

# CH402 Chemical Engineering Process Design

Class Notes L4

Agitators

# Agitator Design – General Features

# Spargers

Designed as a run of pipe with fittings and a compressor  
Power requirements are for the compressor (gives cost).

Figures 12-28 to 12-30, pages 531-532 and “PTW online” give costs of various compressors

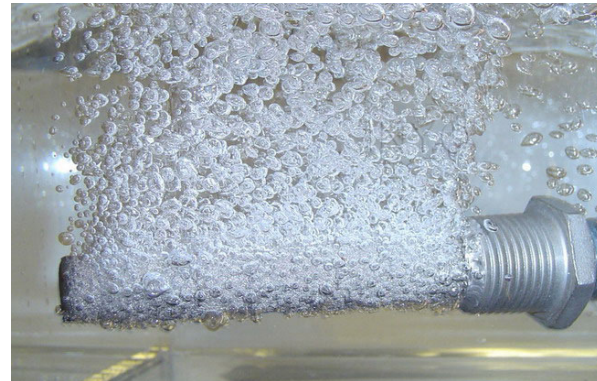
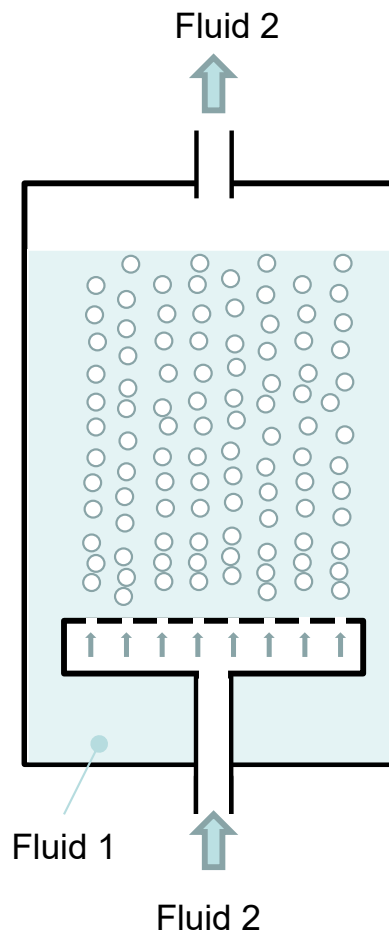
$$P = \frac{\dot{m}_G \cdot \eta \cdot \Delta p}{\rho_G}$$

$\dot{m}_G$  = gas mass flow rate

$\eta$  = compressor efficiency

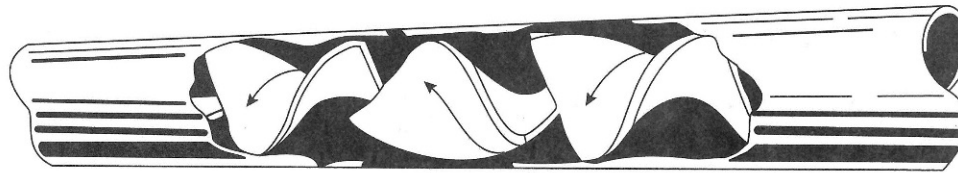
$\Delta p$  = compressor pressure differential

$\rho_G$  = gas density



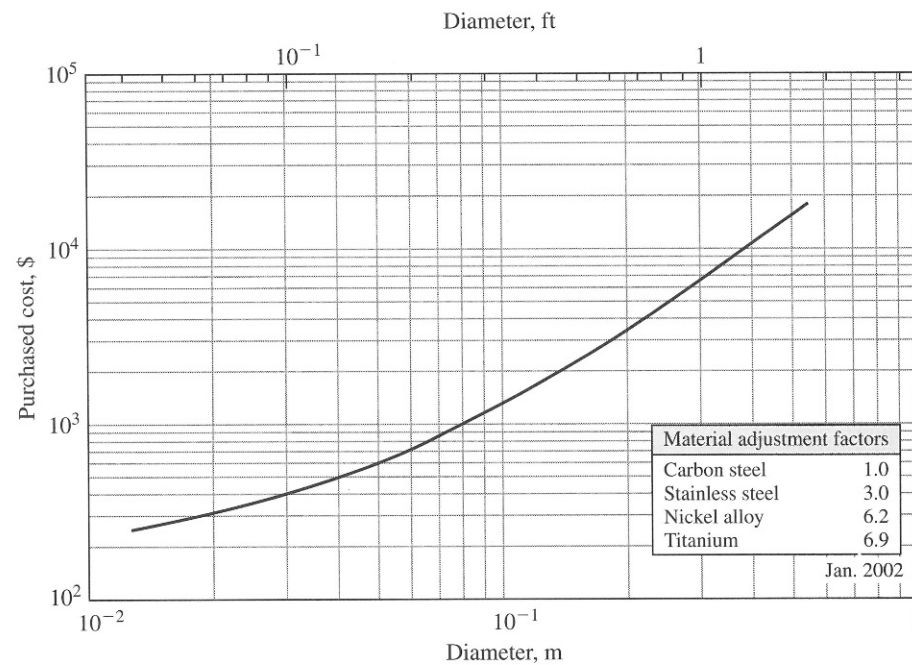
# Motionless Mixers

advantage – no power requirement



**Figure 10.53.** Static mixer (Kenics Corporation).

Towler & Sinnott, page 614

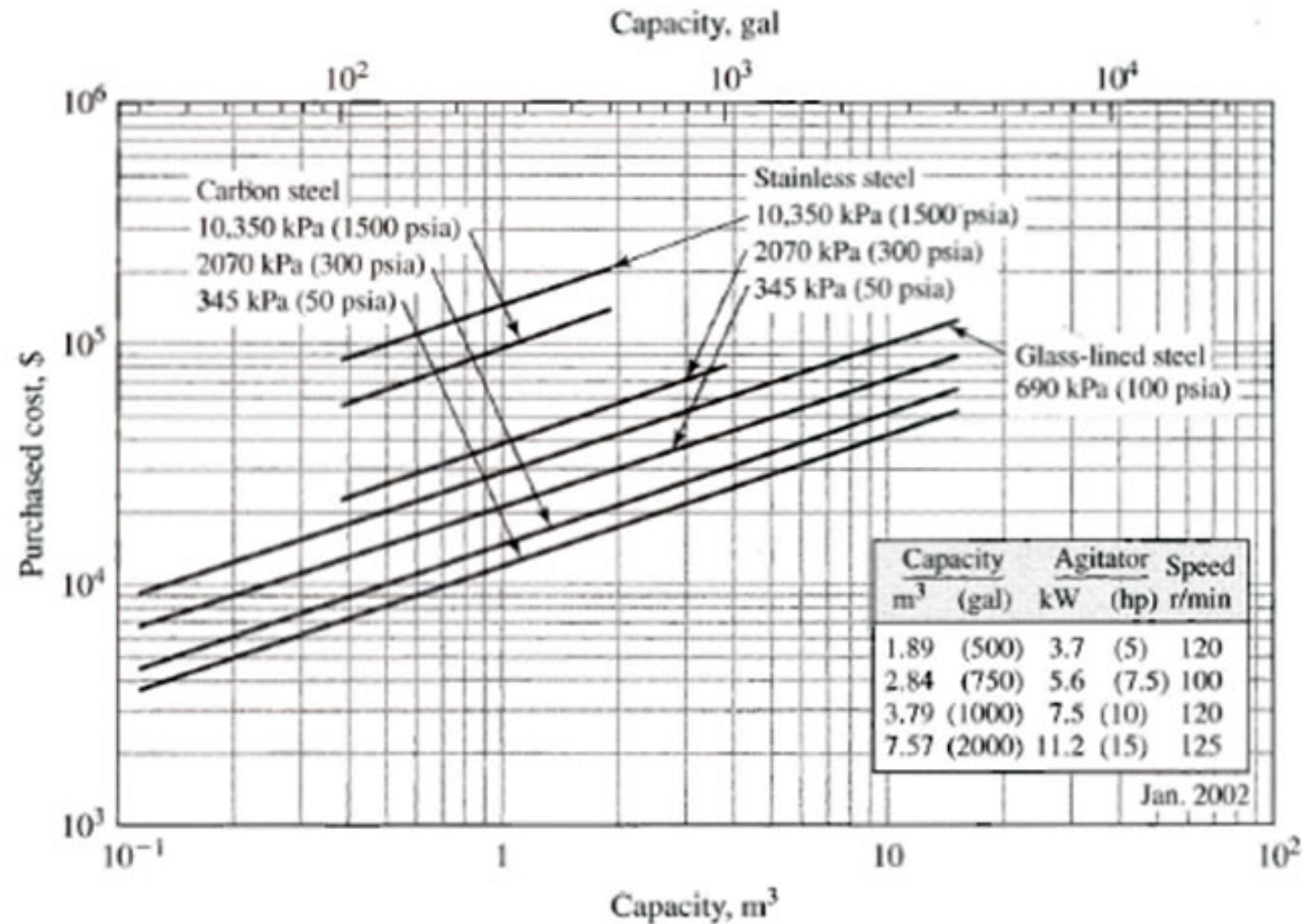
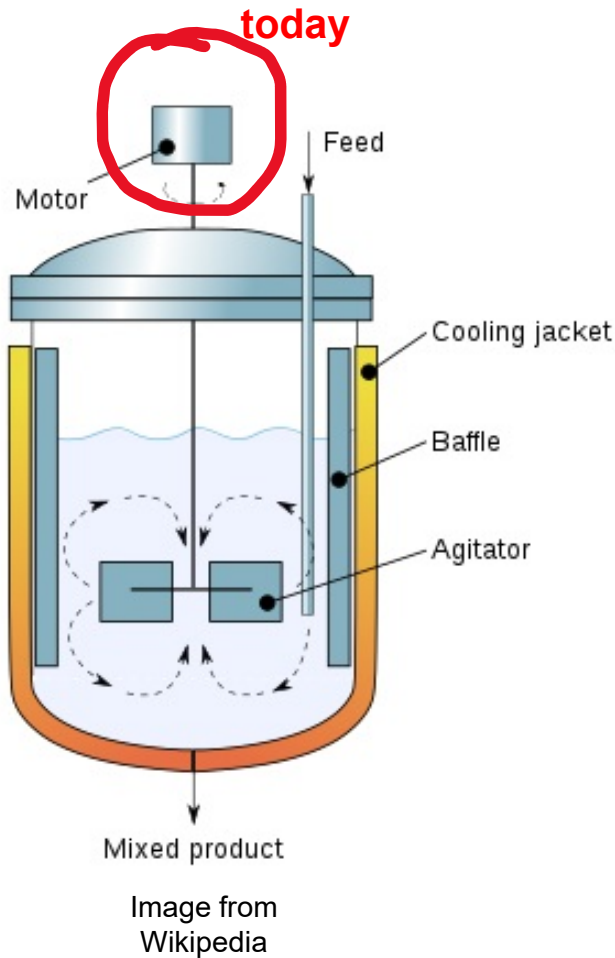


**Figure 12-41**  
Purchased cost of motionless mixers

PTW, page 645

# Tank/Vessel Mixers

PTW, p. 628



**Figure 13-15**

Purchased cost of jacketed and stirred reactors

Volume of a CSTR:  
(CH364)

$$V = F_{A_0} \frac{x_A}{-r_A}$$

$$-r_A = k \cdot C_{A_0} x_A$$

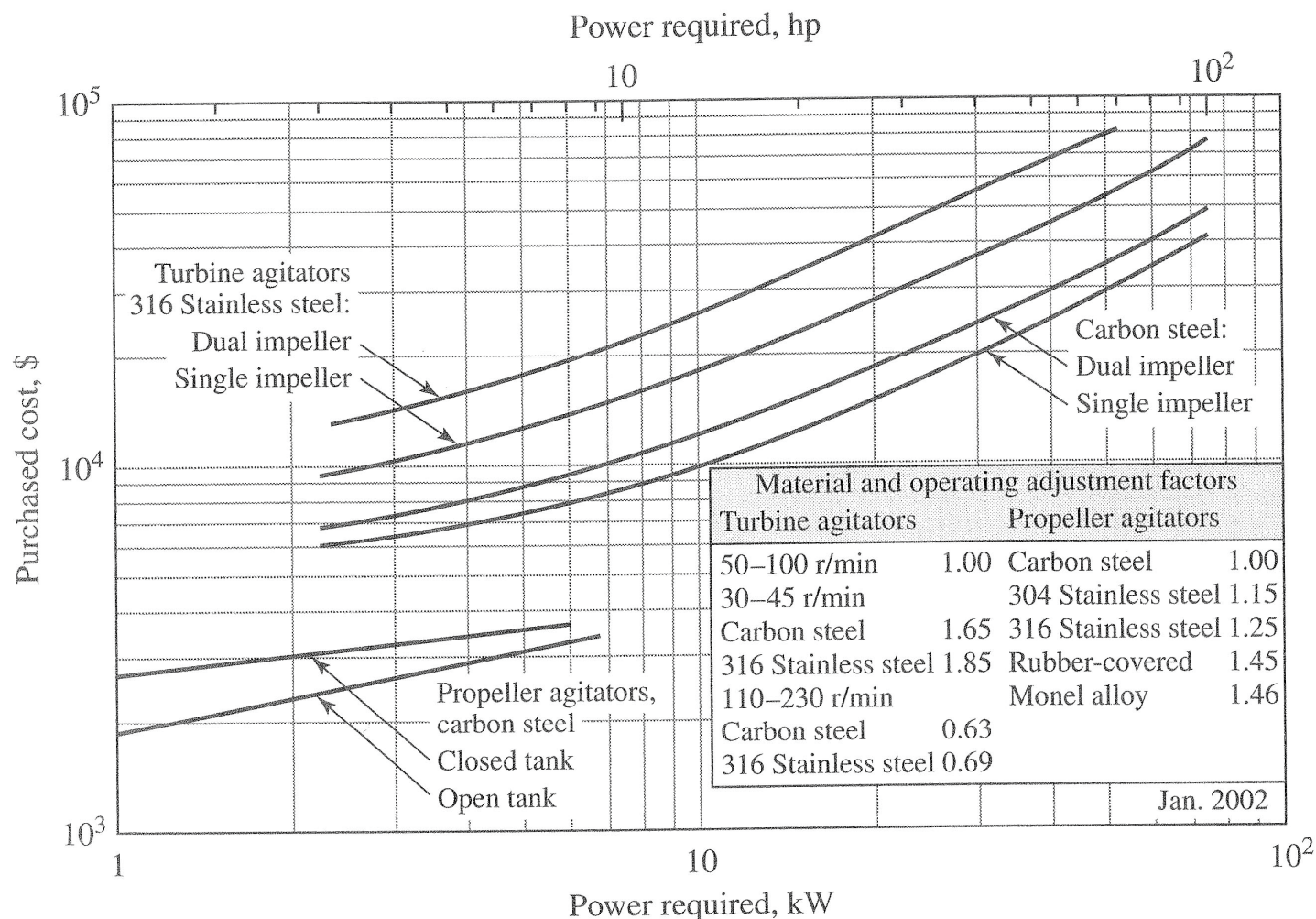
$x_A$  = fractional conversion of A  
 $F_{A_0}$  = molar flow rate of A in feed  
 $C_{A_0}$  = molar concentration of A in feed

For stirred tanks, also need power...

... to size and price motors and mixers.  
... predict electricity requirement.



<http://www.gmmpfaudler.com>



**Figure 12-42**

Purchased cost of turbine and propeller agitators

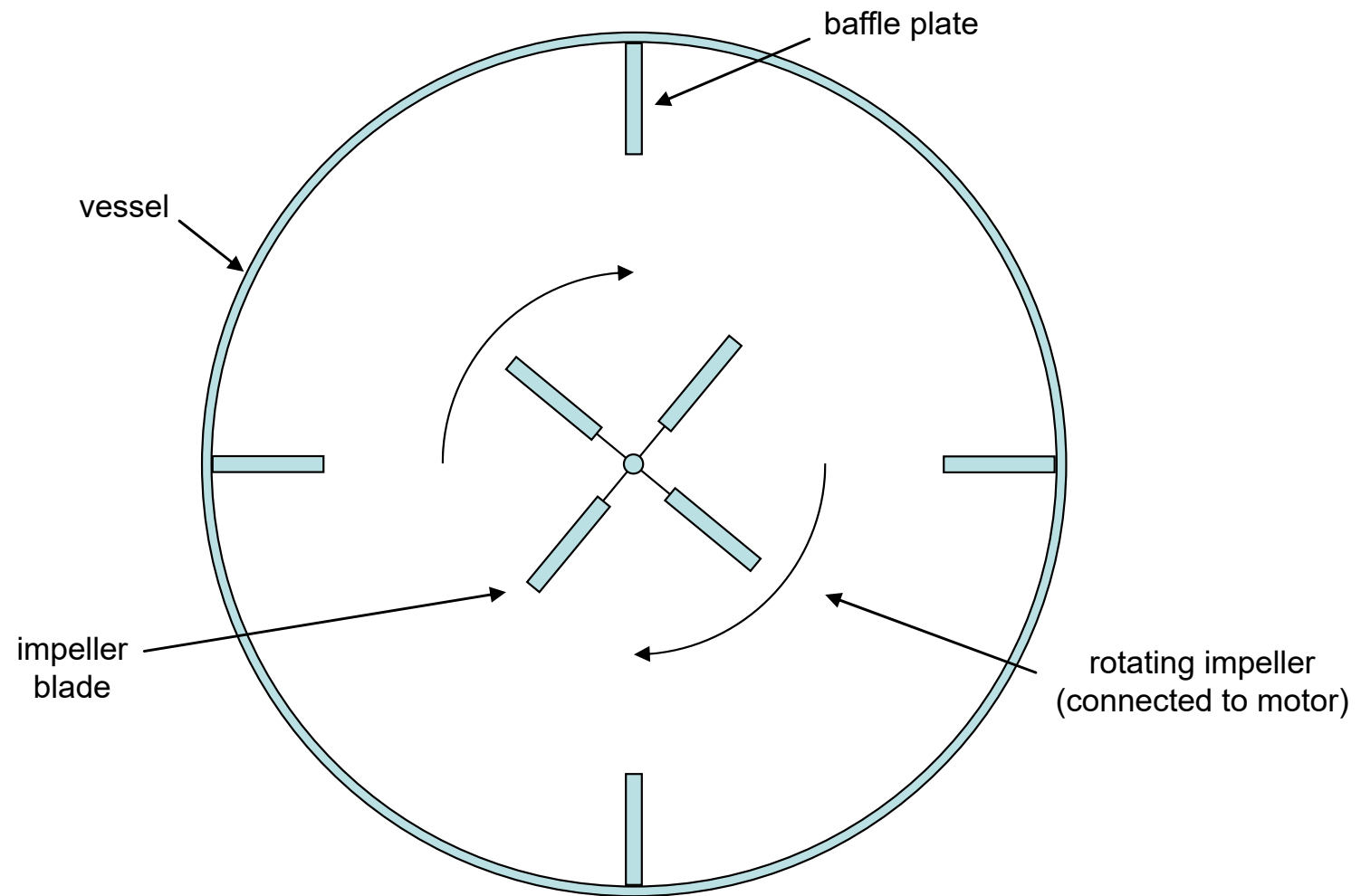
Other designs - Figs. 12-41 through 12-49, pages 545-549

# Agitator Design – Method 1

(Stirred Tank Impeller Agitators)

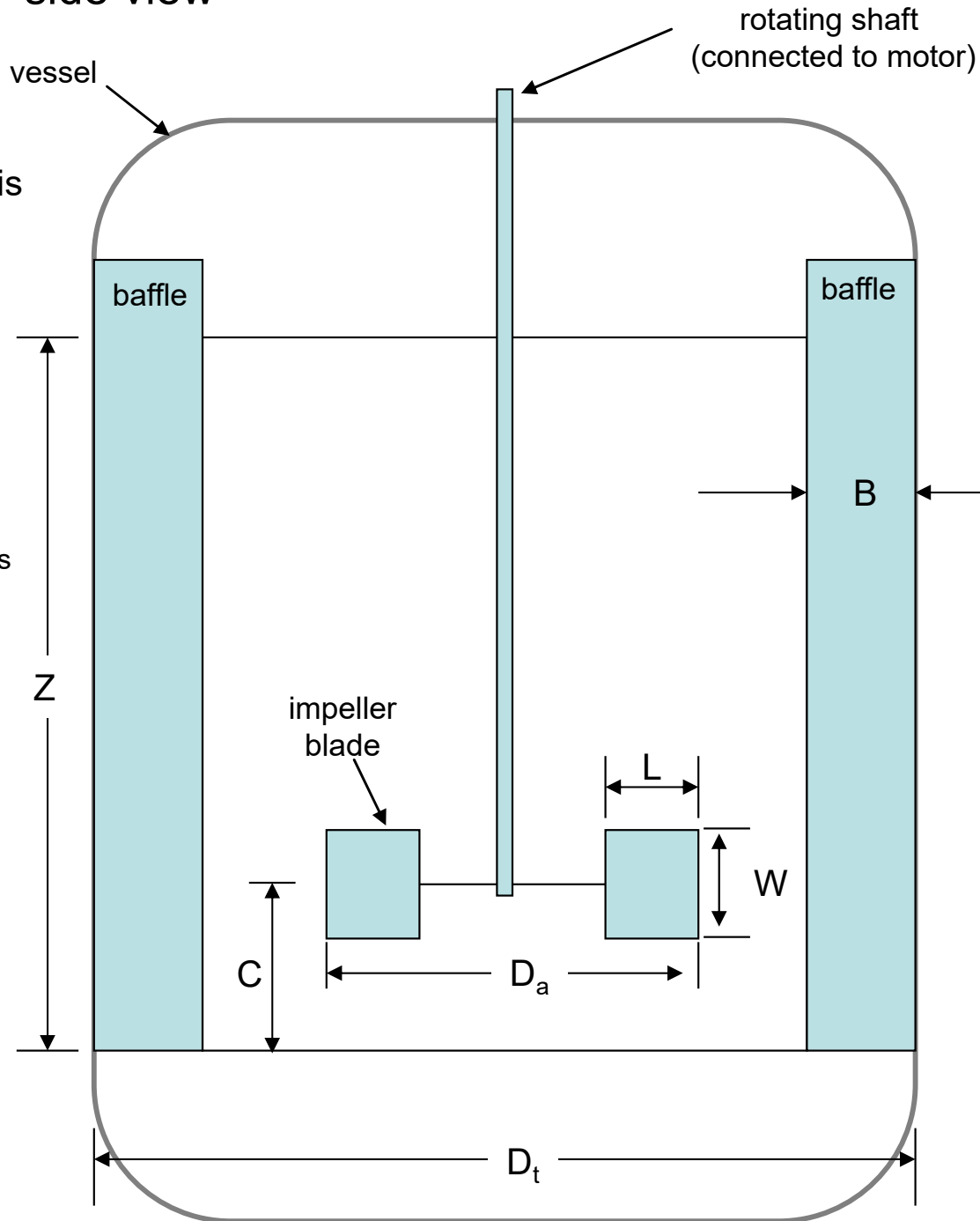


## Basic Design - top view





## Basic Design - side view



From dimensional analysis  
Rayleigh's Method, a.k.a.  
Buckingham's Pi method

Reynolds Number

$$Re = \frac{D_a^2 \cdot N_r \cdot \rho}{\mu}$$

defined in Fig. 12-40, p. 540

ratio of inertial to frictional forces

Froude Number

$$Fr = \frac{D_a \cdot N_r^2}{g}$$

defined in para. 3, p. 540

ratio of inertial forces to weight

Power Number

$$N_{Po} = \frac{P}{N_r^3 \cdot D_a^5 \cdot \rho}$$

defined in para. 3, p. 540

dimensionless power

shape parameters:

$$S_1 = D_t/D_a$$

$$S_2 = C/D_a$$

$$S_3 = L/D_a$$

$$S_4 = W/D_a$$

$$S_5 = B/D_t$$

$$S_6 = Z/D_t$$

Note typo in Re and Fr formulas in example 12-6. Calculation is OK but formulas have  $D_t$  instead of  $D_a$ .

$$m = \frac{a - \log_{10} Re}{b} \quad (\text{eq 12-41})$$

(p. 540)

$$N_{Po} = f(Re, Fr, S_1, S_2, S_3, S_4, S_5, S_6)$$



$$N_{Po} = \phi \cdot Fr^m$$

$$\phi = f(Re, S_1)$$

$$Re = \frac{D_a^2 N_r \rho}{\mu}$$

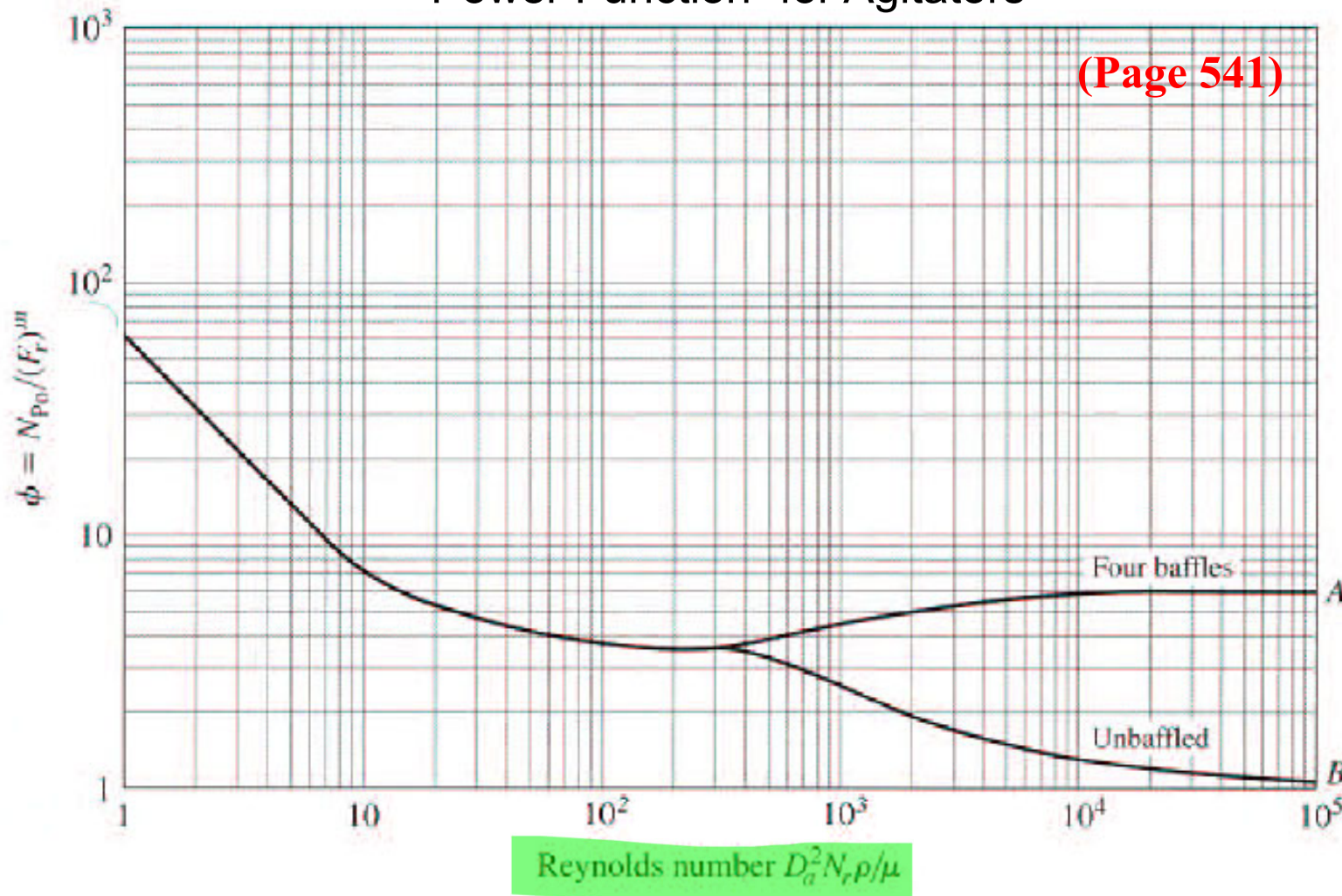
$$Fr = \frac{D_a \cdot N_r^2}{g}$$

$$m = \frac{a - \log_{10} Re}{b}$$

$$N_{Po} = \phi \cdot Fr^m$$

$$N_{Po} = \frac{P}{N_r^3 \cdot D_a^5 \cdot \rho}$$

### “Power Function” for Agitators



shape parameters:

$$S_1 = D_t / D_a = 3.0$$

$$S_2 = C / D_a = 1.0$$

$$S_3 = L / D_a = .25$$

$$S_4 = W / D_a = .20$$

$$S_5 = B / D_t = 0 (= 0.1)$$

$$S_6 = Z / D_t = 1.0$$

(these shape factors go with this chart)

**Figure 12-40**

Relation between the power function  $\phi$  and the Reynolds number for a six-blade turbine mixer. Constants  $a$  and  $b$  in Eq. (12-41) for this mixer have been evaluated as 1.0 and 40.0, respectively.

$$Re = \frac{D_a^2 N_r \rho}{\mu}$$

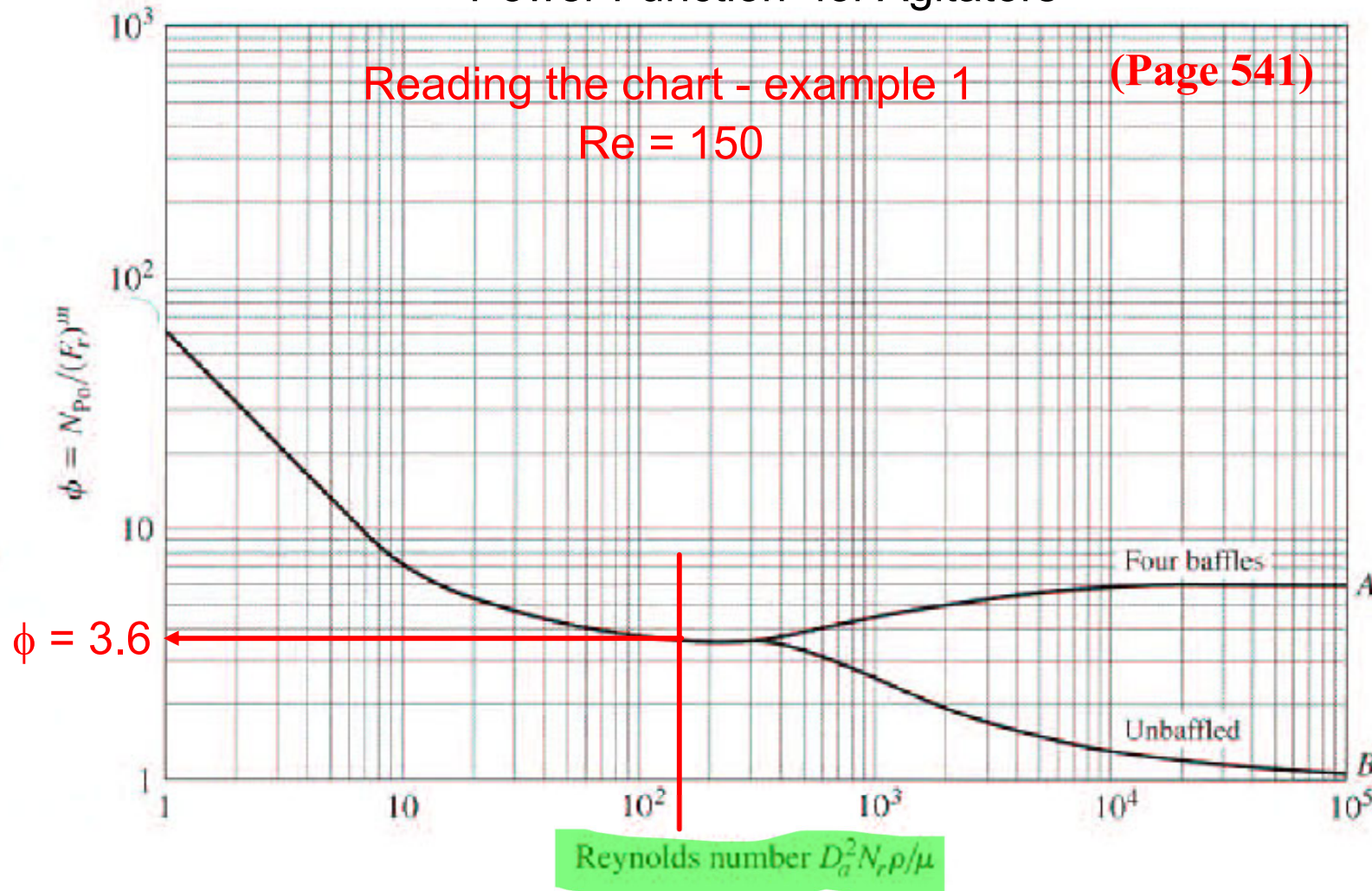
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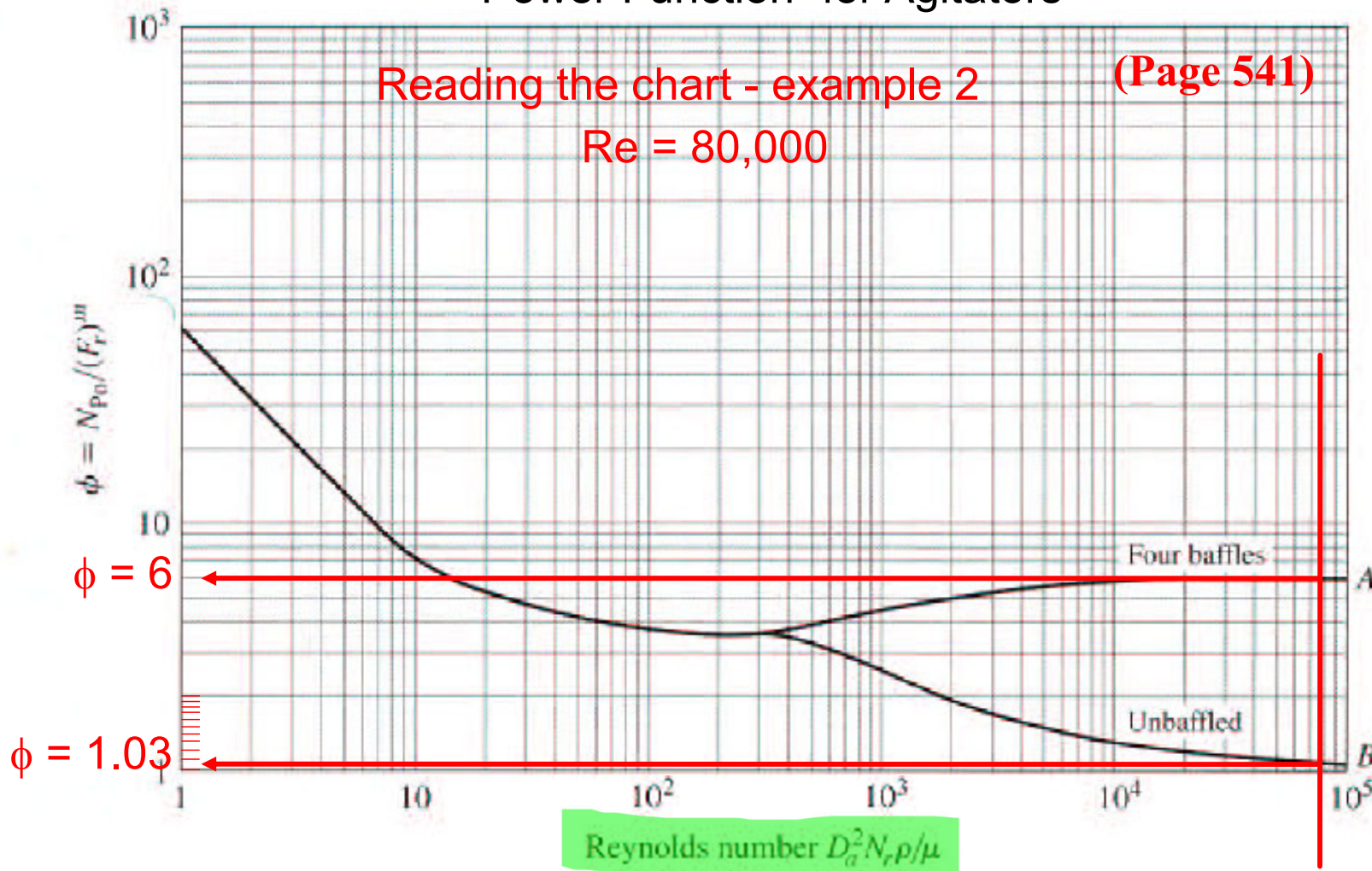
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# Mixing Time ( $\theta$ ) for a Stirred Tank:

$$\theta = 12000 \cdot \left( \frac{\mu \cdot V}{P} \right)^{0.5} \cdot (V)^{0.2}$$

Mixing time in seconds

Equation 12-45, page 542

$V$  = tank volume in  $\text{m}^3$

$P$  = power in watts

$\mu$  = viscosity in  $\text{kg}/(\text{m} \cdot \text{s})$

**Important for CSTR design:**

Compare  $\theta$  to  $\tau$  (space-time)

Generally,  $\theta \ll \tau$

# Calculating Power Requirement – Method 1

1. Determine Fluid Properties

density, viscosity

2. Determine Mechanical Properties

dimensions, propeller speed

3. Calculate dimensionless groups

Reynolds #, Froude #

4. Determine  $m$

5. Determine  $\phi$

6. Calculate Power Number ( $N_{Po}$ ) and then Power ( $P$ )

7. Calculate Mixing Time (Slide 12)

## Agitator Design – Method 2

(Stirred Tank Impeller Agitators)



# Calculating Power Requirement – Method 2

(Table 12-9 Method)

This method is for baffled tanks only.

impeller	$K_L$	$K_T$
propeller, square pitch, three blades	41.0	0.32
propeller, 2:1 pitch, three blades	43.5	1.00
turbine, 6 flat blades	71.0	6.30
turbine, 6 curved blades	70.0	4.80
turbine, 6 arrowhead blades	71.0	4.00
fan turbine, 6 blades	70.0	1.65
flat paddle, 2 blades	36.5	1.70
shrouded turbine	97.5	1.08

$$\text{Re} < 10$$

$$N_{Po} \cdot \text{Re} = K_L$$

$$\text{Re} = \frac{D_a^2 \cdot N_r \cdot \rho}{\mu}$$

$$N_{Po} = \frac{P}{N_r^3 \cdot D_a^5 \cdot \rho}$$

$$\text{Re} > 10,000$$

$$N_{Po} = K_T$$

# Calculating Power Requirement – Method 2

(Table 12-9 Method)

## 1. Determine Fluid Properties

density, viscosity

## 2. Determine Mechanical Properties

dimensions, propeller speed, type of impeller

## 3. Use Table 12-9 to determine $K_L$ and $K_T$

## 4. Calculate Reynolds Number

## 5. Calculate Power Number ( $N_{Po}$ ) and then Power (P)

### 5a. Laminar (Reynolds <10)

$$N_{Po} \text{ Re} = K_L$$

### 5b. Turbulent (Re>10,000) with baffles:

$$N_{Po} = K_T$$

## 6. Calculate Mixing Time (Slide 12)

# Homework

**Problem 12-13**

What power will be required to mix an aqueous solution of 50% NaOH in a baffled tank, 2 m in diameter? The mixing will be performed in the vertical tank filled to a height of 2 m by a disk turbine with six flat blades. The turbine is 0.67 m in diameter and is positioned 0.67 m above the bottom of the tank. The turbine blades are 0.134 m wide and turn at 90 r/min. The solution has a viscosity of 0.012 Pa·s and a density of 1500 kg/m<sup>3</sup>.

Solve by methods 1 and 2

Determine mixing time by methods 1 and 2

# Questions?