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 can occur in the 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 concentration

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

Mixing

- Three phenomena contribute to mixing;

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

Ref:
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 \( \rightarrow \) 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)
\( \mu \): Absolute viscosity of water (Ns/m²)
V: Basin volume (m³)
G: Velocity gradient (s⁻¹)
Example -1

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

\[ G = \frac{1.5 \text{ m/s}}{0.05 \text{ m}} = 30 \text{ s}^{-1} \]
Velocity Gradient (G) for baffle basin

\[ G = \frac{\sqrt{\gamma h_L}}{\mu T} \]

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

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

\( h_L \): head loss (m)

\( T \): detention time (s)

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

\[ P = \gamma Q h_L = \rho g Q \Delta h_L \]

\( \gamma \)=specific weight of water (kgm\(^2\)/s\(^2\) OR kN/m\(^3\))
\( \rho \)=density of water (kg/m\(^3\))
\( g \)=gravitational acceleration (m/s\(^2\))
\( Q \)=flow rate (m\(^3\)/s)
\( h_L \)=headloss (m)
Hydraulic Mixers
Venturi Sections

- Turbulence is generated at the throat, which causes mixing

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

$C_D$: coefficient of discharge

Hydraulic Mixers
Hydraulic Jumps

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


Ref: [http://einstein.atmos.colostate.edu/~mcnoldy/HydraulicJump.html](http://einstein.atmos.colostate.edu/~mcnoldy/HydraulicJump.html)
Hydraulic Mixers

Hydraulic Jumps

• Jump caused by a change in channel slope

• Submerged jump

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/T0848E/t0848e-09.htm

Ref: http://www.fao.org/docrep/T0848E/t0848e-09.htm
A weir is an obstruction on a channel bottom over which the fluid must flow.

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

- 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 mixing of chemicals.
Hydraulic Mixers
Static Mixers


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 effectiveness of mixing

Ref:
http://www.flickr.com/photos/esaruoho/favorites/?view=lg
Mechanical Mixers
Turbine or Propeller Mixers \textit{Vortexing}

To eliminate vortexing:

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

\[ Baffle \ width = \frac{1}{10}\sqrt{WL} \]

\[ Baffle \ width = \frac{1}{10}D \]

\[ W \]

\[ L \]
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)

$\rho =$ density of the liquid (kg/m$^3$)

$\gamma =$ Specific weight of the liquid (N/m$^3$)

$\mu =$ 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** →

<table>
<thead>
<tr>
<th>Description</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power imparted in an unbaffled tank</td>
<td>= 1/6 of the power imparted in the same tank with baffles</td>
</tr>
<tr>
<td>Power imparted in an unbaffled square tank</td>
<td>= 75% of the power imparted in a baffled square or a baffled circular tank</td>
</tr>
<tr>
<td>Power in a baffled vertical square tank</td>
<td>= Power in a baffled vertical circular tank having $D=$ width of square tank</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>TYPE OF IMPELLER</th>
<th>$K_L$</th>
<th>$K_T$</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>60.0</td>
<td>5.31</td>
</tr>
<tr>
<td>Turbine, 6 flat blades, vaned disc</td>
<td>65.0</td>
<td>5.75</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), $D_i/W_i = 4$</td>
<td>43.0</td>
<td>2.25</td>
</tr>
<tr>
<td>Flat paddles, 2 blades, $D_i/W_i = 6$</td>
<td>36.5</td>
<td>1.70</td>
</tr>
<tr>
<td>Flat paddles, 2 blades, $D_i/W_i = 8$</td>
<td>33.0</td>
<td>1.15</td>
</tr>
<tr>
<td>Flat paddles, 4 blades, $D_i/W_i = 6$</td>
<td>49.0</td>
<td>2.75</td>
</tr>
<tr>
<td>Flat paddles, 6 blades, $D_i/W_i = 6$</td>
<td>71.0</td>
<td>3.82</td>
</tr>
</tbody>
</table>

Mechanical Mixers

Turbine or Propeller Mixers \textbf{Power Requirement}

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

\[ \phi = k R_e^p \]

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

Lecture notes of Assist. Prof. Bilge Alpaslan Kocamemi
Rapid mixing devices

Propeller Impellers

Propeller Mixer

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


Lecture notes of Assist. Prof. Bilge Alpaslan Kocamemi
Turbine Impellers

Figure 5-15

Turbine Impellers

(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>High</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></td>
</tr>
</tbody>
</table>

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

Turbine - Impeller

Turbine Impeller

Lecture notes of Assist. Prof. Bilge Alpaslan Kocamemi
Paddle Mixers

- Paddle mixers consist 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
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 turbulence
- Paddle tip speed is generally 0.6 to 0.9 m/s
Paddle Mixers

Four blade paddle
Gate paddle

FIGURE 8.12 Types of Paddle Impellers
(a) Two Blades
(b) Six Blades

FIGURE 8.13 Flow Regime in a Paddle


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\(^2\))
- \( \rho \) = Density (kg/m\(^3\))
- \( V_p \) = Relative velocity of paddles with respect to the fluid (m/s), usually assumed to be 0.6 to 0.75 times the paddle tip speed
- \( P \) = Power requirement (W)
Power imparted to water by a paddle impeller

\[ P = F_{D} V_{P} = \frac{C_{D} A \rho V_{p}^{3}}{2} \]

- **P**: Power
- **F**: Force
- **D**: Drag coeff.
- **A**: Cross-sectional area of paddle (ft\(^2\) or m\(^2\))
- **\( \rho \)**: Density of fluid (slug/ft\(^3\) or kg/m\(^3\))
- **V\(_{P}\)**: Relative velocity of paddles with respect to water

\[ 1 \text{min/60sec} \]

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

- **r**: Distance from shaft to paddle center (m)
- **N**: Shaft (N, rpm)

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.

<table>
<thead>
<tr>
<th>L/W ratio</th>
<th>Cd</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>
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

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

P = Power dissipated (kW)

\( Q_a \) = Air flow rate at atmospheric pressure (m\(^3\)/min)

h = air pressure at the point of discharge (m)

- Problems