

# CH402 Chemical Engineering Process Design

Class Notes L4

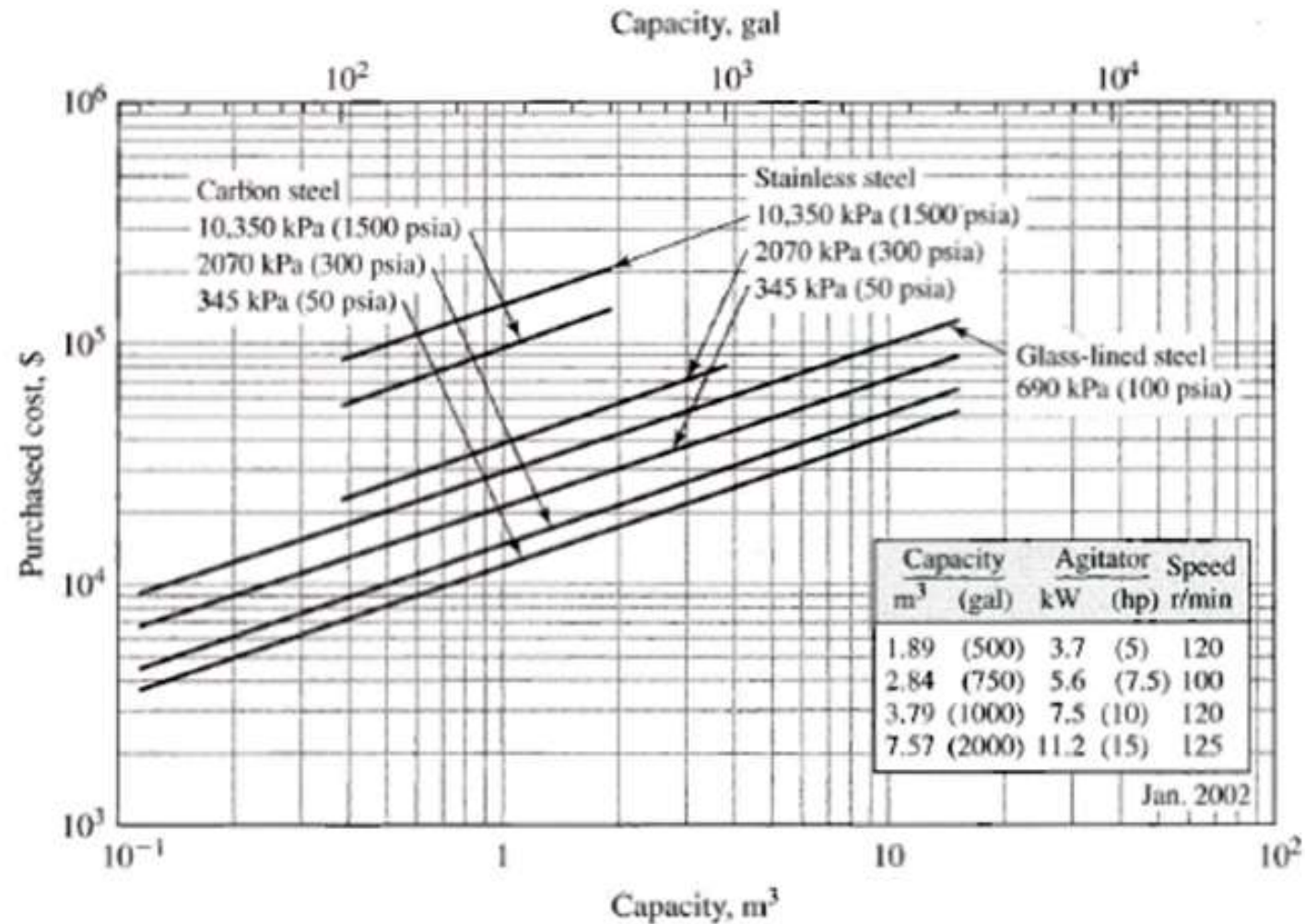
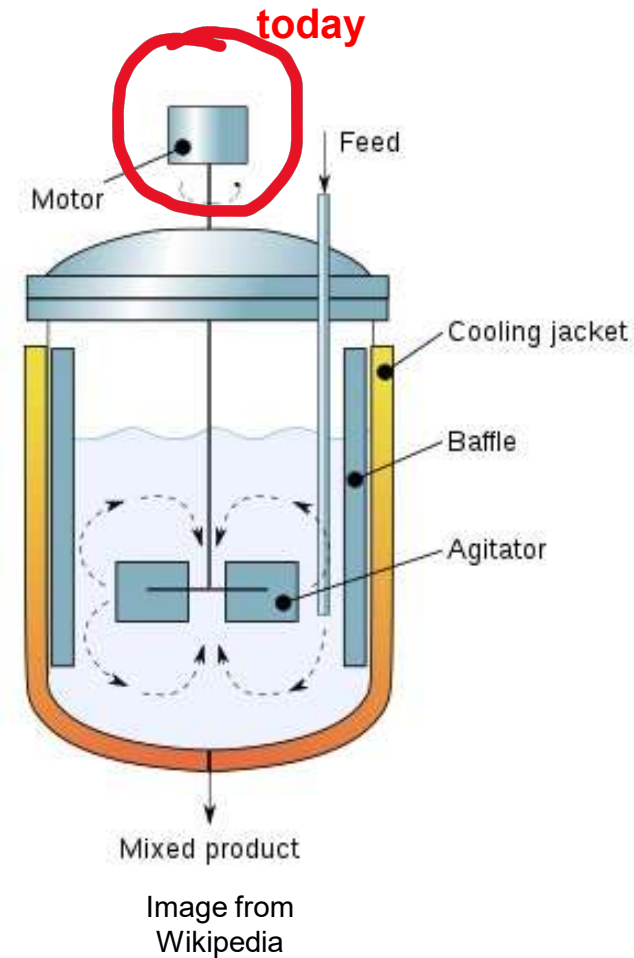
Agitators

## Part I

# Agitator Design – General Features

# Tank/Vessel Mixers

PTW, p. 628



**Figure 13-15**

Purchased cost of jacketed and stirred reactors

Volume of a CSTR:  
(CH364)

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

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

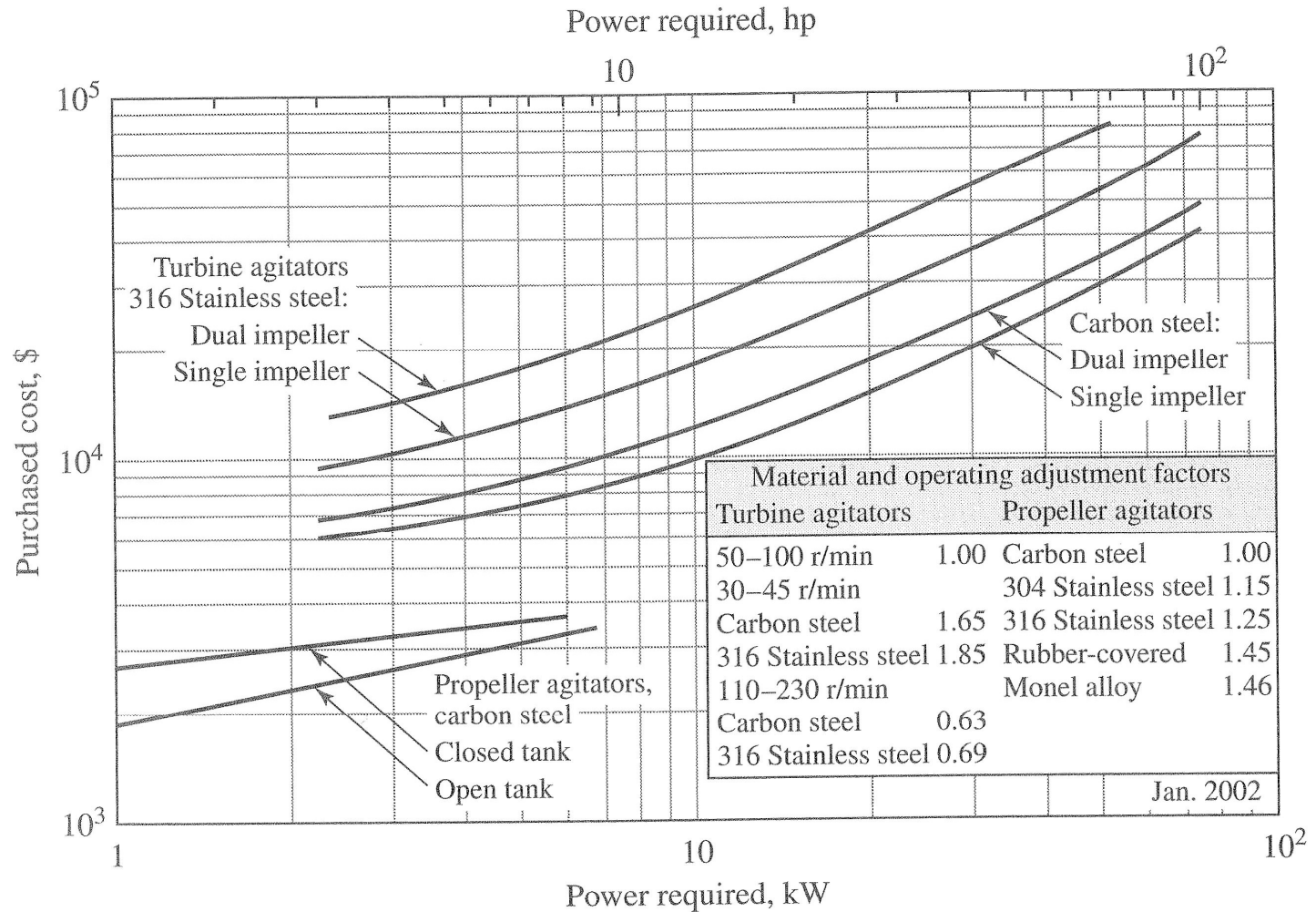
$x_A$  = fractional conversion of A  
 $F_{A_0}$  = molar flow rate of A in feed  
 $C_{A_0}$  = molar concentration of A in feed

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

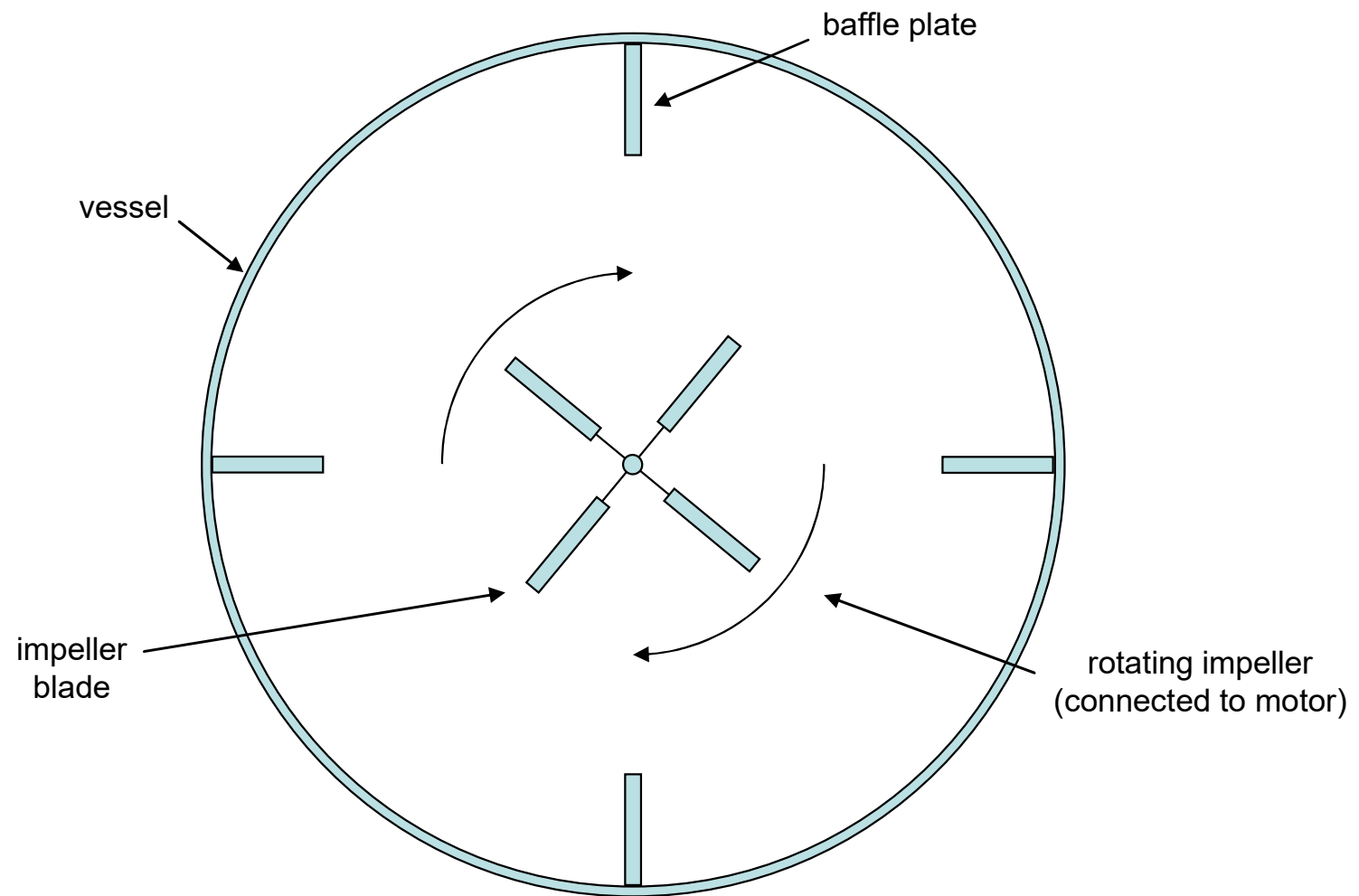
Other designs - Figs. 12-41 through 12-49, pages 545-549

## Part II

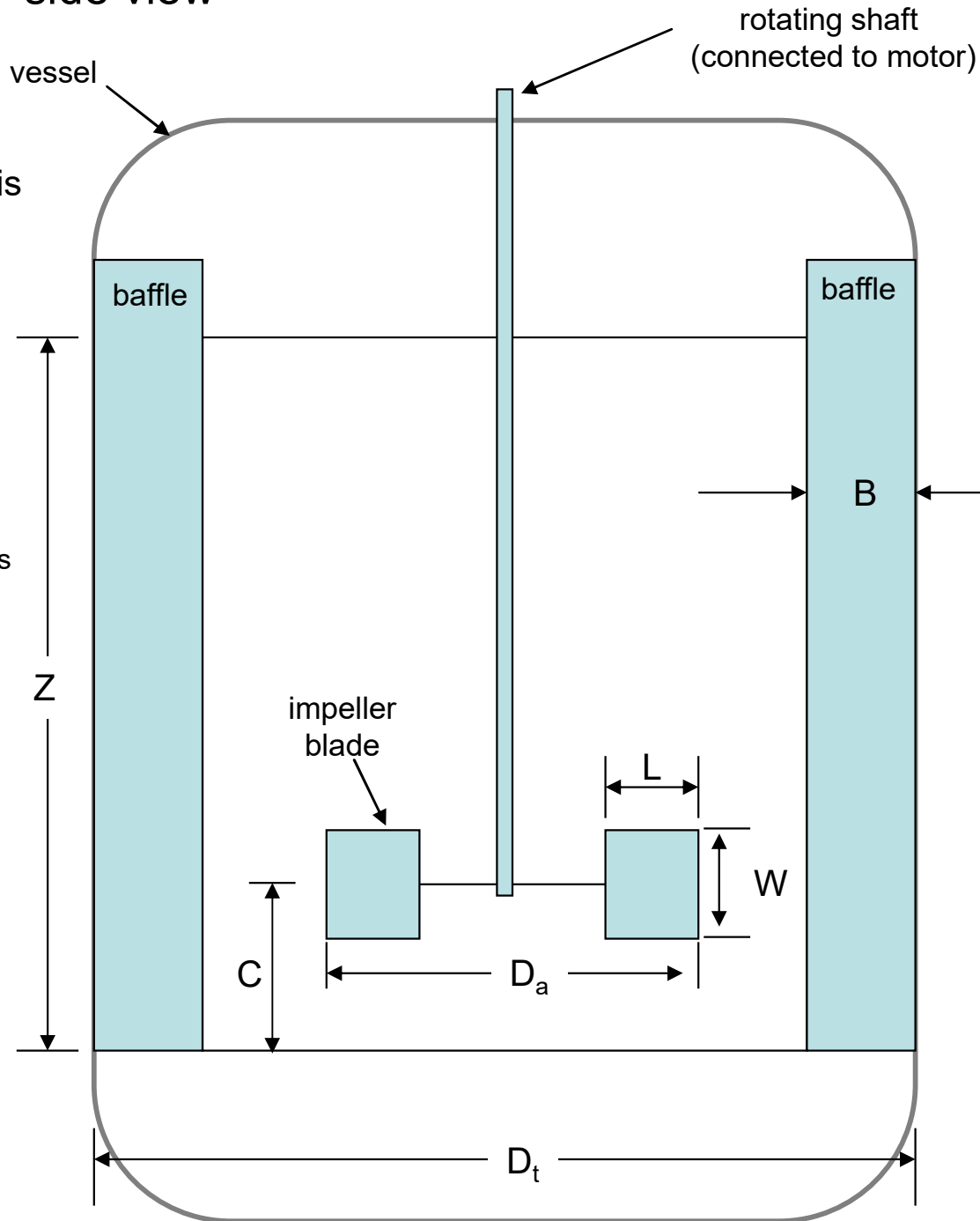
### Agitator Design – Method 1

(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)

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



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

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



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

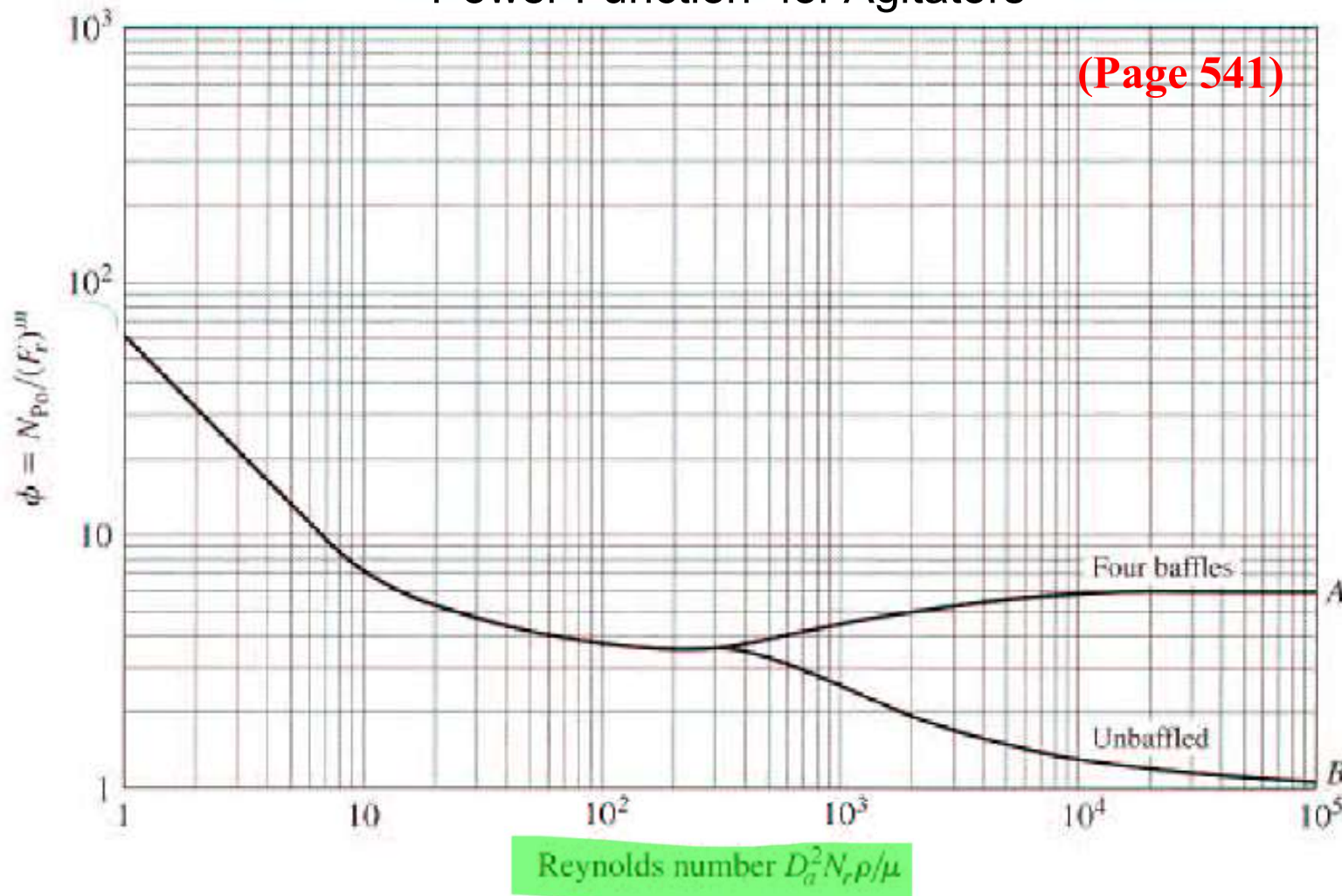
$$Fr = \frac{D_a \cdot N_r^2}{g}$$

$$m = \frac{1 - \log_{10} Re}{40}$$

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

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

### “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.



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

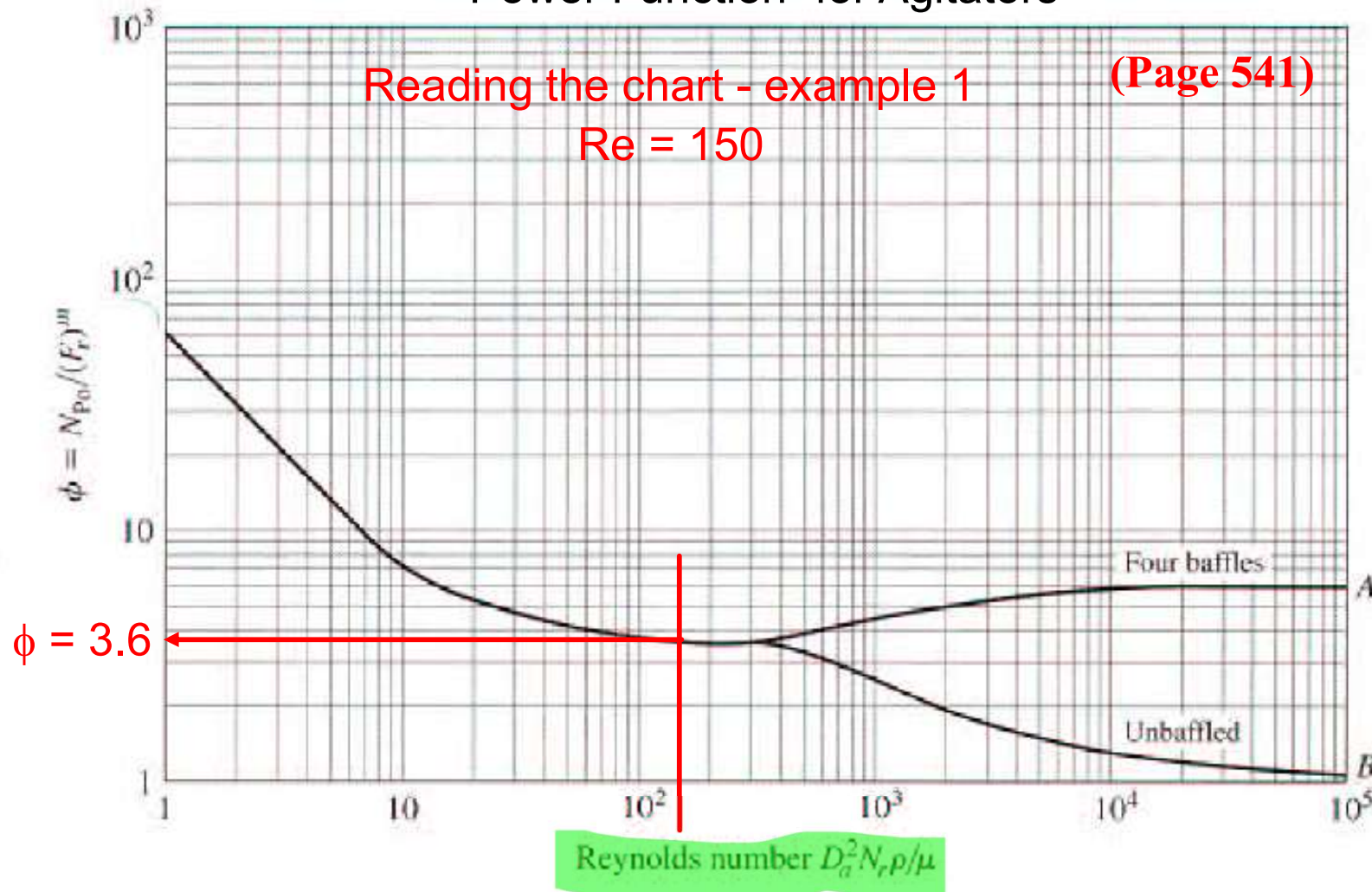
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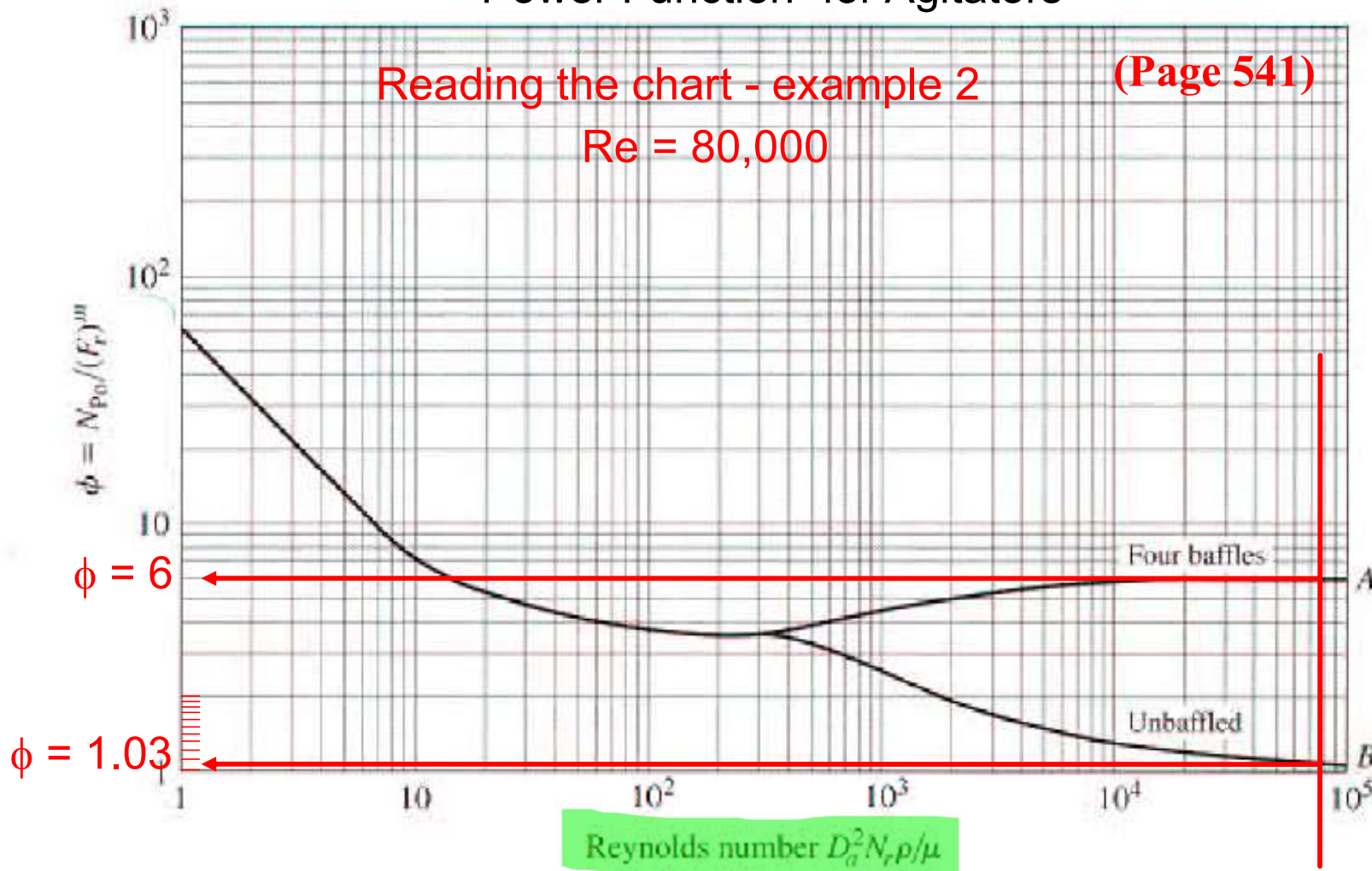
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# Mixing Time ( $\theta$ ) for a Stirred Tank:

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

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)

## Part III

### Agitator Design – Method 2

(Method used on the FE Exam Method)

# Calculating Power Requirement – FEE Method

(a.k.a. Table 12-9 Method)

Turbulent Flow Impeller Mixer

$$P = K_T (n)^3 (D_i)^5 \rho_f$$

where

$K_T$  = impeller constant (see table)

$n$  = rotational speed (rev/sec)

$D_i$  = impeller diameter (m)

Turbulent  
mixing

$$Re > 10,000$$

$$N_{Po} = K_T$$

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

**Values of the Impeller Constant  $K_T$**   
(Assume Turbulent Flow)

Type of Impeller	$K_T$
Propeller, pitch of 1, 3 blades	0.32
Propeller, pitch of 2, 3 blades	1.00
Turbine, 6 flat blades, vaned disc	6.30
Turbine, 6 curved blades	4.80
Fan turbine, 6 blades at 45°	1.65
Shrouded turbine, 6 curved blades	1.08
Shrouded turbine, with stator, no baffles	1.12

Note: Constant assumes baffled tanks having four baffles at the tank wall with a width equal to 10% of the tank diameter.

Source: Reprinted with permission from *Industrial & Engineering Chemistry*, "Mixing of Liquids in Chemical Processing," J. Henry Rushton, 1952, v. 44, no. 12. p. 2934, American Chemical Society.

Viscous mixing  
(not in FEE)

$$Re < 10$$

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

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

$K_L$  is in Table 12-9  
on page 542

This method is for  
baffled tanks only.

**FEE Manual, Page 344**  
(Control-F "mixer")

# 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 $K_T$ . FEE will not have viscous mix

## 4. Calculate Reynolds Number

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

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

$$N_{Po} Re = K_L$$

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

$$N_{Po} = K_T$$

## 6. Calculate Mixing Time (Slide 12)



Questions?