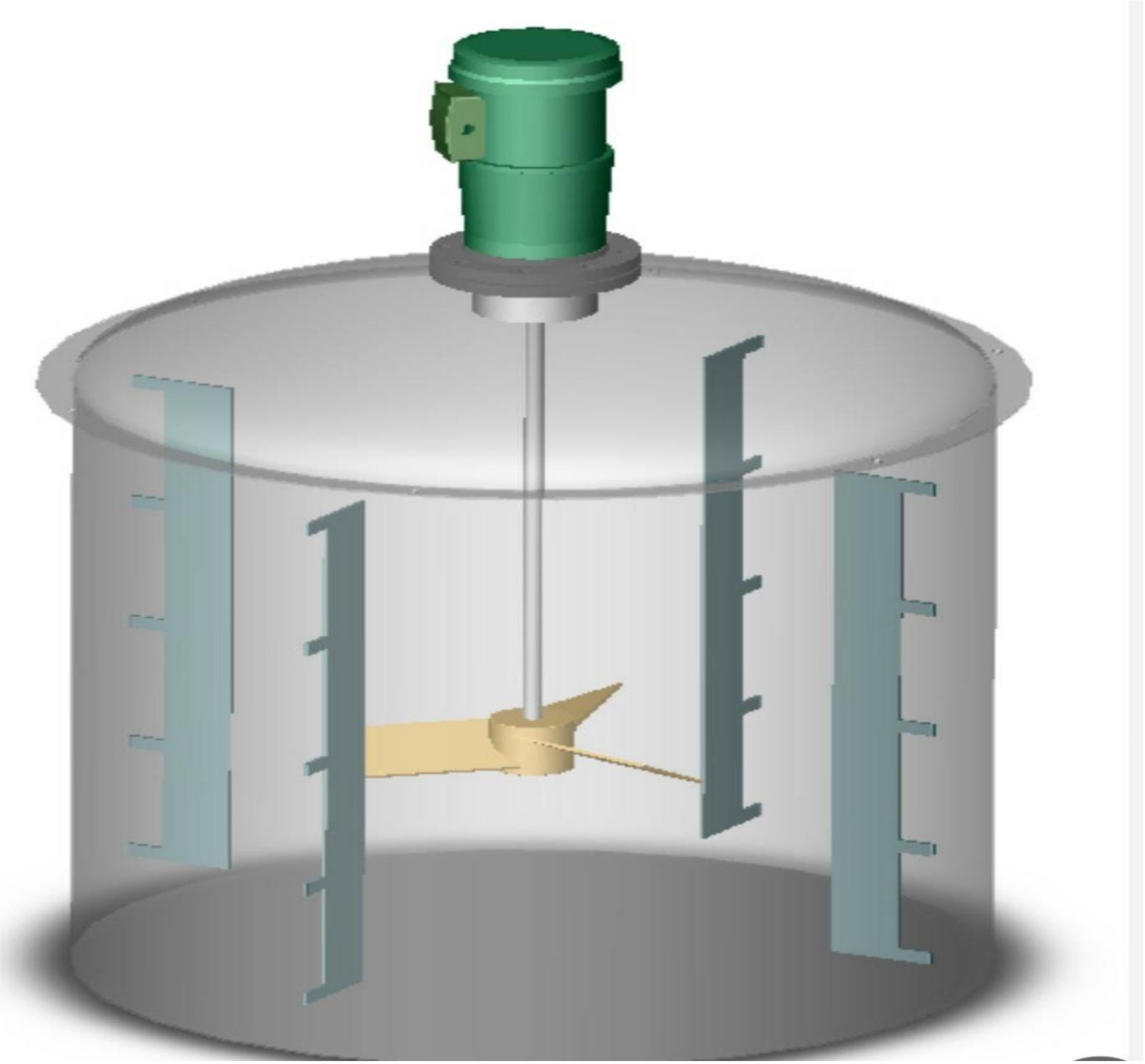
Agitating tank design (mixer)

Industry Mixer Tank



Agitation & Mixing of fluids

- In process industries many operations are dependent on effective agitation and mixing of fluids.

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

- Mixing usually implies the blending 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.

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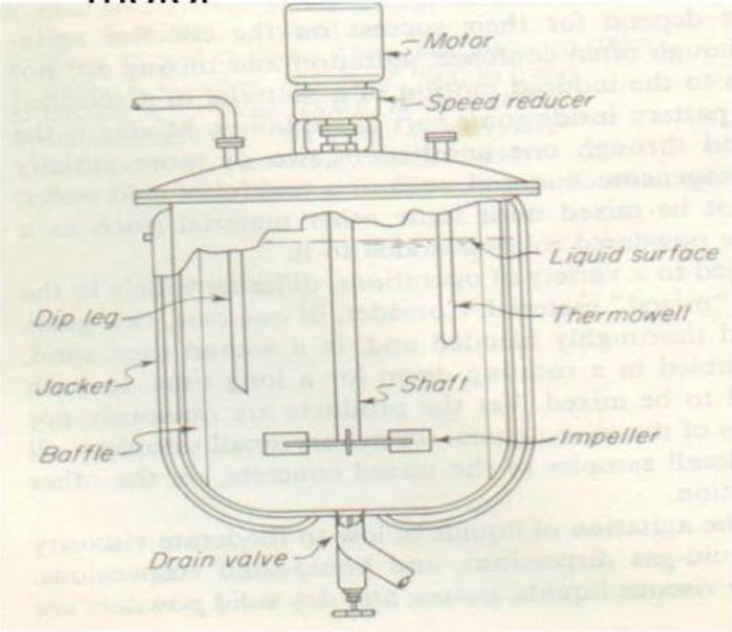
Equipment for agitation

- Generally, liquids are agitated in a cylindrical vessel which can be closed or open to the air.
- The height of liquid is approximately equal to the tank dia.
- An impeller mounted on a shaft is driven by an electric motor



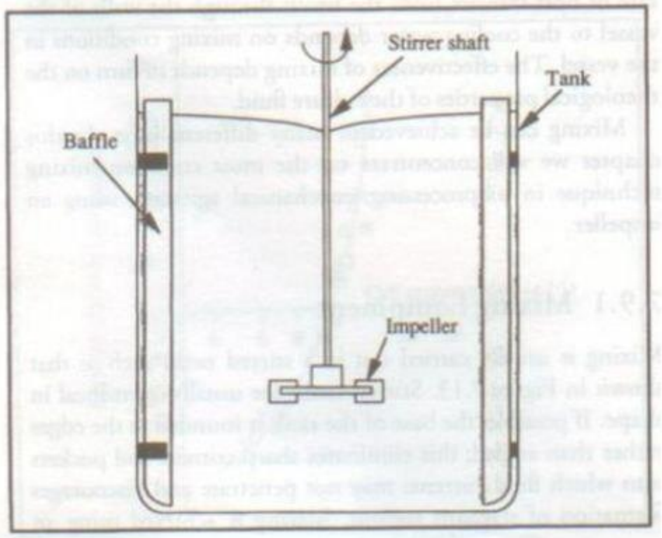
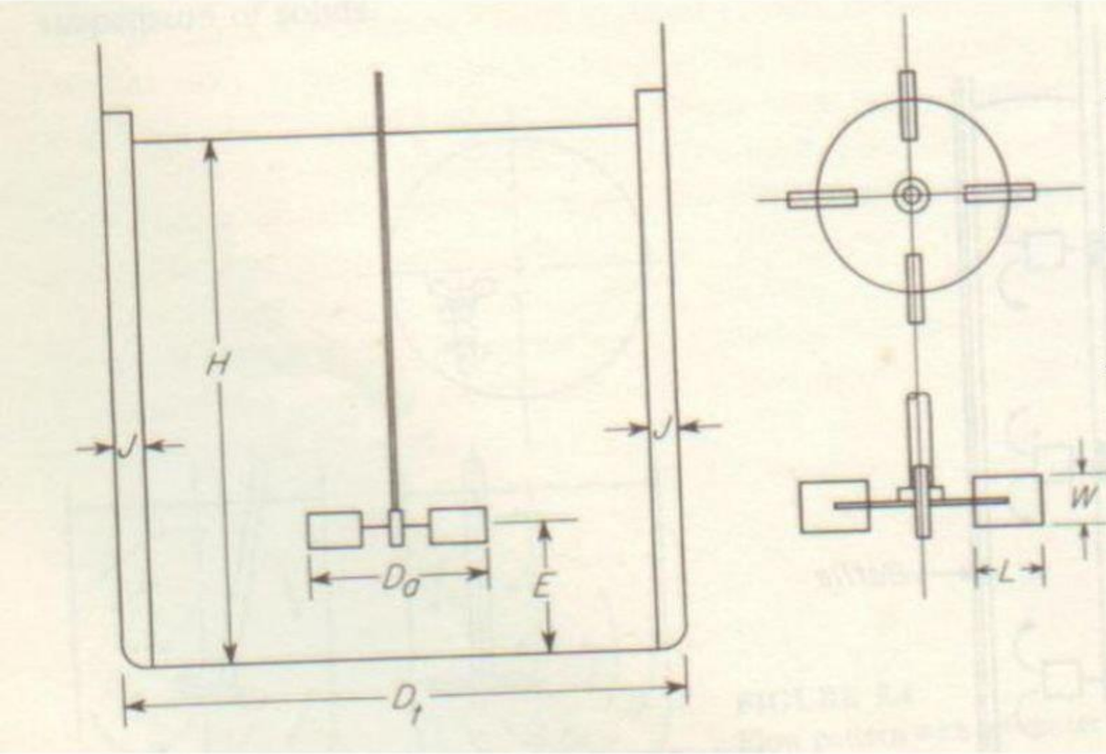


Figure 7.13 Typical configuration of a stirred tank.

Measurements of turbine



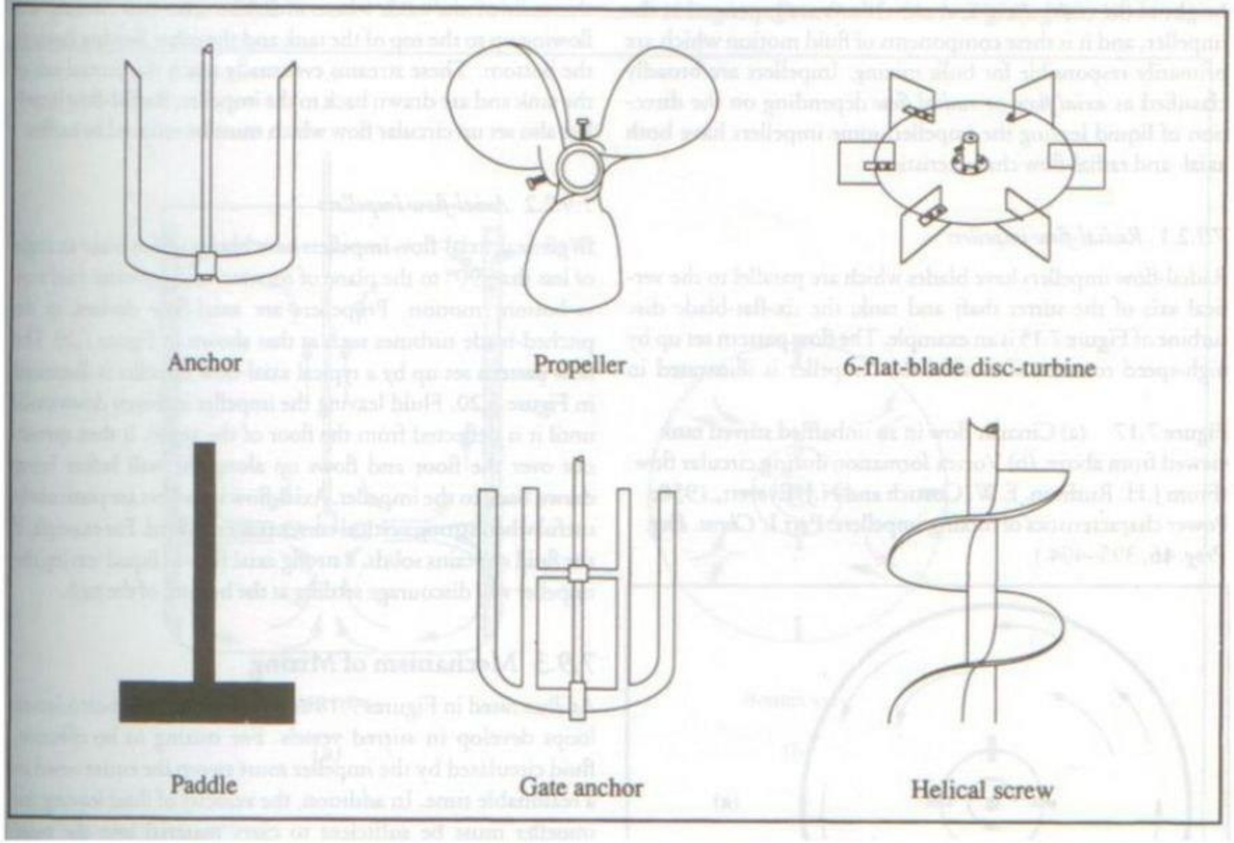
$$\frac{D_a}{D_t} = \frac{1}{3} \qquad \frac{H}{D_t} = 1$$

$$\frac{J}{D_t} = \frac{1}{12} \qquad \frac{E}{D_t} = \frac{1}{3}$$

$$\frac{W}{D_a} = \frac{1}{5} \qquad \frac{L}{D_a} = \frac{1}{4}$$

Various types of agitators

Figure 7.15 Impeller designs.



Power needed in Agitated vessels

- In the design of an agitated vessel, an important factor is the power required to drive the impeller.

- The presence or absence of turbulence can be correlated with the impeller Reynolds number $N_{Re,i}$, defined as,

$$N_{\mathrm{Re},i} = \frac{D_a (N D_a) \rho}{\mu}$$

$$\boxed{\Rightarrow N_{\mathrm{Re},i} = \frac{N D_a^2 \rho}{\mu}}$$

$$N_{\mathrm{Re},i} < 10 \quad Laminar$$

$$N_{\mathrm{Re},i} > 10^4 \quad Turbulent$$

$$10 < N_{\mathrm{Re},i} < 10^4 \quad Transition$$

Power number vs. Reynolds number

- One of important dimensionless number used in Agitation is Power number, N_P

$$N_P = \frac{P}{\rho N^3 D_a^5}$$

- There are standard graphs to calculate power required for agitation with respect to the type of impeller.

- From the graph of N_P *vs.* $N_{Re,i}$ we can calculate the power required for agitation

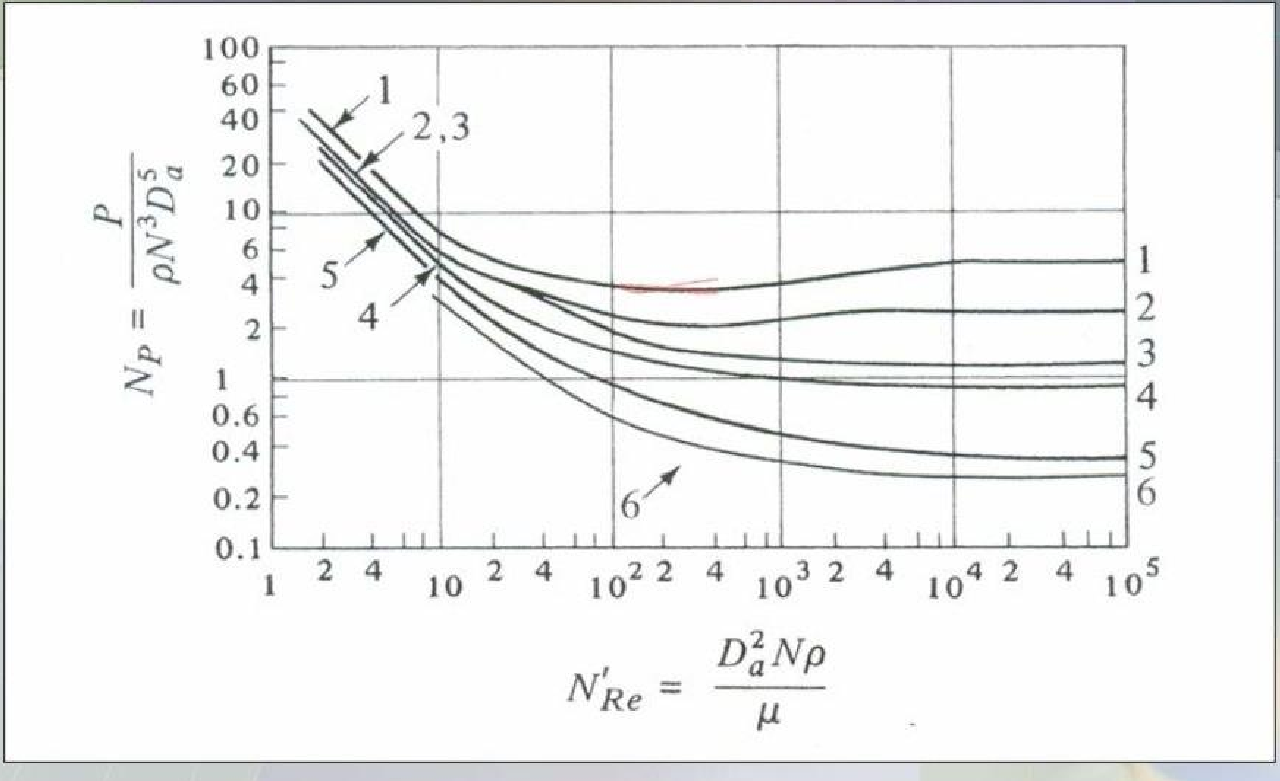
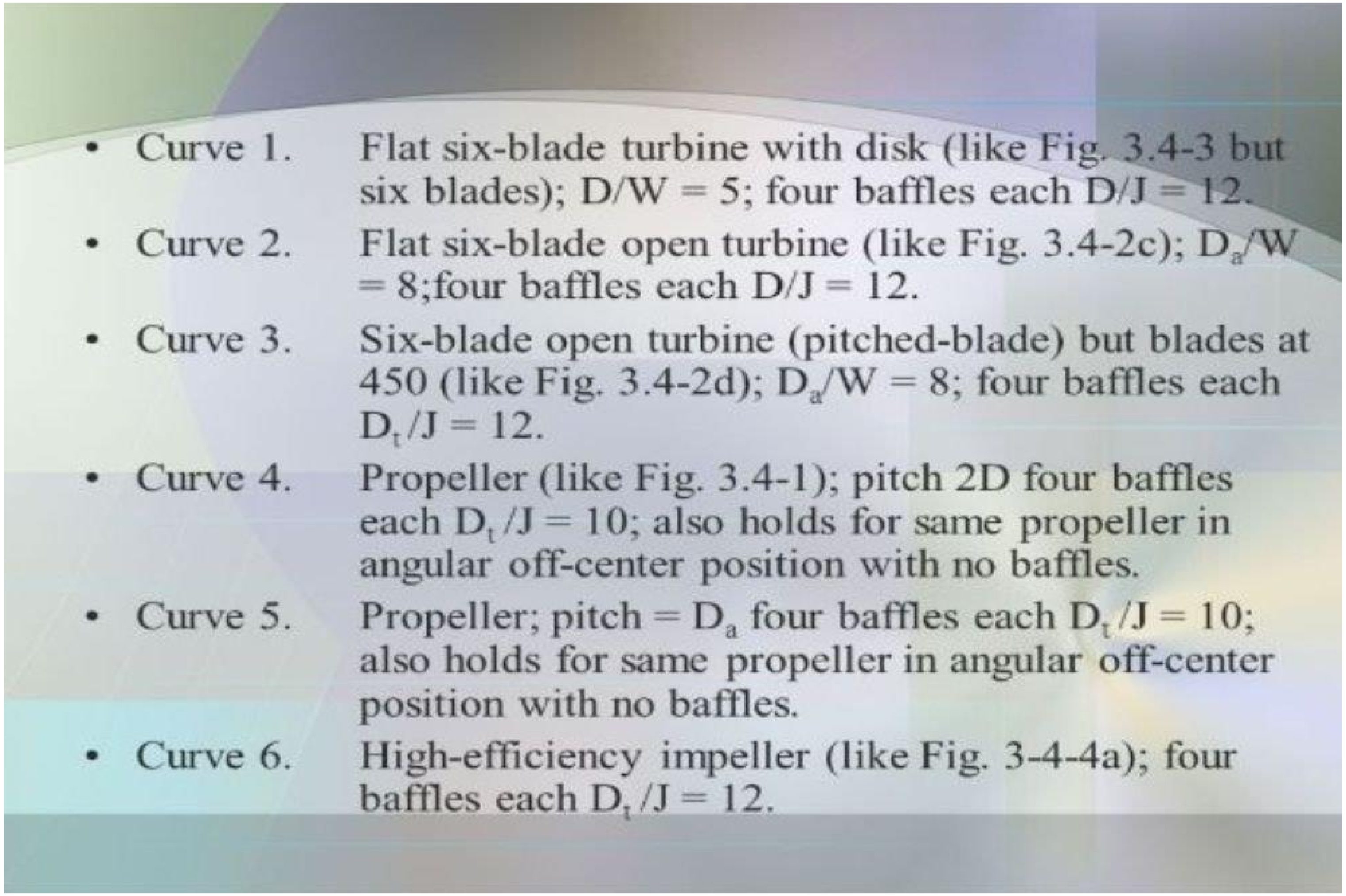
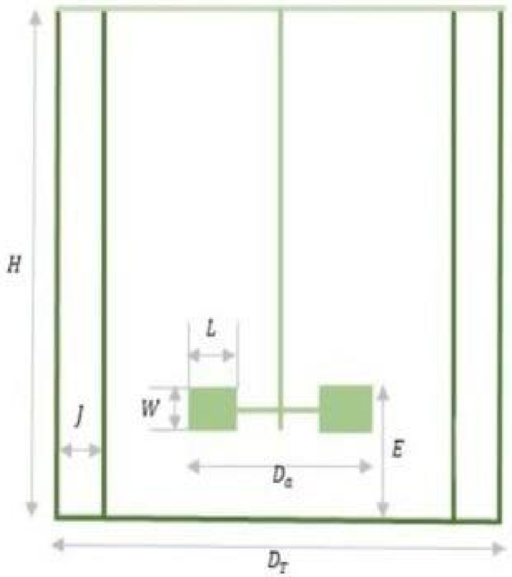


Figure 3.4-5 Power correlations for various impellers and baffles (Geankoplis, 4th ed.)



- Curve 1. Flat six-blade turbine with disk (like Fig. 3.4-3 but six blades); D/W = 5; four baffles each D/J = 12.
- Curve 2. Flat six-blade open turbine (like Fig. 3.4-2c); $D_a/W = 8$;four baffles each D/J = 12.
- Curve 3. Six-blade open turbine (pitched-blade) but blades at 450 (like Fig. 3.4-2d); $D_a/W = 8$; four baffles each $D_t/J = 12$.
- Curve 4. Propeller (like Fig. 3.4-1); pitch 2D four baffles each $D_t/J = 10$; also holds for same propeller in angular off-center position with no baffles.
- Curve 5. Propeller; pitch = D_a four baffles each $D_t/J = 10$; also holds for same propeller in angular off-center position with no baffles.
- Curve 6. High-efficiency impeller (like Fig. 3-4-4a); four baffles each $D_t/J = 12$.

DESIGN OF AGITATION /MIXING TANK



Ideal Size:

$$H = D_T \qquad W = \frac{1}{5}D_a$$

$$D_a = E = \frac{1}{3}D_T \qquad L = \frac{1}{4}D_a$$

$$J = \frac{1}{12}D_T$$

DESIGN CONSIDERATIONS:

Impeller Reynold's Number

$$N_{\mathrm{Re}} = \frac{\rho N {D_a}^2}{\mu}$$

N = rotational speed, rps

$N_{\mathrm{Re}} \geq 20{,}000$	*Turbulent*
$20{,}000 > N_{\mathrm{Re}} > 10$	*Transition*
$N_{\mathrm{Re}} \leq 10$	*Laminar*

Mixing Power

$$P = N_p \rho {D_a}^5 N^3$$

N_p = *Power Number*

= *Obtained from graph of* N_{Re} *vs Impeller type*

Mixing time, t_m *(or* t_b*)*

$$t_m N\left(\frac{D_a}{D_T}\right)^2 = 5(N_{Fr})^{\frac{1}{6}}\left(\frac{H}{D_T}\right)^{0.5}$$

$$t_m = \frac{45(N_{Fr})^{\frac{1}{6}}}{N} \quad \textit{(Ideal Size)}$$

N_{Fr} = *Froude Number*

$$N_{Fr} = \frac{N^2 D_a}{g}$$

Tip Speed, v

$$v = \pi D_a N$$

(usually $\geq 4\ m/s$*)*

Equipment Scaling

with Power: $P = k{D_a}^5 N^3$

with Tip Speed: $v = \pi N D_a$

with Mixing time: $t_m = \dfrac{kN_{Re}}{N}$

Other Dimensionless Groups:

Pumping Number: $N_Q = \dfrac{Q}{N{D_a}^3}$

Q = *total volumetric flowarte discharged by an impeller*

Sample Problem no.1 (Coulson and Richardson Vol. 4 Problem 7.8)

An agitated tank with a standard Rushton impeller is required to disperse gas in a solution of properties similar to those of water. The tank will be 3 m diameter (1 m diameter impeller). A power level of 0.8 kW/m3 is chosen. Assuming fully turbulent conditions and that the presence of the gas does not significantly affect the relation between the Power and Reynolds numbers (Np = 0.7)

(a) What power will be required by the impeller?

(b) At what speed should the impeller be driven?

(c) If a small pilot scale tank 0.3 m diameter is to be constructed to test the process, at what speed should the impeller be driven?

(a)

$$P = 0.8\frac{kW}{m^3}xV$$

$$V = \frac{\pi}{4}{D_T}^2H$$

$$Assuming\ D_T = H = 3m$$

$$V = \frac{\pi}{4}(3)^3 = 21.2m^3$$

$$\boxed{P = 17\ kW}$$

(b)

$$P = N_p\rho {D_a}^5N^3$$

$$N_p = 0.7$$

$$\rho = 1000\frac{kg}{m^3}$$

$$D_a = 1m$$

$$17x10^3 = 0.7(1000)(1)^5N^3$$

$$\boxed{N = 2.90Hz = 173\frac{rev}{\min}}$$

(c) *for large tank:*

$$P = k{D_a}^5N^3$$

$$17x10^3 = k(1)^5(2.90)^3$$

$$\underline{k = 697}$$

for small tank:

$$Assuming\ D_T = H = 0.3\ m$$

$$P = 0.8\frac{kW}{m^3}\left(\frac{\pi}{4}\right)(0.3)^2(0.3) = 17W$$

$$Assuming\ D_a = \frac{1}{3}D_T = \frac{1}{3}(0.3) = 0.1m$$

$$17 = 697(0.1)^5N^3$$

$$\boxed{N = 13.5Hz = 807\frac{rev}{\min}}$$

Equipment Scaling

with Power: $P = k{D_a}^5N^3$

Sample Problem no.2 (Coulson and Richardson Vol. 4 Problem 7.5)

For producing an oil-water emulsion, two portable three-bladed propeller mixers are available; a 0.5 m diameter impeller rotating at 1 Hz and a 0.35 m impeller rotating at 2 Hz. Assuming turbulent conditions prevail, which unit will have the lower power consumption?

for 0.5 *m diameter*:

$$P_{0.5} = kD_a{}^5N^3$$

$$P_{0.5} = k(1)^3(0.5)^5 = 0.03125k$$

for 0.35 *m diameter*:

$$P_{0.35} = kD_a{}^5N^3$$

$$P_{0.35} = k(2)^3(0.35)^5 = 0.0420k$$

$$\frac{P_{0.5}}{P_{0.35}} = 0.744$$

Thus the 0.5 *m diameter impeller will have the lower power consumption*; 74.4 % *of the* 0.35 *m diameter impeller*.

Example 1 Power Consumption in an Agitator

A flat blade turbine agitator with disk having six blades is installed in a tank similar to Fig. 3.4-3. The tank diameter D_t is 1.83 m, the turbine diameter D_a is 0.61 m, $D_t = H$, and the width W is 0.122 m. The tank contains four baffles, each having a width J of 0.15 m. The turbine is operated at 90 rpm and the liquid in the tank has a velocity of 10 cp and a density of 929 kg/m3.

a) Calculate the required kW of the mixer.

b) For the same conditions, except for the solution having a viscosity of 100,000 cp, calculate the required kW.

Solution

- For part (a) the following data are given:

$$D_a = \mathbf{0.61\,m} \qquad W = 0.122\,\mathrm{m} \qquad D_t = \mathbf{1.83\,m} \qquad J = 0.15\,\mathrm{m}$$

$$N = \frac{90}{60} = 1.50\ \mathrm{rev/s} \qquad \mu = (10\ \mathrm{cp})(1\times 10^{-3}) = 0.01\ \frac{\mathrm{kg}}{\mathrm{m.s}} = \mathrm{Pa.s}$$

$$\rho = 929\ \mathrm{kg/m^3}$$

- Using Eq. (1), the Reynolds number is:

$$N'_{\mathrm{Re}} = \frac{D_a^2 N\rho}{\mu} = \frac{(0.61)^2(1.50)(929)}{0.01} = 5.187\times 10^4$$

- Using Curve 1 in Fig 3.4-5, since

$$D_a/W = 5 \text{ and } D_t/J = 12,\ N_p = 5 \text{ for } N'_{\mathrm{Re}} = 5.187\times 10^4$$

- Solving for *P* in Eq. (3.4-2) and substituting known values

$$P = N_p\rho N^3 D_a^5 = (5)(929)(1.50)^3(0.61)^5$$

$$P = \mathbf{1324\ J/s = 1.324\ kW\ (1.77\ hp)}$$

- For part (b)

$$\mu = 100{,}000(1 \times 10^{-3}) = 100\ \frac{\text{kg}}{\text{m.s}}$$

$$N'_{\text{Re}} = \frac{D_a^2 N \rho}{\mu} = \frac{(0.61)^2(1.50)(929)}{100} = 5.185$$

- This is the laminar flow region. From Figure 3.4-5, $N_p = 14$.

$$P = N_p \rho N^3 D_a^5 = (14)(929)(1.50)^3(0.61)^5$$

$$P = 3707\ \text{J/s} = 3.71\ \text{kW}\ (4.98\ \text{hp})$$

- Hence, a 10,000-fold increase in viscosity only increases the power from 1.324 to 3.71 kW.

Agitator Scale-Up

- Scale-up the laboratory-size or pilot-size agitation system t full-scale unit.
- Scale-up procedure:

1. Calculate the scale-up ratio R. Assuming that the original vessel is a standard cylinder with $D_{T1} = H_1$, the volume is:

$$V_1 = \left(\frac{\pi D_{T1}^2}{4}\right)(H_1) = \left(\frac{\pi D_{T1}^3}{4}\right) \qquad \text{---------------- Eq. (3.4-}$$

The ratio of the volume is

$$\frac{V_2}{V_1} = \left(\frac{\pi D_{T2}^2 / 4}{\pi D_{T1}^2 / 4}\right)(H_1) = \left(\frac{D_{T2}^3}{D_{T1}^3}\right) \qquad \text{---------------- Eq. (3.4}$$

The scale-up ratio is then

2. Using this value of R, apply it to all of the dimensions in Table 3.4-1 to calculate the new dimensions. For Example,

$$D_{a2} = RD_{a1}, \quad J_2 = RJ_1 \ldots$$

3. Determine the agitator speed N_2, to be used to duplicate the small scale results using N_1. The equation is:

$$N_2 = N_1\left(\frac{1}{R}\right)^n = N_1\left(\frac{D_{T1}}{D_{T2}}\right)^n \qquad \text{---------------- Eq. (3.4-10)}$$

Where $n = 1$ for equal liquid motion, $n = 3/4$ for equal

Example 2 Scale up of Turbine Agitation System

An existing agitation system is the same as given in Example 1a for a flat-blade turbine with a disk and six blades. The given conditions and sizes are D_{T1} = 1.83 m, D_{a1} = 0.61 m, W_1 = 0.122 m, $J_1 = 0.15\ m$, N_1 = 90/60 = 1.50 rev/s, ρ = 929 kg/m^3 and μ = 0.01 Pa.s. It is desired to scale up these results for a vessel whose volume is 3.0 times as large. Do this for the following two process objectives:

a) Where equal rate of mass transfer is desired.

b) Where equal liquid motion is needed.

Solution

Since $H_1 = D_{T1} = 1.83$ m,

the original tank volume, $V_1 = (\pi D_{T1}^2 / 4)(H_1) = \pi(1.83)^3 / 4 = 4.813 \text{ m}^3$

Volume $V_2 = 3.0\ (4.813) = 14.44 \text{ m}^3$.

Following the steps in the scale-up procedure, and using Eq.(3.4-8):

$$R = \left(\frac{V_2}{V_1}\right)^{1/3} = \left(\frac{14.44}{4.813}\right)^{1/3}$$

The dimensions of the larger agitation system are as follows:

$D_{T2} = RD_{T1} = 1.442\ (1.83) = 2.64$ m, $D_{a2} = 1.442\ (0.61) = 0.880$ m,
$W_2 = 1.442\ (0.122) = 0.176$ m and $J_2 = 1.442\ (0.15) = 0.216$ m.

For part (a), for equal mass transfer, $n = 2/3$ in Eq. (3.4-10):

$$N_2 = N_1\left(\frac{1}{R}\right)^{2/3} = (1.50)\left(\frac{1}{1.442}\right)^{2/3} = 1.175 \text{ rev/s } (70.5 \text{ rpm})$$

- Using Eq (3.4-1)

$$N'_{\mathrm{Re}} = \frac{D_a^2 N \rho}{\mu} = \frac{(0.880)^2(1.175)(929)}{0.01} = 8.453 \times 10^4$$

- Refer to Figure 3.4-5, Curve 1 and $N_{Re} = 8.453 \times 10^4$, gives $N_p = 5.0$
- Using $N_p = 5.0$ in Eq. (3.4-2)

$$P_1 = N_p \rho N_1^3 D_{a1}^5 = (5)(929)(1.5)^3(0.61)^5$$

$$P_1 = 1324 \text{ J/s} = 1.324 \text{ kW}$$

$$P_2 = N_p \rho N_2^3 D_{a2}^5 = (5)(929)(1.175)^3(0.880)^5$$

$$P_2 = 3977 \text{ J/s} = 3.977 \text{ kW}$$

- The power per unit volume is $$\frac{P_1}{V_1} = \frac{1.324}{4.813} = 0.2752\,\mathrm{kW/m^3}$$

$$\frac{P_2}{V_2} = \frac{3.977}{14.44} = 0.2752\,\mathrm{kW/m^3}$$

- The value of $0.2752\,\mathrm{kW/m^3}$ is somewhat lower than the approximate guidelines of 0.8 to 2.0 for mass transfer.

For part (b), for equal liquid motion, $n = 1.0$

$$N_2 = N_1\left(\frac{1}{R}\right)^{1.0} = (1.50)\left(\frac{1}{1.442}\right)^{1.0} = 1.040\,\mathrm{rev/s}$$

$$P_2 = N_p \rho N_2^3 D_{a2}^5 = (5)(929)(1.040)^3(0.880)^5$$

$$P_2 = 2757 = 2.757\,\mathrm{kW}$$

$$\frac{P_2}{V_2} = \frac{2.757}{14.44} = 0.1909\,\mathrm{kW/m^3}$$

Problems

- A flat blade turbine agitator with disk having six blades is installed in a tank. The tank dia Dt is 1.83m, the turbine dia Da is 0.61m. The tank contains four baffles. The turbine is operated at 90rpm and the liquid in the tank has a viscosity of 10cP and a density of 929kg/m³.
- Calculate the required kW of the mixer.
- For the same conditions, except for the solution having a viscosity of 100 000cP, cal the required kW

- $N_{Rei} = 5.185 \times 10^4$
- $N_P = 5 \text{---} \rightarrow P = 1.324\text{kW}$
- $N_{Rei} = 5.185$
- $N_P = 14 \rightarrow P = 3.71\text{kW}$

- It is desired to agitate a liquid having a viscosity of 1.5×10^{-3} Pa.s and a density of 969 kg/m^3 in a tank having a dia of 0.91m. The agitator will be a six-blade open turbine having a dia of 0.305m operating at 180rpm. The tank has four vertical baffles each with a width of 0.076m. Calculate the required kW
- $N_P = 2.5$
- Power = 0.172kW

- A fermentation broth with viscosity 10^{-2} Pa-s and density 1000kg/m^3 is agitated in a 50m3 baffled tank using a marine propeller (refer curve 5) 1.3 m in dia. Calculate the power required for a stirred speed of 4 rps.
- P = 83kW