ENVE 301
Environmental Engineering Unit Operations

Lecture 7
Mixing

SPRING 2014

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Mixing

- Mixing liquids is used to:
  - Blending of two immiscible liquids (ethyl alcohol/water)
  - Dissolving solids in liquids
  - Dispersing a gas in a liquid as fine bubbles
  - Agitation of the fluid to increase heat transfer
- Mixing in water treatment is used to:

  achieve coagulation
  - achieve flocculation

Mixing Chemicals in Water Treatment

- Coagulation
  - Coagulants
- Disinfection
  - Chlorine contact chamber (Chlorine is mixed with water)
  - Ozone contact chamber (Ozone is mixed with water)

Mixing

- Mixing can occur in following locations;
  - Water intake (Pumps, pipes)
  - Flash mix tanks
  - Flocculation tanks
  - Other

Mixing

- Three phenomena contribute to mixing;

1) Molecular diffusion

Diffusion: Random motion of molecules from high concentration to low conentration

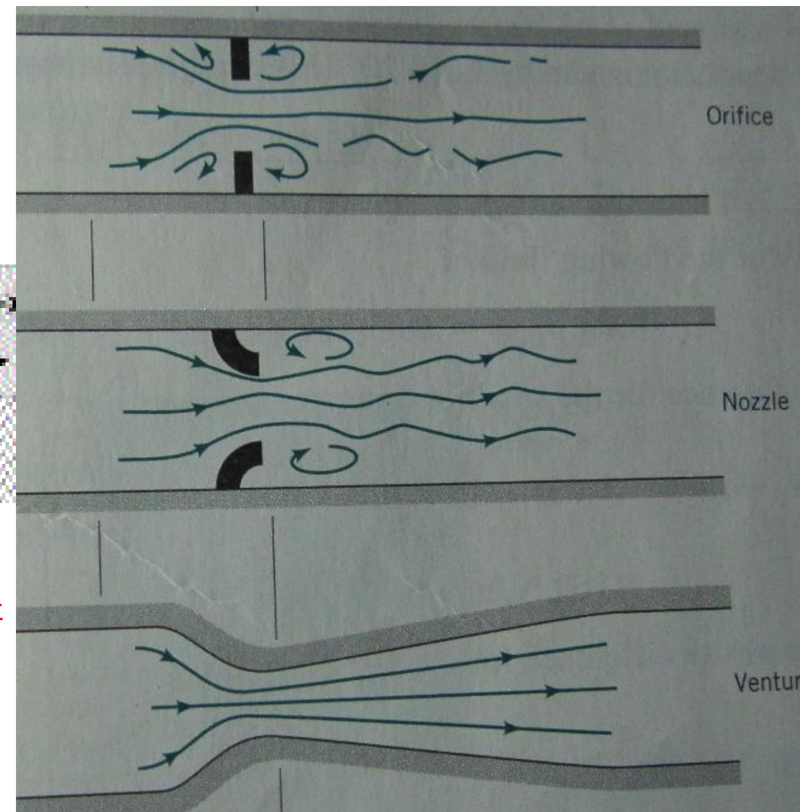
Molecular Diffusion: Moving molecules self propelled by thermal energy, not affected by concentration (Brownian motion)

Ref: http://webworld.unesco.org/water/ihp/db/glossary/glu/EN/GF0330EN.HTM

Mixing

- Three phenomena contribute to mixing;

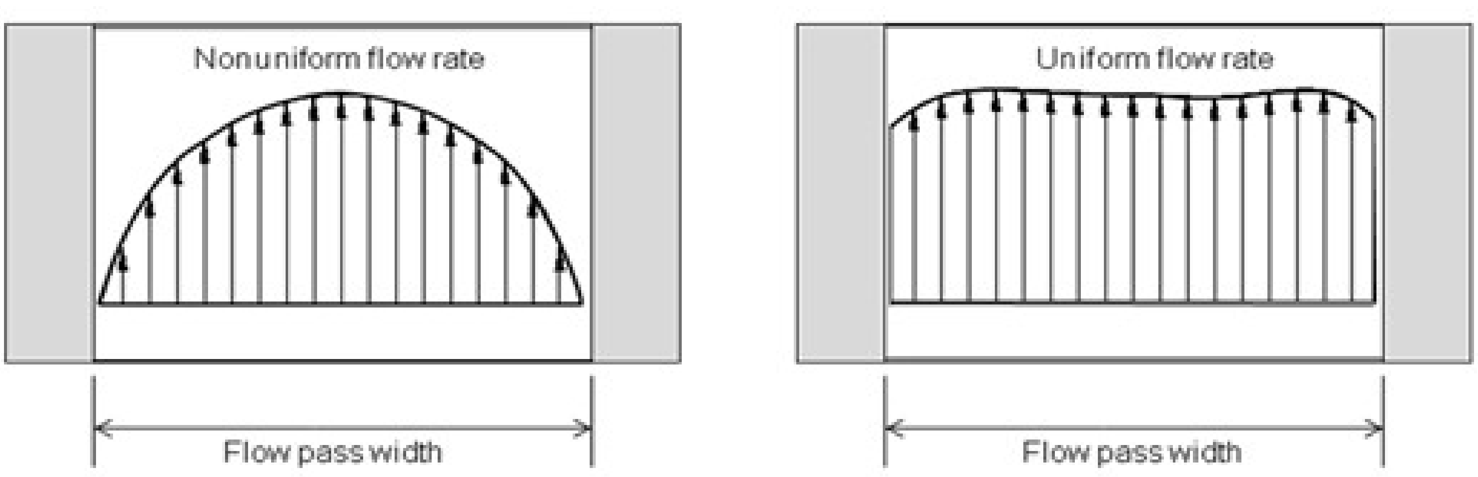
2) Eddy Current (Circular flow): Water flows opposite to the original flow (whirlpools – function of a degree of turbulance)



Ref:
http://ohiodnr.com/water/pubs/fs_st/stfs20/tabid/4175/Default.aspx
Munson BR, Young DF, Okiishi TH. Fundamentals of Fluid Mechanics. 1998.ISBN: 0-471-17024-0

Mixing

3) Non-uniform flow: At any given time, velocity is not same at every point of the flow.



Ref: http://en.engormix.com/MA-aquaculture/articles/aquafeed-extrusion-t1669/p0.htm

Factors that affect mixing

- Number of particles
- Size of particles
- Mixing time
- Water temperature
- Chemical dosage

Mixing

- Power input per unit volume of liquid can be used as a rough measure of mixing effectiveness.
- More input power creates more turbulence, and greater turbulence leads to better mixing
- Power imparted to the water can also be measured by the **Velocity Gradient** (Camp, 1955)

Velocity Gradient (G) for mechanical or pneumatic mixing

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

Velocity gradient →Ratio of relative velocity of two particles to the distance between the particles

- Rate of particulate collision is proportional to G
- G must be sufficient enough to achieve desired rate of collisions

P: Power imparted to the water (Nm/s OR W)

μ: Absolute viscosity of water (Ns/m^2)

V: Basin volume (m^3)

G: Velocity gradient (s^{-1})

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Example -1

- Two particles moving 1.5 m/sec relative to eachother at a distance of 0.05 m would have a velocity gradient of :

$$G = \frac{1.5\ m/s}{0.05\ m} = 30\ s^{-1}$$

Velocity Gradient (G) for baffle basin

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

γ: specific weight of water (kgm^2/s^2 OR kN/m^3)

μ: Absolute viscosity of water (Ns/m^2)

h_L: head loss (m)

T: detention time (s)

G: Velocity gradient (s^{-1})

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Mixers

1) **Hydraulic mixing devices**
   a) Venturi sections, Orifices
   b) Hydraulic jumps
   c) Parshall flume
   d) Weirs
   e) Baffled mixing devices
   f) Static mixers
2) **Mechanical mixing devices**
   a) Propeller mixer
   b) Turbine mixer
   c) Paddle mixer
3) **Pneumatic mixers**
   a) Air diffusers

Hydraulic Mixers

- Principally identified by their lack of moving parts.
- In-line mixers are commonly used for the mixing of chemicals
- Over and under baffle channels are used for flocculation
- Degree of turbulence is measured by the loss in head

Power dissipation in a hydraulic mixer;

$$P = \gamma Q h_L = \rho g Q \Delta h_L$$

γ=specific weight of water (kgm^2/s^2 OR kN/m^3)
ρ=density of water (kg/m^3)
g=gravitational acceleration (m/s^2)
Q=flow rate (m^3/s)
hL=headloss (m)

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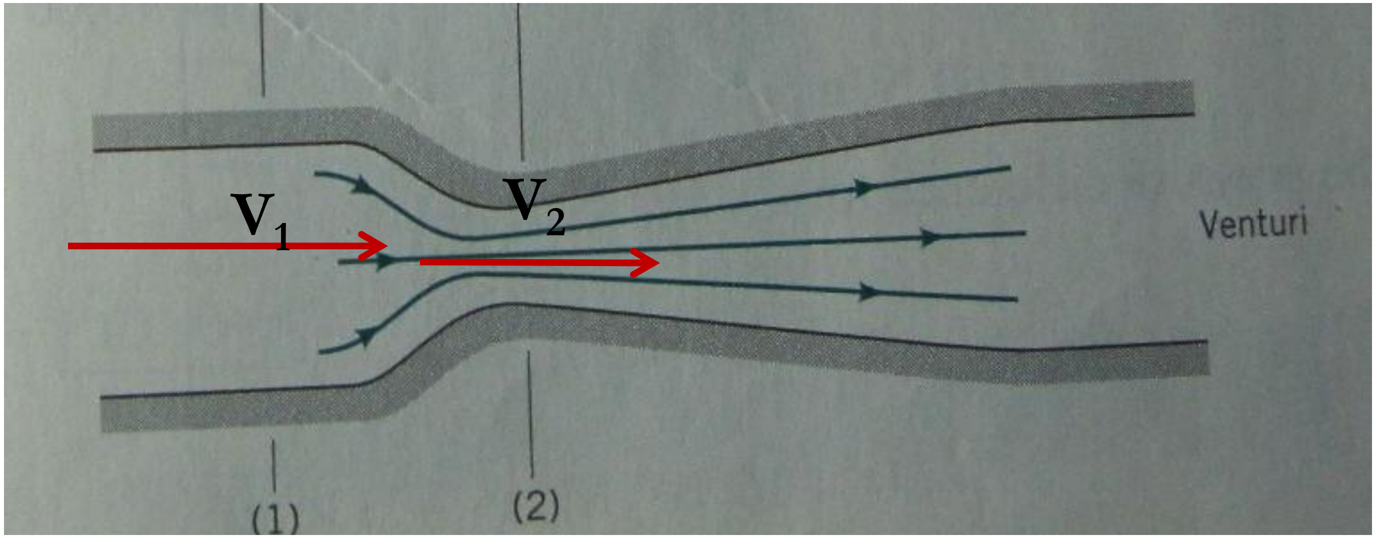
Hydraulic Mixers
Venturi Sections

- Turbulance is generated at the throat, which causes mixing

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

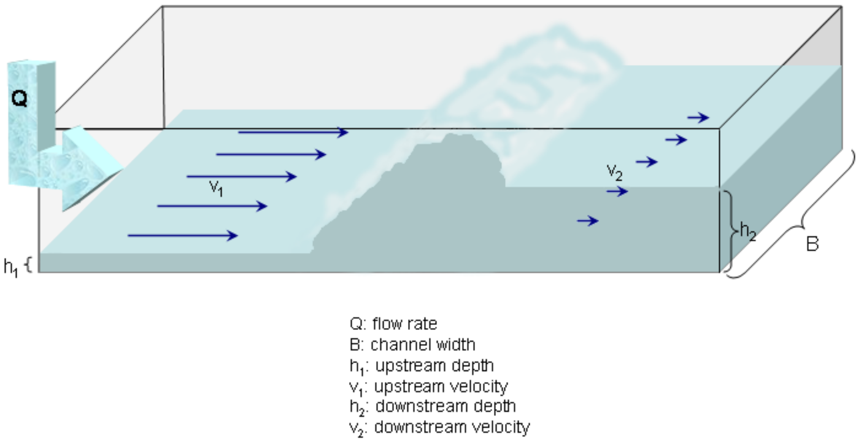
C_D: coefficient of discharge



Ref: Munson BR, Young DF, Okiishi TH. Fundamentals of Fluid Mechanics. 1998.ISBN: 0-471-17024-0

Hydraulic Mixers
Hydraulic Jumps

Ref: http://www.philip-lutzak.com/weather/GRAVITY WAVES - GOM/GRAVITY WAVES - GOM HOME.htm



Ref: http://einstein.atmos.colostate.edu/~mcnoldy/HydraulicJump.html

- Water flow creates supercritical flow
- Turbulence generated in the jump, which causes effective mixing

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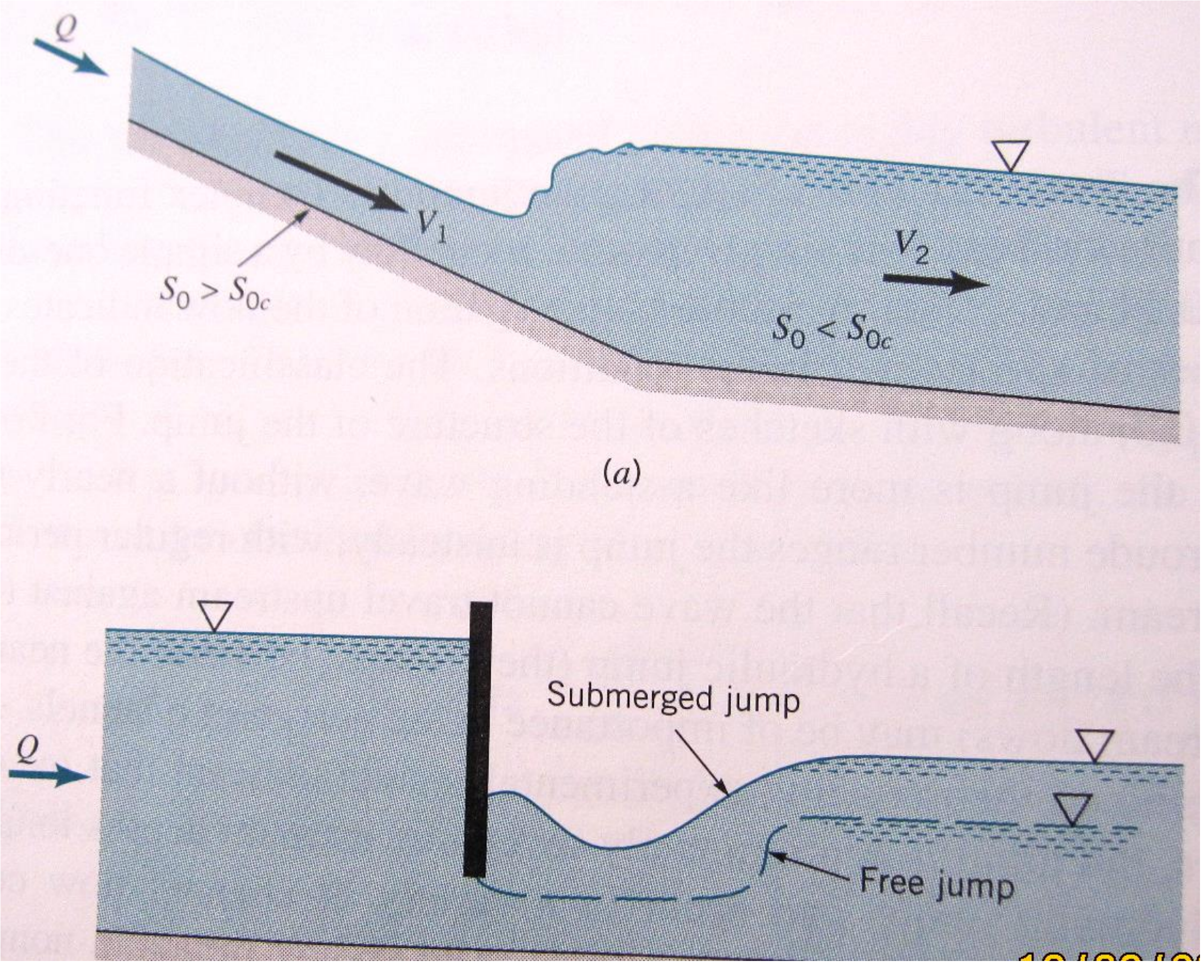
Hydraulic Mixers
Hydraulic Jumps



- Jump caused by a change in channel slope
- Submerged jump

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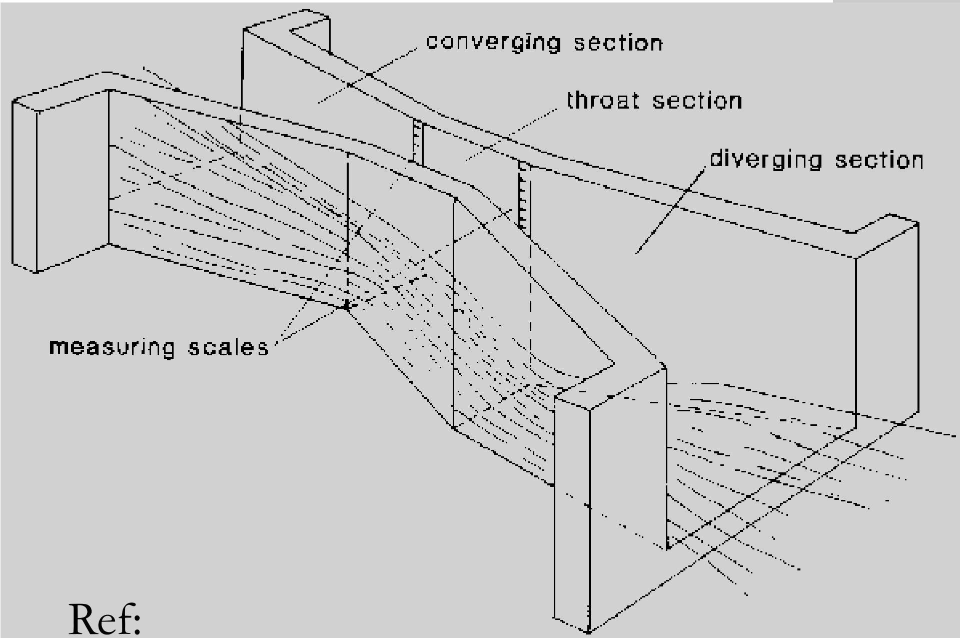
Ref: Munson BR, Young DF, Okiishi TH. Fundamentals of Fluid Mechanics. 1998.ISBN: 0-471-17024-0

Hydraulic Mixers
Parshall Flume

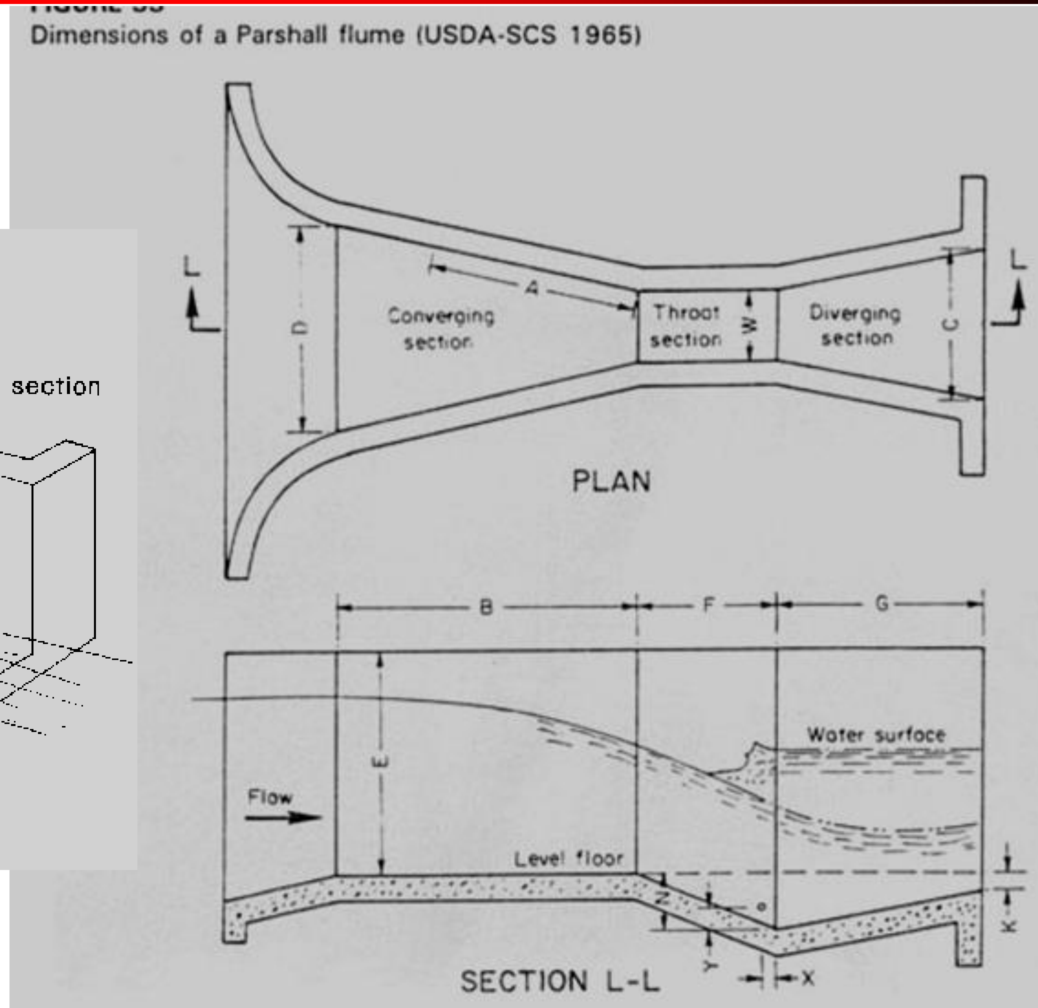
- Parshall flumes are devices used to measure flow of water in open channels. They are modified versions of venturi meters.
- The flume consists of a converging section with a level floor, a throat section with a downward sloping floor, and a diverging section with an upward sloping floor.
- Effective mixing occurs when hydraulic jump is followed by downstream of a flume
- On the basis of throat width partial flumes can be:
  - Very small - 25.4 mm to 76.2 mm.
  - (Small 152.40 mm to 2438.4 mm.
  - Large 3048 mm to 15240 mm.

Ref:http://www.flowmeterdirectory.com/parshall.html

Hydraulic Mixers
Parshall Flume



Ref: http://www.fao.org/docrep/R4082E/r4082e06.htm



Ref: http://www.fao.org/docrep/T0848E/t0848e-09.htm

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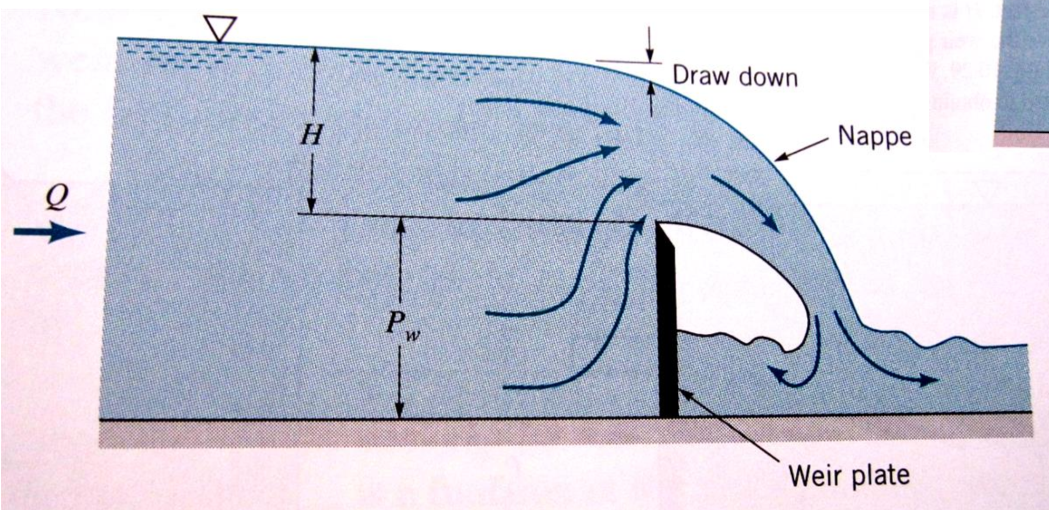
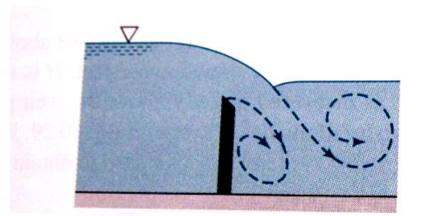
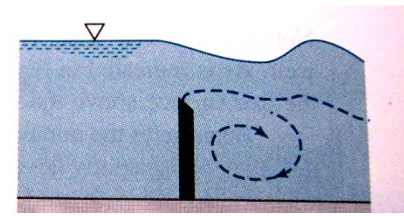
Hydraulic Mixers
Weirs

- A weir is an obstruction on a channel bottom over which the fluid must flow.







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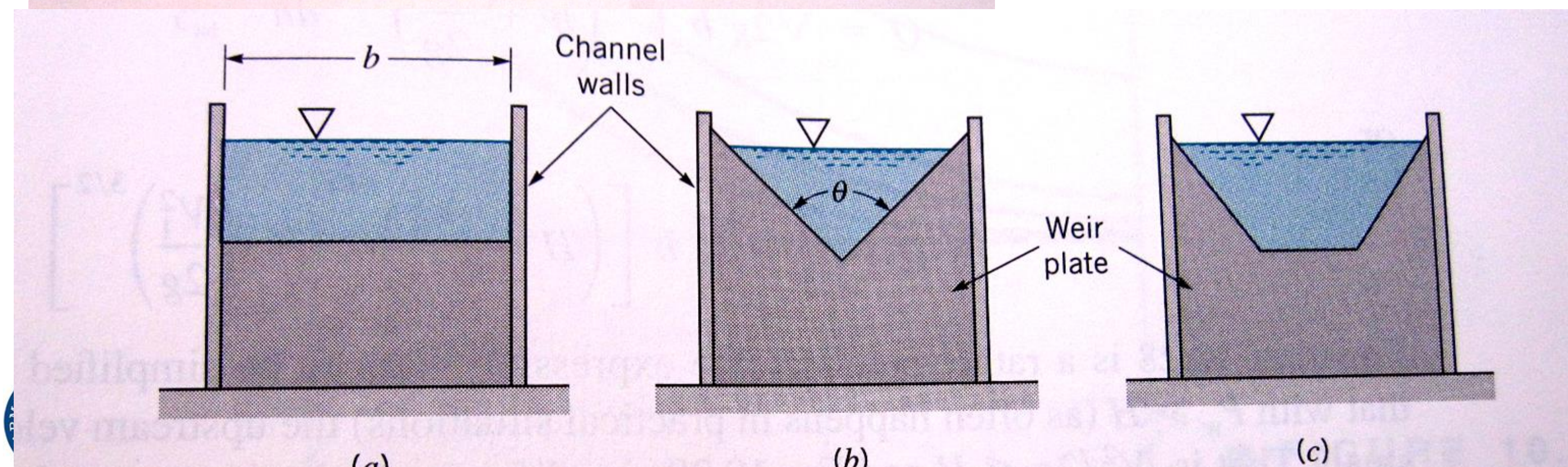


Hydraulic Mixers
Weirs

- A sudden drop in a hydraulic level over a weir induces the turbulence in water → causes mixing
- Vertical fall over the weir should be at least **0.1 m** to ensure sufficient mixing
- The height of the coagulant diffused over the weir should be at least **0.3 m** to penetrate the nappe thickness.

Hydraulic Mixers
Weirs

Both pictures are the courtesy of
Assist. Prof. Bilge Alpaslan Kocamemi

Hydraulic Mixers
Baffled Mixing Chambers

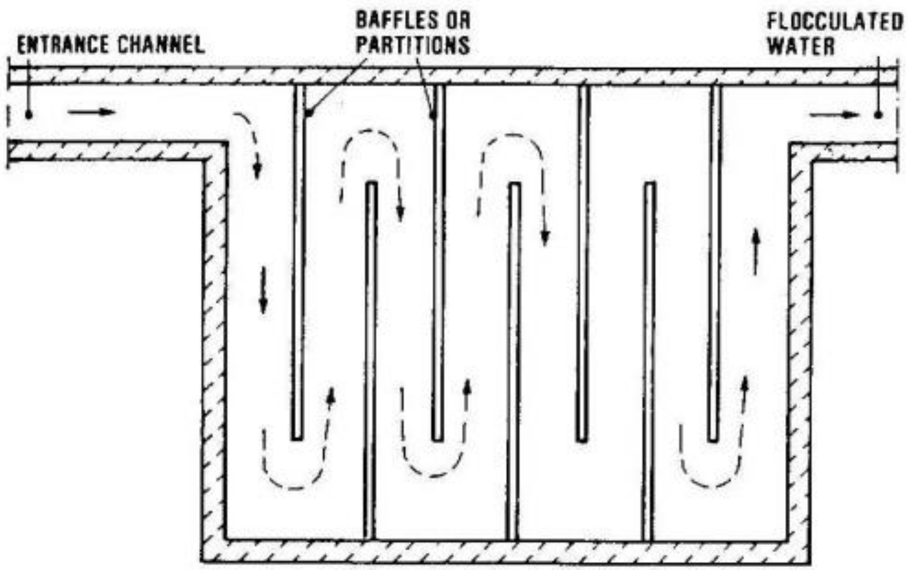


Figure 6.2. Horizontal-flow baffled channel flocculator (plan). *Source:* IRC, 1981b.

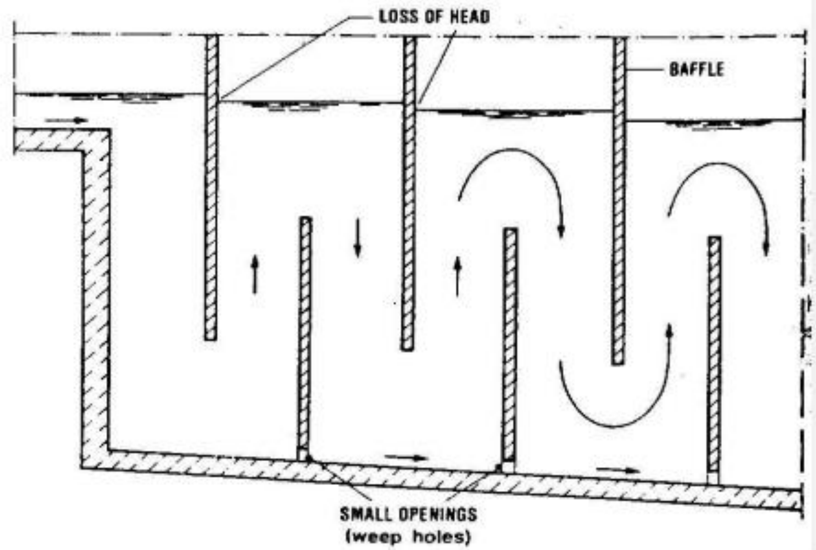


Figure 6.3. Vertical-flow baffled channel flocculator (cross-section). *Source:* IRC, 1981b.

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

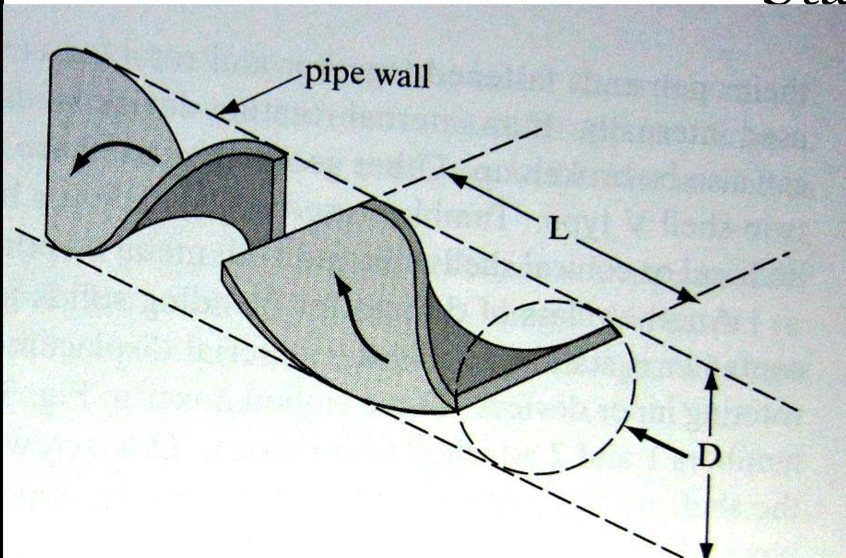
- Mixing achieved by reversing the flow through the openings
  - Around the end: Horizontal-flow baffles
  - Over and Under: Vertical-flow baffles
- Baffles mainly used for flocculation

Hydraulic Mixers
Static Mixers

- Static mixers are principally identified by their lack of moving parts.
- Static mixers contain elements that bring about sudden changes in the velocity patterns as well as momentum reversals
- Mixing occurs in a plug flow regime: the longer the mixer, the better the mixing→ higher headloss
- Mixing time is quite short; typically less than 1 sec.
- In-line mixers are commonly used for the mixign of chemicals

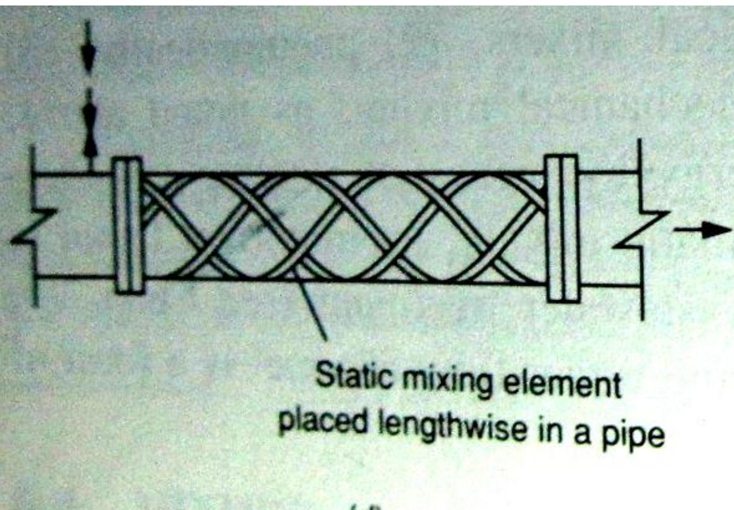
Hydraulic Mixers

Static Mixers

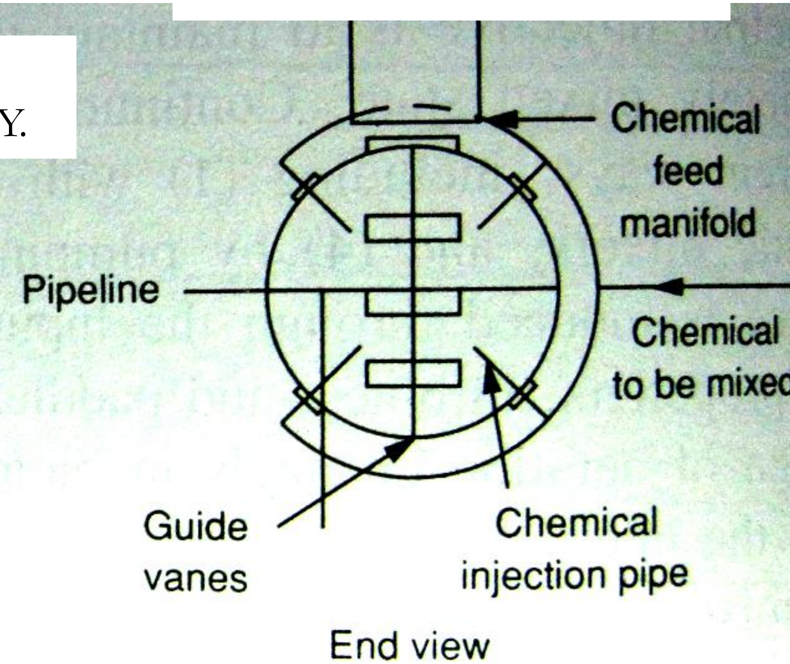


Ref: Munson BR, Young DF, Okiishi TH. Fundamentals of Fluid Mechanics. 1998.ISBN: 0-471-17024-0

•Metcalf & Eddy, Inc. (2003). *Wastewater Engineering-Treatment and Reuse*, 4th ed., McGraw-Hill, New York, NY.



In-line turbine mixer

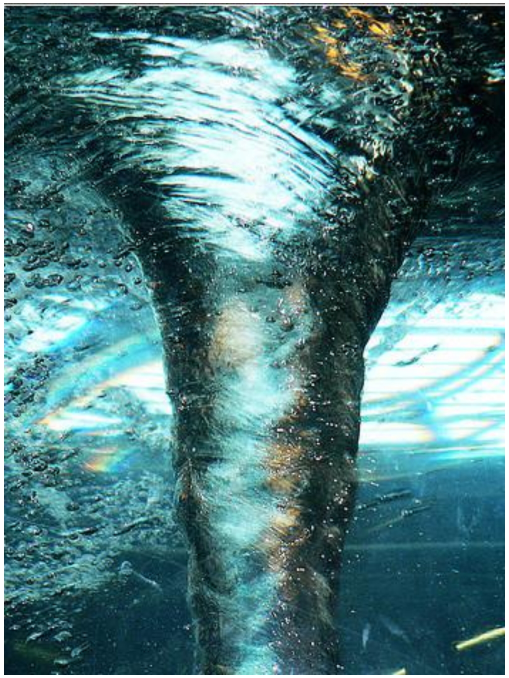


Mechanical Mixers
Turbine or Propeller Mixers

- Mechanical mixing is reliable, very effective and flexible in operation
- Mechanical mixing basins are not affected to any extent by variation in the flowrate.
- Mechanical mixing basins have low head losses.

Mechanical Mixers
Turbine or Propeller Mixers ***Vortexing***

- Vortexing may occur: Liquid to be mixed may rotate with the impeller
- Vortexing causes the difference between the impeller velocity and water velocity to decrease, which decreases effectivenes of mixing



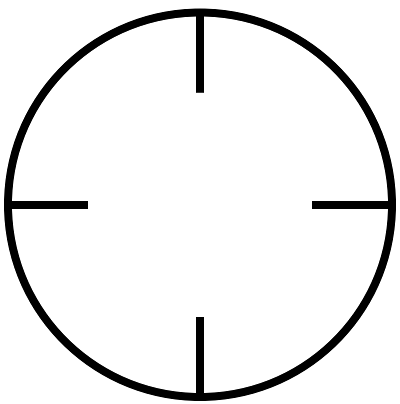
Ref: http://www.flickr.com/photos/esaruoho/favorites/?view=lg

Mechanical Mixers
Turbine or Propeller Mixers ***Vortexing***

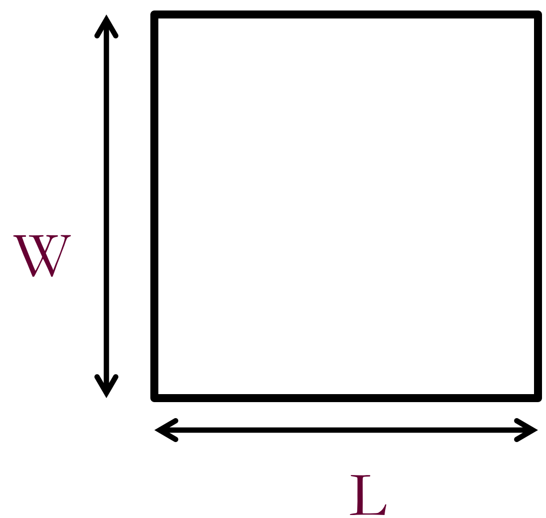
To eliminate <u>vortexing</u>:

- Four baffles can be placed vertically at the tank wall. Each baffle width = 10% - 12% of the tank diameter

$$Baffle\,width = 1/10\sqrt{WL}$$



$$Baffle\,width = 1/10D$$



Mechanical Mixers
Turbine or Propeller Mixers ***Vortexing***

- To prevent vortexing in small tanks
  - Impeller should be mounted off-center
  - Impeller can be mounted at an angle
  - Impeller can be mounted 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

3. Make an angle of less than 90° with drive shaft

Mechanical Mixers
Turbine or Propeller Mixers ***Power Requirement***

- Laminar Flow;
- Re<10 to 20

$$P = K_L \mu n^2 D_i^3$$

Power imparted by **baffled** or **unbaffled** tank

- Turbulent Flow;
- Re>10000

$$P = K_T \rho n^3 D_i^5$$

Power imparted by **baffled** tank

P=Power requirement (Nm/s)
K_L=Impeller constant for laminar flow
K_T=Impeller constant for turbulent flow
n=rotational speed (rps)
D_i=Impeller diameter (m)
ρ=density of the liquid (kg/m^3)
γ=Specific weight of the liquid (N/m^3)
μ=dynamic viscosity (Ns/m^2)

$$Re = \frac{D_i^2 n \rho}{\mu}$$

Mechanical Mixers
Turbine or Propeller Mixers ***Power Requirement***

In laminar flow → power imparted is independent of the presence of baffles

In turbulent flow →		
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

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Mechanical Mixers

Turbine or Propeller Mixers ***Power Requirement***

TABLE 8.2 *Values of Constants K_L and K_T in Eqs. (8.11) and (8.12) for Baffled Tanks Having Four Baffles at Tank Wall, with Width Equal to 10% of the Tank Diameter*

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	60.0	5.31
Turbine, 6 flat blades, vaned disc	65.0	5.75
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	1.70
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

•Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

Mechanical Mixers
Turbine or Propeller Mixers ***Power Requirement***

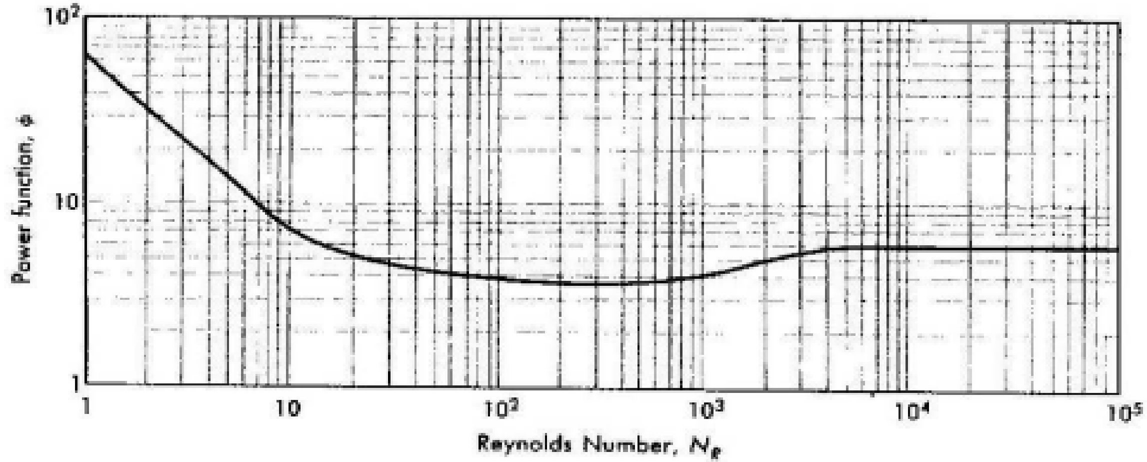

FIGURE 12.9 Ref: Tchobanoglous and Scroeder, 1985, Addison-Wesley Publishing Company

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)

ϕ = Power function dimensionless = $\dfrac{P}{\rho N^3 D^5}$

$\phi = kR_e^p$

k= constant of an impeller & tank geometry
P= -1 (for laminar)
P= 0 (for turbulent)

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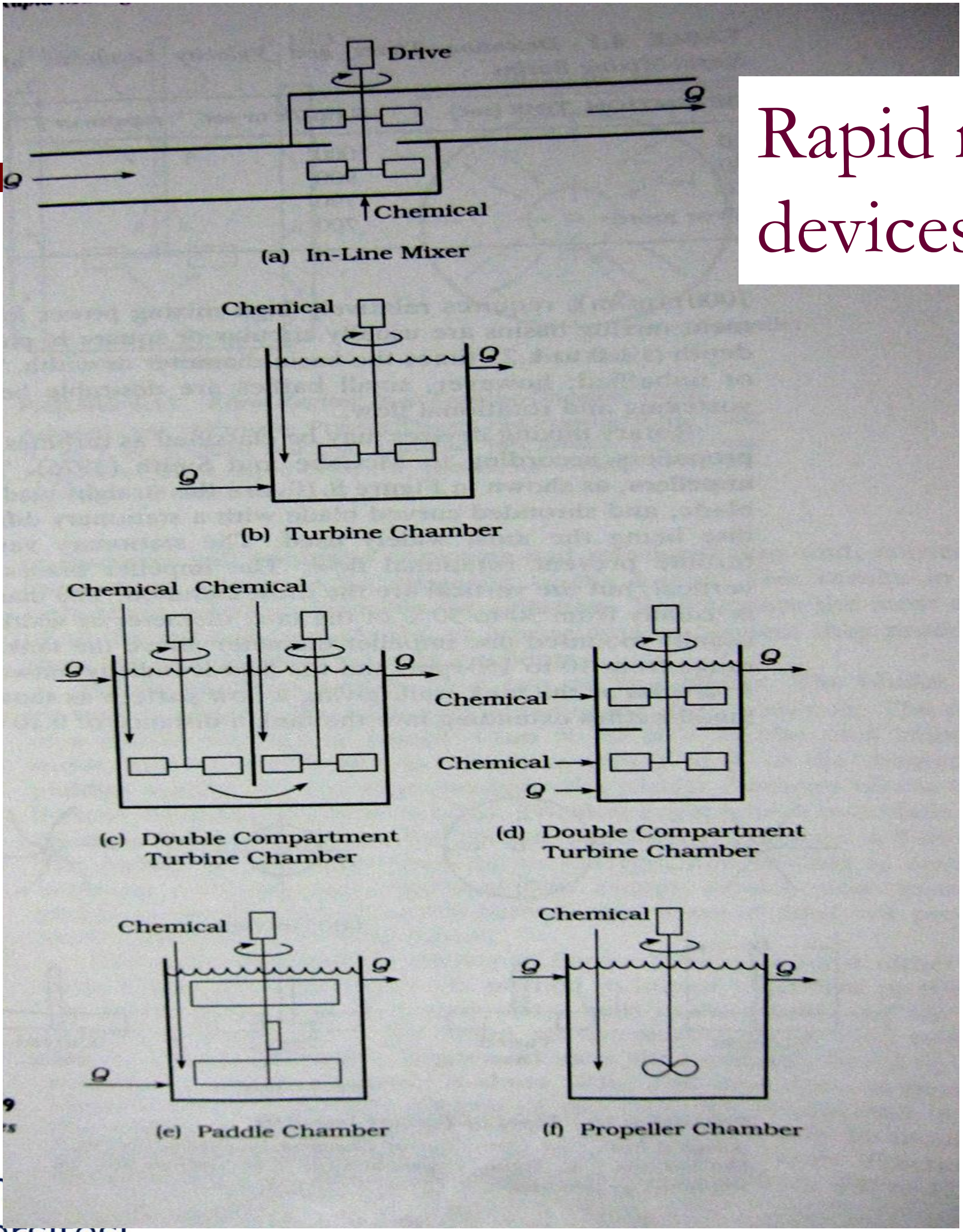
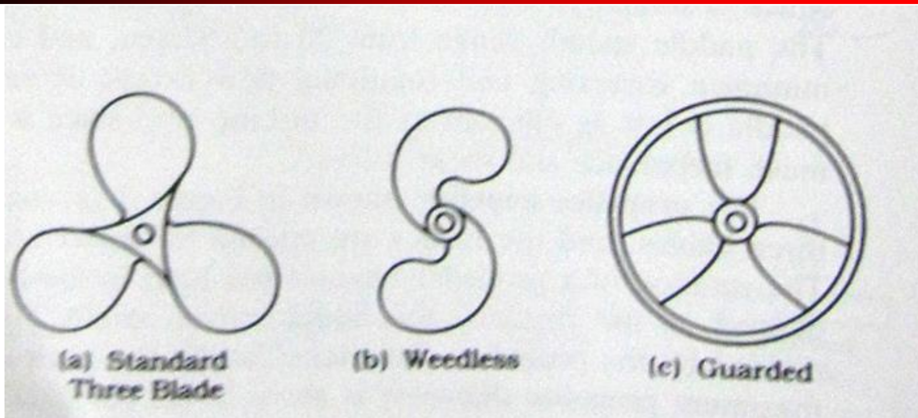
Rapid mixing devices



Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

Propeller Impellers



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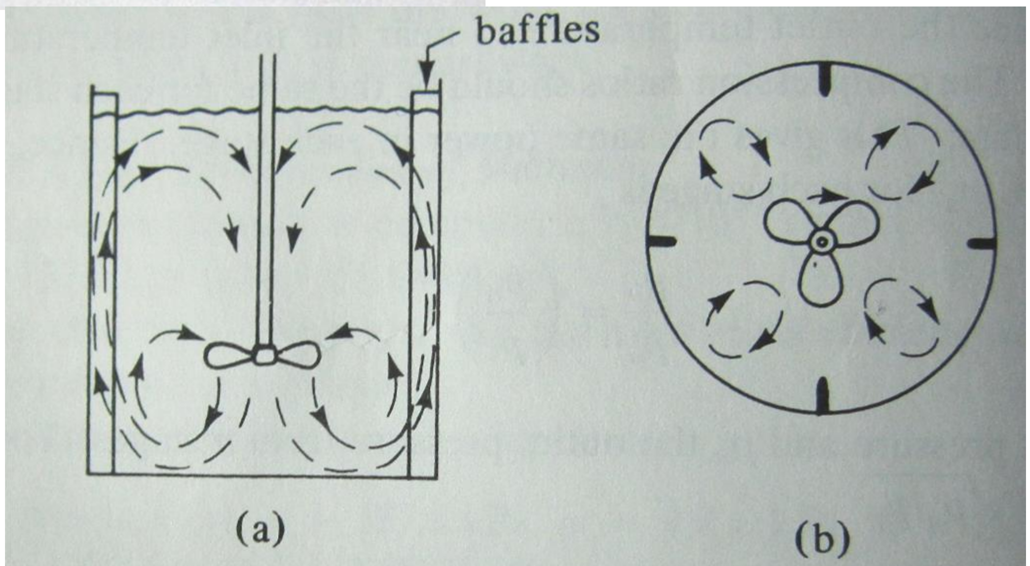


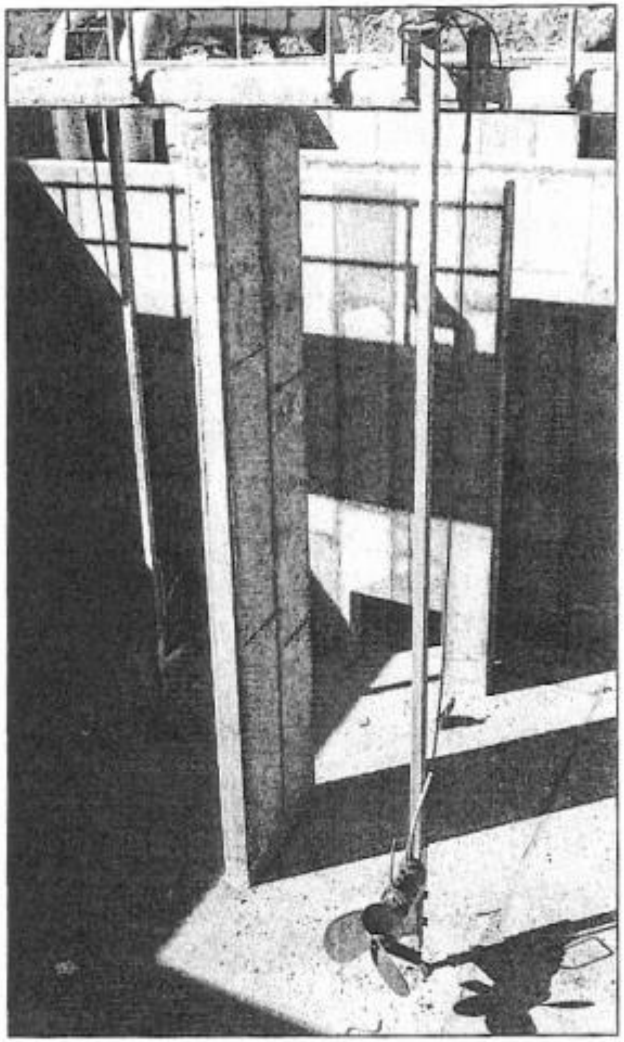
FIGURE 3.4-1. *Baffled tank and three-blade propeller agitator with axial-flow pattern: (a) side view, (b) bottom view.*

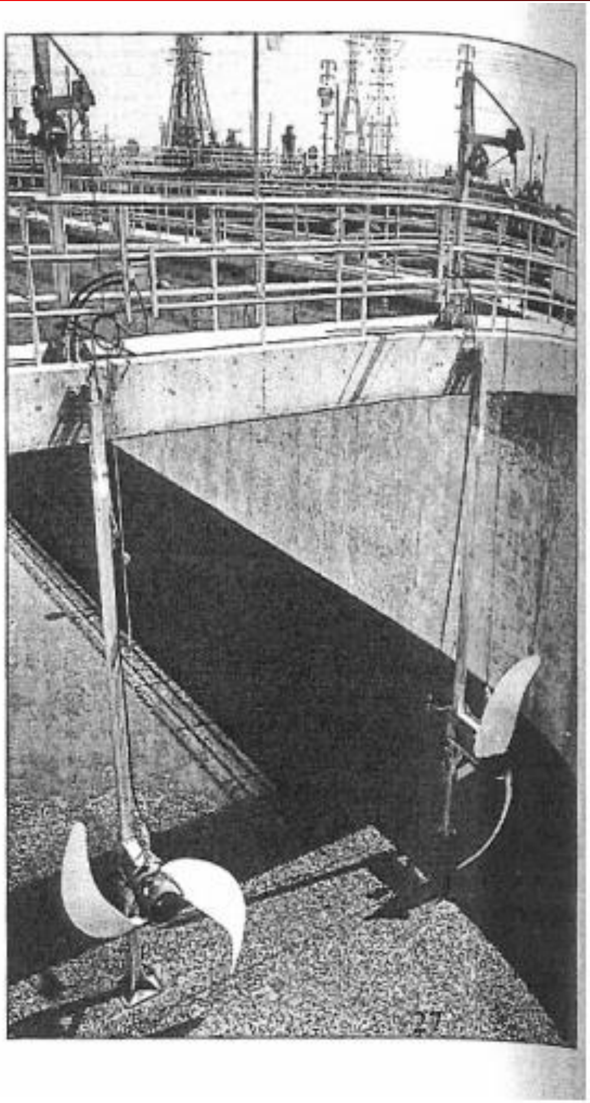
Propeller Mixer

Propeller Mixer

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

Ref: Metcalf Eddy,1991, McGraw Hill





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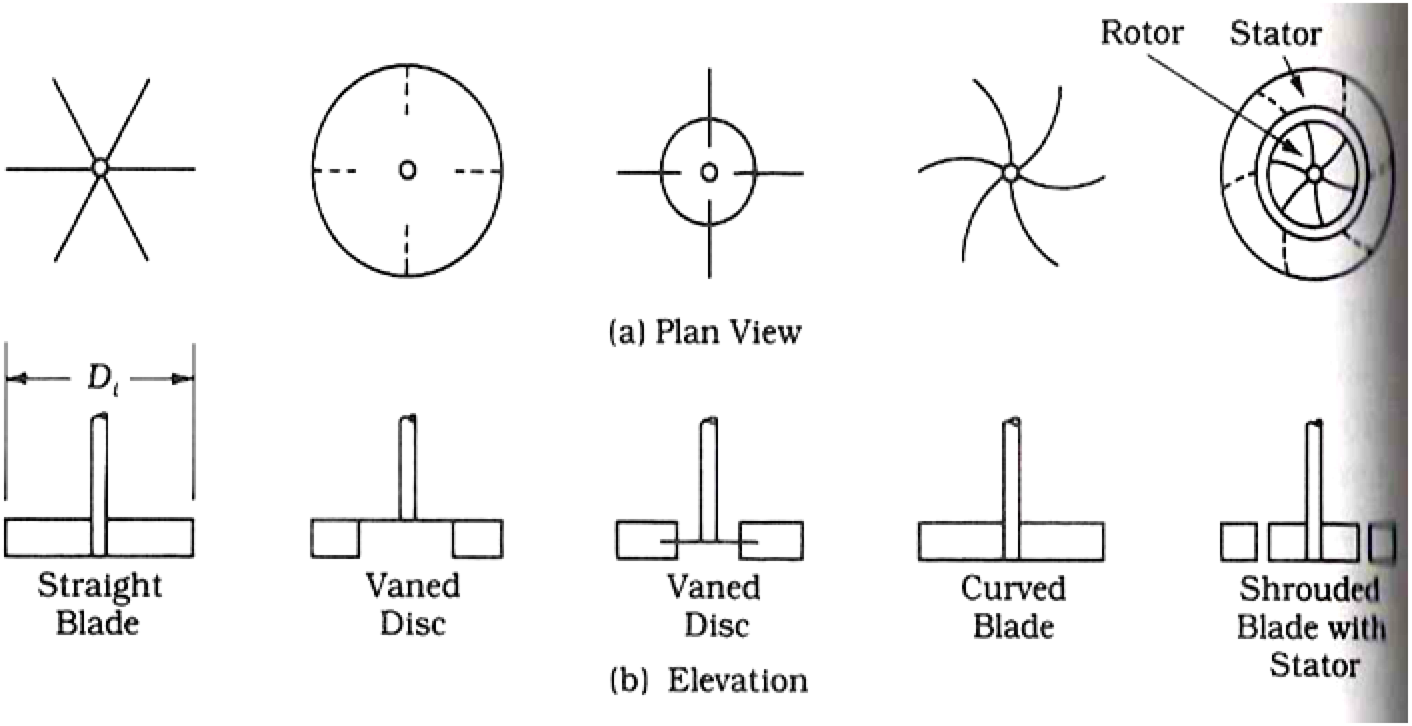
Turbine Impellers



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Turbine Impellers

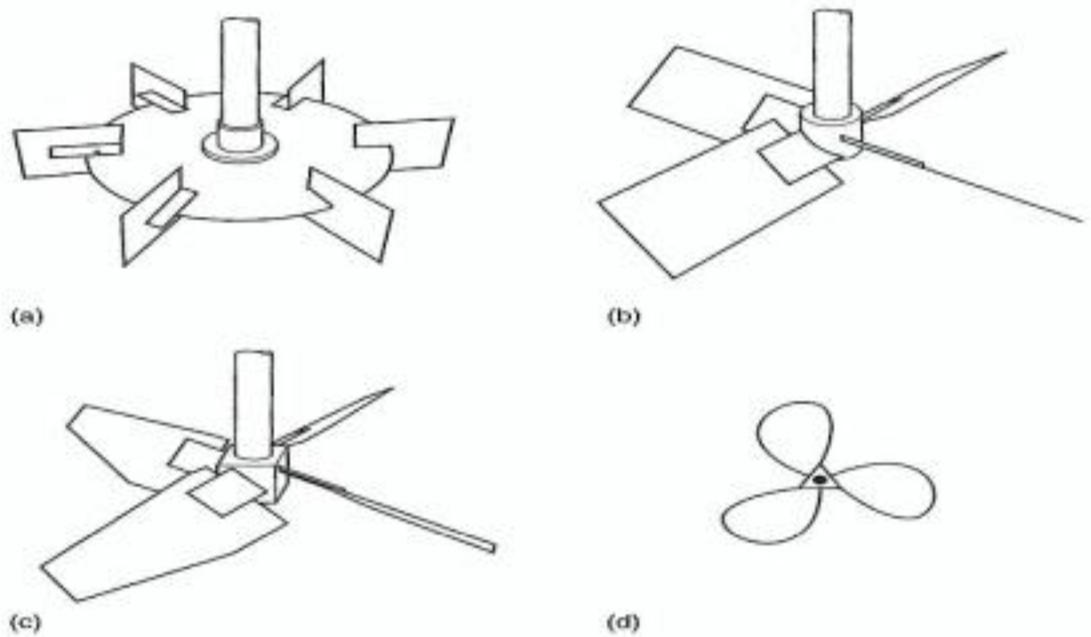


Figure 5–15

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.

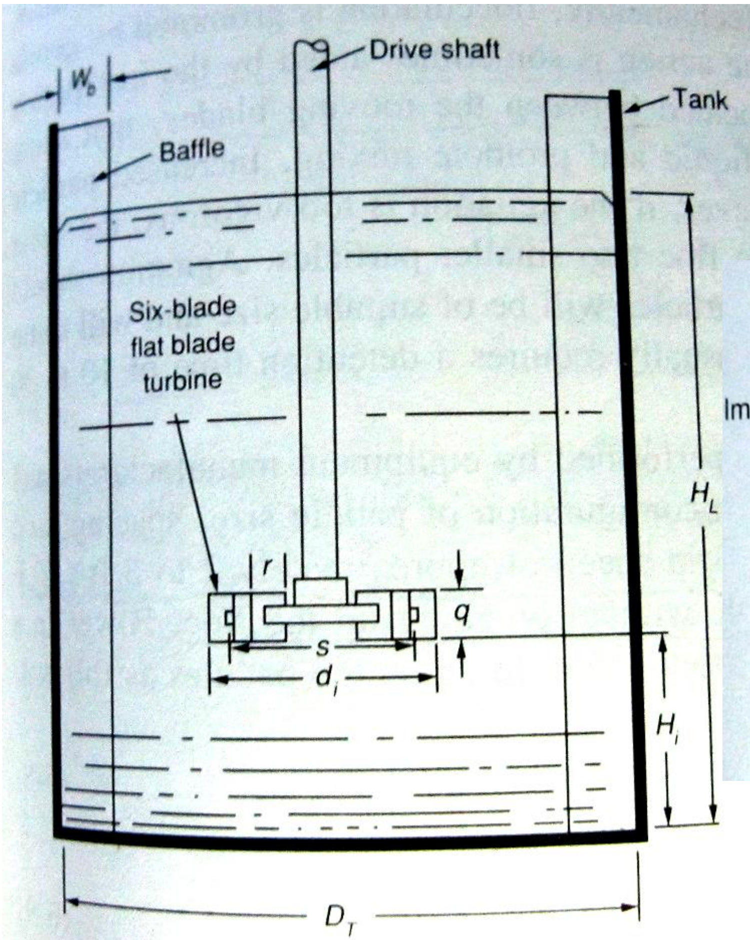
Ref: Metcalf Eddy,1991 , McGraw Hill

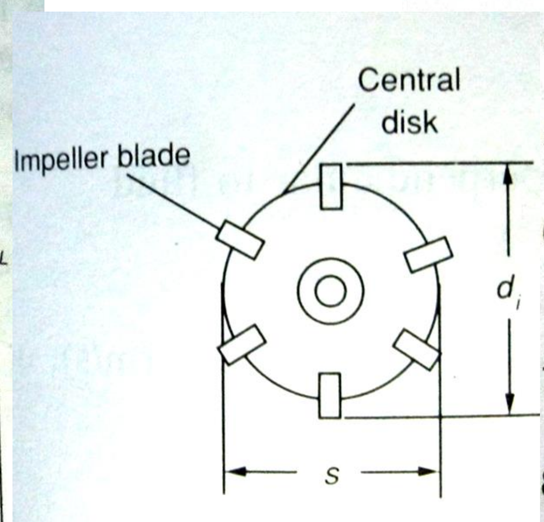
Table 5–11

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

Turbine impeller 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

•Metcalf & Eddy, Inc. (2003). *Wastewater Engineering-Treatment and Reuse*, 4th ed., McGraw-Hill, New York, NY.

Turbine - Impeller

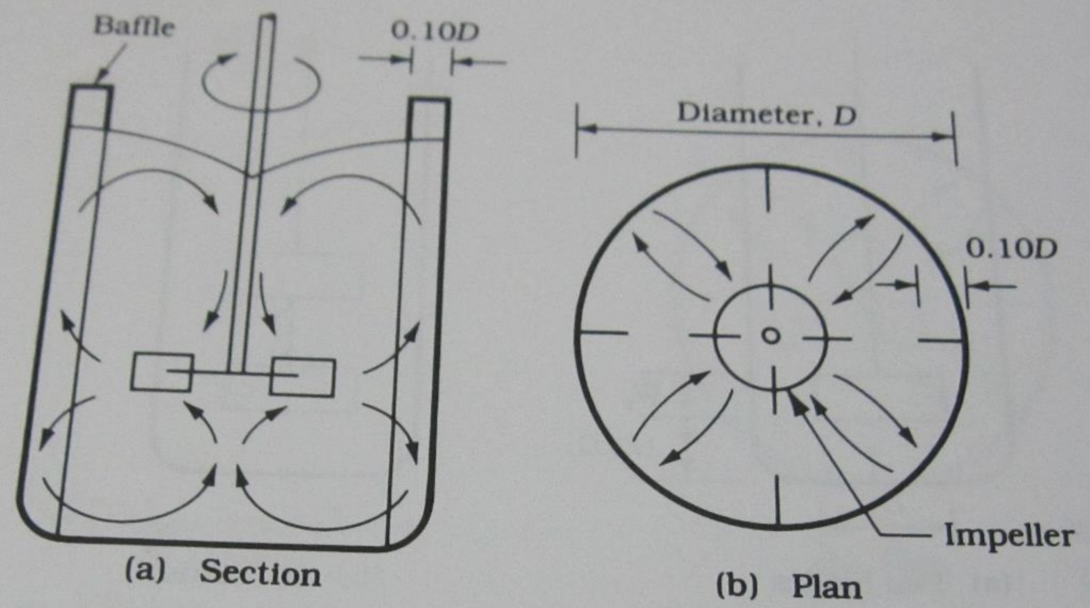


FIGURE 8.11 *Flow Regime in a Turbine-Impeller Tank*

Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

Turbine Impeller

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Paddle Mixers

- Paddle mixers consists of series of appropriately spaced paddles mounted on either a horizontal or vertical shaft
- Generally rotate slowly
- Paddles are commonly used as flocculation devices

•Ref: http://www.myersequipment.com/jms_gallery_hpwf_12.html

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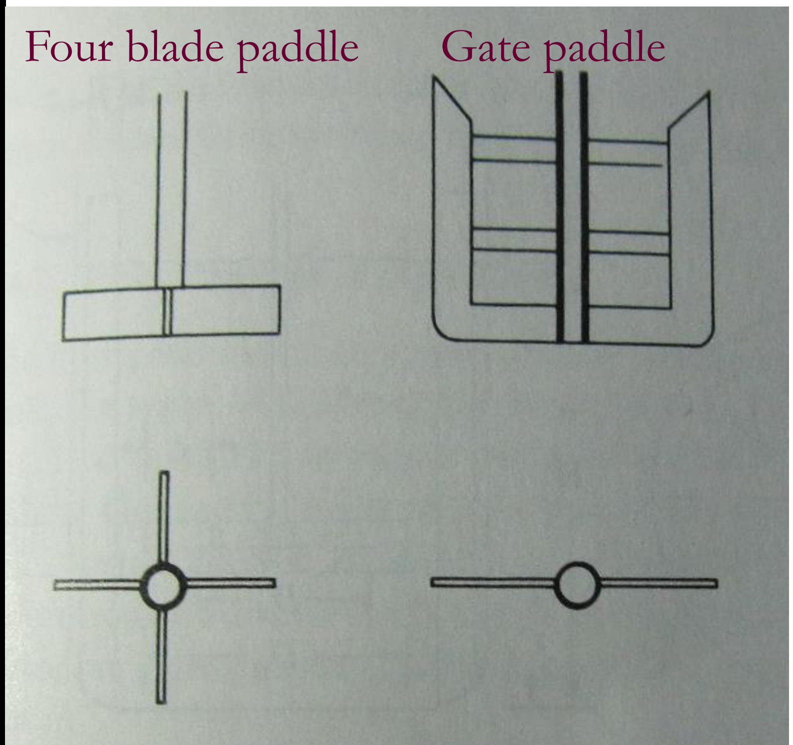
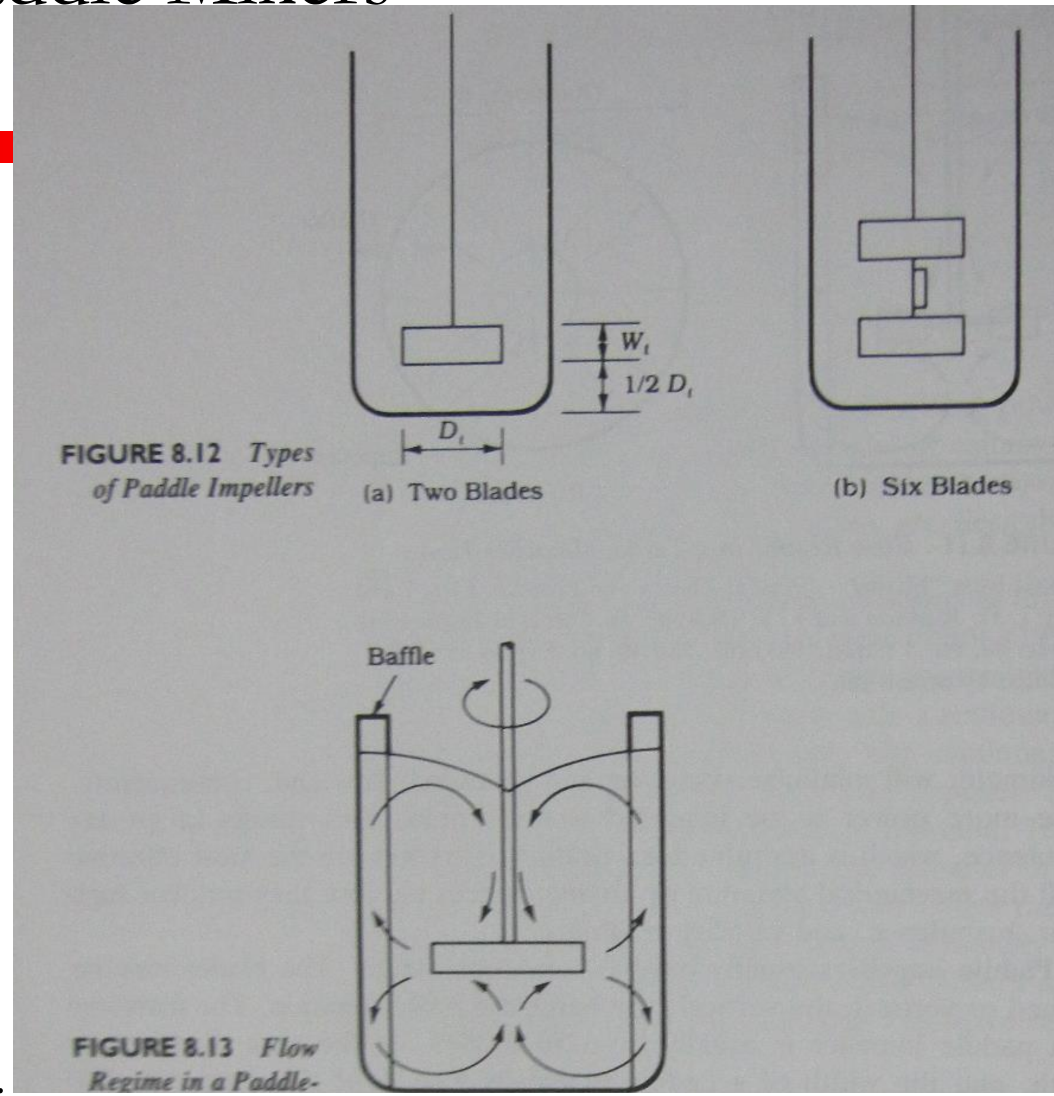
Paddle Mixers

- The diameter of a paddle impeller is usually 50-80% of the tank diameter or width
- Width of a paddle is usually 1/6 to 1/10 of the diameter
- Paddles are mounted ½ of a paddle diameter above the tank bottom
- The paddle speeds range from 20 to 150 rpm
- Paddles do not produce turbulance
- Paddle tip speed is generally 0.6 to 0.9 m/s

Paddle Mixers



Ref: Geankoplis C.J. Transport Processes and Separation Process Principles. 4th ed. New Jersey. Prentice Hall. 2003.



Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

Power imparted to water by a paddle impeller

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

F_D=Drag force (N)
C_D=Coefficient of drag of paddle moving perpendicular to fluid
A=Cross sectional area of paddles (m^2)
ρ=density (kg/m^3)
V_p=Relative velocity of paddles with respect to the fluid (m/s), usually assumed to be 0.6 t o0.75 times the paddle tip speed
P=Power requirement (W)

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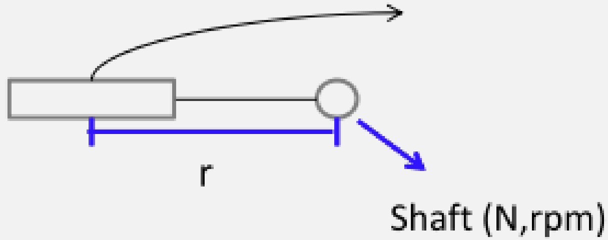
Power imparted to water by a paddle impeller



Velocity of paddle (paddle tip velocity)

$$\frac{2\pi N}{60} r$$

→ m/sec

1min/60sec

Distance from shaft to paddle center(m)

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

Power — Force — Velocity

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

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.

Lecture notes of Assist. Prof. Bilge Alpaslan Kocamemi

Power imparted to water by a paddle impeller

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

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Pneumatic Mixers

- When air injected in mixing or flocculation tanks or channels, the power dissipated by the rising air bubbles can be estimated by the following equation

$$P = 1.689 Q_a \ln\left(\frac{h + 10.33}{10.33}\right)$$

P=Power dissipated (kW)
Q_a=Air flow rate at atmospheric pressure (m^3/min)
h=air pressure at the point of discharge (m)

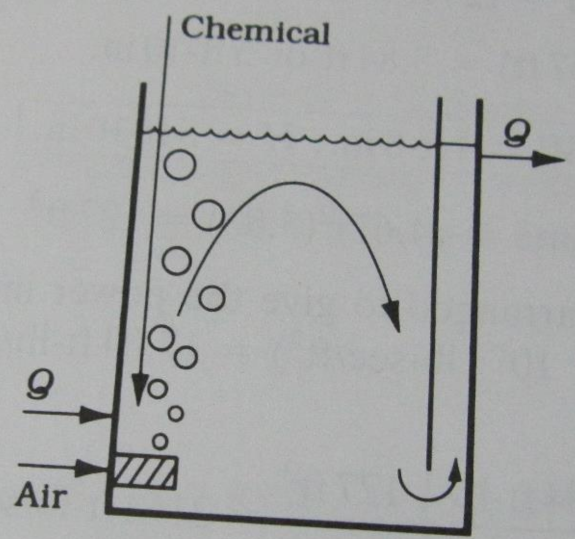

FIGURE 8.16 *Pneumatic Rapid Mixing*

Ref: Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996.

- Problems