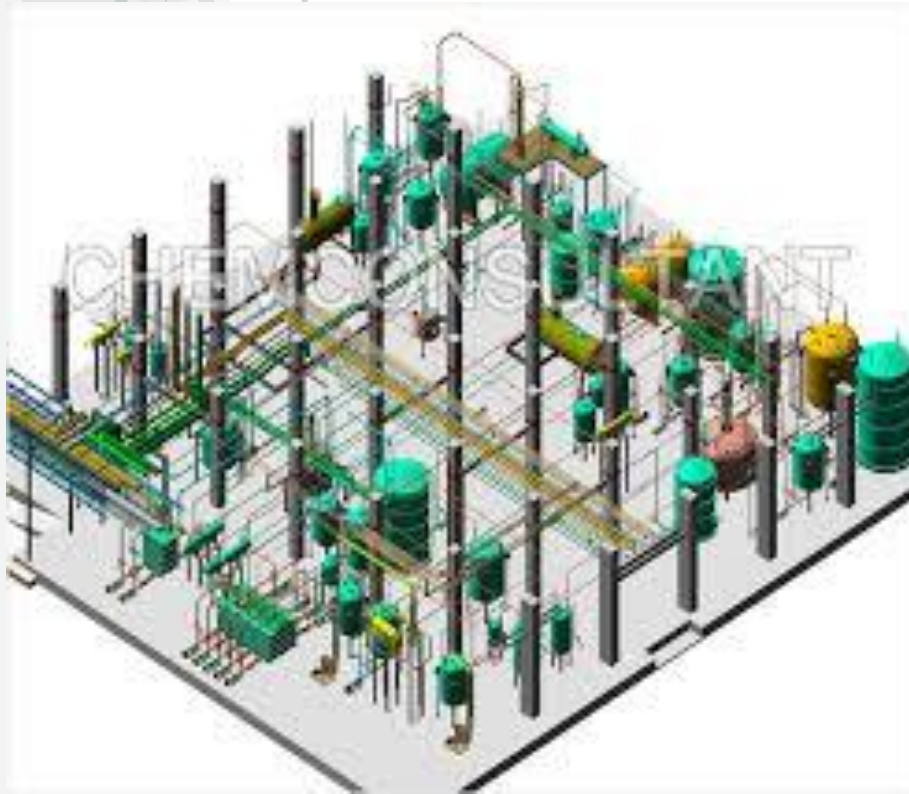
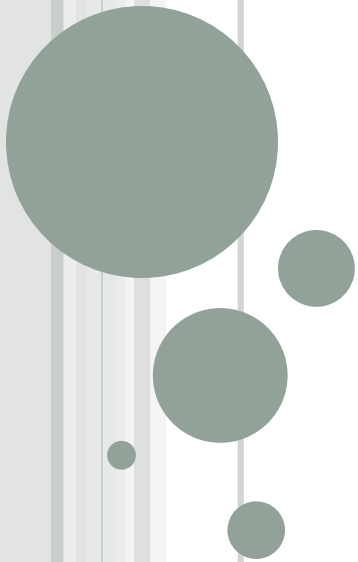


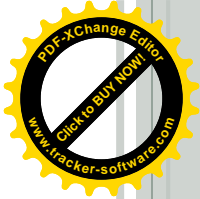
Reactor Design





DESIGN OF STIRRER TANK REACTOR (STR)





AGITATION & MIXING OF LIQUIDS

“Many processing operations depend for their success on the effective agitation & mixing of fluids”McCabe

Agitation

- It is an induced motion of a material in a specified way.
- Pattern is normally circulatory.
- Normally taken place inside a container.

Mixing

- Random distribution, into & through one another of two or more initially separate phases





Agitators and Mixing Equipment

- Suspend solids
- Disperse gases and liquids
- Emulsify one liquid in another
- Promote heat transfer
- Blending two or more materials together

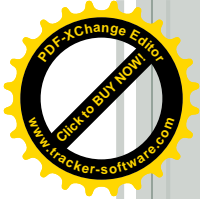
Overmixing maybe undesirable

- in biological application, high shear may damage organisms
- polymer molecules may be damaged by long mixing or high shear

For design or consideration of mixing process should understand:

- mechanism of mixing
- scale-up criteria
- power consumption
- flow patterns
- mixing time/rates
- types of equipment available





Stirrer Tank Reactor

The preparation of mixtures of solids, liquids and gases is an essential part of most production processes in the chemical and allied industries; covering all processing stages, from the preparation of reagents through to the final blending of products. The equipment used depends on the nature of the materials and the degree of mixing required. Mixing is often associated with other operations, such as reaction and heat transfer. Liquid and solids mixing operations are frequently carried out as batch processes.





Stirrer Tank Reactor

Liquid mixing

The following factors must be taken into account when designing liquid mixing equipment's:

1. Batch or continuous operation.
2. Nature of the process: miscible liquids, preparation of solutions, or dispersion of immiscible liquids.
3. Degree of mixing required.
4. Physical properties of the liquids, particularly the viscosity.
5. Whether the mixing is associated with other operations: reaction, heat transfer.



Stirrer Tank Reactor

For the continuous mixing of low viscosity fluids inline mixers can be used. For other mixing operations stirred vessels or proprietary mixing equipment will be required.

Inline mixing: The static inline mixer shown in Figure below is effective in both laminar and turbulent flow, and can be used to mix viscous mixtures. The division and rotation of the fluid at each element causes rapid radical mixing.





Stirrer Tank Reactor

Stirred tanks: Mixing vessels fitted with some form of agitator are the most commonly used type of equipment for blending liquids and preparing solutions.

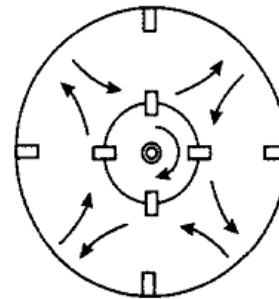
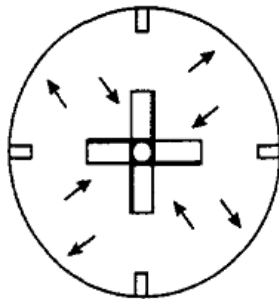
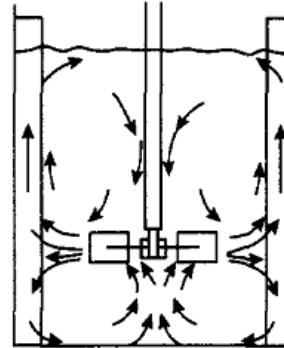
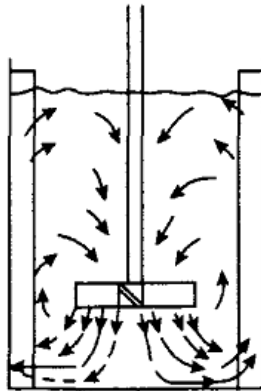
Impellers are mixing devices that commonly used to provide a definite flow pattern in liquid during mixing, moving at various speeds.





Stirrer Tank Reactor

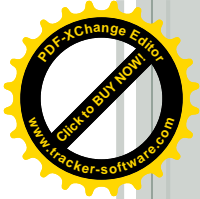
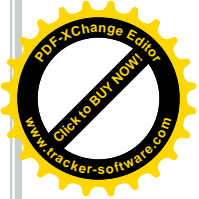
A typical arrangement of the agitator and baffles in a stirred tank, and the flow pattern generated, is shown in Figure below.



Axial flow impellers

Radial flow impellers





Radial flow impellers:

Impellers where they make 90° angle with the shaft & blades are parallel to the axis of drive shaft. In this type of impeller, the direction of flow of liquid is perpendicular with the axis of rotation.

More possibility of vortexing.

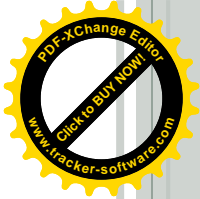
Axial flow impellers:

Impellers where blade makes an angle less than 90° with the plane of rotation.

When the axial flow impellers rotate, the flow of the liquid is parallel to the axis of the rotation. So it is called axial flow.

.



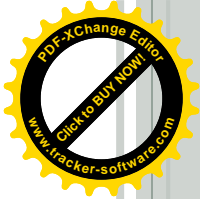


Stirrer Tank Reactor

What is the ideal length to diameter ratio for a agitated vessel?

The optimum height to diameter of a stirred vessel is almost always between $H/D = 0.8-1.5$ with a single impeller. Whereas $H/D=2$ for tall vessels with two impellers for good fluid motion. For large vessel with diameter greater than 4m diameter $H/D \geq 2$.





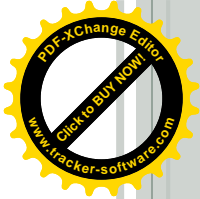
Stirrer Tank Reactor

Mixing occurs through the bulk flow of the liquid and, on a microscopic scale, by the motion of the turbulent eddies created by the agitator.

- Bulk flow is the predominant mixing mechanism required for the blending of miscible liquids and for solids suspension.
- Turbulent mixing is important in operations involving mass and heat transfer; which can be considered as shear controlled processes.

The most suitable agitator for a particular application will depend on the type of mixing required, the capacity of the vessel, and the fluid properties, mainly the viscosity.





Stirrer Tank Reactor

Three types of impeller which are used for high Reynolds numbers (low viscosity) are shown in Figures below *a*, *b*, *c*. These types can be classified according to the predominant direction of flow leaving the impeller.

- a. The flat-bladed (Rushton) turbines are essentially radial-flow devices, suitable for processes controlled by turbulent mixing (shear controlled processes).
- b. The propeller and pitched-blade turbines are essentially axial-flow devices, suitable for bulk fluid mixing.
- c. Low speed agitators with are used for effectively mix viscous liquids or semisolids.



Stirrer Tank Reactor

(a) radial-flow devices



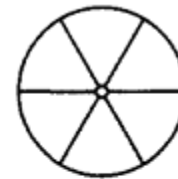
Disc-mounted flat-blade turbine



Hub-mounted flat-blade turbine



Hub-mounted curved-blade turbine

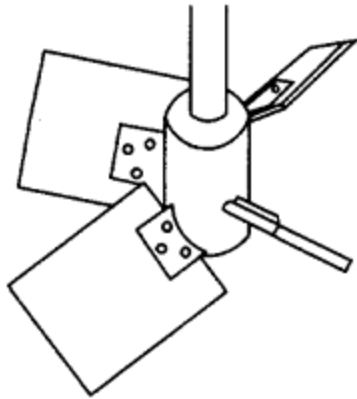


Shrouded turbine impeller



Stirrer Tank Reactor

(b) Axial-flow devices



(i)



(ii)

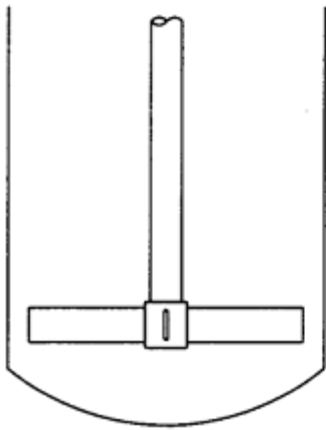
(i) Pitched bladed turbine (ii) Marine propeller



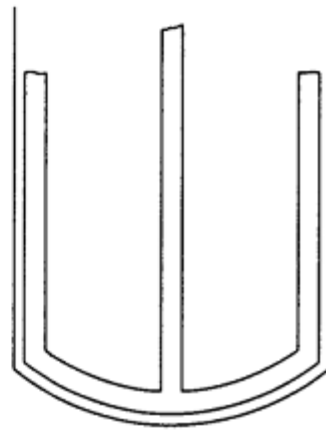
Stirrer Tank Reactor

(c) Low-speed agitators

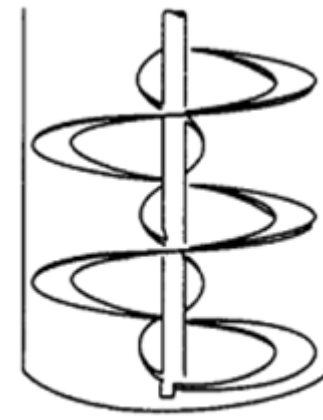
Paddle, anchor and helical ribbon agitators (Figure below), and other special shapes, are used for more viscous fluids.



(i)



(ii)



(iii)

(i) Paddle (ii) Anchor (iii) Helical ribbon



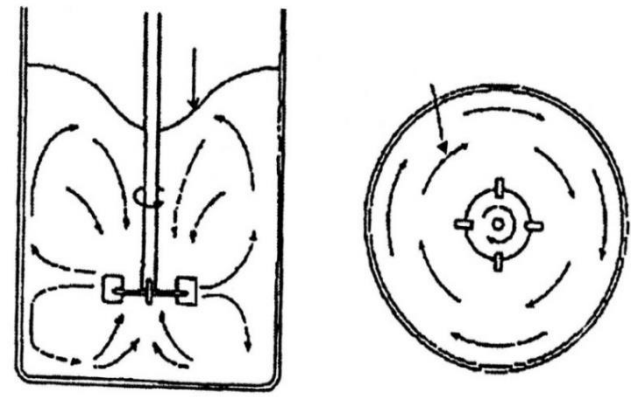
VORTEX

What is vortex?

Vortex: If a low viscosity liquid is stirred in an un-baffled tank by an axially mounted agitator, tangential flow follows a circular path around the shaft & a swirling flow pattern is developed. This is vortex. (Fig.)

How is it formed?

In an un-baffled tank, a vortex is produced due to the centrifugal force on the rotating liquid. This creates a swirling motion in the liquid & the surface tends to go upward near the vessel rim & downward near the shaft. So a V-shaped surface is formed which is the vortex.



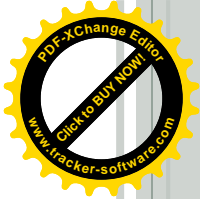


Reasons:

1. If the shaft is placed symmetrically in the tank.
2. If the blades of the turbines are arranged perpendicular to the central shaft.
3. At high impeller speeds
4. Unbaffled tank

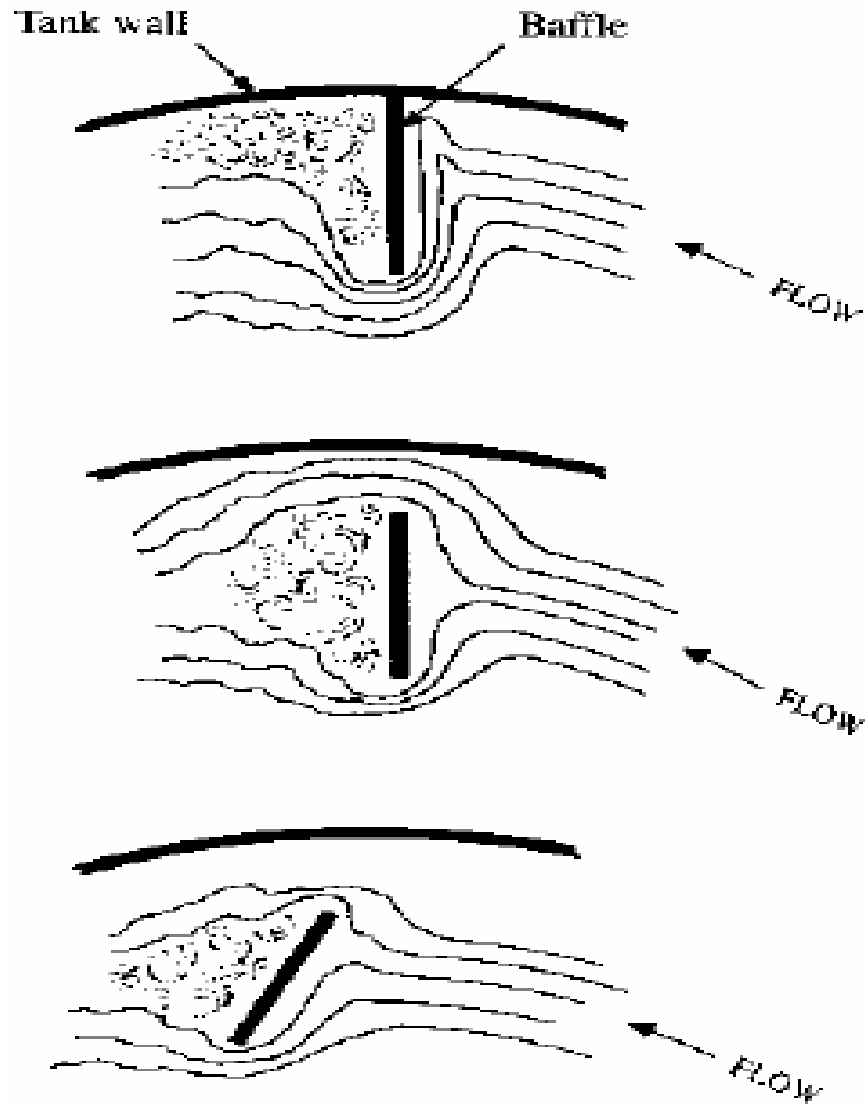
Problems:

1. Vortex decreases mixing intensity by reducing velocity of the impeller relative to the surrounding fluid.
2. When vortex reaches the impeller, air from the surface of the liquid are drawn (**air entrapment**) and air bubbles are produced.
3. Air bubbles in the fluid can create **uneven loading** of the impeller blades.
4. Entrapped air **causes oxidation** of the substances in certain cases.
5. Possibility of **foam formation**
6. Possibility of **throwing out some material out of container.**



Baffles are used to prevent gross vortexing (no longer a deep center vortex) and to achieve good top to bottom circulation and solid suspension.

Baffles are often fitted to the walls of the vessel. These take the form of thin strips about one-tenth of the tank diameter in width, and typically four equi-spaced baffles may be used.





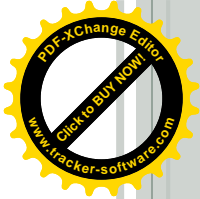
Power Requirements for Mixing

Usually, electrical power is used to drive impellers in stirred tanks. For a given stirred speed, the power required depends on the resistance offered by the fluid to rotation of the impeller.

Average power consumption per unit volume for industrial bioreactors ranges from 10 kW/m³ for small vessels to 1~2 kW/m³ for large vessels. Friction in the stirrer motor gearbox and seals reduces the energy transmitted to the fluid; therefore, the electrical power consumed by stirrer motors is always greater than the mixing power by an amount depending on the efficiency of the drive.

Energy costs for operation of stirrers in bioreactors are an important consideration in process economics.





Stirrer Tank Reactor

Agitator power consumption: The shaft power required to drive an agitator for **Ungassed Newtonian Fluids with Turbulent mixing** can be estimated using the following generalized dimensionless equations.

$$Re = \frac{D^2 \rho N}{\mu}$$

$$P = D^5 N^3 \rho N_p$$

Where:

P = shaft power (W)

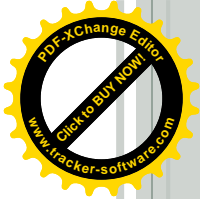
ρ = fluid density (kg/m³)

μ = fluid viscosity (Ns/m²)

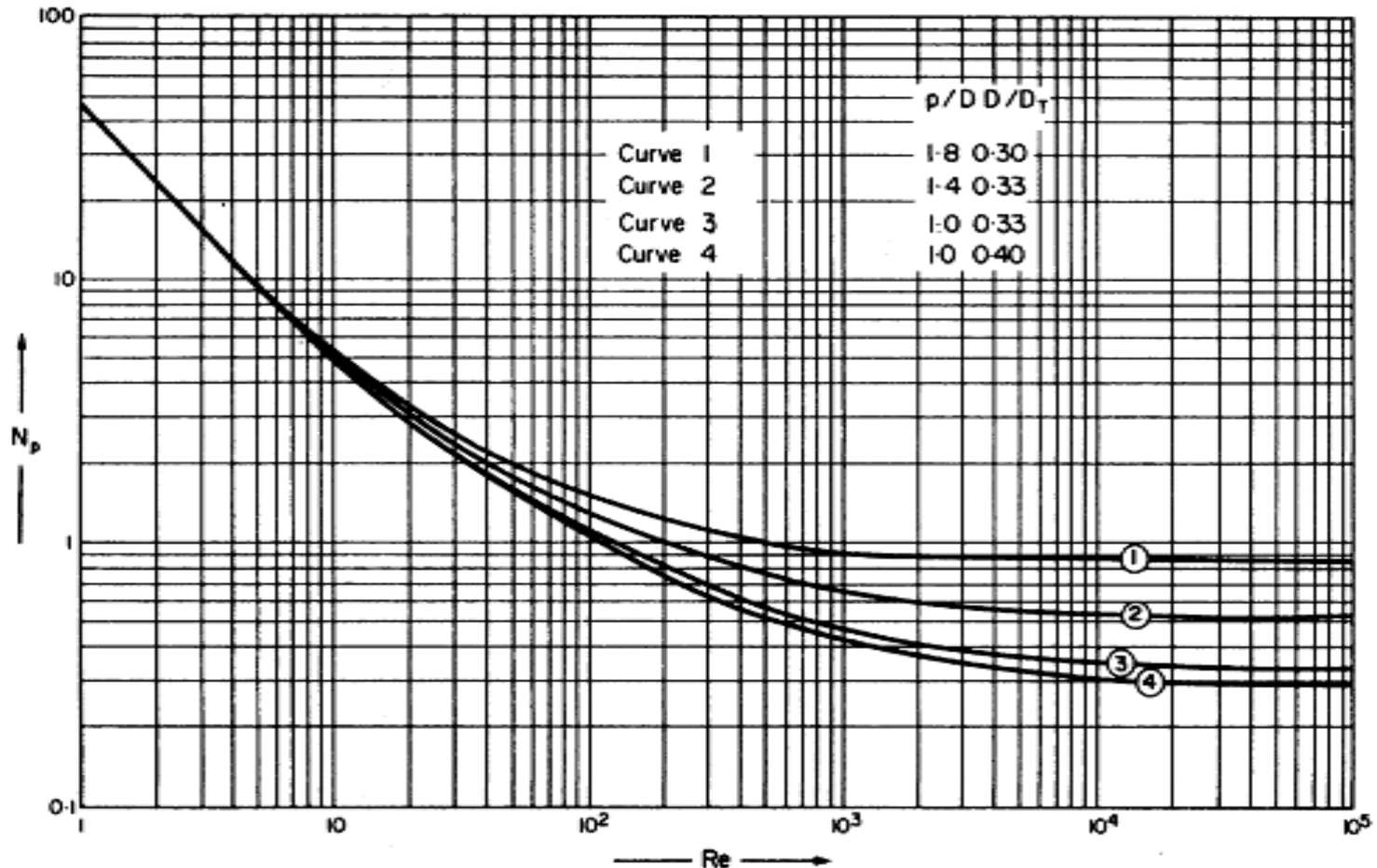
N = agitator speed (revolutions per second - rps)

D = agitator diameter (m)

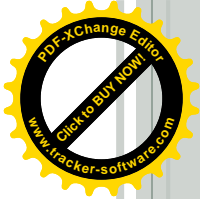




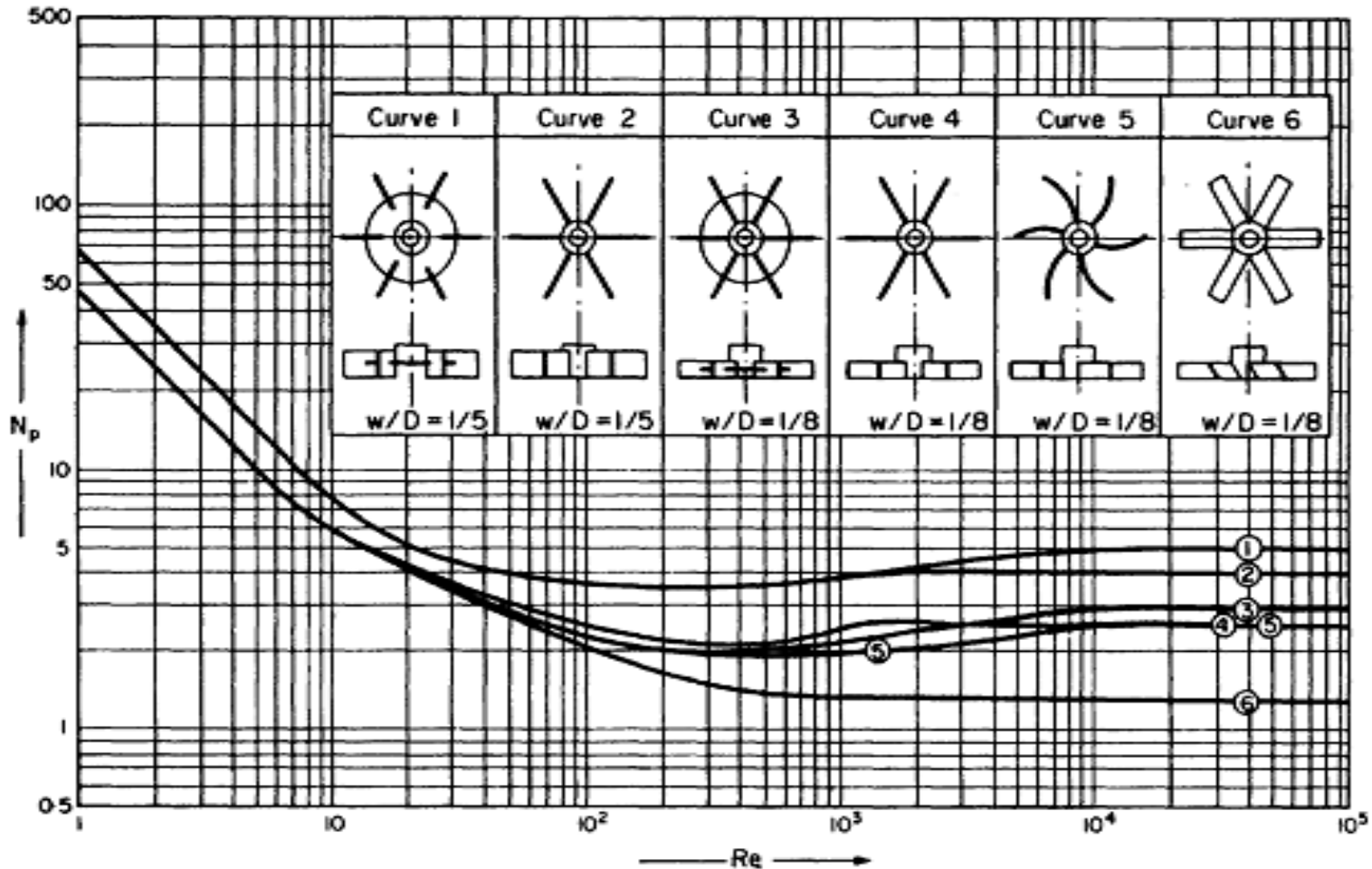
Stirrer Tank Reactor



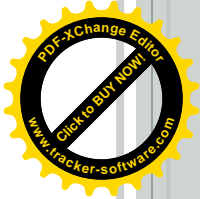
Power correlation for single three-bladed propellers baffled, (from Uhl and Gray (1967))
 p = blade pitch, d = impeller diameter, D = tank diameter



Stirrer Tank Reactor



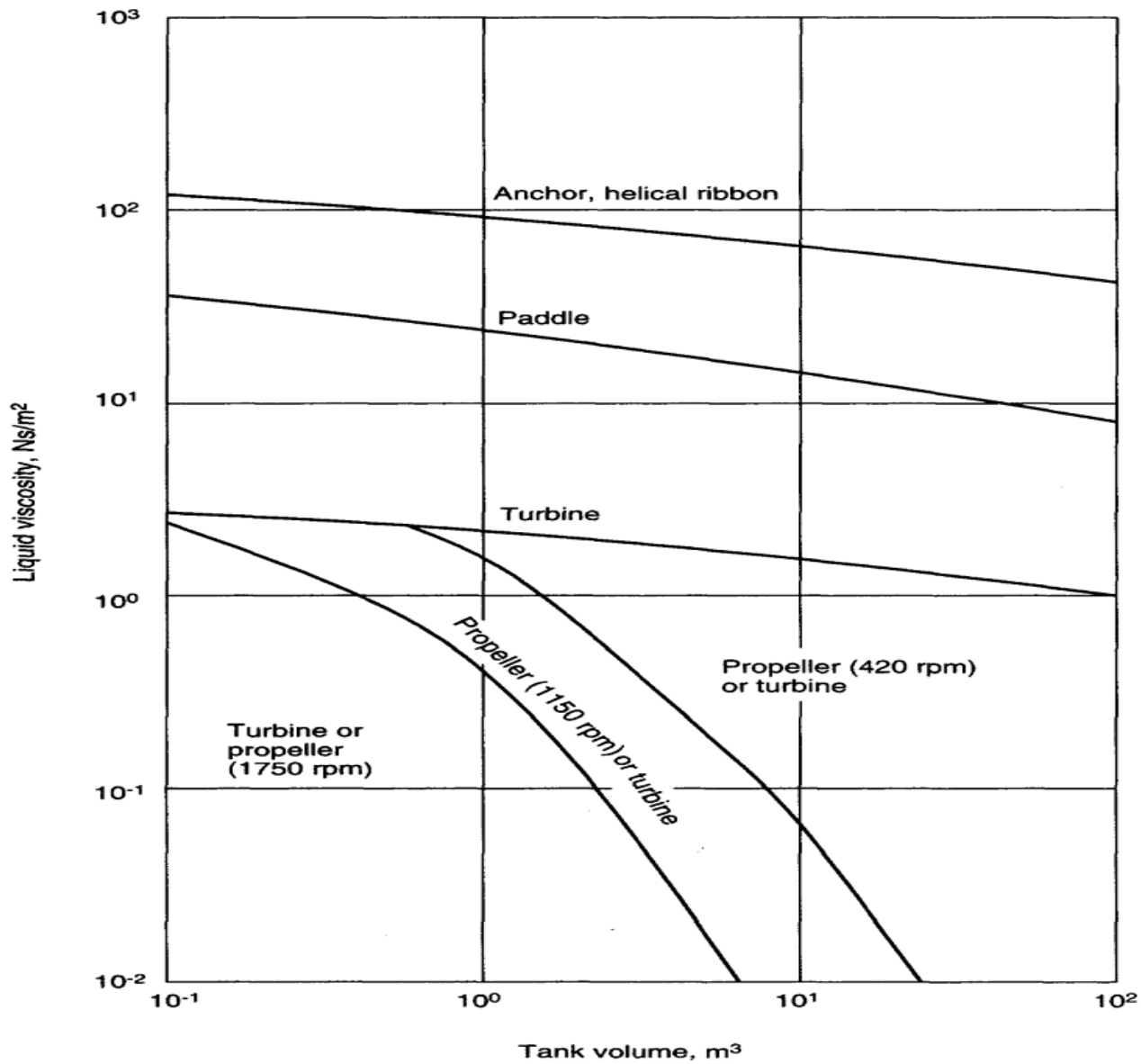
Power correlations for baffled turbine impellers, for tank with 4 baffles (From Uht & Gray (1967))
W = width, D = impeller diameter



Stirrer Tank Reactor

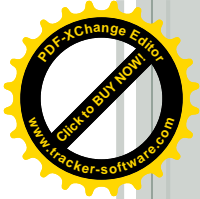
Agitator selection guide: The selection chart given in Figure below, which has been adapted from a similar chart given by Penney (1970), can be used to make a preliminary selection of the agitator type, **Choice of impeller depends on several factors, including viscosity of the liquid to be mixed and sensitivity of the system to mechanical shear and tank volume.** The recommended viscosity ranges for a number of common impellers are indicated in Figure below. For turbine agitators, impeller to tank diameter ratios of up to about 0.6 are used, with the depth of liquid equal to the tank diameter. Baffles are normally used, to improve the mixing and reduce problems from vortex formation. Anchor agitators are used with close clearance between the blades and vessel wall, anchor to tank diameter ratios of 0.95 or higher.





Agitator selection Eifure





Stirrer Tank Reactor

Design Procedure for Stirrer Tank

□ Batch or continuous tank reactor

1. Collect physical properties and process temperature (ρ , μ , C_p , k ...etc.)
2. From process calculation, estimate the process volume V_s
3. Calculate the reactor volume (V_T) from equation below;

$$V_s = (0.25 - 0.7)V_T$$

4. Calculate The reactor height and diameter fro equations below;

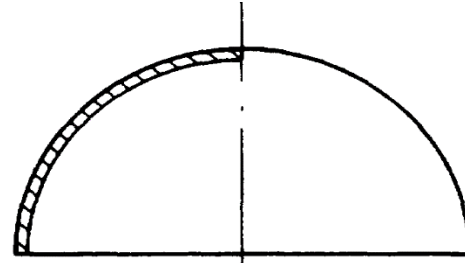
$$V_T = \frac{\pi}{4} D_T^2 H + \frac{D_T^3}{24} \quad \text{(Elliptical dish end)}$$

$$V_T = \frac{\pi}{4} D_T^2 H + \frac{D_T^3}{12} \quad \text{(Hemispherical dish end)}$$

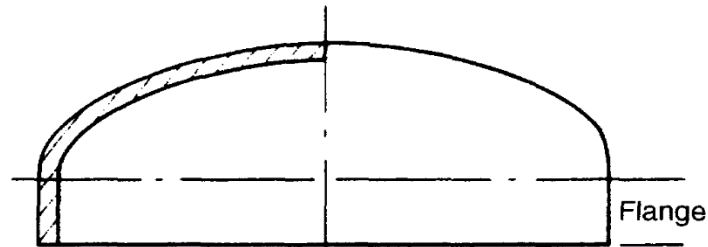
$$V_T = \frac{\pi}{4} D_T^2 H + \frac{D_T^3}{12.36} \quad \text{(Torispherical dish end)}$$



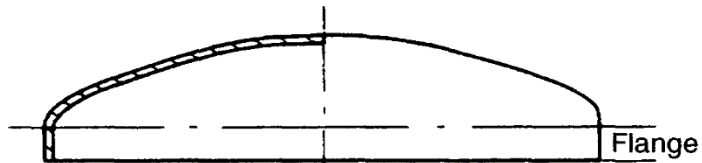
Stirrer Tank Reactor



(a)



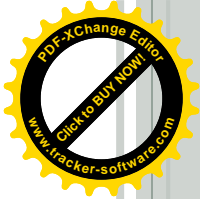
(b)



(c)

Dish ends (a) Hemispherical (b) Ellipsoidal (c) Torispherical





Stirrer Tank Reactor

5. Specify H/D from preferred arrangement and dimensions depend on V_T and physical properties.
6. Specify other dimension of reactor
7. Calculate cleared volume from the top using equation below;

$$\Delta V = V_T - V_S = \frac{\pi}{4} D_T^2 \Delta l$$

8. Calculate the height of solution from the reactor bottom using equation below;
9. a. $l = D_T/4$ (Elliptical & Torispherical Dish end)
10. b. $l = D_T/2$ (Hemispherical Dish end)
11. Calculate the total height of the liquid inside the reactor using equation below; $L_S = (H - \Delta l) + l$





Stirrer Tank Reactor

12. Select number of blades of agitator
13. Select number of baffles and specify their dimensions from the following equations;

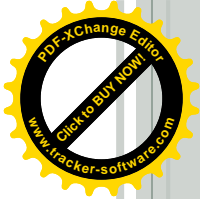
$$W_b = \frac{D_T}{10} \quad \frac{L_b}{L_s} = 1.1 \quad \frac{C_b}{D_T} = 0.01$$

14. Calculate the mechanical power required for mixing from the following equations;

$$Re = \frac{D^2 \rho N}{\mu}$$

$$P = D^5 N^3 \rho N_p$$





Stirrer Tank Reactor

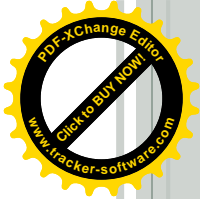
□ Submerged Fermenter

1. Repeat steps (1-4) for CSTR
2. Estimate H/D_T from equations below;

$$H = 2D_T \quad \text{Fermenter with agitator}$$

$$H = 5D_T \quad \text{Fermenter without agitator}$$





Stirrer Tank Reactor

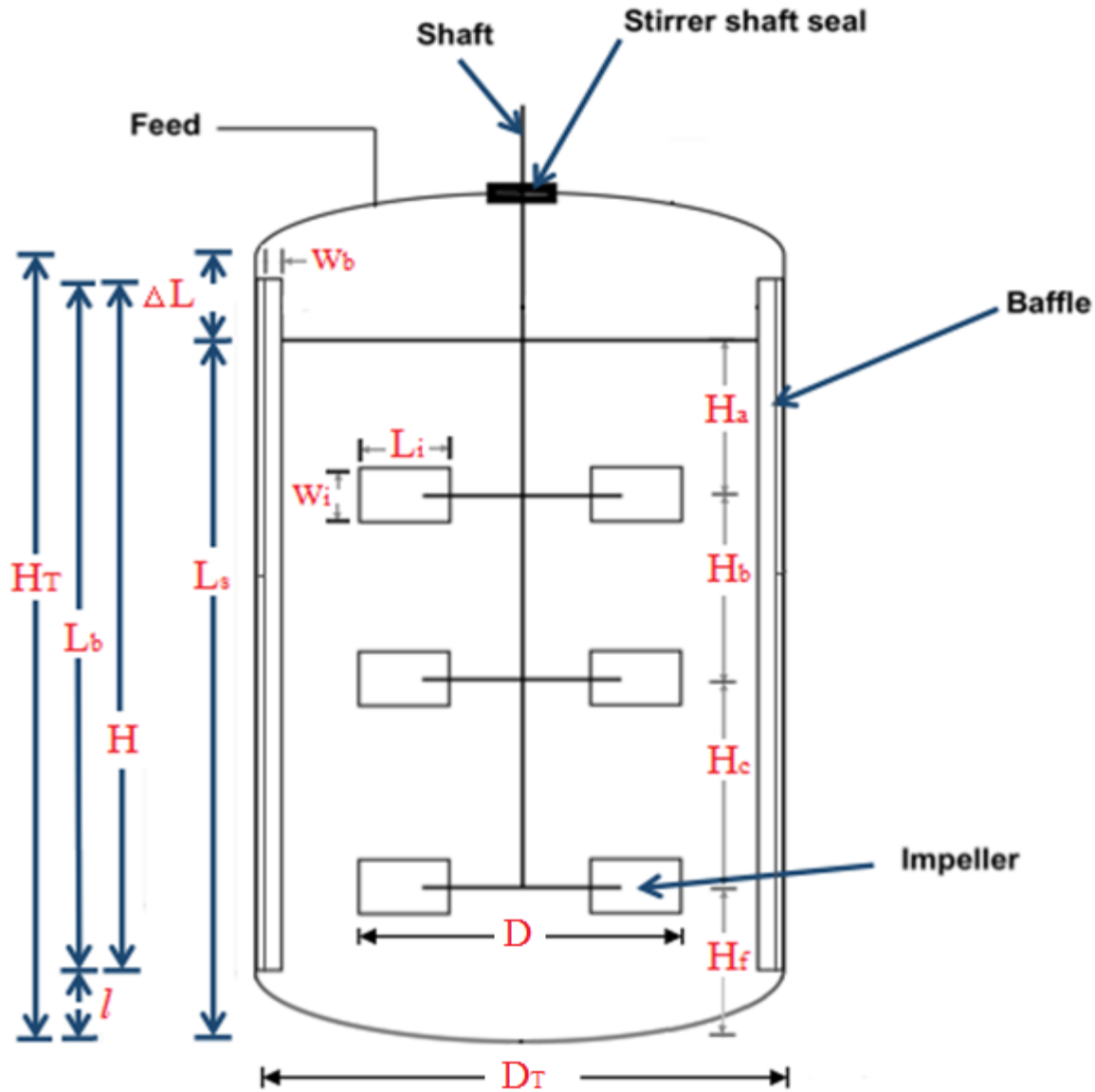
3. Select number of impeller and fermenter dimension from table below:

Symbols	Description		
No of impellers	1	2	3
L_s/D_T	1	1.3	1.3
D/D_T	0.3	0.3	0.3
H_a/D	-	1.3	1
H_b/D	-	-	1.3
H_c/D	-	-	1.3
H_f/D	-	1.3	1





Stirrer Tank Reactor



Stirrer Tank Reactor

□ Sparger:

Sparging is a technical term for injecting gas into a liquid or for spraying a liquid onto a solid. Spargers are porous disc or tube assemblies that are also referred to as Bubblers, Aerators, Porous Stones and Diffusers.





Stirrer Tank Reactor

A common example of sparging can be seen in an aquarium where air is bubbled into the tank through a fine porous “stone” in order to maintain the level of the dissolved oxygen in the water. Spargers are also used to carbonate beverages such as Beer and Soda. Gas Liquid Contacting can also be used to extend the shelf life of foods and beverages such as Orange Juice, Wine and Yogurt. Spargers are also utilized to control process chemistry or the pH of process such as Water Treatment, Fermentation and Hydrogenation. Sparging Ozone is being used to kill bacteria in water and eliminates the need to add Chlorine





Stirrer Tank Reactor

Sparger Design Considerations

- Uniform flow through distributor orifices
- Low pressure drop while avoiding channeling
- Avoid plugging due to solid particles
- Avoid gas jets impingement on vessel walls – can lead to pitting



Stirrer Tank Reactor

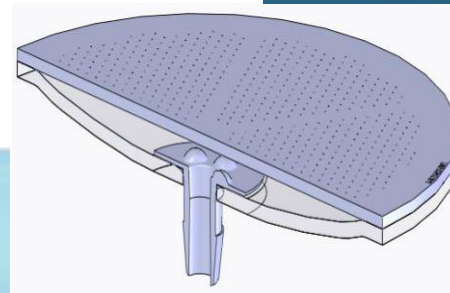
The spargers are designed based on experience and are used based on convenience and availability. The most common types of spargers used for process are;

Ring sparger ($>1\text{mm}$)

Perforated Plate sparger (1-3mm)

Perforated pipe sparger (1-3mm)

Porous sparger ($<1\text{ mm}$)





Stirrer Tank Reactor

Sparger design

A simplified method of ring sparger design is stated in the following steps;

1. Calculate pipe diameter of the sparger using the following equation;

$$D_p = 0.005765 \frac{w^{0.408}}{\rho^{0.343}}$$

Where:

D_p = Sparger pipe diameter (m)

w = fluid mass flowrate (kg/hr)

ρ = fluid density (kg/m³)





Stirrer Tank Reactor

2. Calculate sparger ring diameter

$$D_s = 0.5D_T$$

Where:

D_s = Sparger ring diameter (m)

D_T = Tank diameter (m)

3. Calculate sparger ring length

$$L_p = \pi D_s$$

Where:

D_s = Sparger ring diameter (m)

L_p = Sparger length (m)





Stirrer Tank Reactor

4. Select sparger orifice spacing (0.1-0.3) m
5. Calculate number of sparger orifices

$$N_o = \frac{L_p}{\textit{Orifice spacing}}$$

Where:

N = number of orifices in sparger

L_p = length of sparger (m)

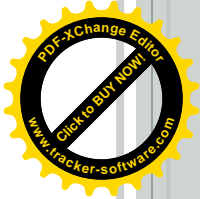
6. Calculate the Sparger location (S_L) from equation below;

$$S_L = (0.7 - 0.8)D$$

Where:

D = Impeller diameter (m)





Stirrer Tank Reactor

7. Calculate orifice diameter

$$D_o = 0.7 \frac{D_p}{\sqrt{N}} \quad \text{for} \quad \left(\frac{L_p}{D_p} \leq 150\right)$$

$$D_o = \frac{D_p}{\left[1 + \frac{L_p N^2}{39 D_p}\right]^{0.25}} \quad \text{for} \quad \left(\frac{L_p}{D_p} \geq 150\right)$$

Where:

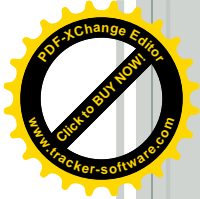
D_o = Orifice diameter (m)

N_o = Number of orifices in sparger

L_p = Length of sparger (m)

D_p = Sparger diameter (m)





Stirrer Tank Reactor

8. Calculate pipe pressure drop

$$\Delta P_p = 2f \frac{L}{D_p} \rho v_p^2$$

$$f = 0.0035 + 0.264 (\text{Re})^{-0.42}$$

Where:

A_o = Orifice cross section area (m²)

A_p = Sparger pipe cross section area (m²)

v_p = Gas velocity through sparger pipe (m/s)

ρ_g = fluid density (kg/m³)

ΔP_p = Orifice pressure drop (Pa)

f = Fanning friction factor





Stirrer Tank Reactor

9. Calculate orifice pressure drop

$$\Delta P_o = 2.6 \frac{\rho_g v_o^2}{2} \left[1 - \left(\frac{A_o}{A_p} \right)^2 \right]$$

$$\frac{\Delta P_p}{\Delta P_o} \leq 0.1$$

$$v_o N A_o = v_p A_p \quad (\text{Continuity equation})$$

Where:

A_o = Orifice cross section area (m²)

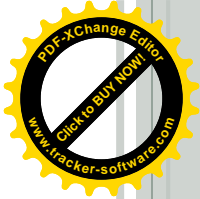
A_p = Sparger pipe cross section area (m²)

v_o = Gas velocity through orifice (m/s)

ρ_g = fluid density (kg/m³)

ΔP_o = Orifice pressure drop (Pa)





Stirrer Tank Reactor

10. Calculate power consumption with sparging

$$\frac{P_g}{P} = 0.1 \left(\frac{Q}{NV_s} \right)^{-0.25} \left(\frac{N^2 D^4}{gwV_s^{2/3}} \right)^{-0.2}$$

where

P_g power consumption with sparging (watt)

P is power consumption without sparging (watt)

Q is volumetric gas flow rate, (m^3/s)

N is stirrer speed (rps)

V_s is liquid volume (m^3)

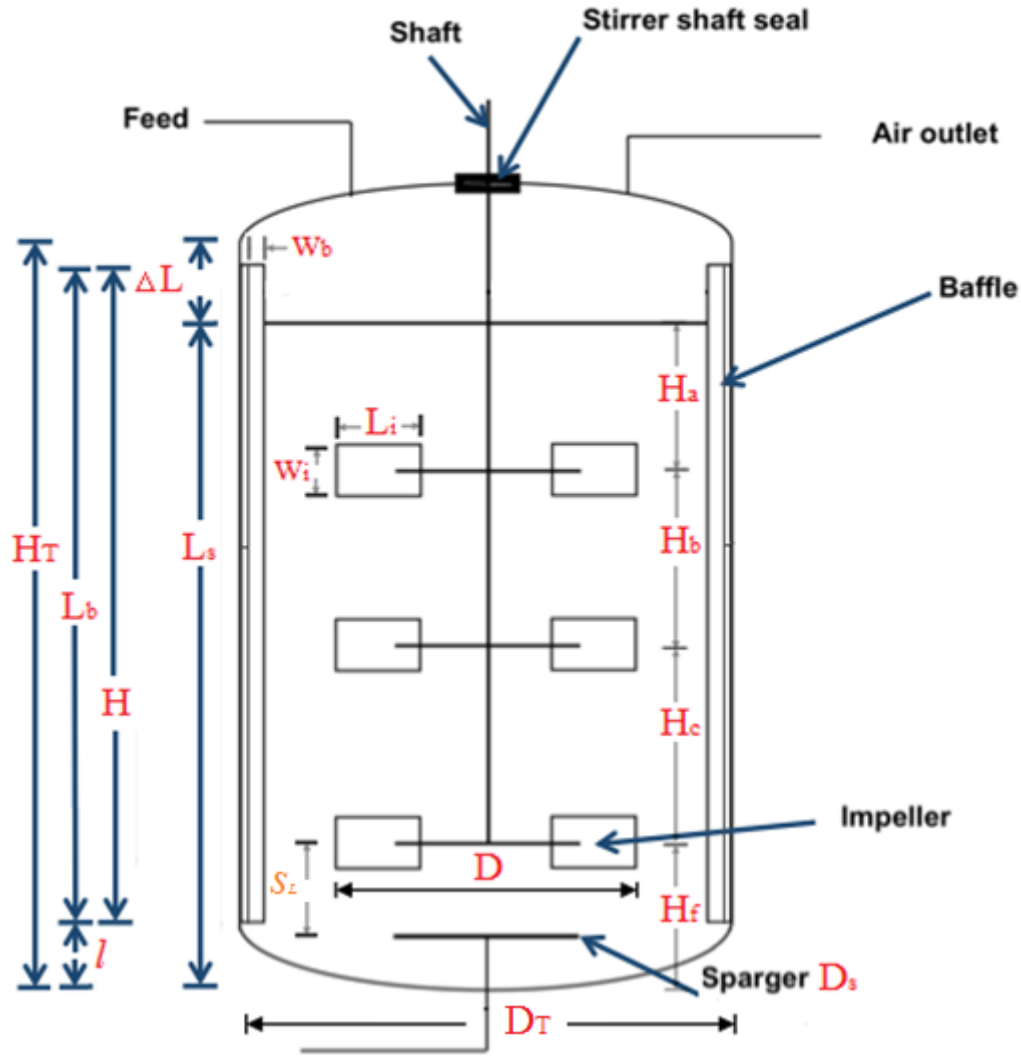
D is impeller diameter (m)

g is gravitational acceleration ($9.8 m/s^2$)

w is impeller width (m)



Stirred Tank Configuration for Microbial Culture





Stirrer Tank Reactor

Design Problem:

Calculate the dimension of Fermenter and power required for agitation of 4 m³ of nutrient solution equipped with six blade pitch blade turbine and air sparging system, using information below:

Density of solution = 1050 Kg/m³, Viscosity = 1.1 CP

air flowrate = 120 m³/hr @ 2 bar (g) with M.wt = 29





OLUTION

a. Fermenter sizing

$$V/V_T = 0.7$$

$$H/D_T = 2$$

$$D/D_T = 0.3$$

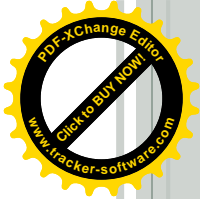
$$W_b/D_T = 0.1$$

$$L_b/L_s = 1.1$$

$$C_b/D_T = 0.01$$

$$\text{Dish end elliptical} = (1/24)D_T^3$$





$$V_T = \frac{V_S}{0.7} = \frac{4}{0.7} = 5.714 \text{ m}^3$$

$$V_T = \frac{\pi}{4} D_T^2 H + \frac{D_T^3}{24}$$

$$5.714 = \frac{\pi}{4} D_T^3 \times 2 + \frac{D_T^3}{24}$$

$D_T = 1.5246 \text{ m}$, $H = 3.0292 \text{ m}$, $D = 0.4574 \text{ m}$, $W_b = 0.1524 \text{ m}$, $C_b = 0.0152 \text{ m}$.

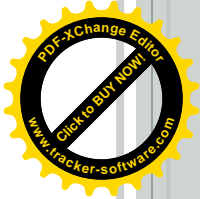
$$\Delta V = V_T - V_S = \frac{\pi}{4} D_T^2 \Delta l$$

$$\Delta V = 5.714 - 4 = 0.714 \text{ m}^3$$

$$\Delta l = 0.7427 \text{ m}$$

$$l = D_T/4 = 1.5246/4 = 0.3811 \text{ m}$$





$$L_s = (H - \Delta l) + l$$

$$L_s = 3.0292 - 0.7427 + 0.3811 = 2.6876 \text{ m}$$

$$L_b = 1.1 \times L_s = 1.1 \times 2.6876 = 2.9564 \text{ m}$$

- Calculate the mechanical power required for mixing

$$Re = \frac{D^2 \rho N}{\mu}$$

$$P = D^5 N^3 \rho N_p$$

$$Re = \frac{1100 \times 3 \times 0.4574}{1.1 \times 10^{-3}} = 627699.168$$

From Fig of Power correlations for baffled turbine impellers, Curve 6,

$N_p = 1.4$ and $w/D = 1/8 \rightarrow w = 0.4574/8 = 0.057175 \text{ m}$

$$P = 0.4574^5 \times 3^3 \times 1100 \times 1.4 = 907.9592 \text{ watt}$$





b. Sparger sizing

- Calculate sparger pipe diameter

$$D_p = 0.005765 \frac{W^{0.408}}{\rho^{0.343}}$$

$$\rho = \frac{PM}{RT}$$

$$\rho = \frac{3 \times 1.0135 \times 100000 \times 29}{8.314 \times 1000 \times 298} = 3.5547 \text{ Kg/m}^3$$

$$W = Q \times \rho = 120 \times 3.5547 = 427.0452 \text{ kg/hr}$$

$$D_P = \frac{427.0452^{0.408}}{3.5547^{0.343}} = 0.0442 \text{ m}$$





- Calculate sparger ring diameter

$$\begin{aligned}D_s &= 0.5D_T \\ &= 0.5 \times 1.5246 = 0.7623 \text{ m}\end{aligned}$$

- Calculate sparger ring length

$$\begin{aligned}L_p &= \pi D_s \\ &= \pi \times 0.7623 = 2.3948 \text{ m}\end{aligned}$$

- Select sparger orifice spacing (0.15) m
- Calculate number of sparger orifices

$$\begin{aligned}N_o &= \frac{L_p}{\text{Orifice spacing}} \\ &= \frac{2.3948}{0.15} = 15.9656 \rightarrow 16\end{aligned}$$





- Calculate the Sparger location S_L

$$S_L = (0.7 - 0.8)D$$

$$S_L = 0.8 \times 0.4574 = 0.3659 \text{ m}$$

- Calculate orifice diameter

$$\frac{L_P}{D_p} = \frac{2.3948}{0.0442} = 54.2423 < 150$$

$$\begin{aligned} D_o &= 0.7 \frac{D_p}{\sqrt{N}} \\ &= 0.7 \frac{0.0442}{\sqrt{16}} = 0.0077 \text{ m} \end{aligned}$$





Calculate power consumption with sparging

$$\frac{P_g}{P} = 0.1 \left(\frac{Q}{NV_s} \right)^{-0.25} \left(\frac{N^2 D^4}{gwV_s^{2/3}} \right)^{-0.2}$$

$$P_g = 0.1 \times \left(\frac{120/3600}{3 \times 4} \right)^{-0.25} \times \left(\frac{3^2 \times 0.4574^4}{9.81 \times 0.057175 \times 4^{2/3}} \right)^{-0.2} \times 907.9591 = 1471.6415 \text{ watt}$$





Calculate pipe pressure drop

$$\Delta P_p = 2f \frac{L}{D_p} \rho v_p^2$$

$$f = 0.0035 + 0.264 (\text{Re})^{-0.42}$$

$$A_p = \frac{\pi}{4} D_p^2$$

$$= \frac{\pi}{4} \times 0.0442^2 = 0.0015 \text{ m}^2$$

$$Q = v_p A_p$$

$$v_p = \frac{Q}{A_p} = \frac{120}{3600 \times 0.0015} = 21.7726 \text{ m/s}$$





$$Re = \frac{\rho v_p D_p}{\mu} = \frac{3.5545 \times 21.7726 \times 0.0442}{0.01504/1000} = 227454.3952$$

$$f = 0.0035 + 0.264 (Re)^{-0.42}$$

$$f = 0.0035 + 0.246 \times 227454.3952^{-0.42} = 0.003759$$

$$\Delta P_p = 2f \frac{L}{D_p} \rho v_p^2$$

$$\Delta P_p = 2 \times 0.00379 \times \frac{2.3948}{0.0442} \times 3.5545 \times 21.7726^2 = 912.3068 \text{ Pas.}$$





- Calculate orifice pressure drop

$$\Delta P_o = 2.6 \frac{\rho_g v_o^2}{2} \left[1 - \left(\frac{A_o}{A_p} \right)^2 \right]$$

$$A_o = \frac{\pi}{4} D_o^2 = \frac{\pi}{4} \times 0.0077^2 = 4.69\text{E-}5$$

$$v_o = \frac{v_p A_p}{N_o A_p} = \frac{21.7726 \times 0}{16 \times} = 44.7 \text{ m/s}$$

$$\Delta P_o = 2.6 \times \frac{3.55 \times 44^2}{2} \left[1 - \left(\frac{4.6\text{E} - 5}{0.0015} \right)^2 \right] = 9125.5 \text{ Pas}$$

$$\frac{\Delta P_p}{\Delta P_o} = \frac{912.3068}{9125.5} = 0.09997 < 0.1 \text{ (OK)}$$

