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

3. Non-uniform flow

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.

$G \uparrow$ shear force $\uparrow$

$P =$ Power dissipated, $W$ (Nm/sec)
$\mu =$ Dynamic viscosity, (Nsec/m$^2$)
$V =$ Volume to which the power is applied, (m$^3$)

$G = \sqrt{\frac{P}{\mu V}}$ 1/sec
Example:
Two water particles moving 1m/sec relative to each other at a distance 0.1m would have

\[ G = \frac{1\text{m/sec}}{0.1\text{m}} = 10\text{sec}^{-1} \]

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
The degree of turbulence is measured by the loss in head.

Dependent on flow

Power dissipation in a hydraulic device = \( \rho gQ \Delta h \)

Headloss
Hydraulic Mixers (continue)

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.

\[ h_L = C_d \frac{V_2^2}{2g} \]

Ref: Droste, 1997, John Wiley & Sons, Inc.
B) Hydraulic Jumps

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.

Ref: Schulz & Okun, 1984, John Wiley & Sons
C) Parshall Flume

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

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

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

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

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

Reynolds number for impellers \( R_e = \frac{D^2 n \rho}{\mu} \)

- \( D \): diameter of impeller, m
- \( n \): rev/sec
- \( \rho \): density of liquid, kg/m\(^3\)
- \( \mu \): dynamic viscosity, Ns/m\(^2\)
- \( R \): reynolds number (unitless)

Reynolds number: \( R_e < 10 \rightarrow \) laminar
\( R_e > 1000 \rightarrow \) 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)

*In circular or rectangular tanks the usual method used to limit vortexing.*

To install 4 or more vertical baffles extending approximately 1/10\textsuperscript{th} the diameter out from the wall.

\[
\begin{align*}
1/10 \text{ or } 1/12 \ D \\
1/10 \text{ or } 1/12 \sqrt{WL}
\end{align*}
\]
Power imparted in an unbaffled tank = \frac{1}{6} \text{ of the power imparted in the same tank with baffles}

\text{Power imparted in a baffled square tank} = 75\% \text{ of the power imparted in a baffled square or a baffled circular tank.}

\text{Power in a baffled vertical square tank having } D=\text{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° with drive shaft.
Turbine and Propeller Mixers (continue)

Laminar flow

for Re<10

Developed by Rushton

\[ P = k \mu n^2 D^3 \]

- Power (watt)
- Impeller constant
- Revolutions per second (rev/sec)
- Diameter of impeller (m)
- Dynamic viscosity

Power imparted in either baffled or unbaffled tank
Turbulent flow (for Re>10000)

\[ P = k \rho n^3 D^5 \]

- Power (watt)
- Nm/sec
- Impeller constant
- Revolutions per second (rev/sec)
- Diameter of impeller (m)
- Density (kg/m³)

Power imparted in a baffled tank
Turbine and Propeller Mixers (continue)

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

<table>
<thead>
<tr>
<th>Impeller</th>
<th>Laminar range, ( \text{Eq. 6-5} )</th>
<th>Turbulent range, ( \text{Eq. 6-6} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propeller, square pitch, 3 blades</td>
<td>41.0</td>
<td>0.32</td>
</tr>
<tr>
<td>Propeller, pitch of two, 3 blades</td>
<td>43.5</td>
<td>1.00</td>
</tr>
<tr>
<td>Turbine, 6 flat blades</td>
<td>71.0</td>
<td>6.30</td>
</tr>
<tr>
<td>Turbine, 6 curved blades</td>
<td>70.0</td>
<td>4.80</td>
</tr>
<tr>
<td>Fan turbine, 6 blades</td>
<td>70.0</td>
<td>1.65</td>
</tr>
<tr>
<td>Turbine, 6 arrowhead blades</td>
<td>71.0</td>
<td>4.00</td>
</tr>
<tr>
<td>Flat paddle, 6 blades</td>
<td>38.5</td>
<td>1.70</td>
</tr>
<tr>
<td>Shrouded turbine, 2 curved blades</td>
<td>97.5</td>
<td>1.08</td>
</tr>
<tr>
<td>Shrouded turbine with stator (no baffles)</td>
<td>172.5</td>
<td>1.12</td>
</tr>
</tbody>
</table>

Table 2.2. Values of Constants \( K_c \) and \( K_e \) 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

<table>
<thead>
<tr>
<th>Type of Impeller</th>
<th>( K_c )</th>
<th>( K_e )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propeller, pitch of 1, 3 blades</td>
<td>41.0</td>
<td>0.32</td>
</tr>
<tr>
<td>Propeller, pitch of 2, 3 blades</td>
<td>43.5</td>
<td>1.00</td>
</tr>
<tr>
<td>Turbine, 4 flat blades, vaned disc</td>
<td>71.0</td>
<td>6.30</td>
</tr>
<tr>
<td>Turbine, 6 flat blades, vaned disc</td>
<td>71.0</td>
<td>6.30</td>
</tr>
<tr>
<td>Turbine, 6 curved blades</td>
<td>70.0</td>
<td>4.80</td>
</tr>
<tr>
<td>Fan turbine, 6 blades at 45°</td>
<td>70.0</td>
<td>1.65</td>
</tr>
<tr>
<td>Shrouded turbine, 6 curved blades</td>
<td>97.5</td>
<td>1.08</td>
</tr>
<tr>
<td>Shrouded turbine, with stator, no baffles</td>
<td>172.5</td>
<td>1.12</td>
</tr>
<tr>
<td>Flat paddles, 2 blades (single paddle), ( D_h/W_b = 4 )</td>
<td>43.0</td>
<td>2.25</td>
</tr>
<tr>
<td>Flat paddles, 2 blades, ( D_h/W_b = 6 )</td>
<td>36.5</td>
<td>1.60</td>
</tr>
<tr>
<td>Flat paddles, 2 blades, ( D_h/W_b = 8 )</td>
<td>33.0</td>
<td>1.15</td>
</tr>
<tr>
<td>Flat paddles, 4 blades, ( D_h/W_b = 6 )</td>
<td>49.0</td>
<td>2.75</td>
</tr>
<tr>
<td>Flat paddles, 6 blades, ( D_h/W_b = 6 )</td>
<td>71.0</td>
<td>3.82</td>
</tr>
</tbody>
</table>

Power imparted in an unbaffled tank
(valid for laminar and turbulent flow)

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

\[ \phi = k R_e^p \]

- \( k \) = constant of an impeller tank geometry
- \( p \) = \( -1 \) (for laminar)
- \( p \) = \( 0 \) (for turbulent)
(a) In-Line Mixer

(b) Turbine Chamber

(c) Double Compartment Turbine Chamber

(d) Double Compartment Turbine Chamber

(e) Paddle Chamber

(f) Propeller Chamber
Types of Propeller Impellers

Figure 2.11. Types of Propeller Impellers

(a) Standard
Three Blade

(b) Weedless

(c) Guarded

Figure 2.12. Flow Regime in a Propeller-impeller Tank

(a) Section

(b) Plan
Propeller Mixer

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

Propeller Mixer

Types of Turbine Impellers

(a) Plan View

(b) Elevation

FIGURE 8.10 Types of Turbine Impellers

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.


Table 5–11
Typical types of mixing impellers used in wastewater treatment

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

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

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

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 2.18. Vertical-Shaft Paddle Wheel Flocculator

Figure 9.9
Flocculation basins. (a) (b) vertical paddles.
Paddle Impellers

**FIGURE 8.12** Types of Paddle Impellers

(a) Two Blades

(b) Six Blades

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

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

(a) Two Blades

(b) Six Blades

Figure 2.10. Flow Regime in a Paddle-Impeller Tank

Ref: Reynolds/Richards 2nd Edition
Newton’s Law for the drag force exerted by a submerged object moving in a liquid.

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

- \( F_D \): Drag force (1bf or N)
- \( C_D \): Drag coefficient
- \( A \): Cross-sectional area of paddle (ft\(^2\) or m\(^2\))
  (paddle-blade area at right angle to the direction of movement)
- \( \rho \): Density of fluid (\( \frac{\text{slug}}{\text{ft}^3} \) or \( \frac{\text{kg}}{\text{m}^3} \))
- \( V_p \): Relative velocity of paddles with respect to water.

Relative velocity of paddles:
- \( 0.6 - 0.75 \) \( V_{\text{paddle tip}} \)
- \( V_{\text{paddle tip}} = 2-3 \) ft/sec (0.6-0.9 m/sec)
Velocity of paddle (paddle tip velocity)

\[\frac{2\pi N}{60} \frac{r}{\text{m/sec}}\]

Distance from shaft to paddle center (m)

A = Cross-sectional area of paddle \((\text{ft}^2 \text{ or } \text{m}^2)\)

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

\(V_p = \text{Relative velocity of paddles with respect to water.}\)

\(C_d = \text{Drag coeff.}\)
THE DRAG COEFFICIENT (Cd) depends basically on the geometry of the paddle

<table>
<thead>
<tr>
<th>$L/W$ ratio</th>
<th>$C_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1.20</td>
</tr>
<tr>
<td>20</td>
<td>1.5</td>
</tr>
<tr>
<td>$\infty$</td>
<td>1.90</td>
</tr>
</tbody>
</table>
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$^3$.

\[
\begin{align*}
\text{Water temperature} &= 15^0 \text{C} \quad \rightarrow \quad \rho = 999.5 \frac{\text{kg}}{\text{m}^3} \quad \mu = 1.139.10^{-3} \frac{\text{N} \cdot \text{sec}}{\text{m}^2} \\
C_D &= \text{for rectangular paddle} = 1.8 \\
Paddle \text{ tip velocity} &= 0.6 \text{m/sec} \\
\text{Relative velocity of paddle} &= 0.75 V_{\text{paddle tip}}
\end{align*}
\]
Pneumatic Mixers

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

\[
P = 35.28 Q_a \ln \left( \frac{h + 33.9}{33.9} \right) \quad \text{US customary units}
\]

\[
P = 1.689 Q_a \ln \left( \frac{h + 10.33}{10.33} \right) \quad \text{SI units}
\]

- \(P\) = power dissipated (ft.lb/sec OR kW)
- \(Q_a\) = 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 $6200 \text{ ft}^3$ is to be designed to provide G value of $60 \text{ sec}^{-1}$. Assume that the basin depth is to be 12ft and air will be released into the basin 0,5ft above the tank bottom.

$(\text{Temp} = 60^\circ \text{F} \quad \rightarrow \quad \mu = 2.359 \cdot 10^{-5} \frac{\text{1bf.sec}}{\text{ft}^2})$