AGITATED VESSEL HEAT TRANSFER

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Agitation

- Agitation refers to forcing a fluid by mechanical means to flow in a circulatory or other pattern inside a vessel.

- Mixing usually implies the taking of two or more separate phases, such as a fluid and a powdered solid or two fluids, and causing them to be randomly distributed through one another.

Purpose of Agitation

1. Blending of two miscible liquids, such as ethyl alcohol and water.
2. Dissolving solids in liquids, such as salt in water.
3. Dispersing a gas in a liquid as fine bubbles,

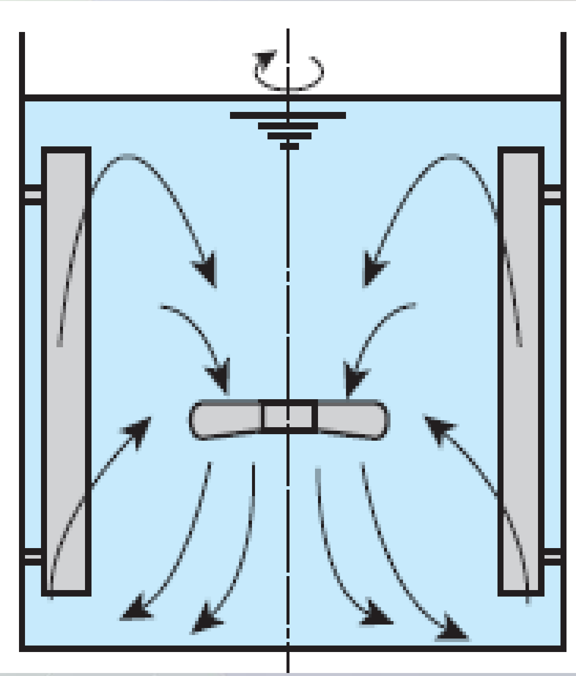
   - such as oxygen from air in a suspension of microorganisms for fermentation or for the activated sludge process in waste treatment.
4. Suspending of fine solid particles in a liquid,

   - in the catalytic hydrogenation of a liquid, solid catalyst particles and hydrogen bubbles are dispersed in the liquid.
5. Agitation of the fluid to increase heat transfer between the fluid and a coil or jacket in the vessel wall.

Equipment for Agitation

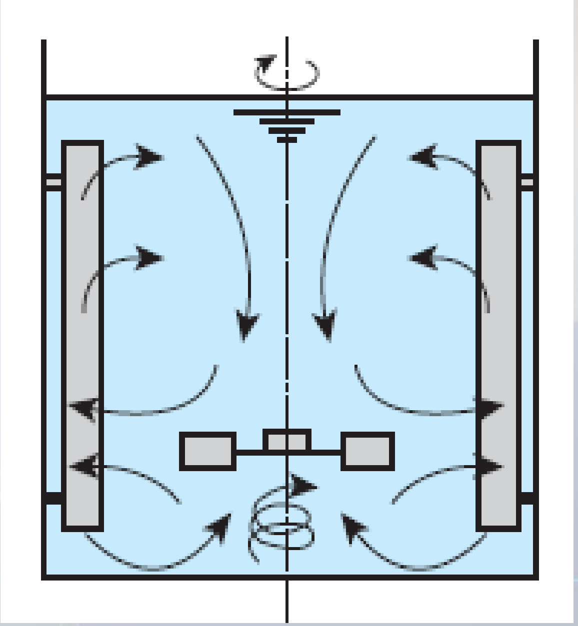
- Three-blade propeller agitator
- Paddle agitators
- Turbine agitators
- Helical-ribbon agitators

Three-blade propeller agitator



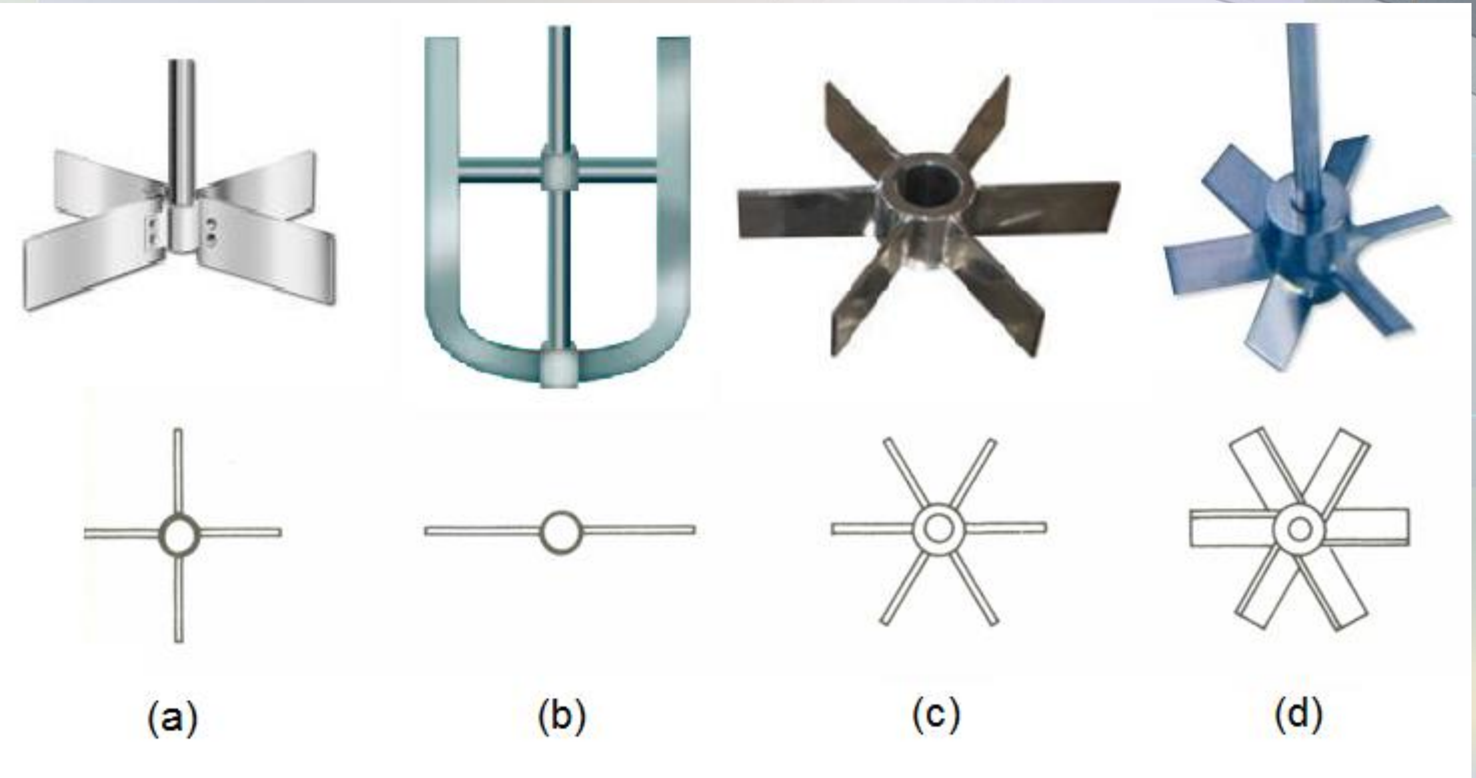
Baffled tank and three-blade propeller agitator with flow pattern: (a) side view, (b) propeller view

Six-blade flat disk turbine agitator



Baffled tank and 6-blade flat disk turbine with flow pattern: (a) side view, (b) agitator view

- Generally used at low speeds, between about 20 and 200 rpm.



Various types of agitators:

(a) four-blade paddle, (b) gate or anchor paddle, (c) six-blade open turbine, (d) pitched-blade (45 degree) turbine.

Helical-Ribbon Agitator

- used in highly viscous solutions
- operates at a low rpm in the laminar region.
- The ribbon is formed in a helical path and is attached to a central shaft.
- The liquid moves in a tortuous flow path down the center and up along the sides in a twisting motion.

Types of agitators: (a) Single helical-ribbon
(b) double-helical-ribbon
(c) helical-screw.

HEAT TRANSFER TO VESSELS

In a mechanically agitated vessel, heat generated or needed for the process is mostly removed or supplied through a jacketed wall or internal coils

- **Jacketed vessels:** Various types of jacket structure commonly used such as

a. ***Plain jacket***

b. ***Jacket with internal baffles***

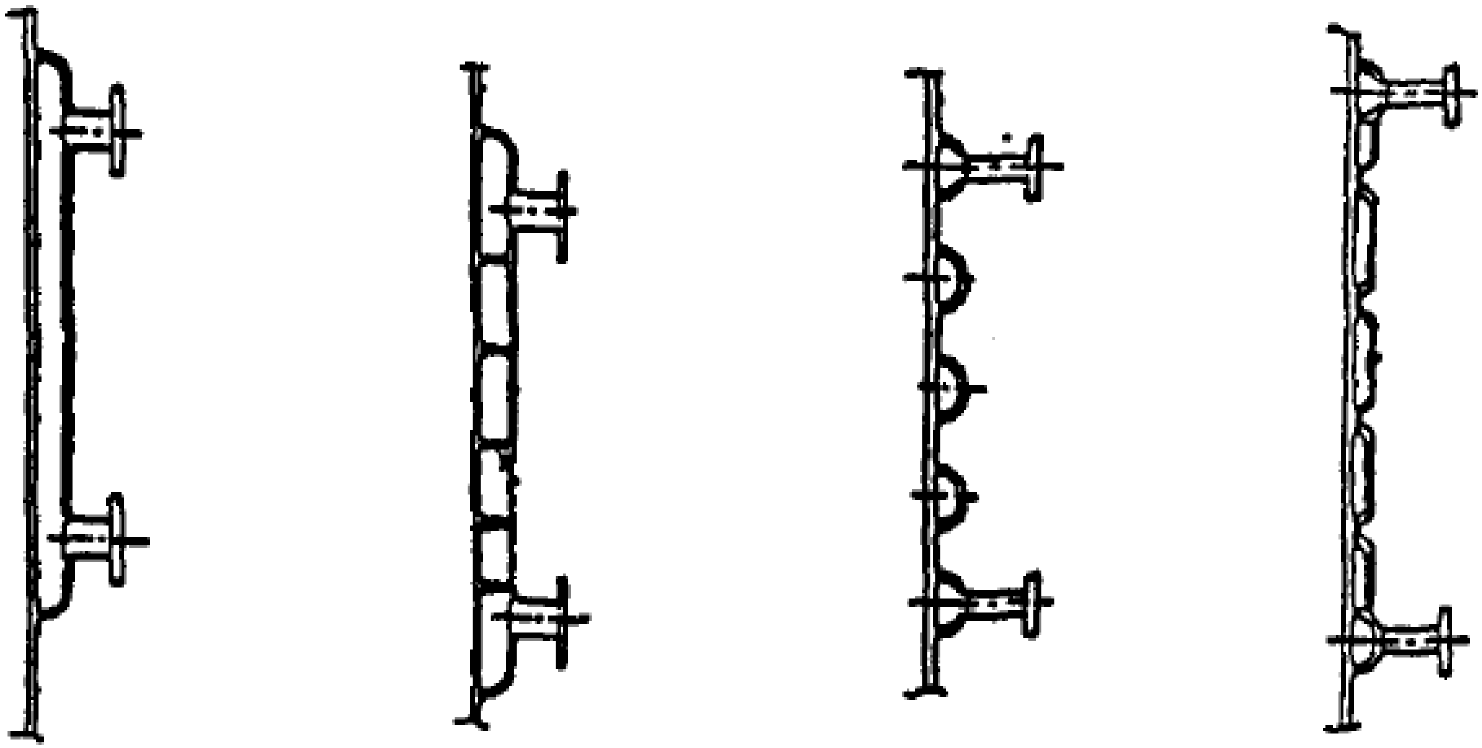
c. ***Hemi-cut pipe jacket***

d. ***Dimple jacket***

The *Plain jacket* is normally used in lower pressure steam heating, or smaller scale vessels, low pressure coolant cooling systems. *Jacket with internal baffles* is in order to increase external side film coefficient, it is often install a spiral flow path for external side heat transfer fluid to increase its flow rate. The spacing between the jacket and vessel wall will depend on the size of the vessel, but will typically range from 50 mm for small vessels to 300 mm for large vessels.

*Hemi-cut pipe jack*et is used to overcome the effect of external pressure exerting on vessel wall. The pitch of the coils and the area covered can be selected to provide the heat transfer area required. Standard pipe sizes are used; ranging from 60 to 120 mm outside diameter. The half-pipe construction makes a strong jacket capable of withstanding pressure better

than the conventional jacket design. *Dimpled jackets* are similar to the conventional jackets but are constructed of thinner plates. The jacket is strengthened by a regular pattern of hemispherical dimples pressed into the plate and welded to the vessel wall. *Hemi-cut pipe jacket or dimple jacket* is often adopted to reduce the required wall thickness of the vessel.



(a) (b) (c) (d)

Jacket selection

Factors to consider when selecting the type of jacket to use are listed below:

1. Cost: in terms of cost the designs can be ranked, from cheapest to most expensive, as:

- ✓ simple, no baffles
- ✓ agitation nozzles
- ✓ spiral baffle
- ✓ dimple jacket
- ✓ half-pipe jacket

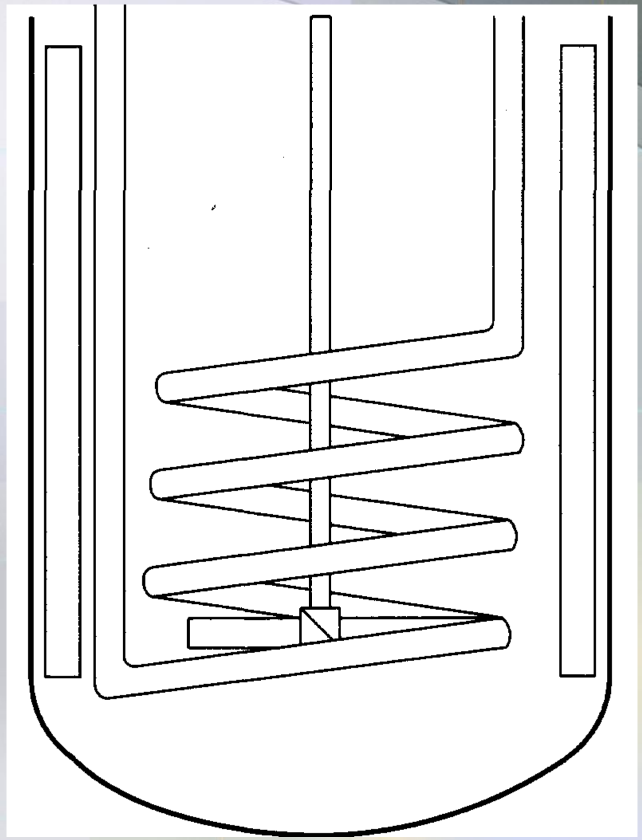
2. Heat transfer rate required: select a spirally baffled or half-pipe jacket if high rates are required.
3. Pressure: as a rough guide, the pressure rating of the designs can be taken as:

- ✓ jackets, up to 10 bar
- ✓ dimpled jackets, up to 20 bar
- ✓ half-pipe, up to 70 bar.

So, half-pipe jackets would be used for high pressure.

❑ Internal coils:

The simplest and cheapest form of heat transfer surface for installation inside a vessel is a helical coil; see Figure below. The pitch and diameter of the coil can be made to suit the application and the area required. The diameter of the pipe used for the coil is typically equal to **D*v*/30**, where D*v* is the vessel diameter. The coil pitch is usually around twice the pipe diameter. Small coils can be self supporting, but for large coils some form of supporting structure will be necessary. Single or multiple turn coils are used.



The correlations used to estimate the heat transfer coefficient to the vessel wall, or to the surface of coils, have the same form as those used for forced convection in conduits, equation below. The fluid velocity is replaced by a function of the agitator diameter and rotational speed, D x N, and the characteristic dimension is the agitator diameter.

$$Nu = C Re^a Pr^b \left(\frac{\mu}{\mu_w} \right)^c$$

For agitated vessels:

$$\frac{h_v D}{k_f} = C\left(\frac{ND^2\rho}{\mu}\right)^a \left(\frac{Cp\mu}{k_f}\right)^b \left(\frac{\mu}{\mu_w}\right)^c$$

where

h_v = heat transfer coefficient to vessel wall or coil, W/m^2 °C

D = agitator diameter, m

N = agitator, speed, rps (revolutions per second)

ρ = liquid density, kg/m^3

k_f = liquid thermal conductivity, W/m°C

Cp = liquid specific heat capacity, J/kg °C

μ = liquid viscosity, N/m^2 °C

The values of constant C and the indices a, b and c depend on the type of agitator, the use of baffles, and whether the transfer is to the vessel wall or to coils. Some typical correlations are given below. Baffles will normally be used in most applications.

1. Flat blade paddle, baffled or unbaffled vessel, transfer to vessel wall, Re < 4000:

$$Nu = 0.36 Re^{0.67} Pr^{0.33} \left(\frac{\mu}{\mu_w} \right)^{0.14}$$

2. Flat blade disc turbine, baffled or unbaffled vessel, transfer to vessel wall, Re < 400:

$$Nu = 0.54 Re^{0.67} Pr^{0.33} \left(\frac{\mu}{\mu_w} \right)^{0.14}$$

3. Flat blade disc turbine, baffled vessel, transfer to vessel wall, Re > 400:

$$Nu = 0.74 Re^{0.67} Pr^{0.33} \left(\frac{\mu}{\mu_w} \right)^{0.14}$$

4. Propeller, 3 blades, transfer to vessel wall, Re > 5000:

$$Nu = 0.64 Re^{0.67} Pr^{0.33} \left(\frac{\mu}{\mu_w} \right)^{0.14}$$

5. Paddle type, transfer to vessel wall, Re =300 -300000

$$Nu = 0.36 Re^{0.67} Pr^{0.33} \left(\frac{\mu}{\mu_w} \right)^{0.21}$$

6. Pitch blade turbine, baffled vessel, transfer to vessel wall, Re =80 -200:

$$Nu = 0.36 Re^{0.67} Pr^{0.33} \left(\frac{\mu}{\mu_w} \right)^{0.24}$$

7. Propeller, 3 blades, transfer to vessel wall, Re > 5000:

$$Nu = 0.64 Re^{0.67} Pr^{0.33} \left(\frac{\mu}{\mu_w} \right)^{0.14}$$

8. Anchor type, transfer to vessel wall, Re =300 -40000

$$Nu = 0.36 Re^{0.67} Pr^{0.33} \left(\frac{\mu}{\mu_w} \right)^{0.18}$$

9. Turbine, flat blades, transfer to coil, baffled. Re = 2000 -700.000:

$$Nu = 1.1 Re^{0.62} Pr^{0.33} \left(\frac{\mu}{\mu_w} \right)^{0.24}$$

10. Paddle, flat blades, transfer to coil, baffled,

$$Nu = 0.87 Re^{0.62} Pr^{0.33} \left(\frac{\mu}{\mu_w} \right)^{0.14}$$

Pressure drop

❑ Jacketed vessels

The fluid velocity and the path length can be calculated from the geometry of the jacket arrangement. The hydraulic mean diameter (equivalent diameter, ***de***) of the channel or half-pipe should be used as the characteristic dimension in the Reynolds and Nusselt numbers. But if the jacket is not baffled, the jacket can be regarded as "double pipe".

$$\Delta P = 2f\,\frac{L}{d_e}\,\rho u^2$$

$$f = \left[0.0035 + 0.264\,(\mathrm{Re})^{-0.42}\right]\left[1 + 3.5\,\frac{d}{D}\right]$$

Where

ΔP = Pressure drop, Pa

L = Path length, m.

de = equivalent diameter, m.

u = Fluid velocity, m/s.

ρ = Fluid density, Kg/m^3

f = Fanning friction factor, dimensionless

❑ Internal coils

The pressure drop through the coil can be estimated using the correlations for flow through pipes

$$\Delta P = 2 f \, \frac{L}{d_e} \, \rho u^2$$

$$f = \left[0.0035 + 0.264 \left(\mathrm{Re} \right)^{-0.42} \right] \left[1 + 3.5 \, \frac{d_e}{D_c} \right]$$

Where

ΔP = Pressure drop, Pa

L = Coil length, m.

d_e = Coil pipe diameter, m.

D_c = Coil diameter, m.

u = Fluid velocity, m/s.

ρ = Fluid density, Kg/m^3

f = Fanning friction factor, dimensionless

Design Procedure for Double Pipe Exchanger

1. Define heat transfer, mass flowrate and temperature deference for heat exchanger

$$Q = mC_p \Delta T$$

2. Collect physical properties at bulk temperature (ρ, μ, *Cp*, *k*…etc.)
3. Calculate the mean deference temperature (LTMD)
4. Decide the heat exchanger layout (jacketed type or immersed coil)
5. Select the overall heat transfer coefficient from the table
6. Calculate the surface area required.
7. Calculate the heat transfer coefficients for each side (h_i, h_o)

8. Predict the fouling factor for two sides of heat exchanger (1/hiD, 1/hoD).
9. Calculate the overall heat transfer coefficient exchanger using equation below;

$$\frac{1}{U}=\frac{D_2}{D_1}\frac{1}{h_i}+\frac{1}{h_o}+\frac{D_2\ln\frac{D_2}{D_1}}{2K_w}+\frac{D_2}{D_1}\frac{1}{h_{iD}}+\frac{1}{h_{oD}}$$

10. Compare the calculated with the assumed overall coefficient. If satisfactory, say 0% to 10% error, proceed. If unsatisfactory return the step 5 using the calculated overall coefficient. Optimize the design calculation by repeating steps 5-10 as necessary to design cheapest heat exchanger.
11. Calculate the pressure drop for two sides of the vessel.