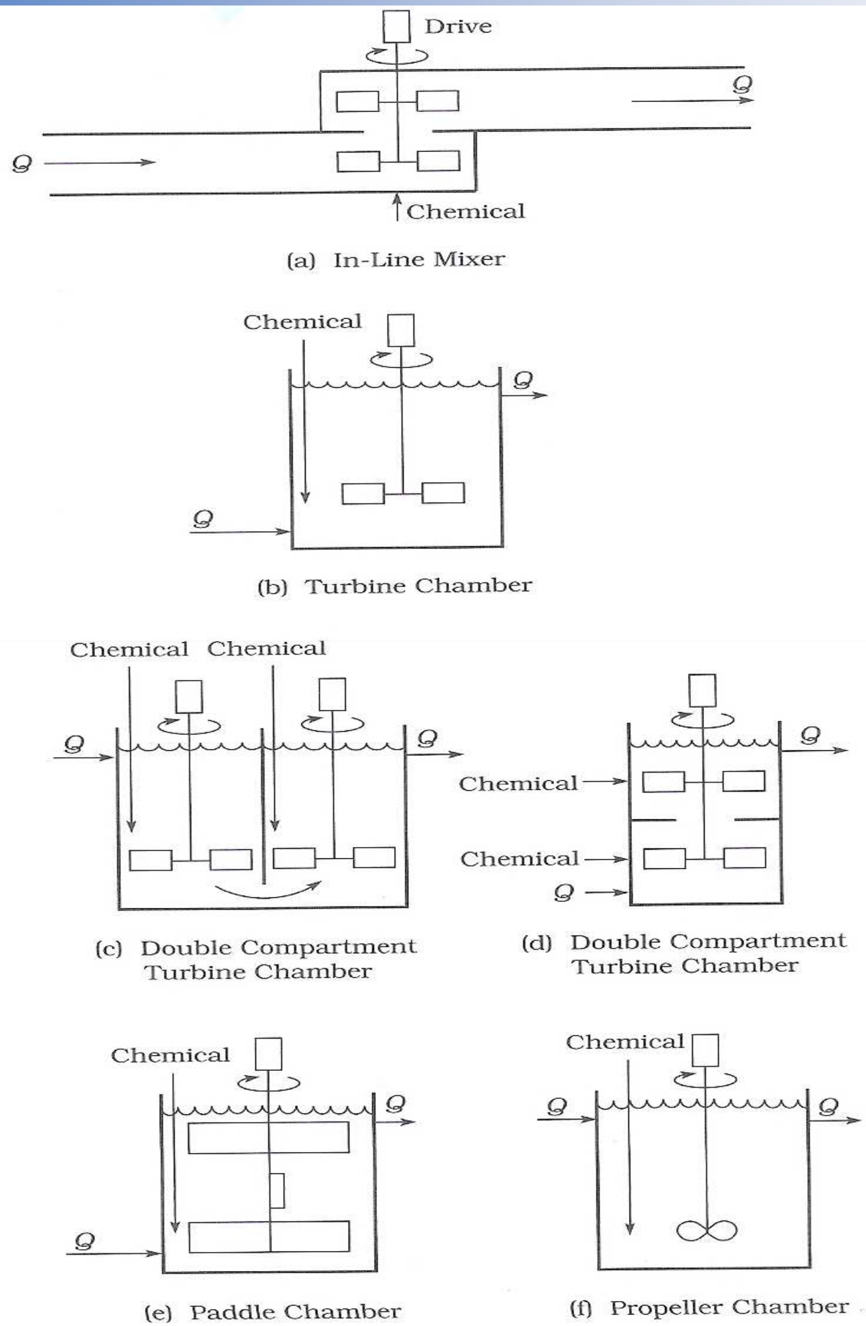


FIGURE 8.9
...ing Devices

Ref: Reynolds/Richards 2nd Edition

Types of Propeller Impellers

Figure 2.11. Types of Propeller Impellers
Adapted from *Unit Operations of Chemical Engineering* by W. L. McCabe and J. C. Smith. Copyright © 1976 by McGraw-Hill Book Co., Inc. Reprinted by permission. Ref: Reynolds/Richards 2nd Edition

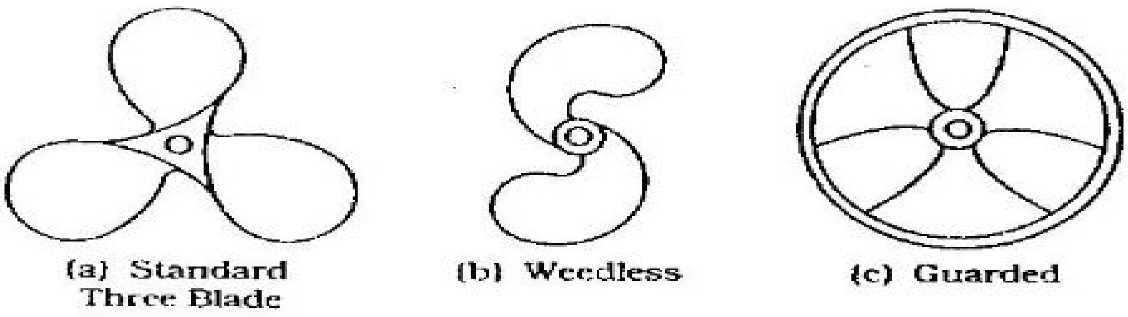
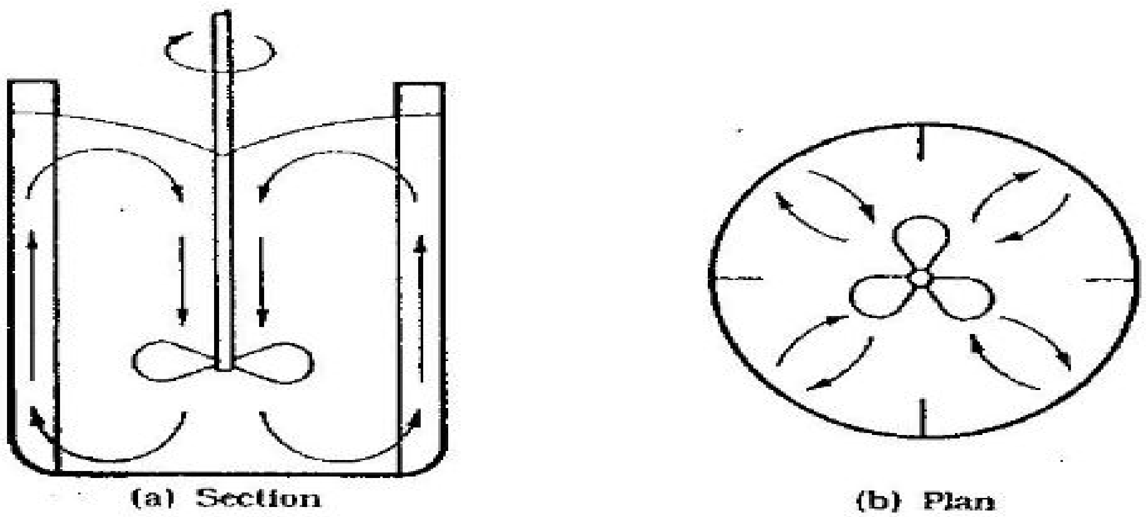


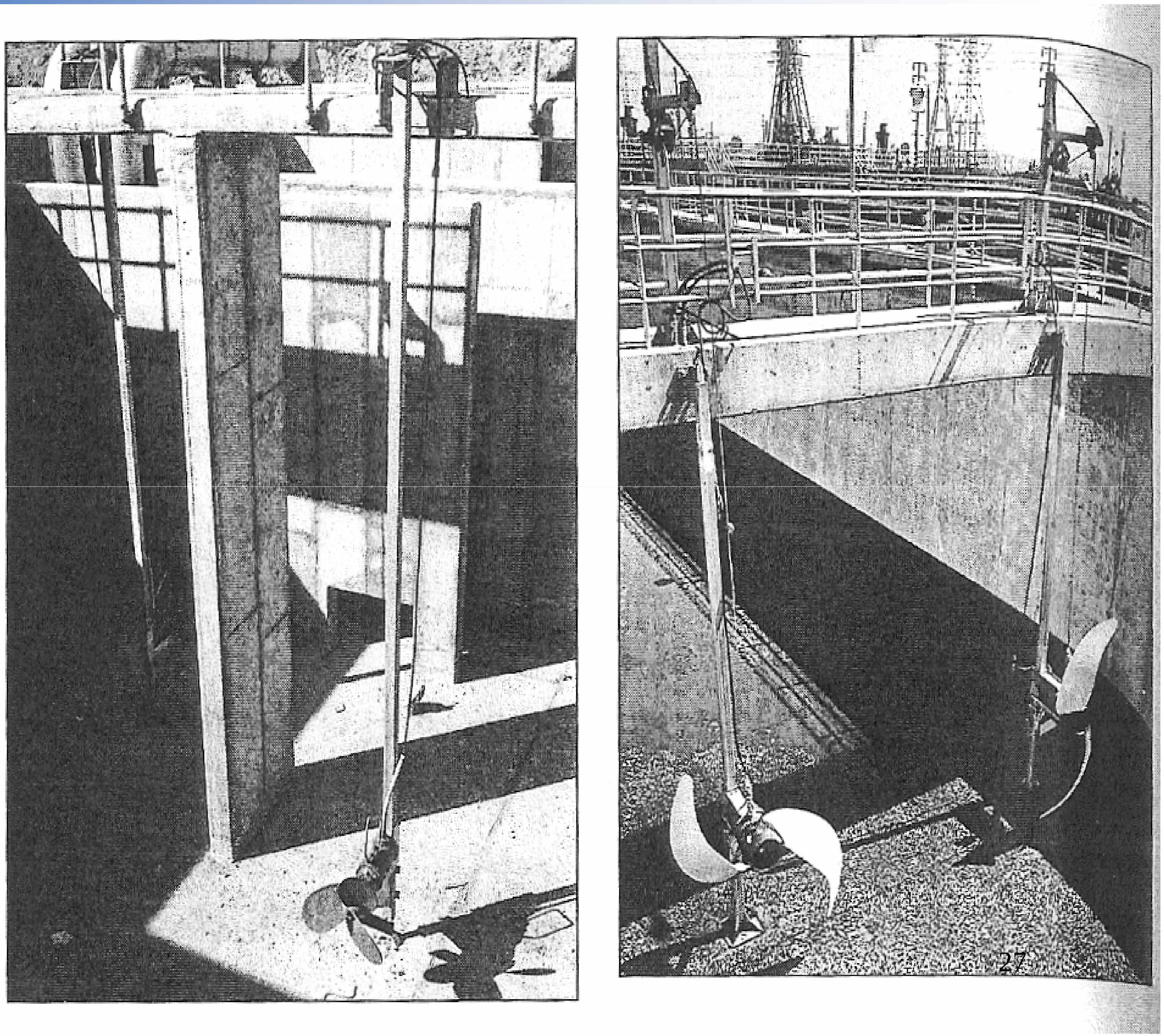
Figure 2.12. Flow Regime in a Propeller-Impeller Tank
Adapted from "Mixing—Present Theory and Practice: Parts I and II," by J. H. Rushton and J. Y. Oldshue. In *Chemical Engineering Progress* 46, no. 4 (April 1953):161; and 49, no. 5 (May 1953):267. Ref: Reynolds/Richards 2nd Edition



Propeller Mixer

Submerged propeller mixers used to mix the contents of an anoxic reactor.

Ref: Metcalf Eddy,1991, McGraw Hill



Propeller Mixer

Ref: http://screw-jack.en.made-in-china.com/product/kqNmSdnCrHWR/China-Propeller-Shaft-Mixers.html

Types of Turbine Impellers

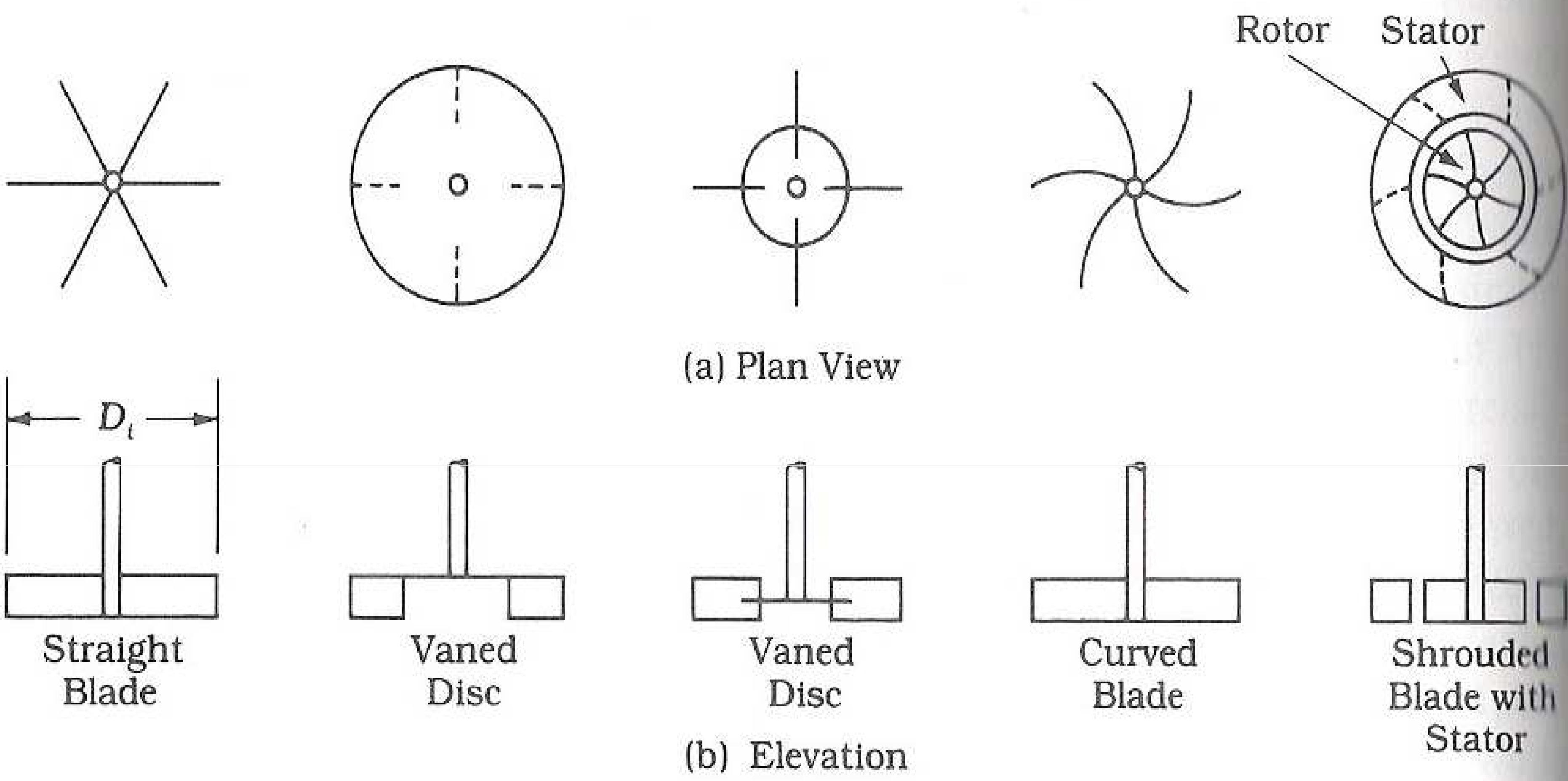


FIGURE 8.10 *Types of Turbine Impellers* Ref: Reynolds/Richards 2nd Edition

Adapted from *Unit Operations of Chemical Engineering* by W. L. McCabe and J. C. Smith. Copyright © 1976 by McGraw-Hill, Inc. Reprinted by permission.

Types of Turbine Impellers

Figure 5–15

Typical impellers used for mixing in wastewater-treatment facilities: (*a*) disk-type radial-flow impeller, (*b*) axial-flow pitched (typically 45°) blade impeller, (*c*) axial-flow hydrofoil-type impeller, and (*d*) propeller mixer. Note: The flat blade radial-flow turbine mixer looks like the axial-flow impeller (*b*) with the exception that the blades are set parallel to the axis of the shaft.

Ref: Metcalf Eddy,1991 , McGraw Hill

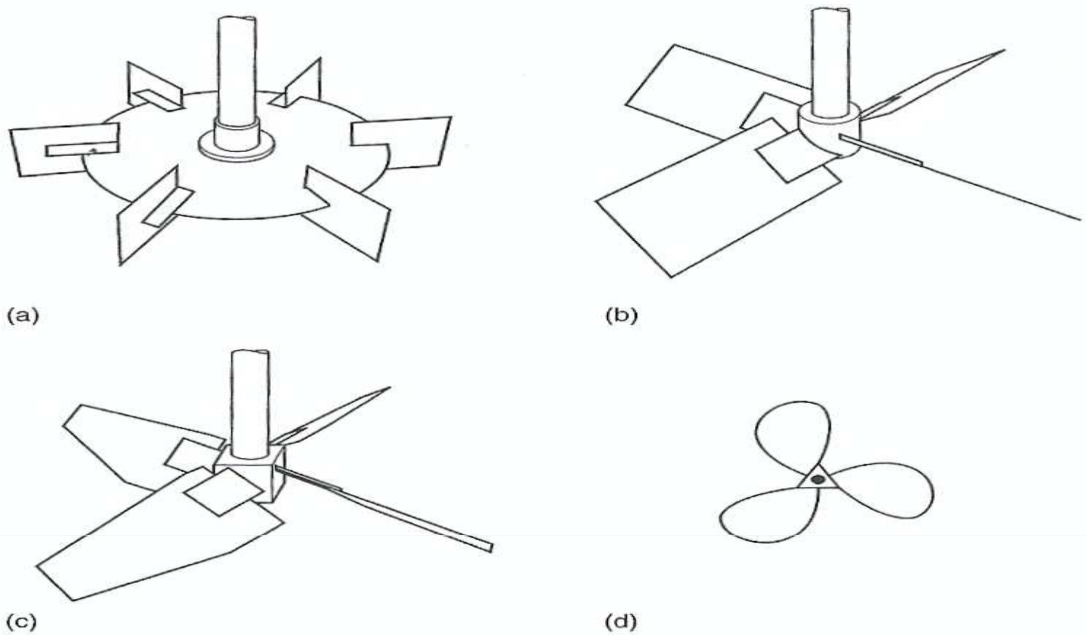


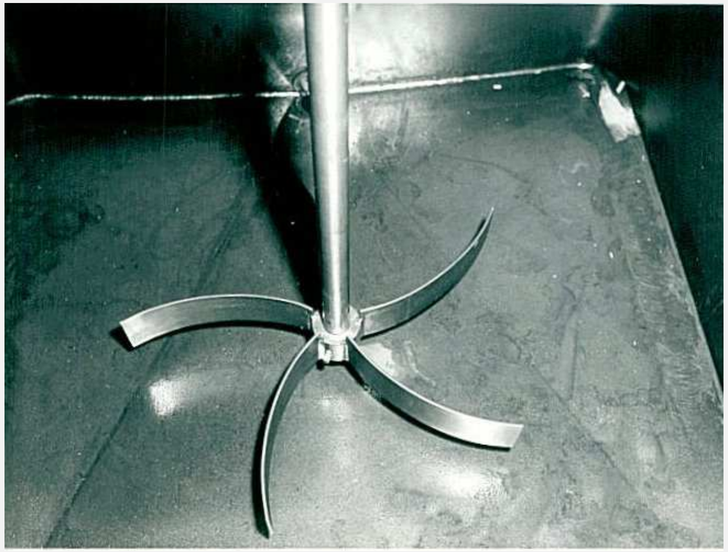
Table 5–11

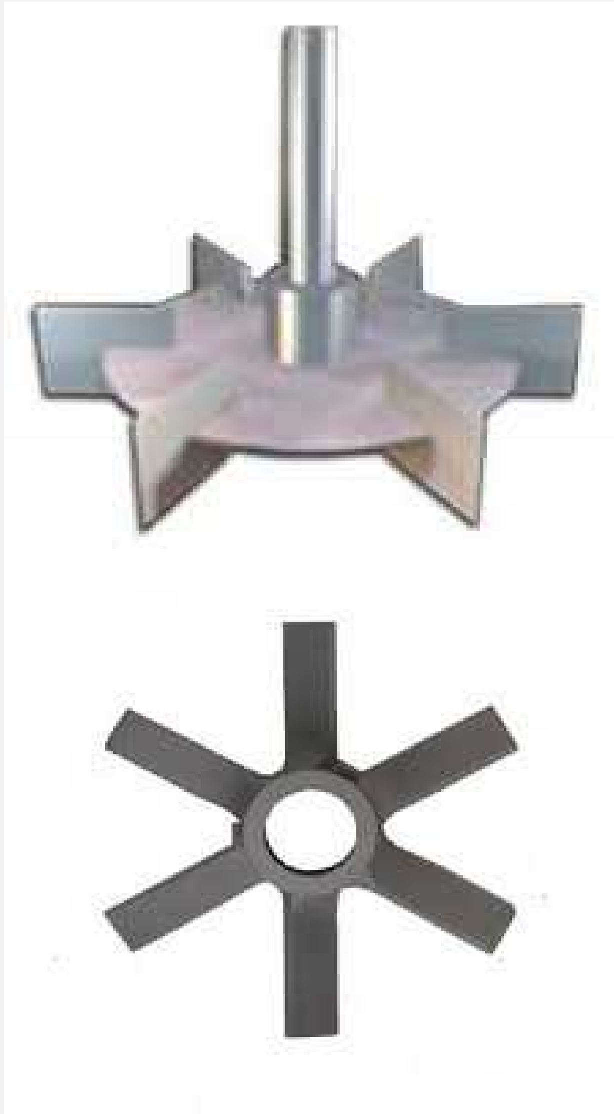
Typical types of mixing impellers used in wastewater treatment[a] Ref: Metcalf Eddy,1991 , McGraw Hill

Type of impeller	Flow	Shear	Pumping capacity	Applications
Vertical flat blade turbine (VFBT)	Radial	High	Low	Vertical-flow flash mixing, suspension of solids, gas dispersion
Disk turbine	Radial	High	Low	Mixing, gas dispersion
Surface impeller	Radial	High	Moderate	Gas transfer
Pitched-blade turbine (45 or 32° PBT)	Axial	Moderate	Moderate	Horizontal flash mixing, suspension of solids
Low-shear hydrofoil (LS)	Axial	Low	High	Horizontal-flow flash mixing, suspension of solids, blending, flocculation
Propeller	Axial	Very low	High	Horizontal-flow flash mixing, suspension of solids, blending, flocculation

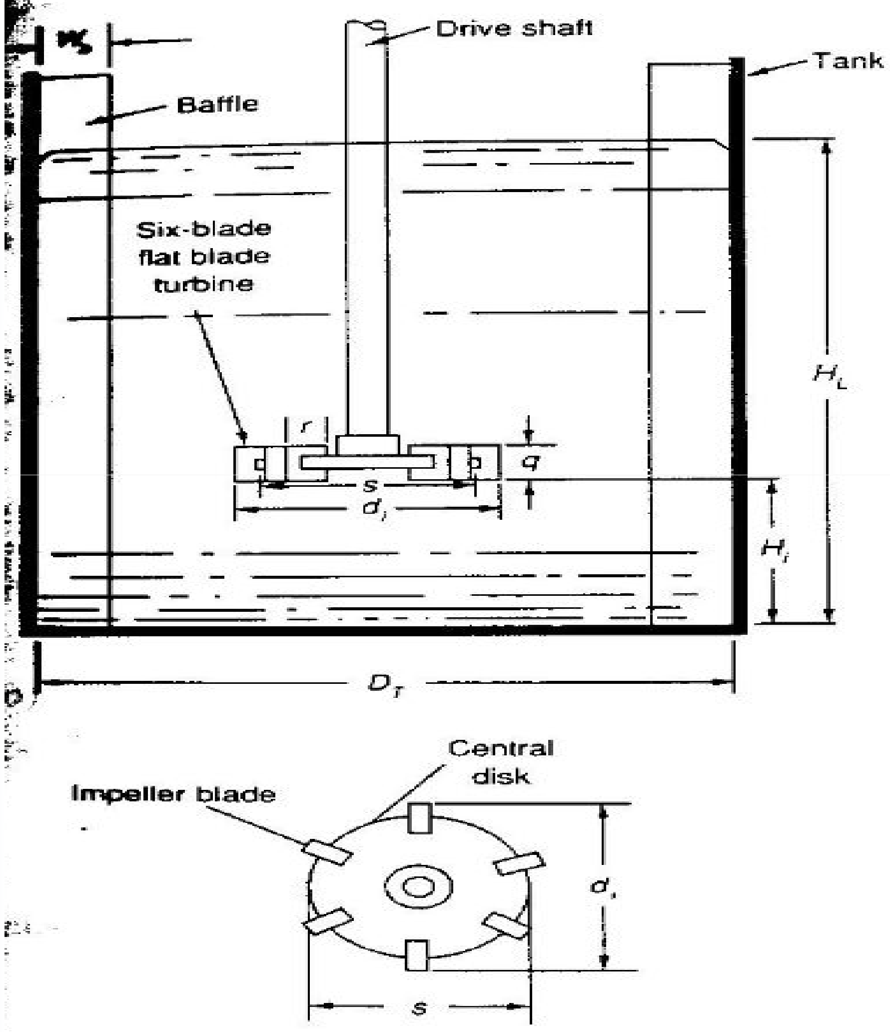
[a] Adapted, in part, from Philadelphia Mixer Catalog.

Types of Turbine Impellers





Turbine Mixer in a Baffled Tank



Notes: 1. The agitator is a six-blade flat turbine impeller
2. Impeller diameter, d_i = 1/3 tank diameter
3. Impeller height from bottom, H_i = 1.0 impeller diameter
4. Impeller blade width, q = 1/5 impeller diameter
5. Impeller blade length, r = 1/4 impeller diameter
6. Length of impeller blade mounted on the central disk = r/2 = 1/8 impeller diameter
7. Liquid height, H_L = 1.0 tank diameter
8. Number of baffles = 4 mounted vertically at tank wall and extending from the tank bottom to above the liquid surface
9. Baffle width, W_b = 1/10 tank diameter
10. Central disk diameter, s = 1/4 tank diameter

Source: Adapted from Ref. 16

URE 6-7 (Ref: Tchobanoglous and Scroeder, 1985, Addison-Wesley Publishing Company)
inition sketch for turbine mixer in baffled tank.

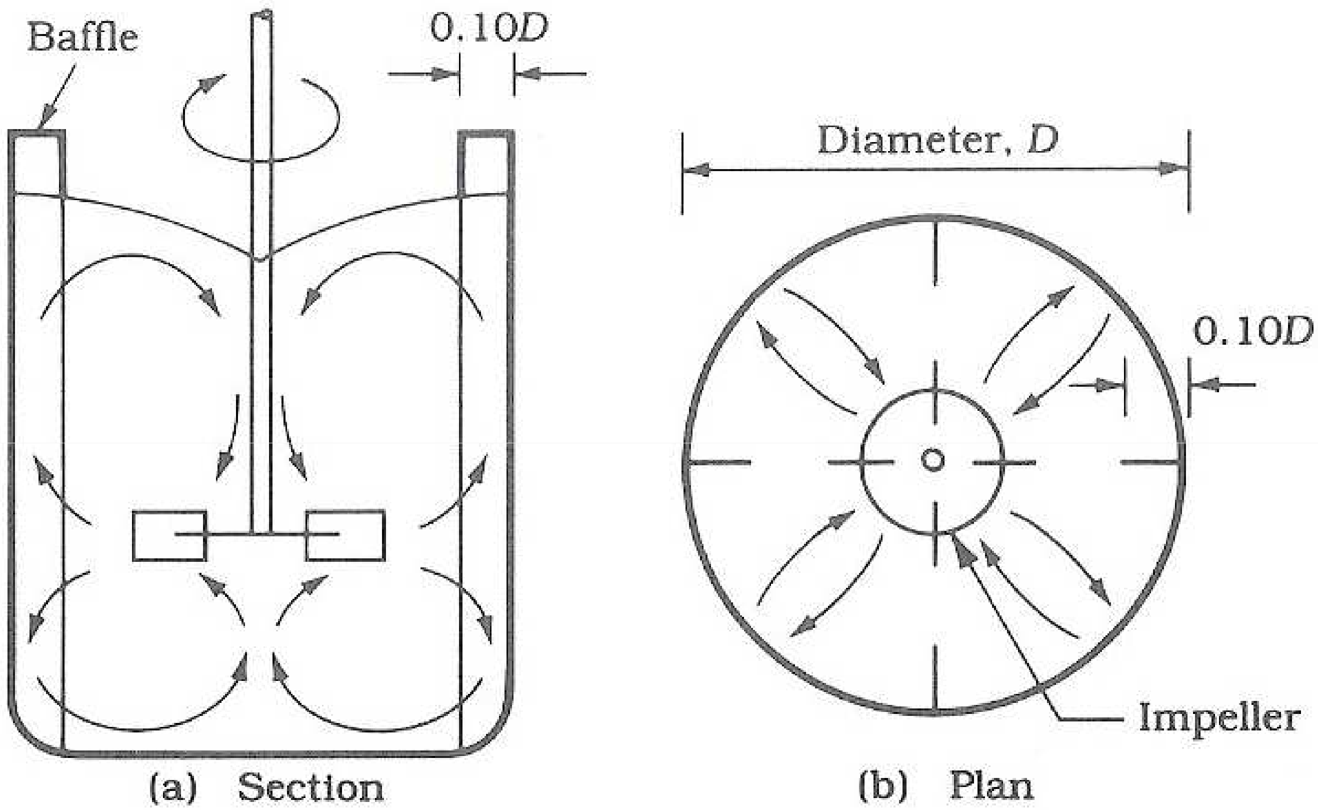


FIGURE 8.11 *Flow Regime in a Turbine-Impeller Tank*

Adapted from "Mixing — Present Theory and Practice: Parts I and II" by J. H. Rushton and J. Y. Oldshue. In *Chemical Engineering Progress* 46, no. 4 (April 1953):161; and 49, no. 5 (May 1953):267. Reprinted by permission. Ref: Reynolds/Richards 2nd Edition

Example:

Determine the power requirements for 3 m diameter, six-blade flat-blade turbine impeller mixer running at 15 rpm in a 10 m diameter mixing tank. Assume the fluid being mixed is water.

$$(T = 15^0 C \;,\; \mu = 1.139 Ns/m^2 , \rho = 999.1 kg/m^3)$$

Padddle Mixers

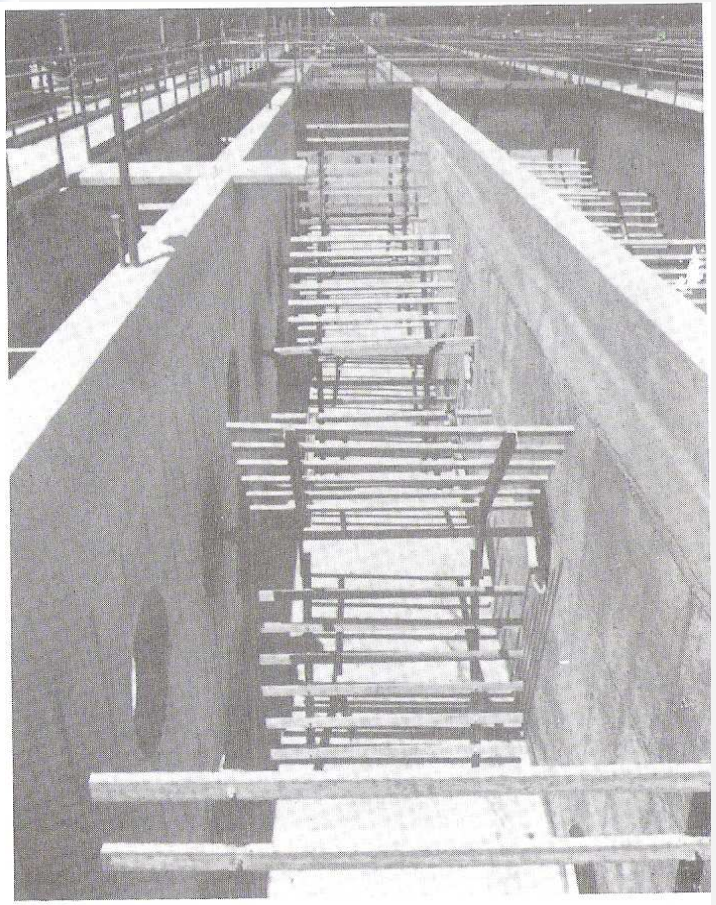


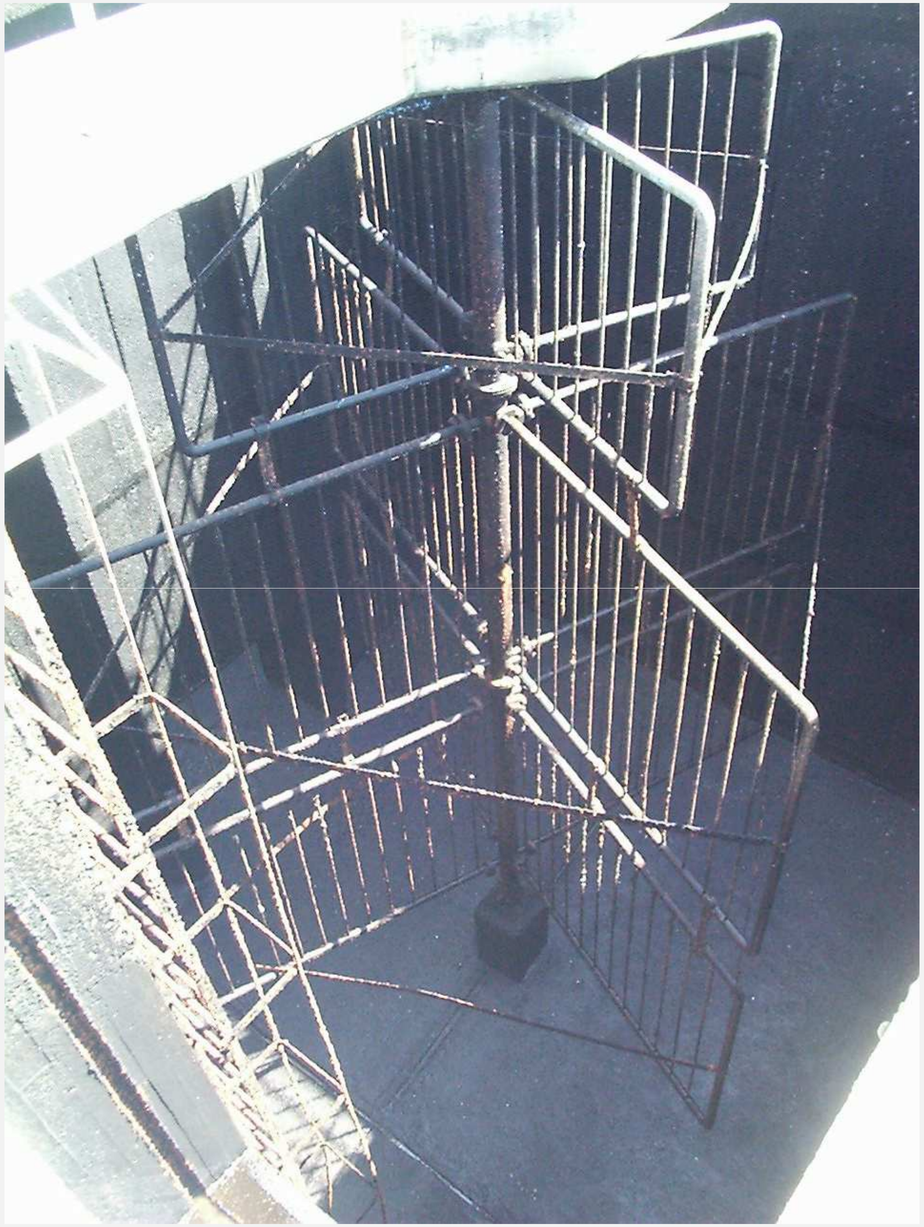
FIGURE 8.1 *A Three-Compartment Paddle-Wheel Flocculation Basin at a Water Treatment Plant. Note that the flow is parallel to the paddle-wheel shafts, as shown in Figure 8.20. The flow passes through the orifices in the walls. Tapered flocculation is provided by varying the size of the compartments and the number and length of the blades on the paddle wheels.*

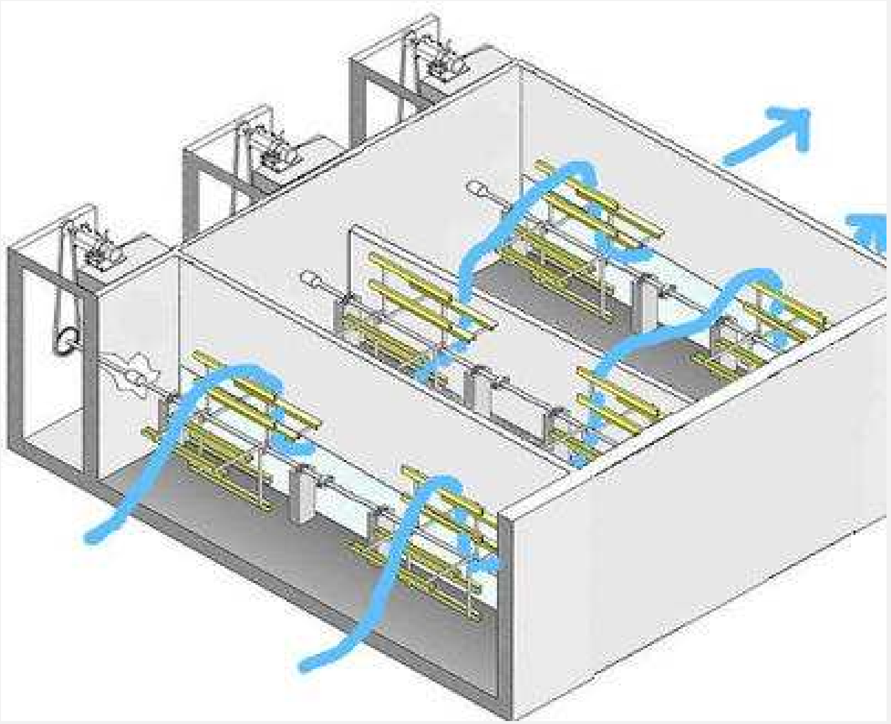
Ref: Reynolds/Richards 2nd Edition

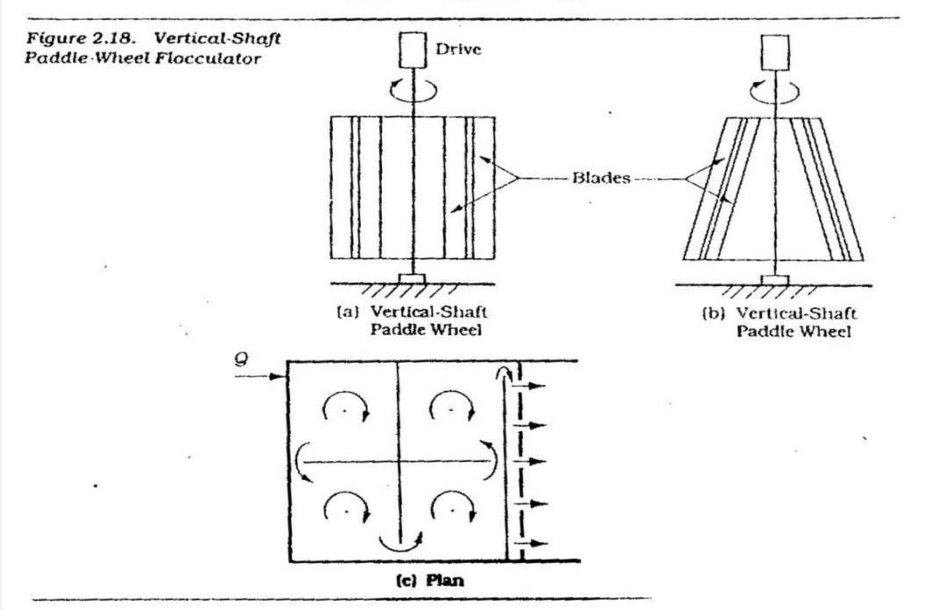
consists of a series of appropriately spaced paddles mounted on either a horizontal or vertical shaft

generally rotate slowly

are commonly used as flocculation devices







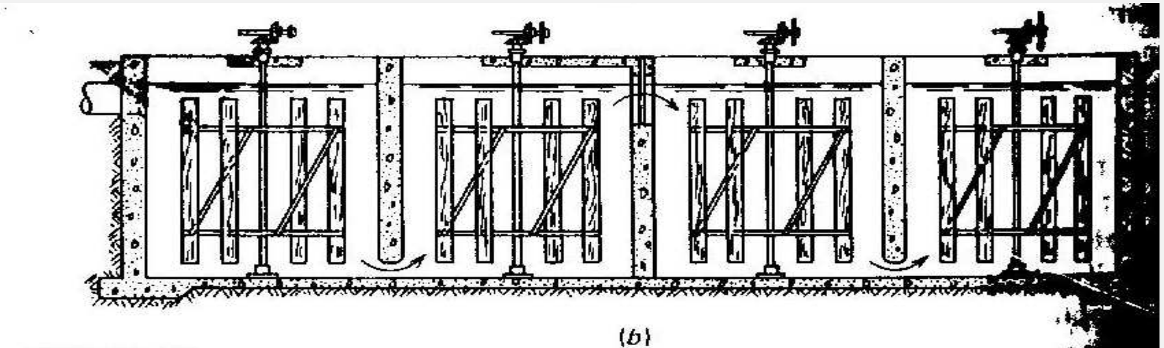


FIGURE 9-9
Flocculation basins. (*a*) (*b*) vertical paddles.

Paddle Impellers

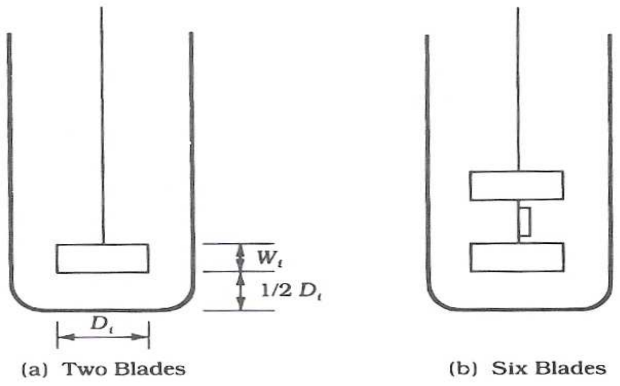


FIGURE 8.12 *Types of Paddle Impellers*

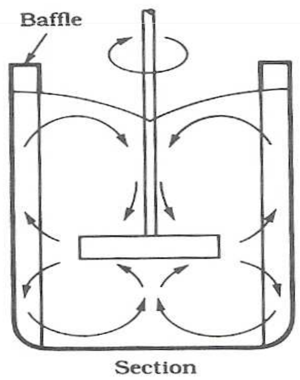
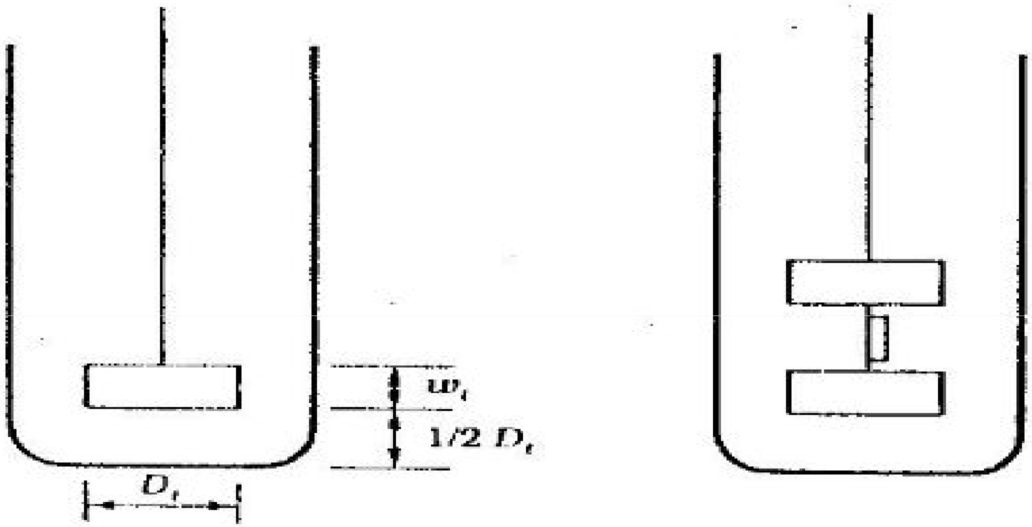


FIGURE 8.13 *Flow Regime in a Paddle-Impeller Tank*

Ref: Reynolds/Richards 2nd Edition

Paddle Impellers

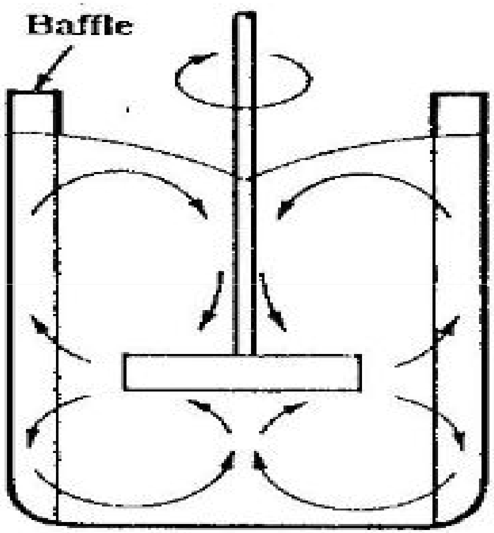
Figure 2.9. Types of Paddle Impellers Ref: Reynolds/Richards 2nd Edition



(a) Two Blades

(b) Six Blades

Figure 2.10. Flow Regime in a Paddle-Impeller Tank
Ref: Reynolds/Richards 2nd Edition



Section

POWER IMPARTED TO THE WATER BY PADDLE → Newton's Law for the drag force exerted by a submerged object moving in a liquid.

$$F_D = \frac{C_D A \rho V_p^2}{2}$$

$F_D = \text{Drag force (1bf or N)}$

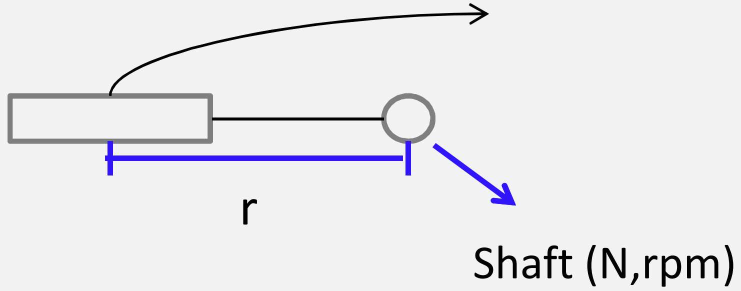
$C_D = \text{Drag coefficient}$

A=Cross-sectional area of paddle $(ft^2 \text{ or } m^2)$
(paddle-blade area at right angle to the direction of movement)

$\rho = \text{Density of fluid } (\frac{slug}{ft^3} \text{ or } \frac{kg}{m^3})$

Vp=Relative velocity of paddles with respect to water.

$$\left\{ \begin{array}{l} 0.6 - 0.75\ V_{paddle\ tip} \\ V_{paddle\ tip} = 2\text{-}3\ ft/sec\ (0.6\text{-}0.9 m/sec) \end{array} \right\}$$



Velocity of paddle (paddle tip velocity)

$$\frac{2\pi N}{60} r \rightarrow \text{m/sec}$$

1min/60sec

Distance from shaft to paddle center(m)

A=Cross-sectional area of paddle (ft^2 or m^2) (paddle-blade area at night angle to the direction of movement)

$$P = F_D V_P = \frac{C_D A \rho V_P^3}{2}$$

Power Force Velocity

ρ = Density of fluid ($\frac{slug}{ft^3}$ or $\frac{kg}{m^3}$)

Vp=Relative velocity of paddles with respect to water.

C_d=Drag coeff.

THE DRAG COEFFICIENT (Cd) → depends basically on the geometry of the paddle

L/W ratio	*C_D*
5	1.20
20	1.5
∞	1.90

Example:

Determine the theoretical power requirement and the paddle area required to achieve a G value of 50 sec^{-1} in a tank with a volume of 2832 m^3.

(Water temperature = $15^0C \rightarrow \rho = 999.5 \frac{kg}{m^3}$ $\mu = 1.139.10^{-3} \frac{N sec}{m^2}$)

C_D=for rectangular paddle =1.8

Paddle tip velocity= 0,6m/sec

Relative velocity of paddle = 0,75 $V_{paddle\ tip}$

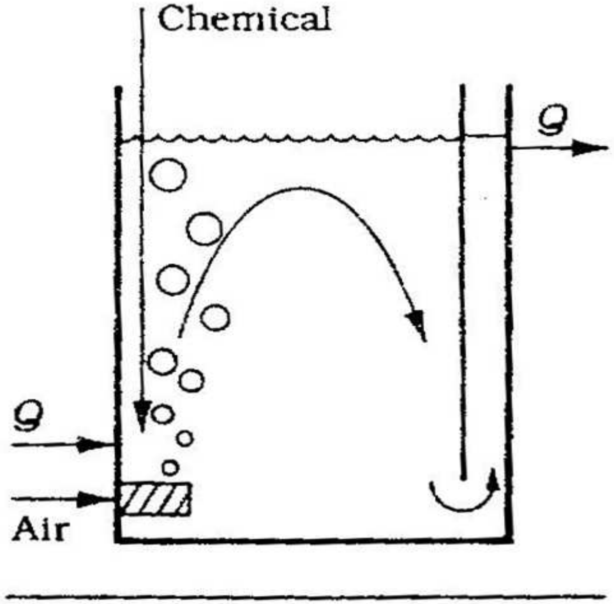
Pneumatic Mixers

When air is injected in mixing tank, power dissipated by the rising air bubbles can be estimated as:

$$P = 35.28\, Q_a \mathrm{Ln}\left(\frac{h + 33.9}{33.9}\right)$$ US customary units

$$P = 1.689\, Q_a \mathrm{Ln}\left(\frac{h + 10.33}{10.33}\right)$$ SI units

Figure 2.13. Ref: Reynolds/Richards 2nd Edition
Pneumatic Rapid Mixing



P=power dissipated (ft.Ib/sec OR kW)

Qa=air flow rate at operating temperature and pressure (ft^3/min or m^3/min)

H=depth to the diffusers in meters of water (air pressure at the point of discharge) (ft or m)

Application of pneumatic mixing:

- → to provide oxygen and to maintain mixed liquor necessary for aerobic bacteria in biological treatory
- → to keep bacteria in suspension in biological treatment.

Example:

A pneumatic mixing basin with a volume of 6200 ft^3 is to be designed to provide G value of 60 sec^{-1}. Assume that the basin depth is to be 12ft and air will be released into the basin 0,5ft above the tank bottom.

(Temp= 60°F → $\mu = 2.359.10^{-5} \frac{1bf.sec}{ft^2}$)

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Pneumatic Rapid Mixing