جامعة النجاح الوطنية

An-Najah National University

An-Najah National University

Faculty Of Engineering And Information Technology

Department of Chemical Engineering

Soap and Detergent Manufacturing (10626475)

Mixing and Agitation

Instructor: Majd Shhadi, PhD

Spring 2019

DEFINITIONS

- **AGITATION** induced motion, gives a specific flow pattern and provides circulation.

  Or it is the **process** to ensure a faster completion of **the mixing process** to reach **homogeneous mixture.**

- **MIXING** random distribution, into and through one another, of two or more initially separate phases **(Various degrees of homogeneity).**

- **BLENDING** is a Mixing process of two or more blending components.

- **The Stirring Mechanism** is a rotating arm that is often powered with a drive/motor.

- Different substances will require different levels of **mixing**, **stirring speeds**, and **elapsed times**.

Purposes of Agitation: Applications

1. **Two-phase: Liquid-liquid**
   a. Homogenization of miscible liquids **(Blending).**
   b. Mixing and **dispersion** of immiscible liquids **(Emulsion)**

2. **Two-phase: Gas-liquid**
   a. Dispersing a gas through the liquid **(Bubble)**

3. **Two-phase: Solid-liquid**
   a. Dispersion of solvable solid **(Dissolving)**
   b. Suspension of solid particles in liquid **(Suspension)**

4. **Two-phase: Gas-Solid**
   a. Gases with granular solids: fluidization, pneumatic Conveying, drying.

Purposes of Agitation: Applications

5. **Three-phase:**
   a) Gas-liquid-liquid **(Emulsion)**
   b) Liquid-liquid-solid

6. **Four-phase:**

   Gas-liquid-liquid-solid

7. **Solids with solids: mixing of powders.**
8. **Acceleration of chemical reaction and physical transport**
9. **Promoting heat transfer**
10. **Enhancement of mass transfer between dispersed phases.**

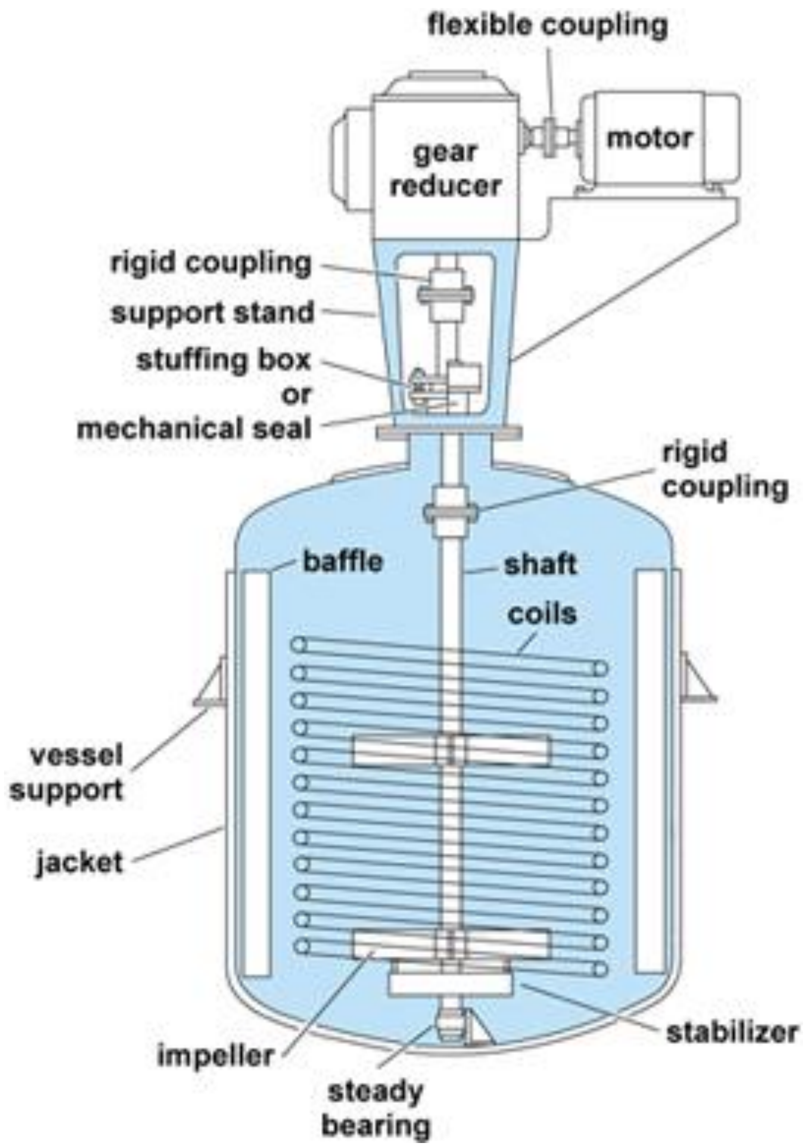
Mechanically Agitated Mixing Equipment

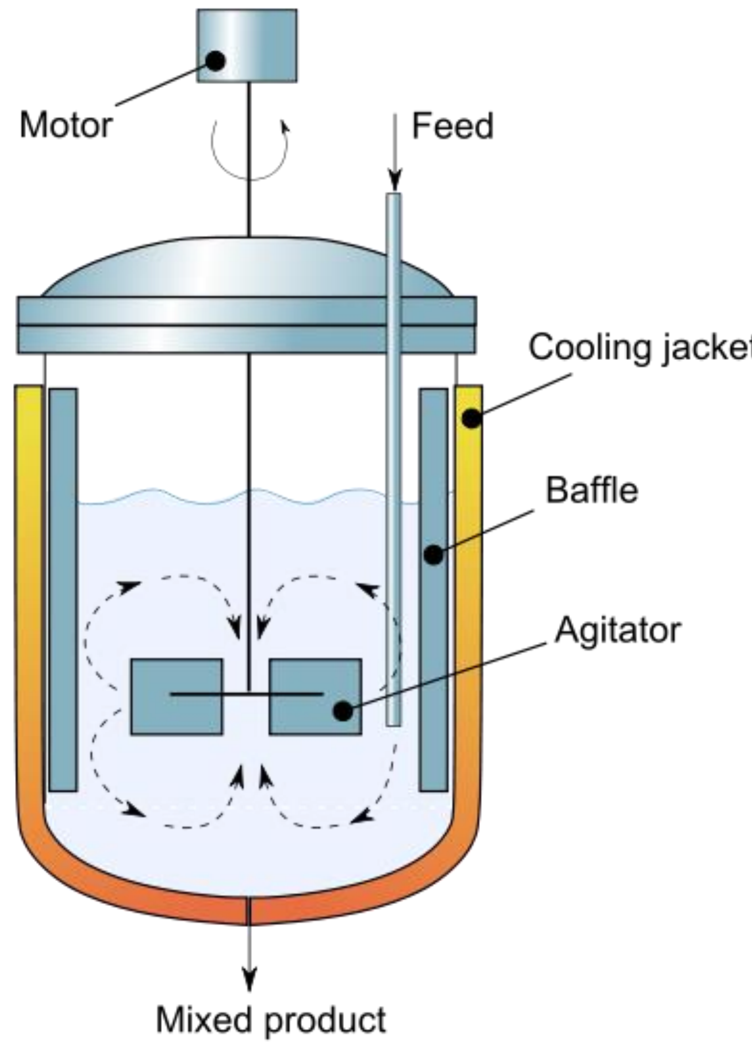
A BASIC STIRRED TANK DESIGN

- The internal arrangements depend on the objectives of the operation: whether it is to **maintain homogeneity** of a reacting mixture or to keep a solid suspended or a gas dispersed or to enhance heat or mass transfer.

- A set of mixing equipment consists of:
  - A mixing tank
  - A driving motor with speed reducer
  - An agitator
  - Some attached parts.

A BASIC STIRRED TANK DESIGN

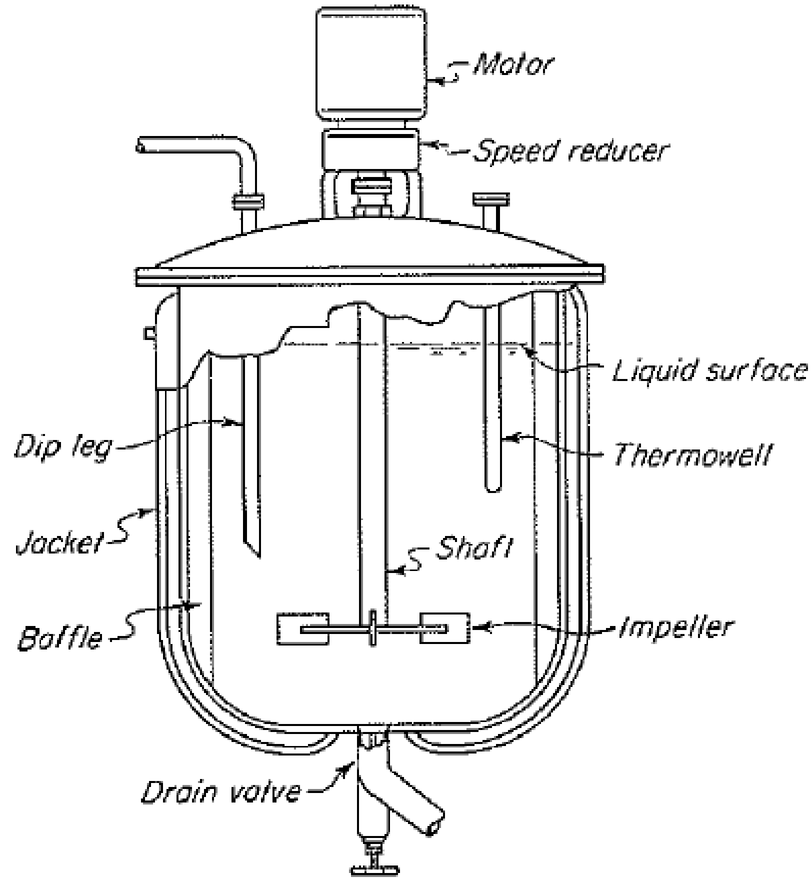




Dr. Majd Shhadi

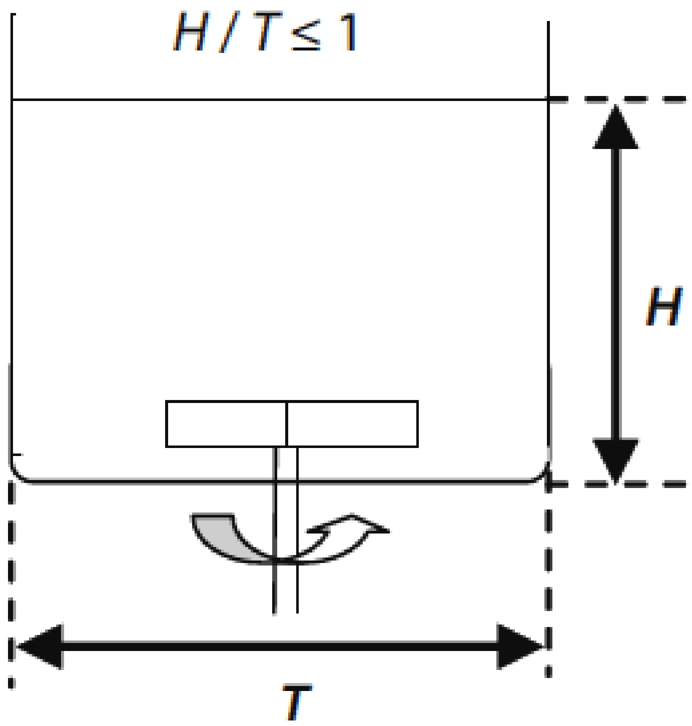
A Basic Stirred Tank Design: The Vessel

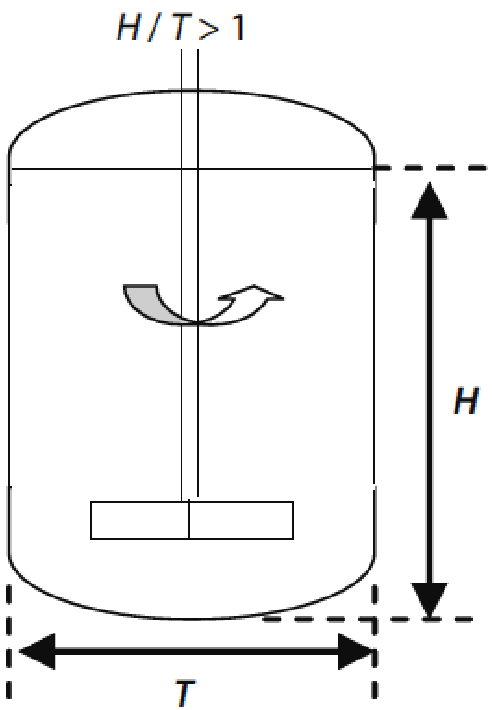
- Cylindrical form, vertical axis, closed or open top
- The tank bottom is rounded, **not flat.**
- When a single impeller is to be used, a liquid level equal to the diameter of the tank.
- Is optimum, with the impeller located at the center for an all-liquid system.



Typical Agitation process vessel

A Basic Stirred Tank Design: The Vessel



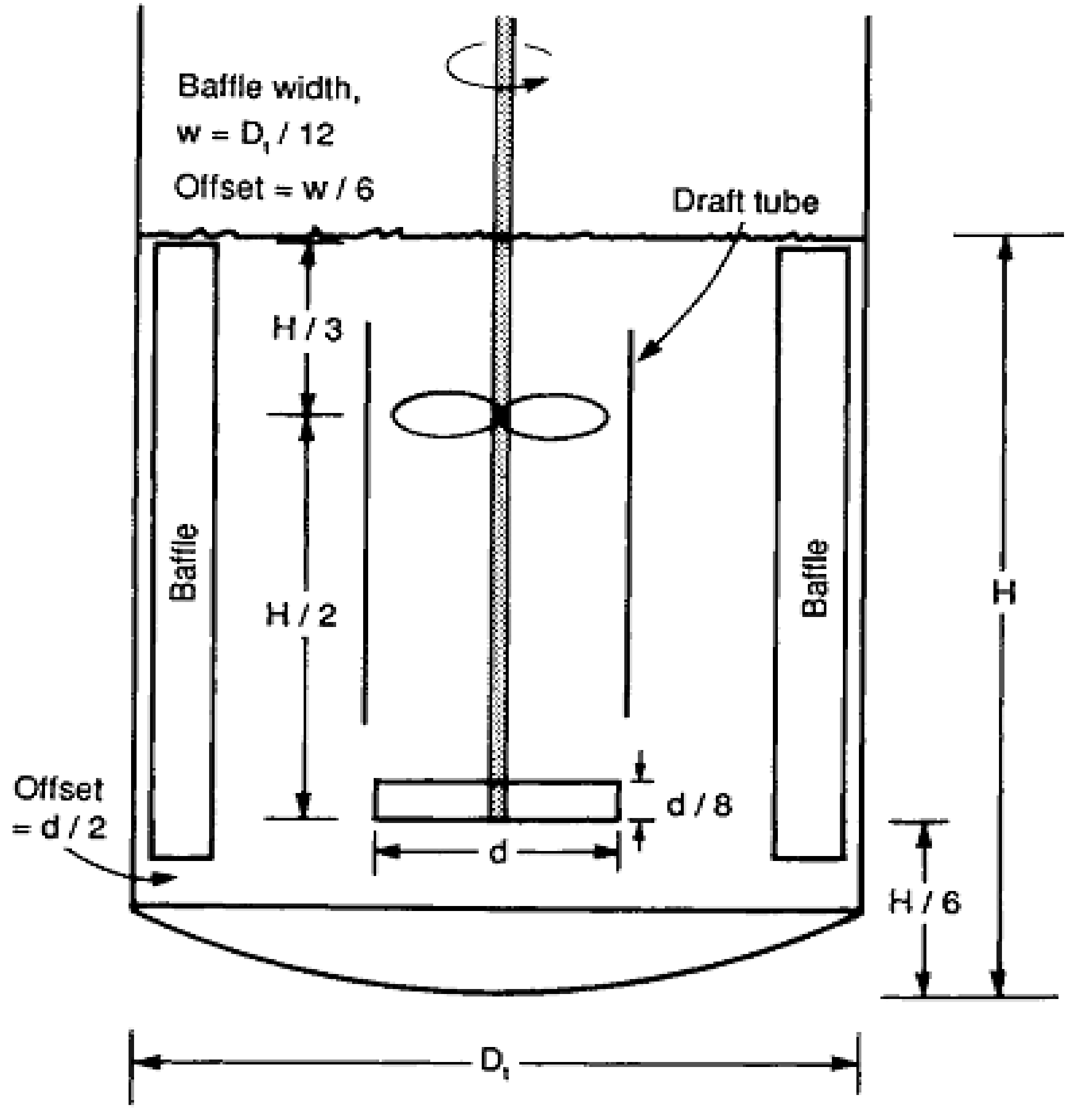


Rectangular cross section that is either cuboid **(H/T = 1)** or rectangular **(H/T < 1).**

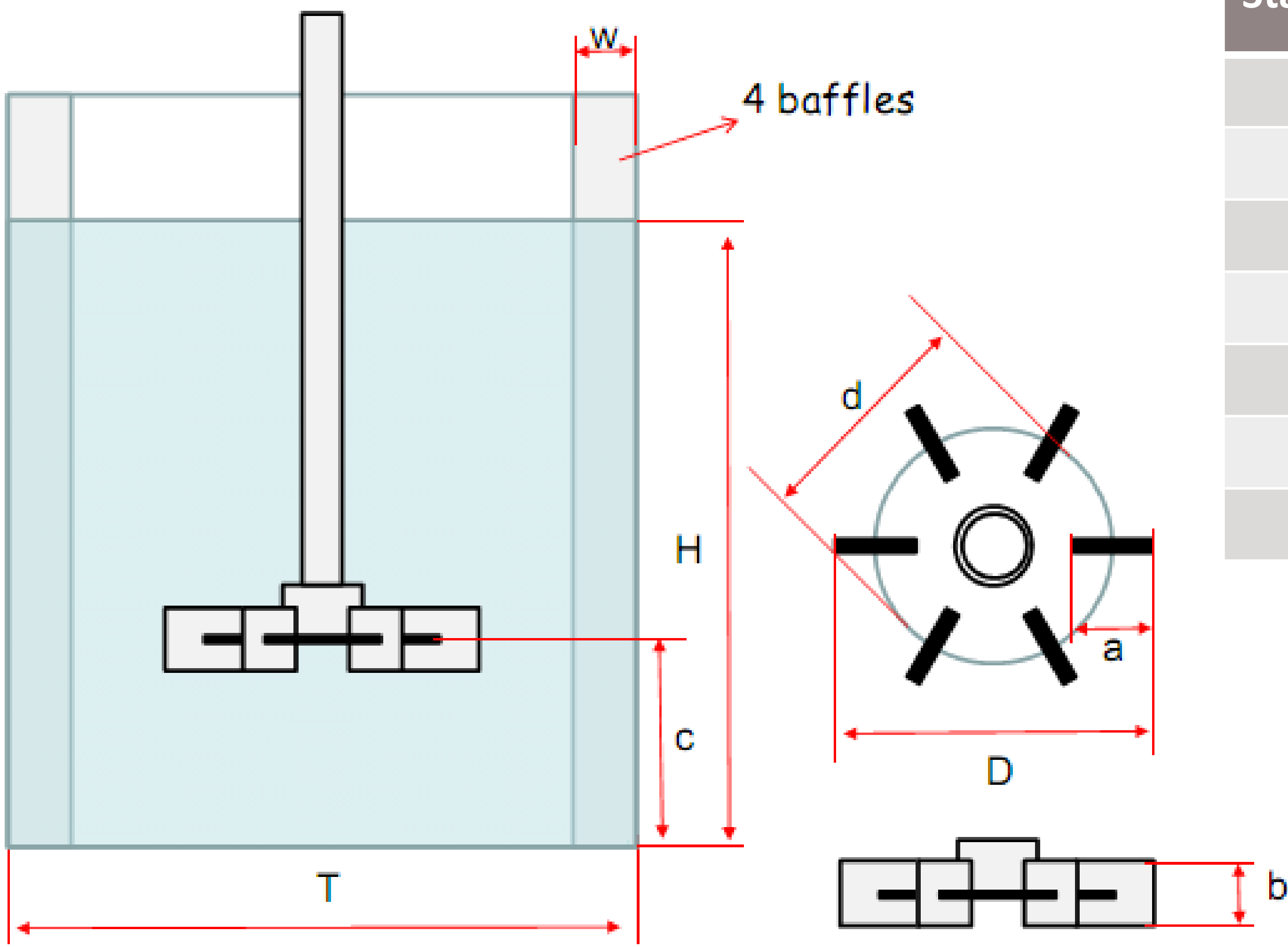
Cylindrical with a liquid height: diameter ratio greater than one **(H/T > 1)**

A Basic Stirred Tank Design

- ❑ Not to scale
- ❑ A lower **radial** impeller and an upper **axial** impeller housed in a draft tube.
- ❑ Four equally spaced **baffles** are standard.



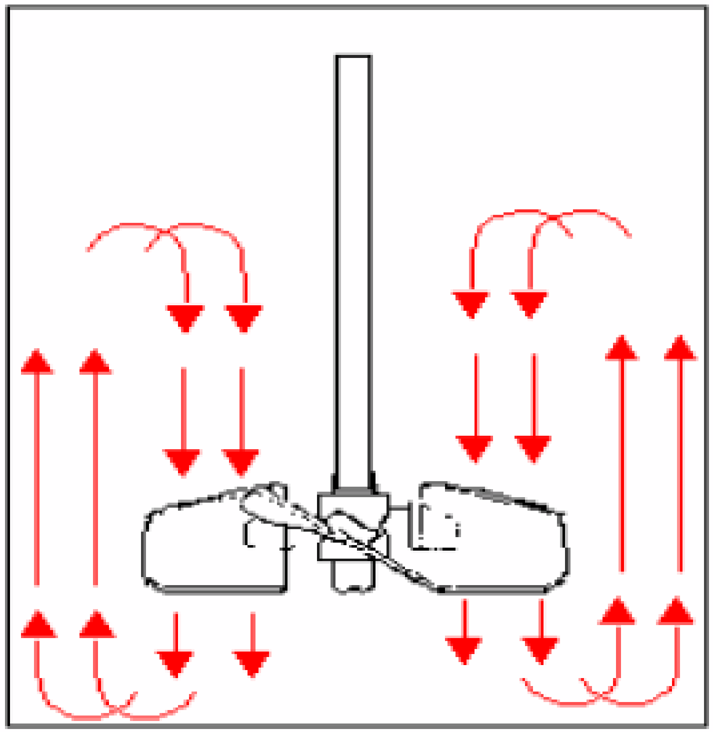
Standard Geometry

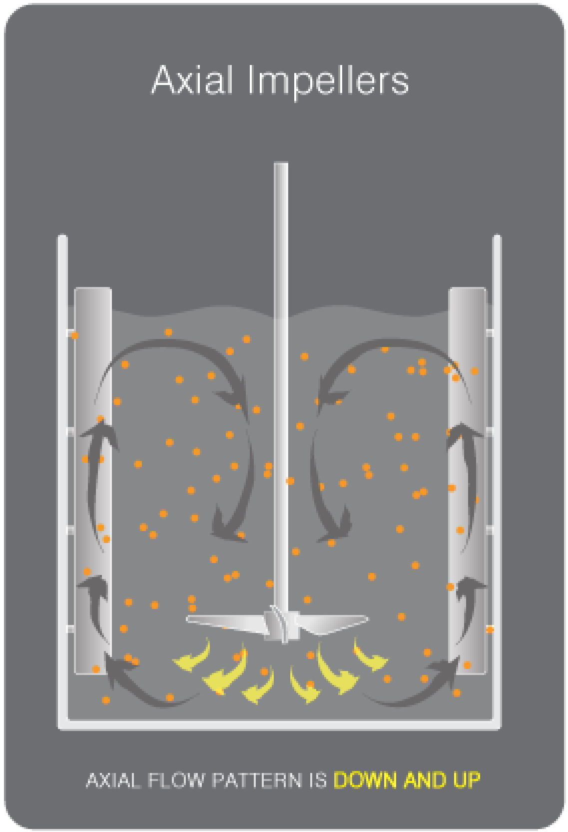


Standard Dimension	
D	T/2, T/3
H	T
a	D/4
b	D/5
c	T/2, T/3
d	0.75 D
w	T/10, T/12

IMPELLER TYPES

Axial

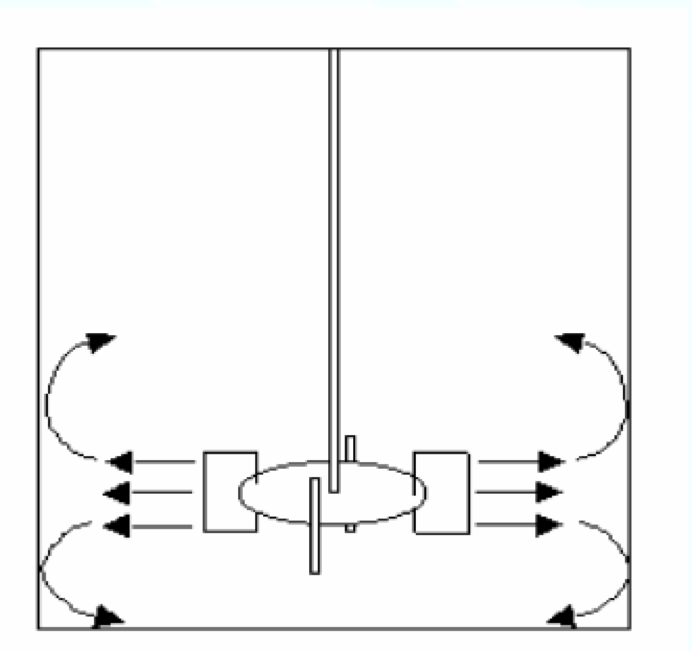


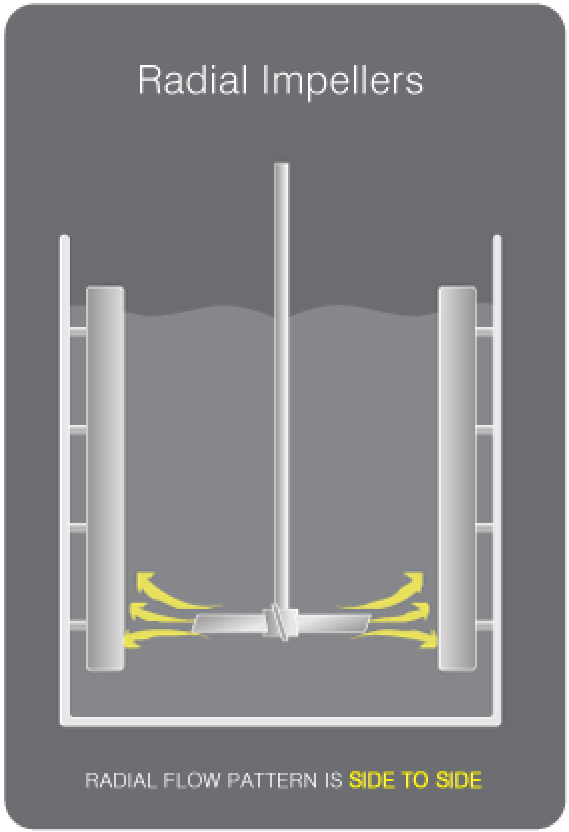


Axial (down and up) the liquid is pushed in a downward direction then up

IMPELLER TYPES

Radial-Flow





Radial (Side to side) the liquid is pushed in towards the wall of the tank

Impeller Types: Radial-Flow

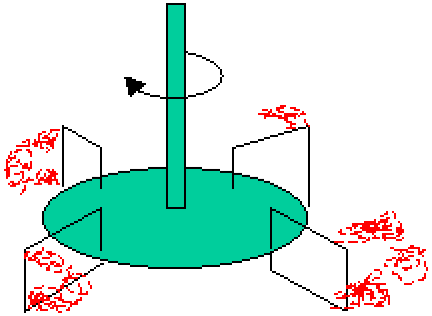
- For **low & middle viscosity liquids** in dispersion of immiscible liquids.
- Chemical reaction and heat transfer

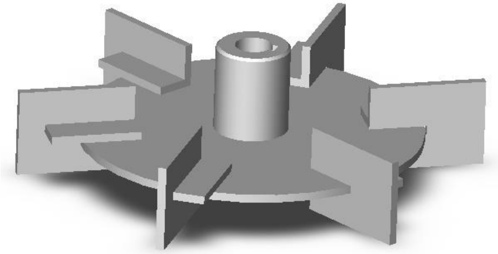
Types

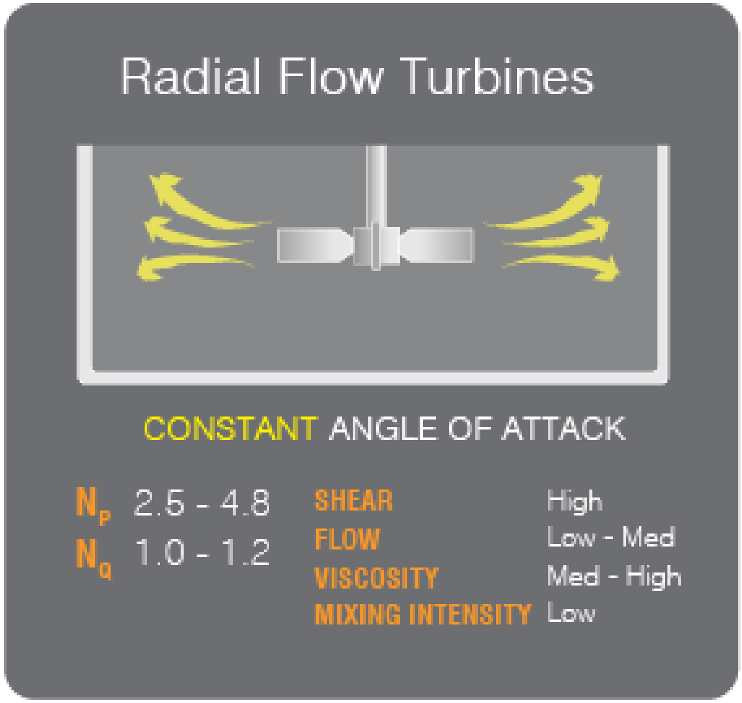
- **Turbines**: high speed, wide blade, low flow rate and high head.
- **Straight Blades**: long vane, low speed and low head, for high viscosity liquids.
- **Anchor And Frame**: very large diameter and mixing range, very low speed and head. Suitable for high viscosity liquids and capable of preventing the deposit on tank wall.

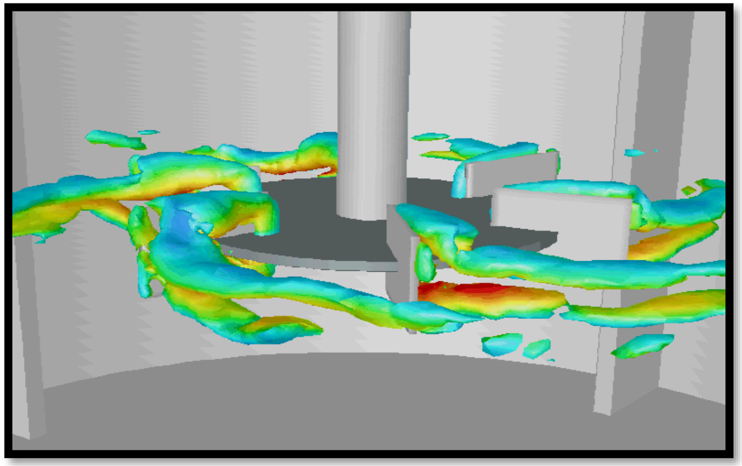
Radial Flow Impellers - Rushton Turbine Impeller

- Mixing is achieved with the use of **baffles**.
- Mixing is not as efficient as **axial** flow mixing.
- **Higher** input of energy.





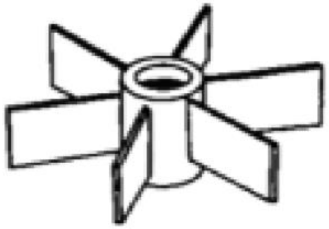




Rushton radial flow Impeller: disc with 6-8 Blades

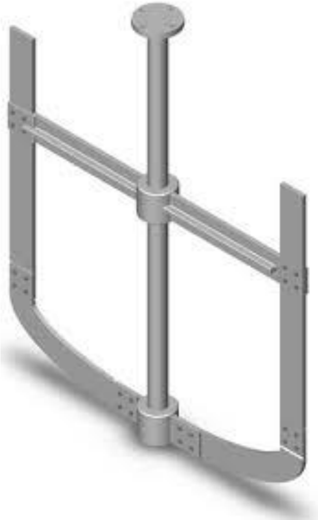
Radial Flow Impellers

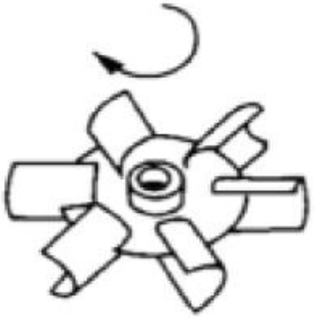
Simple straight-blade turbine (paddle)



Open Flat Blade

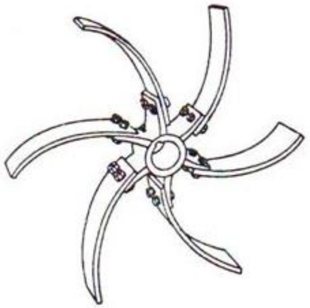
Anchor And Frame





Scaba SRGT
Chemineer CD6
(Smith)

Backswept with disk



Curved blade turbine
(Backswept open)

Impeller Types: Axial-Flow

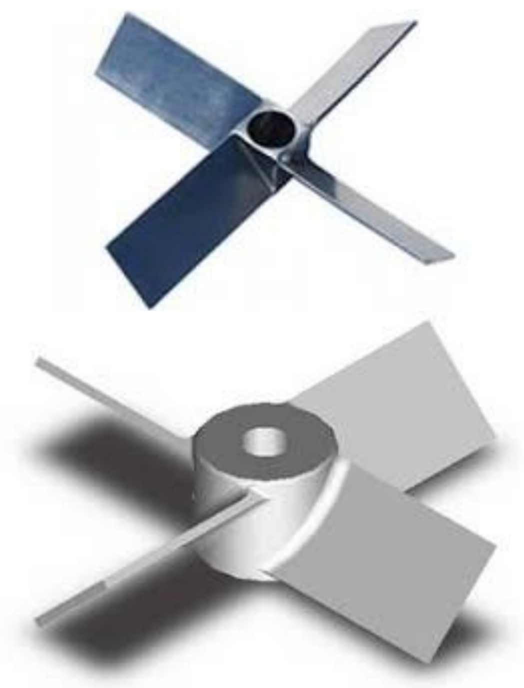
- Suitable for mixing of low viscose liquids
- Particle suspension
- Heat transfer enhance

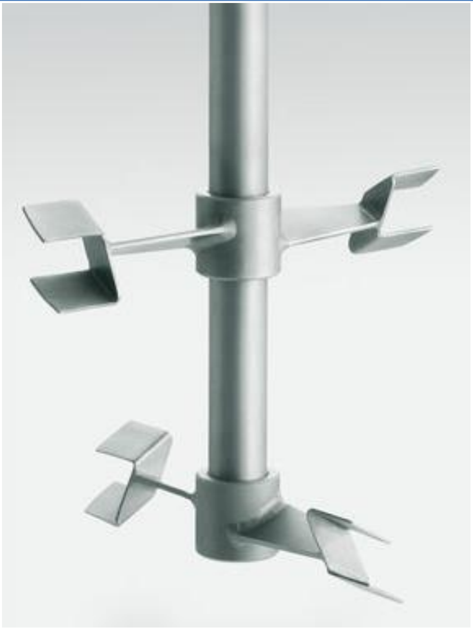
Types:

- **Marine Propeller (The three-bladed mixing propeller:** small diameter, high speed (up to 1800 rpm), with low viscosity fluids, up to about 4000 cP, large flow rate and low head.

- **Helical Ribbon:** large diameter and mixing range, low speed, low head. Special design for high viscosity liquid.

Impeller Types: Axial-Flow



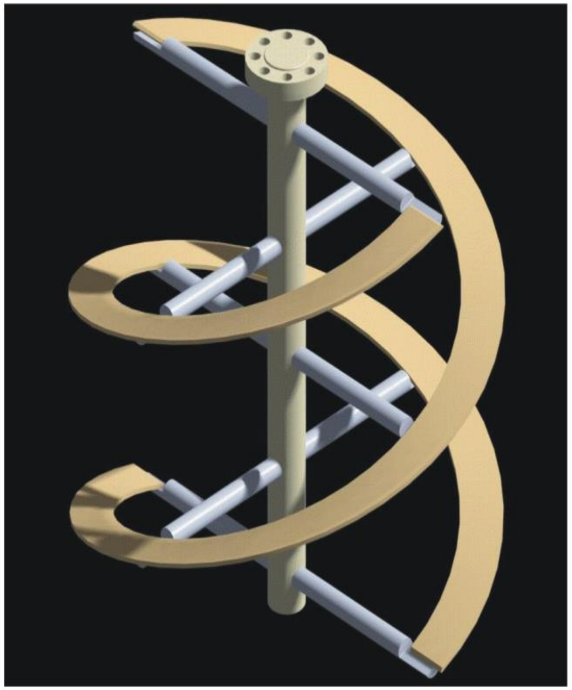


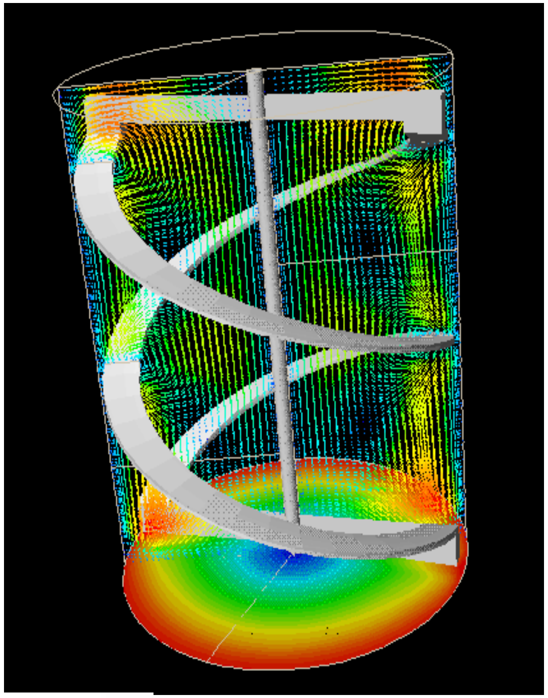
Intermig Impeller-Ekato

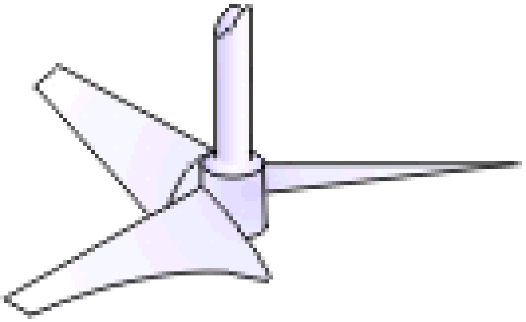
Marine Propeller

Mixed Flow: Both Axial and Radial – Pitched Blade Turbine

Impeller Types: Axial-Flow





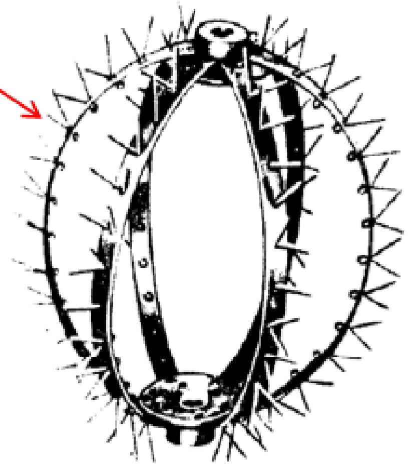


Hydrofoil

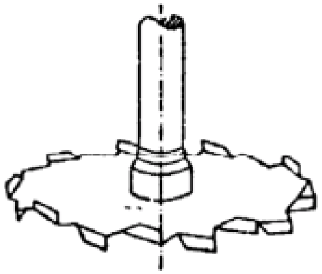
Helical Ribbon

Agitator types

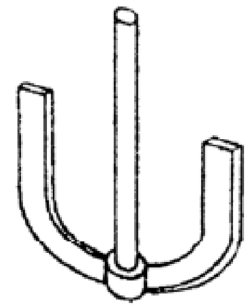
Cage beater impeller (usually mounted on the same shaft with a standard propeller)



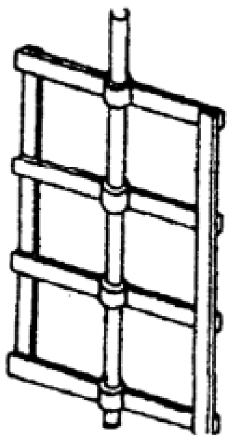
(h)



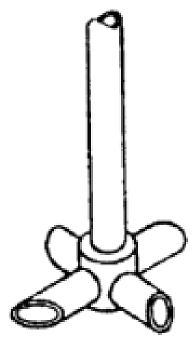
Sawtooth edges flat plate turbine



Anchor paddle

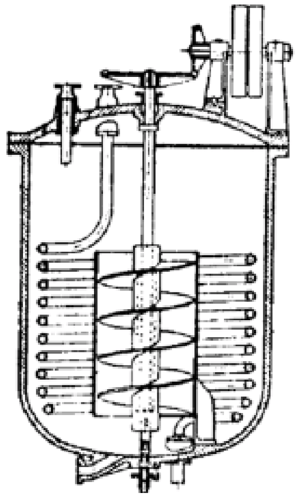


Gate paddle



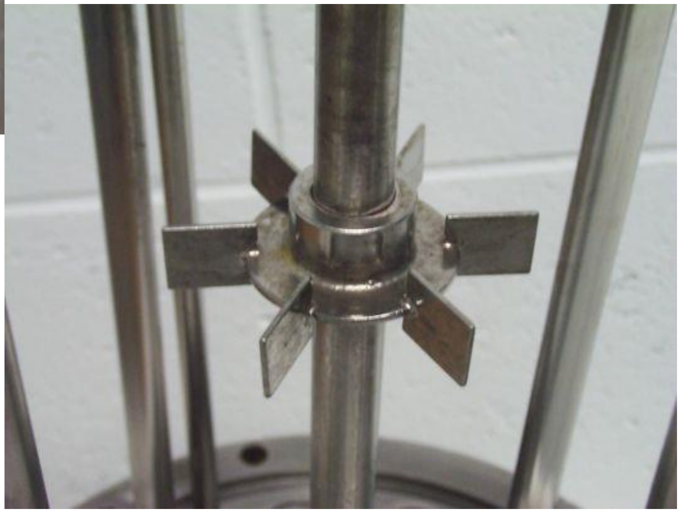
Hollow shaft and hollow impeller assembly

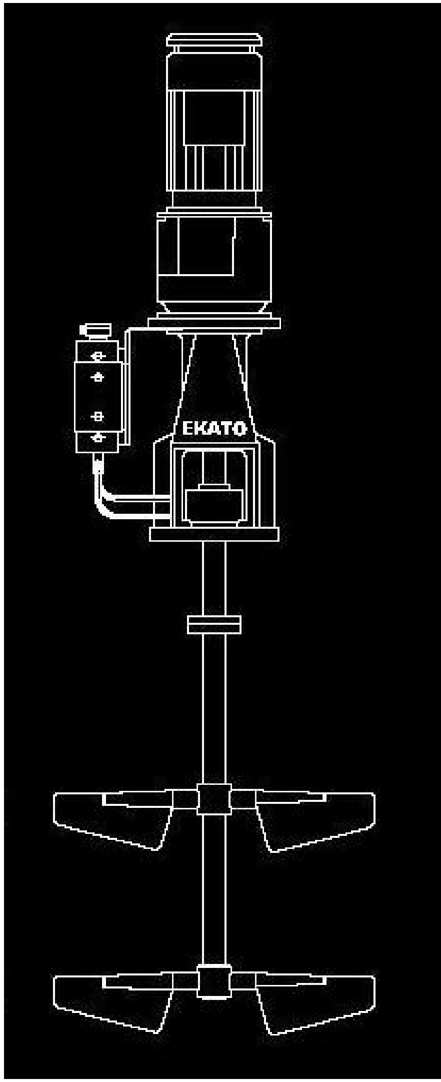
(k)



shrouded screw impeller and heat exchange coil

Impeller Types

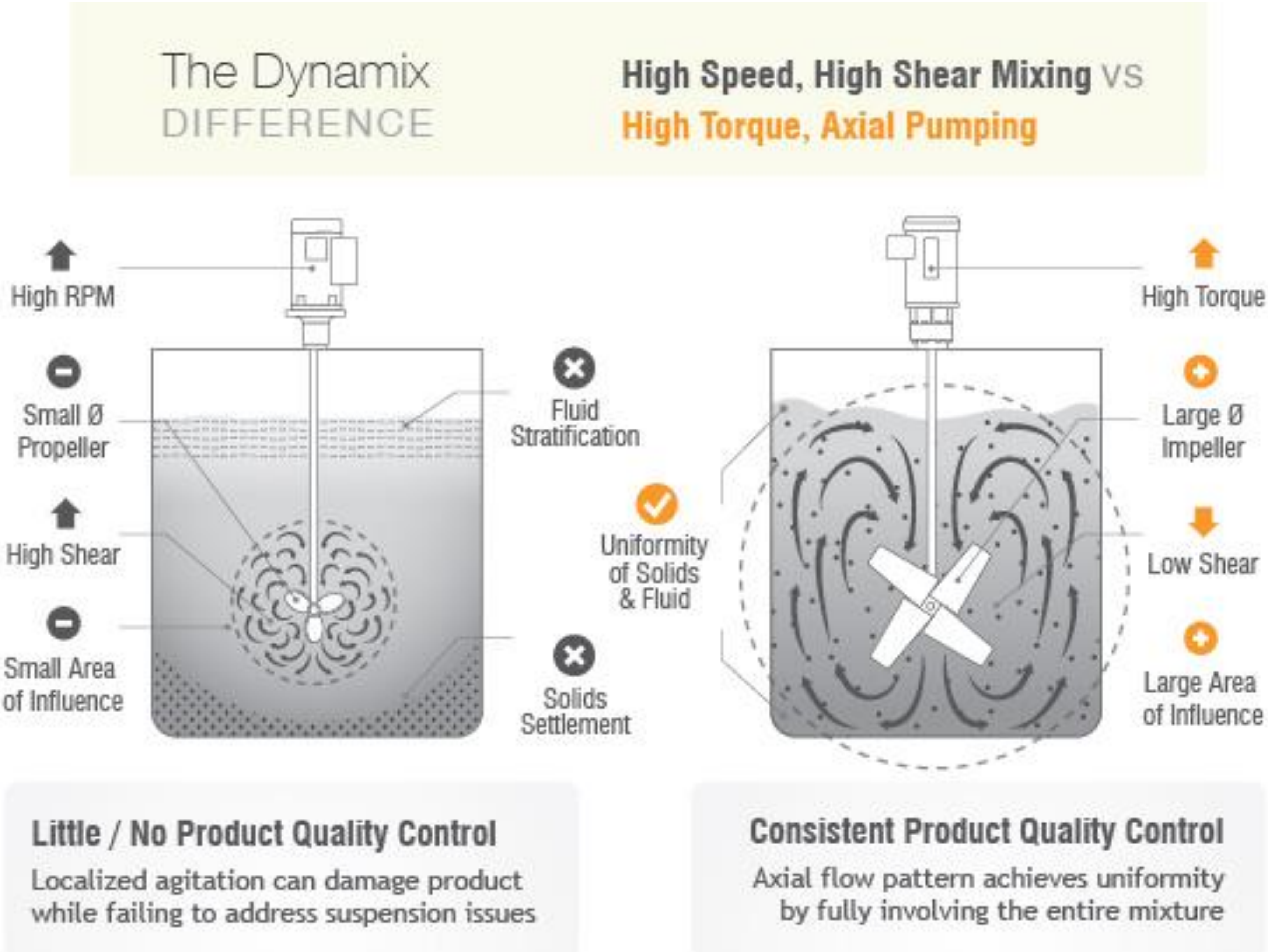




Impeller Size

- This depends on the kind of impeller and operating conditions described by the Reynolds, Froude, and Power numbers as well as individual characteristics whose effects have been correlated.

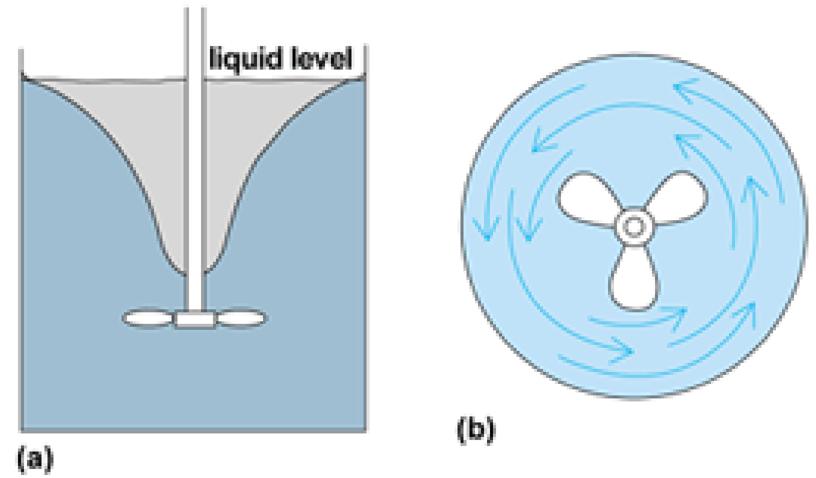
- For the popular turbine impeller, the ratio of diameters of impeller and vessel falls in the range, Diameter of impeller to diameter of tank, **D/T=0.3-0.6**, the lower values at high ***rpm***, in gas dispersion.


The Dynamix
DIFFERENCE
High Speed, High Shear Mixing vs
High Torque, Axial Pumping
High RPM
Small Ø Propeller
High Shear
Small Area of Influence
Fluid Stratification
Solids Settlement
Uniformity of Solids & Fluid
High Torque
Large Ø Impeller
Low Shear
Large Area of Influence
Little / No Product Quality Control
Localized agitation can damage product while failing to address suspension issues
Consistent Product Quality Control
Axial flow pattern achieves uniformity by fully involving the entire mixture

Prevention of Swirling

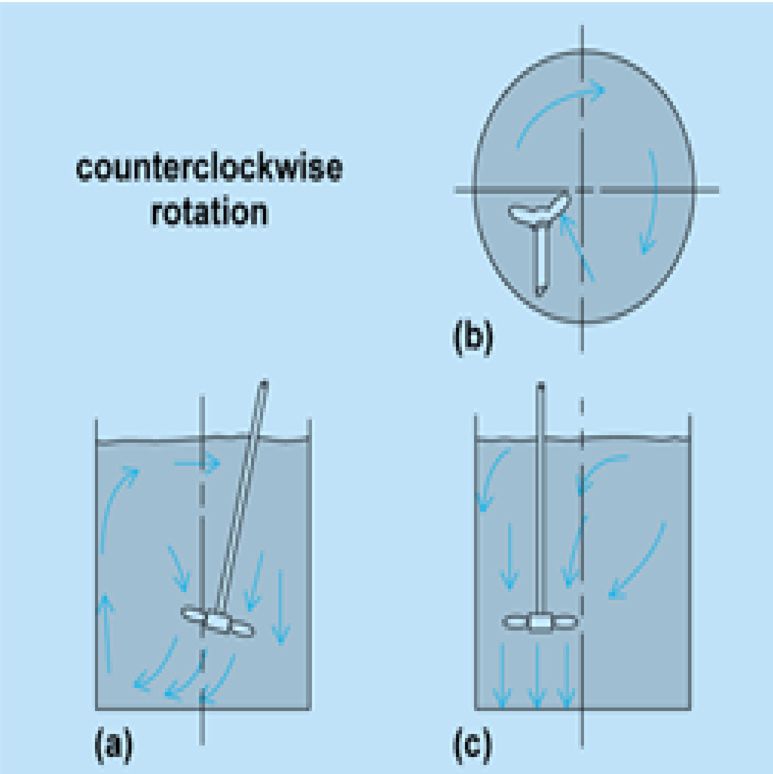
Prevention of Swirling and vortex formation

- Off-centered impeller. The impeller can be mounted off center (small tank).
- Side mounted impeller. The agitator may be mounted in the side of the tank with the shaft in a horizontal plane but an angle with a radius (large tank).
- Baffles: Install baffles (large tank with vertical agitators).

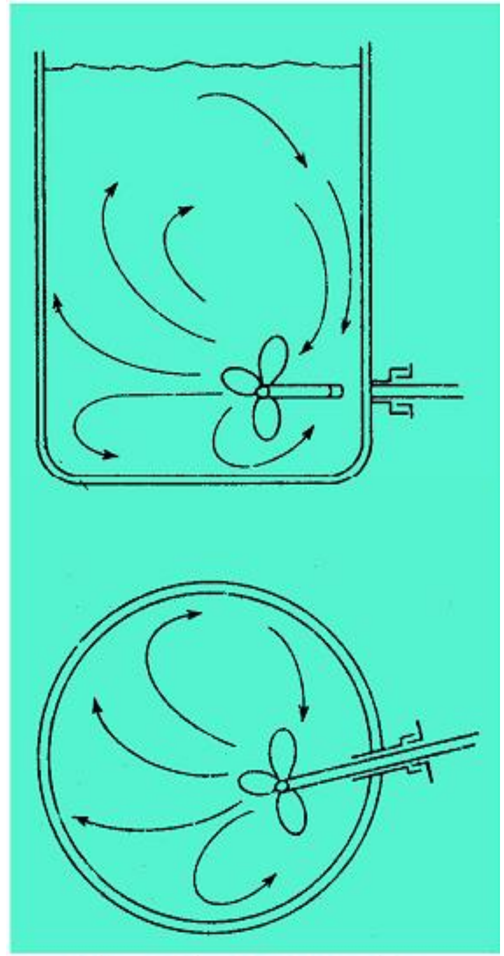


Swirling flow pattern for impeller of any shape, without baffles. **(*a*) Side view. (*b*) Bottom view**

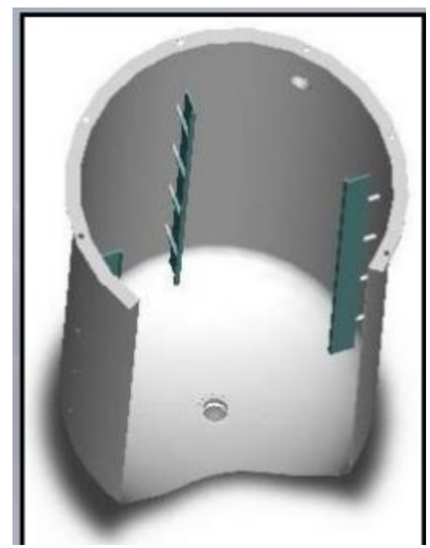
Prevention of Swirling



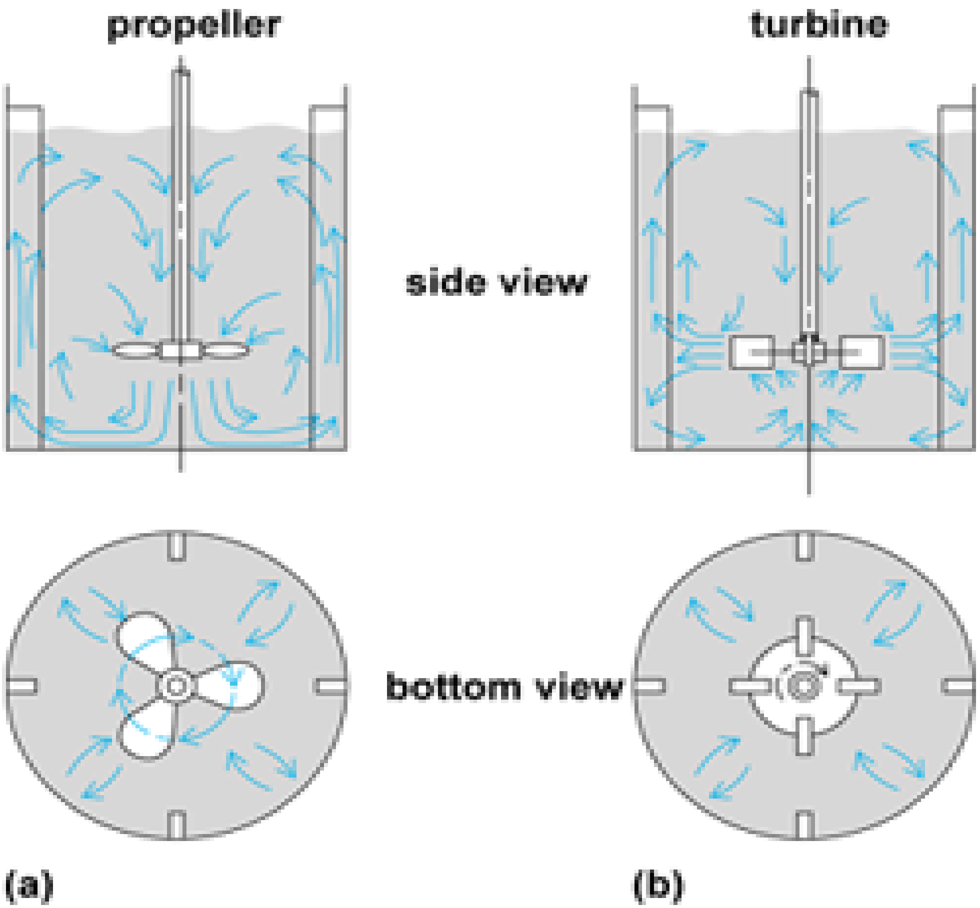
Flow pattern for top-entering, off-center propeller without baffles: (*a*) front, (*b*) top, and (*c*) side views.

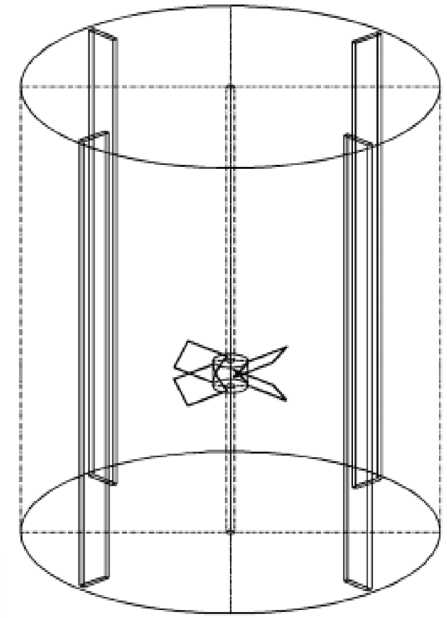


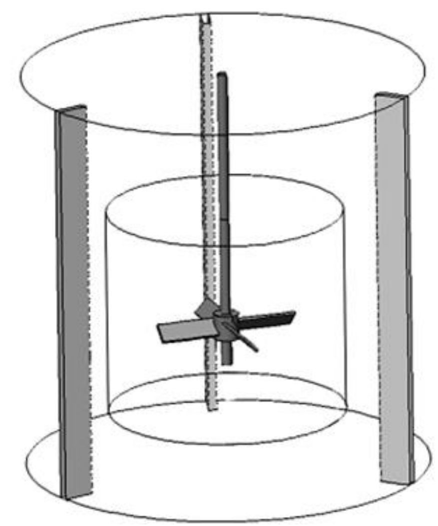
Side entering impellers



Prevention of Swirling





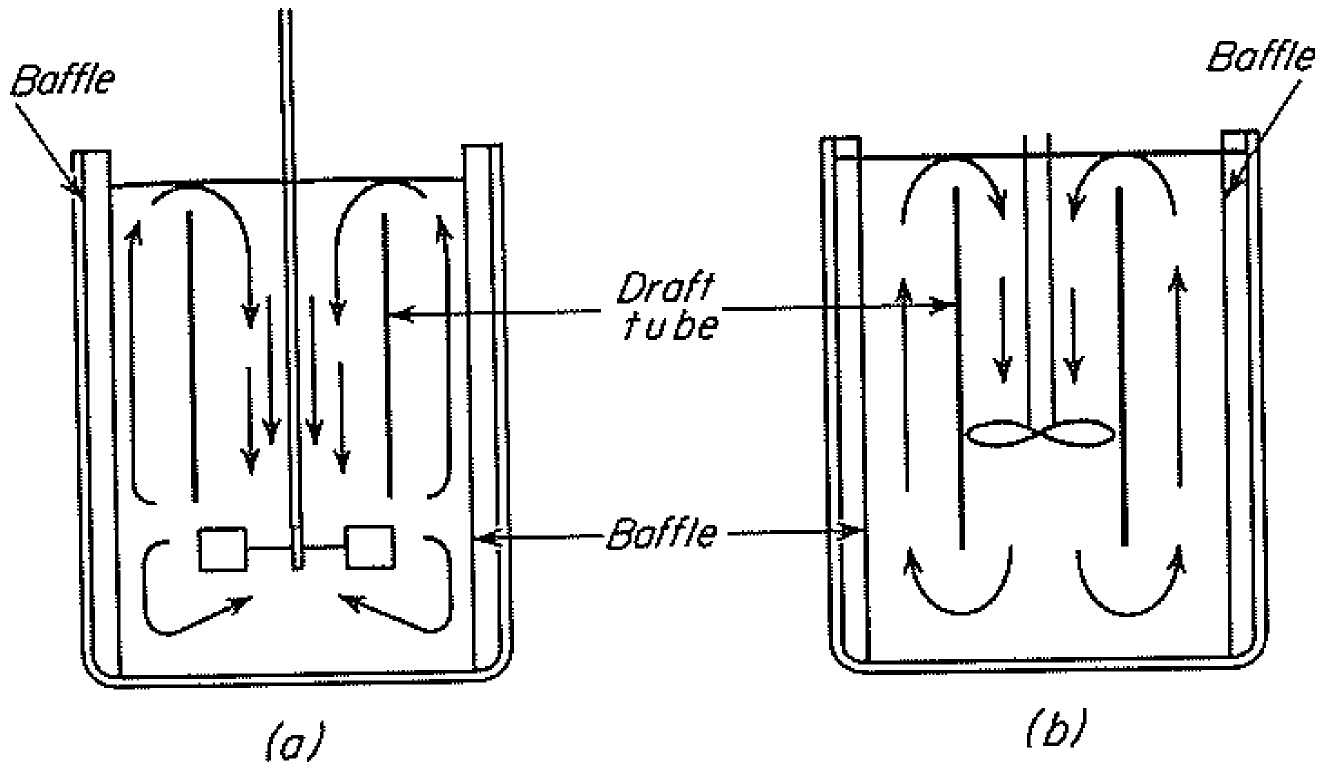


Flow patterns with baffles. (*a*) Flow pattern for propeller with baffles at tank wall. (*b*) Flow pattern for turbine with baffles at tank wall.

DRAFT TUBES

DRAFT TUBES

- Controls direction and velocity of flow
- Useful when high shear is desired such as emulsions and suspensions



Turbine **Propeller**

Circulation, Velocities, & Power Consumption

- Volume of fluid circulated by impeller must be sufficient to sweep out entire vessel in **reasonable time.**
- Velocity of stream leaving impeller must be sufficient to carry current to remotest parts of tank.
- In mixing, also it needs **turbulence**
  - Results from properly directed currents and large velocity gradients in liquid
- Circulation and generation of turbulence both consume energy
  - Large impeller + medium speed = flow
  - Small impeller + high speed = turbulence

Flow Pattern In Mixing Tank

- Flow pattern is related with the geometries of tank, stirrer and baffle, liquid properties and stirrer speed.

- For agitation operation, the useful flows are axial and radial not the tangential.

Impeller Characteristics:

- Reynolds Number for tank

$$\text{Reynolds} \quad N_{Re} = \frac{N D^2 \rho}{\mu}$$

$$u = DN$$

u = tip speed

N: Rotating speed, rps

Flow Pattern In Mixing Tank

- For a fully baffled standard tank with an 6 straight blades turbine, the following flow regimes hold
- **1<Re<10** near the turbine: **laminar flow**, other zones: almost static.
- **Re>10**: laminar axis flow, flow starts from blade's tips.
- **100<Re<10^3** transition, around turbine: turbulent flow, other zones: laminar axis flow.
-
- **Re>10^3:** turbulent in whole tank.

Why Dimensionless Numbers?

- Empirical correlations to estimate the **POWER** required to rotate a given impeller at a given speed, with respect to other variables in system.

- Measurements of tank and impeller
- Distance of impeller from tank floor
- Liquid depth
- Dimensions of baffles
- Viscosity, density, speed

Flow Rates Pumped by the Impeller

- **Pumping flow rate Q:** flow rate pumped through a "reference" surface of the agitator.

$$\text{Pumping Number } N_Q = \frac{Q}{ND^3}$$

- Where **Q** is the volumetric flow rate, measured over a fixed control surface (depending on the agitator type)
- **N** is the rotational speed (*rps*)
- **D** is the impeller diameter.

Flow Rates Pumped by the Impeller

For turbulent flow, N_Q is a constant, not a function of Re

Typical **N_Q** values:

- Standard flat-blade turbine, **N_Q** = 1.3
- Marine propellers, **N_Q** = 0.5-0.9 (dep. on pitch)
- 4-blade 45° turbine, **N_Q** = 0.5

Why Dimensionless Numbers?

- The **power P** dissipated divided $\rho\, N^3 D^5$ corresponds to an important dimensionless parameter of mixers, the Power Number ***Np***:

$$Power\ Number\ N_P = \frac{P}{\rho\, N^3 D^5}$$

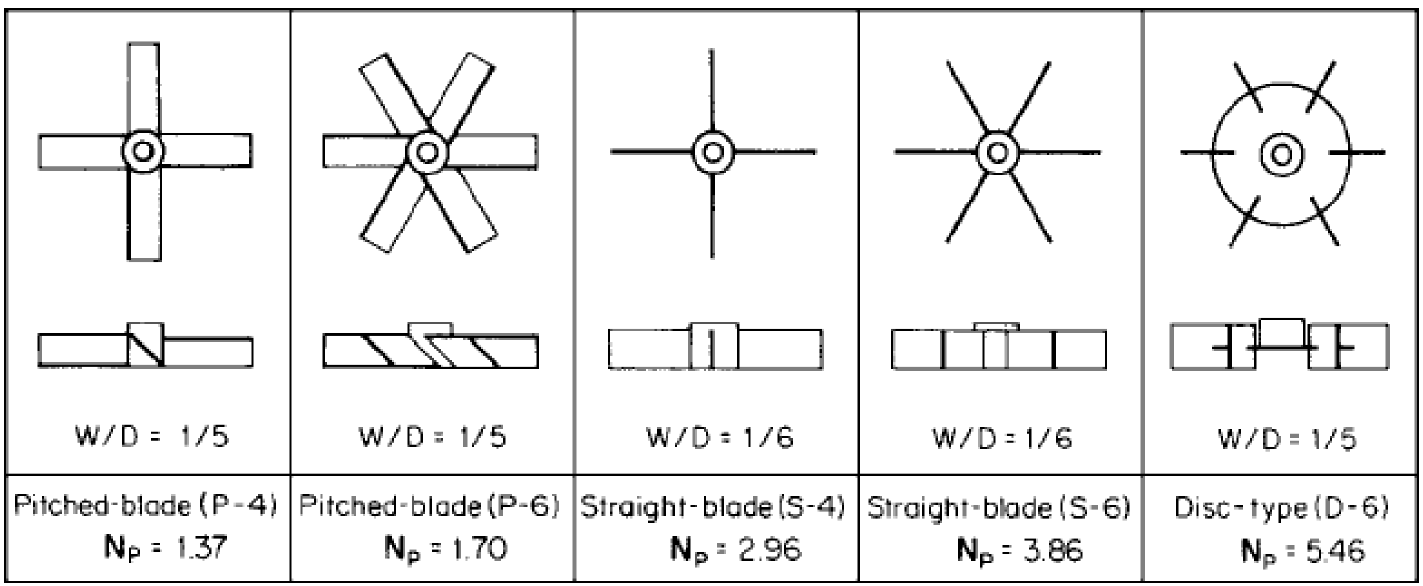
- P is the mechanical power dissipated (watts), measured at the tip of the blades,
- N is the rotational speed (rps),
- D is the impeller diameter and ρ is the fluid density.

The power number is a function of the impeller, blade width, number of blades, blade angle, D/T, baffle configuration and impeller elevation.

Why Dimensionless Numbers?

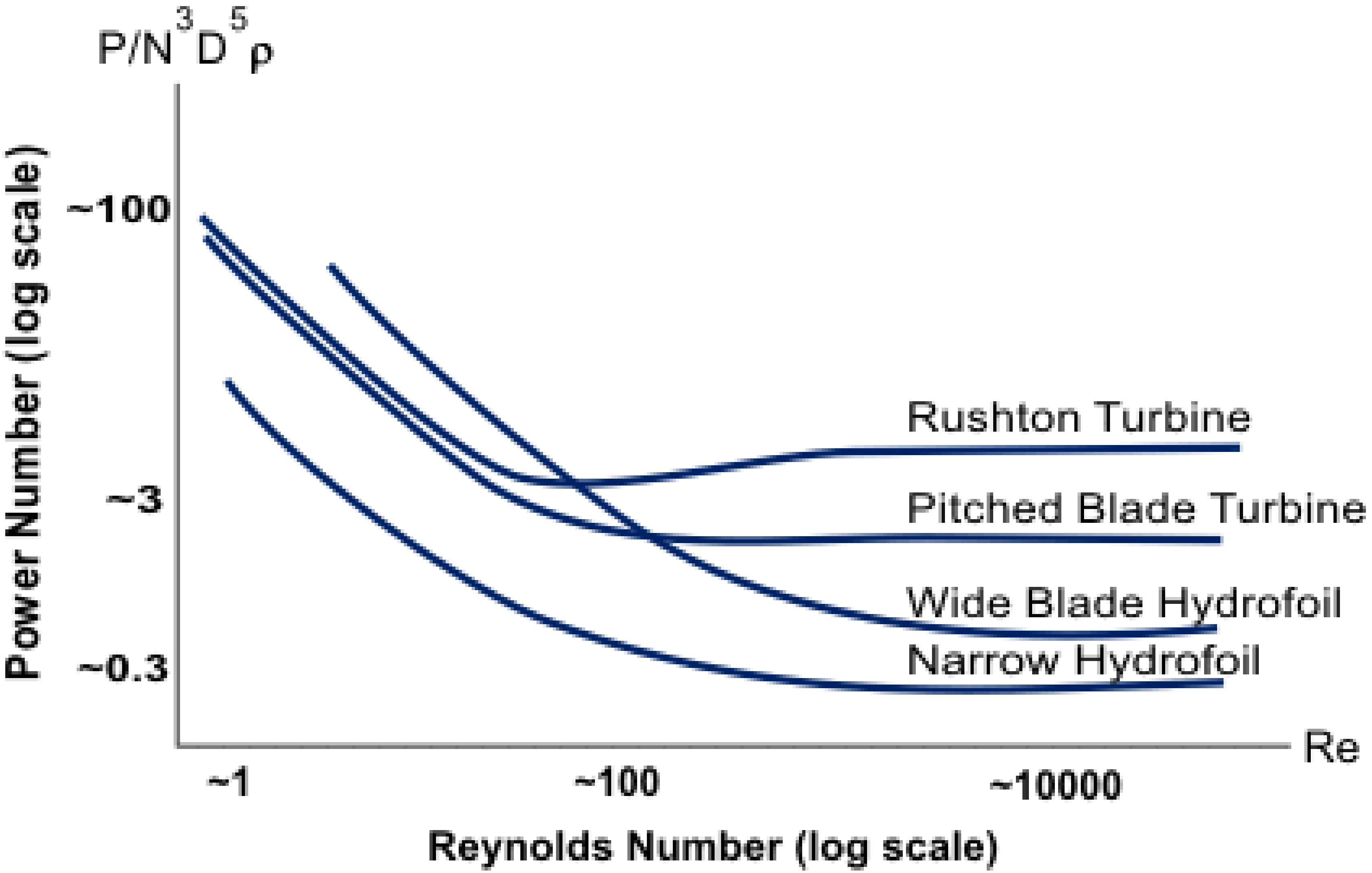
Typical values:

- Standard flat-blade turbine, baffled vessels $N_P = 5$
- Standard flat-blade turbine, unbaffled vessels $N_P = 1$
- Marine propellers, $N_P = 1$

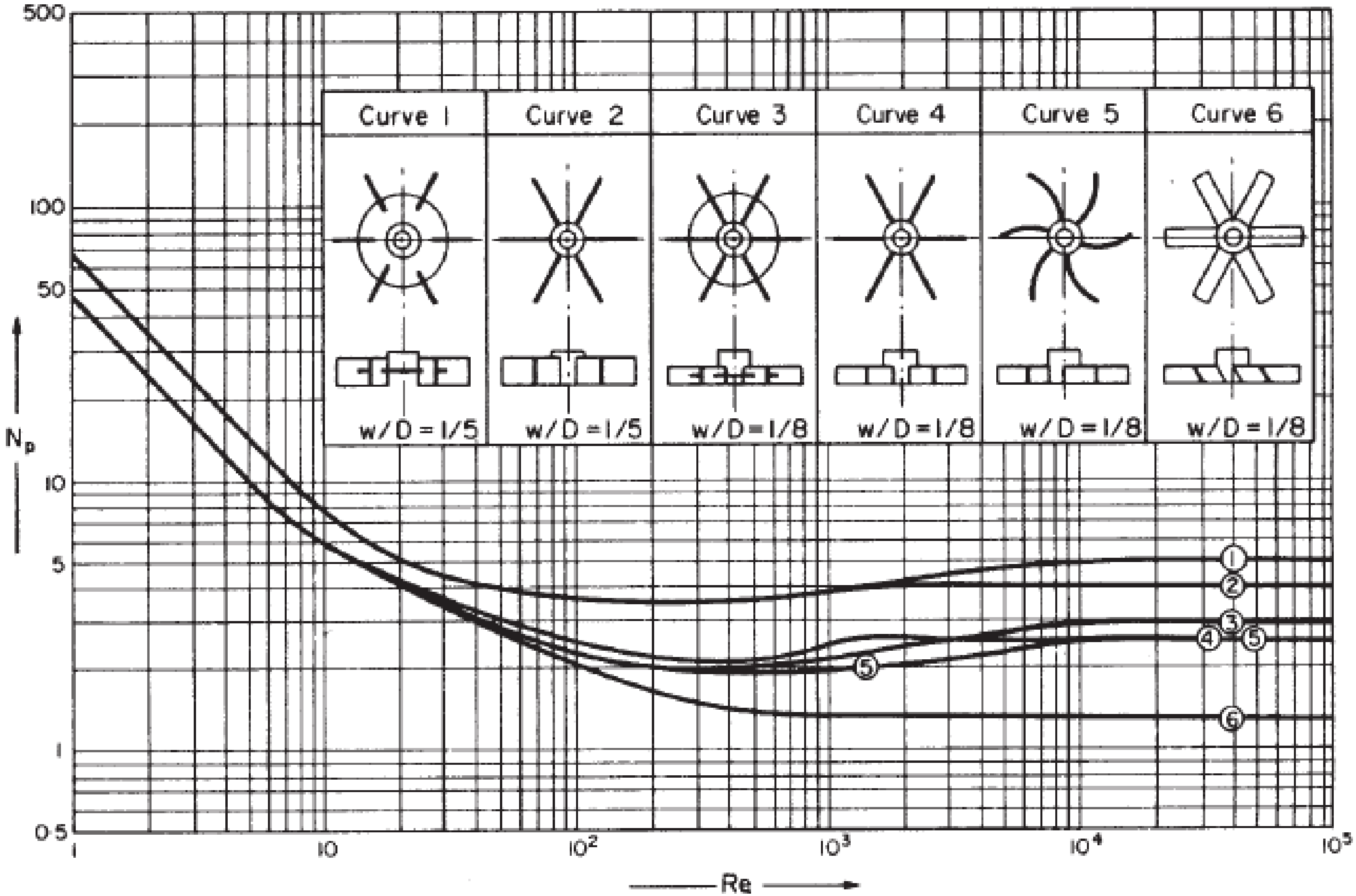


Values of turbulent power number N_P for various impeller geometries.
Note: W/D is actual blade-width-to-impeller-diameter ratio.

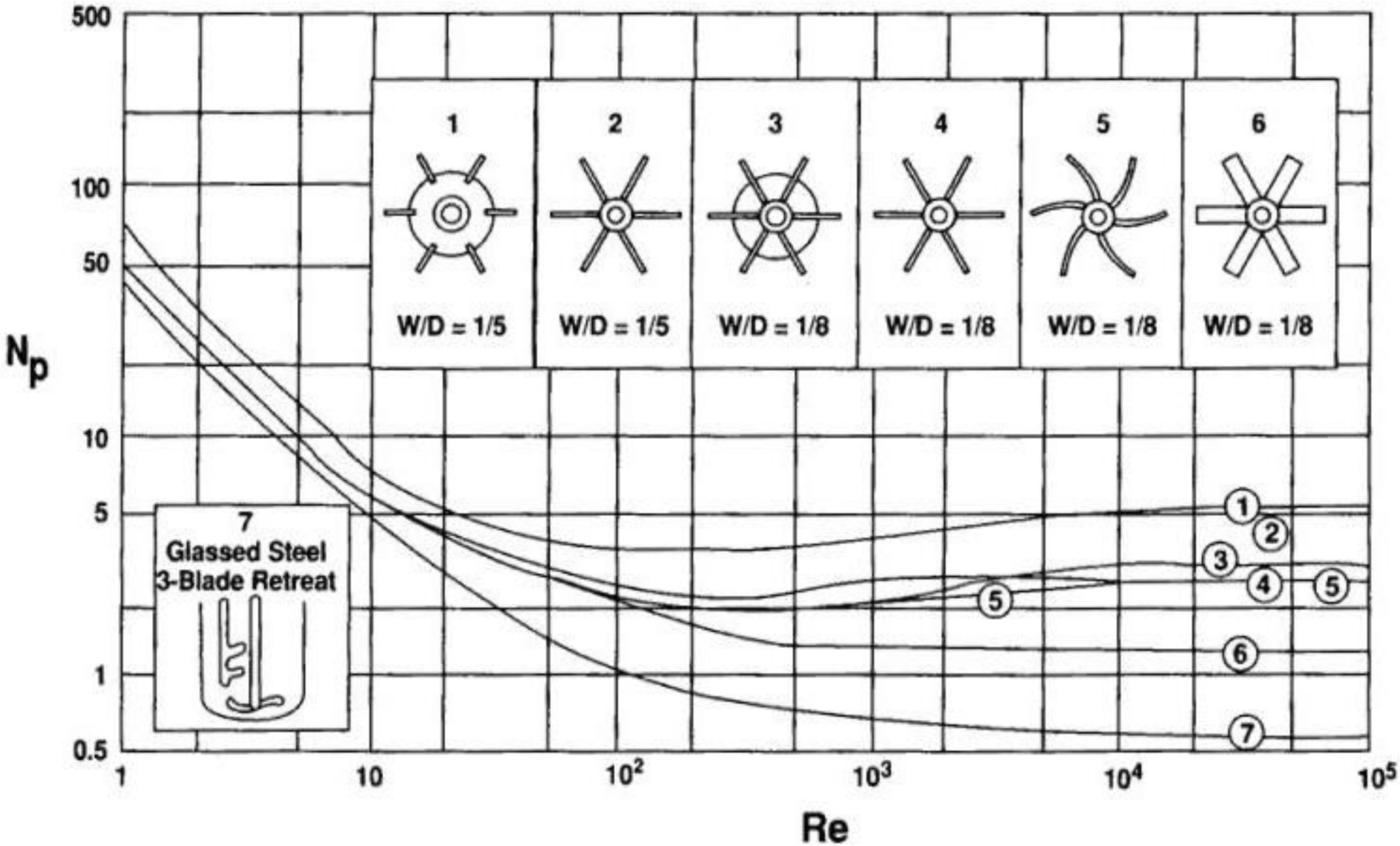
Correlations & Power Curves



N_p vs Re for different turbines

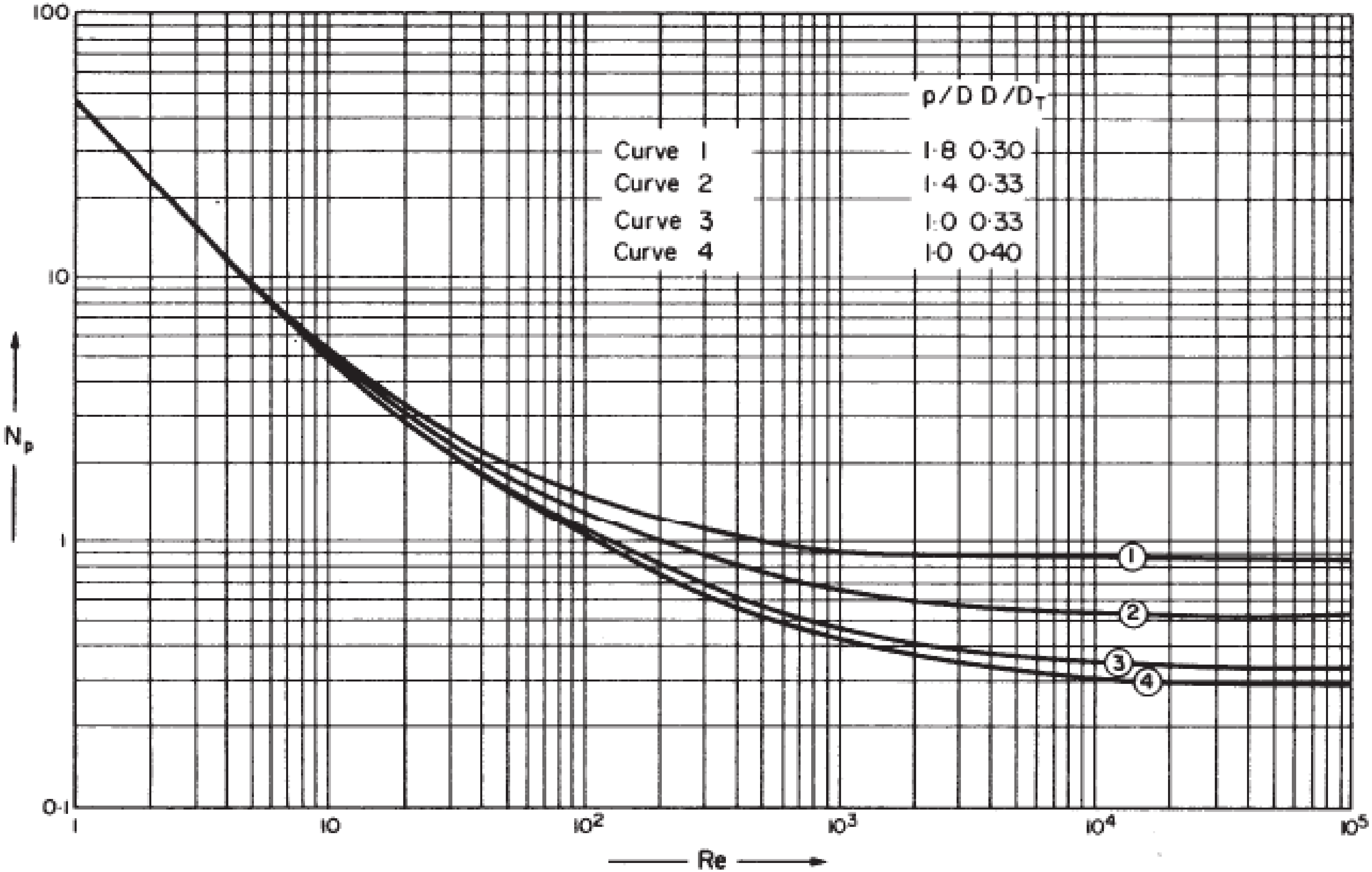


Power correlations for baffled turbine impellers, for tank with 4 baffles



Power Number Plot: Curve 1 is a Rushton Turbine. Curves 2 & 4 are Open Flat Blades. Curve 5 is a Backswept open Impeller. Curve 6 is a Pitched Blade Turbine (PBT).

N_P *vs* Re for propellers



Power correlation for single three-bladed

p = blade pitch D = impeller diameter D_T = tank diameter

Calculation of Power Consumption

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

At low *Re* (<10), density is no longer a factor:

$$N_P = \frac{K_L}{Re} \qquad P = K_L N^2 D^3 \mu$$

At *Re* >10 000 in baffled tanks, P is independent of Reynolds Number and viscosity is not a factor:

$$N_P = K_T \qquad P = K_T N^3 D^5 \rho$$

K_L and K_T are constants for various types of impellers and tanks

Please note the dependency of *P* on μ or ρ depending on the flow regime (laminar or turbulent).

Power constants at low (K_L) and high (K_T) Reynolds number

Type of Impeller	K_L	K_T
Propeller, 3 blades		
Pitch 1.0	41	0.32
Pitch 1.5	55	0.87
Turbine		
6-blade disk (S_3=0.25 S_4=0.2)	65	5.75
6 curved blades (S_4=0.2)	70	4.80
6 pitched blades (45°, S_4=0.2)	-	1.63
4 pitched blades (45°, S_4=0.2)	44.5	1.27
Flat paddle, 2 blades (45°, S_4=0.2)	36.5	1.70
Anchor	300	0.35

Correlations And Power Curves

- For a **complicated mixing** process, **dimensional analysis** is often used to correlate the experimental data and **find the empirical Eqs.**

- With a **standard mixing** unit, following results can be found from the **dimensional analysis**

$$Pw = f\left(N, D, \rho, \mu, g\right) \qquad N_P = \frac{Pw}{\rho N^3 D^5} = f\left(\frac{ND^2\rho}{\mu}, \frac{N^2 D}{g}\right) \qquad N_P = f\left(\mathrm{Re}, \mathrm{Fr}\right)$$

N_P —— power number
Re —— stirring Reynolds number for flow pattern
Fr —— Froude number for circulating flow with free surface

Scaling up criterion

(1) power consumption per volume (*Pw/ V*) =Const.

Used for constant liquid properties and relatively small scaling-up ratio. Good for turbulent mixing dominated situation in fully turbulent flow.

$$N_1^3 D_1^2 = N_2^3 D_2^2$$

(2) Tip speed constant

Keep the agitator torque constant in a geometrical analogue system. Suitable for operation of high head.

$$N_1 D_1 = N_2 D_2$$

(3) Reynolds number, Re= Const.

$$N_1 D_1^2 = N_2 D_2^2$$

Scaling up criterion

(4) Froude number, Fr=Cost.

$$N_1^2 D_1 = N_2^2 D_2$$

(5) Webber number, We= Const.

$$N_1^2 D_1^3 = N_2^2 D_2^3$$

Which scaling up process should be used?

depends on the practical situation.

Example 1

- A flat-blade turbine with six blades is installed centrally in a vertical tank. The tank is 3.6 m in diameter, the turbine is 1.2 m in diameter & is positioned 1.2 m from the bottom of the tank. The turbine blades are 240 mm wide. The tank is filled to a depth of 3.6 m with a solution of 50% caustic soda at 65.6 °C, which has a viscosity of 10.785 P and a density of 1498 kg/m^3. The turbine is operated at 60 rpm. **What power will be required to operate the agitator if:- (a)The tank was baffled & (b) The tank was unbaffled.**

Answer:

$n = 60\text{rpm} / 60\ \text{s} = 1.0\ \text{r/s}$

$D_a = E = 1.2\ \text{m}$

$\mu = 10.785\ \text{P} = 1.0785\ \text{kg/ms}$

(a) Baffled tank

$$N_{RE} = \frac{D_a^2 n \rho}{\mu} = \frac{(1.2)^2 (1)(1498)}{1.0785} = 2000$$

From Fig. 9.12, curve A for baffle, $N_P = 5.0$

$$\therefore P = N_p n^3 D_a^5 \rho = (5)(1)^3 (1.2)^5 (1498) = 1.86x10^4 W$$

(b) Unbaffled tank

From Fig 9.12, curve D, $N_P = 2.0$.

Froude number, $$N_{Fr} = \frac{n^2 D_a}{g} = \frac{(1)^2 (1.2)}{9.81} = 0.122$$

From Table 9.1, a & b are 1.0 & 40.0 respectively

$$m = \frac{a - \log_{10} N_{Re}}{b} = \frac{1.0 - \log_{10} 2000}{40} = -0.0575$$

So the corrected value of NP,

$$N_{P(Corr)} = N_P \, X \, N_{Fr}^m = 2X0.122^{-0.0575} = 2.257$$

Thus power,

$$P = N_p n^3 D_a^5 \rho$$

$$= (2.257)(1)^3 (1.2)^5 (1498)$$

$$= 8413 mN/s = 8413 W$$

Example 2

- A propeller with three blades is installed centrally in a vertical tank. The tank is 2.7 m in diameter, the propeller is 0.81 m in diameter & is positioned 0.81 m from the bottom of the tank. The tank is filled to a depth of 2.7 m with a caustic soda solution, which has a viscosity of 1.5 cP and a density of 1498 kg/m^3. The turbine is operated at 3.21 rpm. **What power will be required to operate the agitator if:- The tank was baffled & (b) The tank was unbaffled**

Answer:

$n = 3.21\text{rpm} / 60\text{ s} = 0.0535\text{ r/s}$

$D_a = E = 0.81\text{ m}$

$\mu = 1.5\text{cP} = 1.5\text{x}10^{-3}\text{ kg/ms}$

(a) Baffled tank

$$N_{RE} = \frac{D_a^2 n \rho}{\mu} = \frac{(0.81)^2 (0.0535)(1498)}{1.5 x 10^{-3}} = 3.51 x 10^4$$

From Fig. 9.13, $N_P = 0.9$

$$\therefore P = N_P n^3 D_a^5 \rho = (0.9)(0.0535)^3 (0.81)^5 (1498) = 0.072 W$$

(b) Unbaffled tank

From Fig 9.13, N_P =0.58.

Froude number, $N_{Fr} = \frac{n^2 D_a}{g} = \frac{(0.0535)^2 (0.81)}{9.81} = 2.36x10^{-4}$

From Table 9.1, a & b are 1.7 & 18.0 respectively

$$m = \frac{a - \log_{10} N_{Re}}{b} = \frac{1.7 - \log_{10} 35055}{18} = -0.158$$

So the corrected value of NP,

$$N_{P(Corr)} = N_P \text{ X } N_{Fr}^m = 0.58 \text{X} (2.36x10^{-4})^{-0.158} = 2.17$$

Thus power,

$$P = N_P n^3 D_a^5 \rho$$
$$= (2.17)(0.0535)^3 (0.81)^5 (1498)$$
$$= 0.173 mN/s = 0.173 W$$