Purpose of agitation:

- intensification of transport processes in agitated batch (heat and mass transfer)
- preparation of materials of required properties (suspension, emulsion)

Examples of industrial applications:

- blending of two miscible liquids as ethyl alcohol and water
- dissolving solids in liquids, such as salt in water
- dispersing a gas in a liquid as fine bubbles, such as oxygen from air in a suspension of microorganisms for fermentation or for the activated sludge process in waste treatment
- liquid-liquid dispersion, such as dispersion of pigment in solvents
- suspending of fine solid particles in a liquid, as in catalytic hydrogenation of a liquid
- agitation of the fluid to increase heat transfer between the fluid and a coil or jacket in the vessel wall
Method of mixing fluids

- **mechanical mixing** (rotating, vibrating)
- hydraulic mixing
- pneumatic mixing
- **pipeline mixing** (turbulent flow, static mixer)

A – mechanical mixing using turbines
B – mechanical mixing using blade impellers
C – hydraulic mixing
D – pneumatic mixing with stationary inputs
E – pneumatic mixing with automatic regulation
F – hydraulic mixing with antifoaming shower
Pipeline mixing – Reynolds experiments

(a) Flow pattern at low mean velocity with dye injection.

(b) Flow pattern at higher velocity with dye injection.

(c) Flow pattern at high velocity with dye injection.

Figure 7-1 Reynolds experiments.
Flow in agitated batch

- **a** – axial-flow pattern, baffled vessel
- **b** – radial-flow pattern, baffled vessel
- **c** – tangential-flow pattern, unbaffled vessel
Equipment for mechanical mixing

Design layout of mixing equipments

A – Centrally placed impeller in bafled vessel, B – Side-entering propeller, C – Agitator with draught tube

A – Equipment with a drive at the top, B – Equipment with a drive at the bottom

Mechanical seal
Design layout of agitators

Close clearance agitator

High-speed impeller
<table>
<thead>
<tr>
<th>No.</th>
<th>Layout of agitator</th>
<th>Name</th>
<th>T/d</th>
<th>Geometrical parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="image" alt="Anchor Agitator" /></td>
<td>Anchor (paddle) agitator</td>
<td>1,11</td>
<td>( h_{v}/d = 0,8 ) ( h/d = 0,12 ) ( H_{2}/d = 0,055 )</td>
</tr>
<tr>
<td>2</td>
<td><img src="image" alt="Helical Screw Agitator" /></td>
<td>Helical-screw agitator with draught tube</td>
<td>2</td>
<td>( h_{v}/d = 1,5 ) ( s/d = 1 ) ( D'/d = 1,1 ) ( H'/D' = 1,15 )</td>
</tr>
<tr>
<td>3</td>
<td><img src="image" alt="Eccentrically Placed Helical Screw Agitator" /></td>
<td>Eccentrically placed helical-screw agitator</td>
<td>2</td>
<td>( h_{v}/d = 1,5 ) ( H_{2}/d = 0,25 ) ( s/d = 1 ) ( c/T = 0,02 )</td>
</tr>
<tr>
<td>No.</td>
<td>Layout of agitator</td>
<td>Name</td>
<td>T/d</td>
<td>Geometrical parameters</td>
</tr>
<tr>
<td>-----</td>
<td>------------------</td>
<td>------</td>
<td>-----</td>
<td>-----------------------</td>
</tr>
</tbody>
</table>
| 4   | ![Helical-ribbon agitator](image) | Helical-ribbon agitator CVS 69 1029 | 1.05 | \[
\frac{h_v}{d} = 1, \quad \frac{s}{d} = 1, \quad \frac{h}{d} = 0.1
\] |
| 5   | ![Leaf agitator](image) | Leaf agitator CVS 69 1016 | 2 | \[
\frac{h}{d} = 1
\] |
| 6   | ![Multi-stage agitator](image) | Multi-stage agitator | 2 | \[
\frac{h}{d} = 0.2, \quad \frac{h_v}{d} = 1.65, \quad \alpha = 45^\circ, \quad \beta = 45^\circ, \quad \frac{c}{T} = 0.02, \quad \frac{H_2}{d} = 0.175
\] |
### Main type of high-speed impellers

<table>
<thead>
<tr>
<th>No.</th>
<th>Layout of impeller</th>
<th>Name</th>
<th>T/d</th>
<th>Geometrical parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="image1.png" alt="Diagram" /></td>
<td>Six-blade turbine with disk (Ruschton turbine)</td>
<td>3 (\div) 4</td>
<td>(h/d = 0.2), (1/d = 0.25), (d_1/d = 0.75), 6 blades</td>
</tr>
<tr>
<td>2</td>
<td><img src="image2.png" alt="Diagram" /></td>
<td>Six-blade open turbine</td>
<td>3 (\div) 4</td>
<td>(h/d = 0.2), 6 blades</td>
</tr>
<tr>
<td>3</td>
<td><img src="image3.png" alt="Diagram" /></td>
<td>Pitched six-blade turbine with pitch angle 45</td>
<td>3 (\div) 4</td>
<td>(h/d = 0.20), (\alpha = 45^\circ)</td>
</tr>
<tr>
<td>No.</td>
<td>Layout of impeller</td>
<td>Name</td>
<td>T/d</td>
<td>Geometrical parameters</td>
</tr>
<tr>
<td>-----</td>
<td>-------------------</td>
<td>------</td>
<td>-----</td>
<td>------------------------</td>
</tr>
<tr>
<td>4</td>
<td><img src="image" alt="Pitched three-blade turbine" /></td>
<td>Pitched three-blade turbine with pitch angle 45° CVS 69 1025.3</td>
<td>3 : 4</td>
<td>h / d = 0.2 &lt;br&gt; α = 45°</td>
</tr>
<tr>
<td>5</td>
<td><img src="image" alt="Propeller" /></td>
<td>Propeller CVS 69 1019</td>
<td>3 : 4</td>
<td>s / d = 1 &lt;br&gt; h / d = 0.22 &lt;br&gt; R / d = 0.4 &lt;br&gt; R_1 / R = 0.16</td>
</tr>
<tr>
<td>6</td>
<td><img src="image" alt="High shear stress impeller" /></td>
<td>High shear stress impeller CVS 69 1038.1, .2</td>
<td>2 : 4</td>
<td>1^st variant &lt;br&gt; h / d = 0.1 &lt;br&gt; d_2 / d = 0.8 &lt;br&gt; 2^nd variant &lt;br&gt; h / d = 0.075 &lt;br&gt; d_2 / d = 0.85</td>
</tr>
</tbody>
</table>
Characteristics of mixing system

Power consumption of agitator

\[ Po = \frac{P}{\rho n^3 d^5} \]

\[ Po = f(Re) \]

\[ Re = \frac{nd^2 \rho}{\mu} \]

- **Creeping flow**
- **Transition zone of flow**
- **Turbulent flow**

\[ Po = \frac{A}{Re} \]

\[ Po = B = \text{const.} \]
Power characteristics of close clearance agitators

Power characteristics of high-speed impellers operated in baffled vessel

1 – six-blade turbine with disk (Ruschton turbine) (CVS 69 1021), 2 – six-blade open turbine, 3 – pitched six-blade turbine with pitch angle 45 (CVS 69 1020), 4 – Pitched three-blade turbine with pitch angle 45° (CVS 69 1025.3), 5 – propeller (CVS 60 1019), 6a,b – high shear stress impeller (CVS 69 1038.1.2)
Blending effect of agitator

During homogenization (or blending) of miscible liquids are compensated temperature and concentration differences in agitated batch.

Homogenization of miscible liquids:  
- due to recirculation flow (convective diffusion)  
- due to turbulent flow (turbulent diffusion)  
- due to molecular diffusion

\[ t^* = n \cdot t_m = f(Re) \]

\[ t^* = n \cdot t_m = \text{konst.} \]
Homogenization characteristics of agitators

\[ t^* = n \cdot t_m = f(Re) \]

1 – helical-screw agitator with draught tub (CVS 69 1028), 2 – eccentrically placed helical-screw agitator, 3 – helical-ribbon agitator (CVS 69 1029), 4 – eccentrically placed multi-stage agitator, 5 – anchor agitator (CVS 69 1014), 6 – six-blade turbine with disk (Ruschton turbine) (CVS 69 1021)
1 – helical-screw agitator with draught tub (CVS 69 1028), 2 – eccentrically placed helical-screw agitator, 3 – helical-ribbon agitator (CVS 69 1029), 4 – eccentrically placed multi-stage agitator, 5 – anchor agitator (CVS 69 1014), 6 – six-blade turbine with disk (Ruschton turbine) (CVS 69 1021)
Mixing of heterogeneous batch

Heterogeneous batch: • liquid – gas
• liquid – liquid (emulsion)
• liquid – solids (suspension)

Purpose of agitation

→ Intensification of mass transfer

\[ \dot{m} = \beta S \Delta \rho_A \]
Dispersion of gas in liquid

- Flooding of impeller

\[ \frac{V_g}{nd^3} \approx 16,6 Fr \left( \frac{d}{T} \right)^{3,4} \]

- Recommended gas flow-rate \( \rightarrow \) VVM = 1 \( \div \) 1,5
  (volumetric flow of gas per liquid volume per minute)

- Size of dispersed bubbles \( \rightarrow \) \( d_b \approx (P/V)^{-0,4} \)

  e.g. water – air:

\[ d_b = 4,15 \frac{\sigma^{0,6} c_v^{0,5}}{\rho^{0,2} (P/V)^{0,4}} + 9 \cdot 10^{-4} \]
Impeller power consumption for gas–liquid dispersing

\[ \frac{P_g}{P} = f \left( \frac{\dot{V}_g}{nd^3} \right) \]
Dispersion of liquid – liquid systems
(preparation of emulsion)

Size of dispersed liquid drops → balance of dynamic and surface forces

\[ d_{32} \approx \left( \frac{\sigma}{\rho_c} \right)^{3/5} \varepsilon^{-2/5} \]

\[ We = \frac{n^2 d^3 \rho_c}{\sigma} \]

\[ \frac{d_{32}}{d} \approx We^{-3/5} \]
Limits of dispergation technology and equipment
Impeller power consumption for liquid – liquid dispersing

\[ Po = \frac{P}{\rho_{mix} n^3 d^5} \]

\[ Re = \frac{nd^2 \rho_{mix}}{\mu_{mix}} \]

\[ \rho_{mix} = c_v \rho_d + (1-c_v) \rho_c \]
Mixing of suspension
Just-suspended impeller speed

\[ Fr' = \frac{\rho n^2 d}{g \Delta \rho} \]

\[ C = A \exp(B c_v) \]

\[ Fr' = C \left( \frac{d_p}{D} \right)^c \]

\[ c = \alpha + \beta c_v \]
Impeller power consumption for mixing of suspension

\[ Po = \frac{P}{\rho_{su} n^3 d^5} \]

\[ Po = f(Re) \]

\[ Re = \frac{nd^2 \rho_{su}}{\mu} \]

\[ \rho_{su} = c_v \rho_s + (1 - c_v) \rho \]
Scale-up of mixing processes

\[ \frac{P}{V} = \text{Constant } V^y \]

\[ \frac{T_Q}{V} = K_T V^x \]

- Constant Blend Time: \( y = 2/3 \)
- Vortex: \( y = 1/6 \)
- Dispersion: \( y = 0 \)
- Solids: \( y = -1/12 \)
- Flow Velocity: \( y = -1/3 \)

Log-Log Plot

- Constant Blend Time: \( X = 2/3 \)
- Vortex: \( X = 1/3 \)
- Dispersion: \( X = 2/9 \)
- Solids: \( X = 1/6 \)
- Flow Velocity: \( X = 0 \)

Log-Log Plot
**EXAMPLE: Blending efficiency of impellers**

Select type of high-speed impeller with minimum energetic requirements for continual blending (homogenization) of two miscible liquids A + B \( (\mu = 5 \text{ mPa} \cdot \text{s}, \rho = 1100 \text{ kg} \cdot \text{m}^{-3}) \) with flow rate of mixture 10 l·s\(^{-1}\). For suitable degree of homogenization must be residence time of liquids in equipment 5 x longer than blending time. Mixing equipment has standard geometrical configuration (baffled cylindrical vessel with diameter \( T = 1200 \text{ mm}, T/d = 3.3; H_2/d = 1, H/T = 1 \)).

**Dimensionless blending time of high-speed impellers in turbulent flow regime**

<table>
<thead>
<tr>
<th>Type of impeller</th>
<th>( T/d )</th>
<th>( H_2/d )</th>
<th>( n \cdot t_m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Six-blade turbine with disk (Ruschton turbine), CVS 69 1021</td>
<td>3.3</td>
<td>1</td>
<td>51.8</td>
</tr>
<tr>
<td>Pitched six-blade turbine with pitch angle 45, CVS 69 1020</td>
<td>3.3</td>
<td>1</td>
<td>53.1</td>
</tr>
<tr>
<td>Pitched three-blade turbine with pitch angle 45°, CVS 69 1025.3</td>
<td>3.3</td>
<td>1</td>
<td>60.5</td>
</tr>
</tbody>
</table>