CH402 Chemical Engineering Process Design

Class Notes L4

Agitators

Part I

Agitator Design – General Features

Tank/Vessel Mixers PTW, p. 628

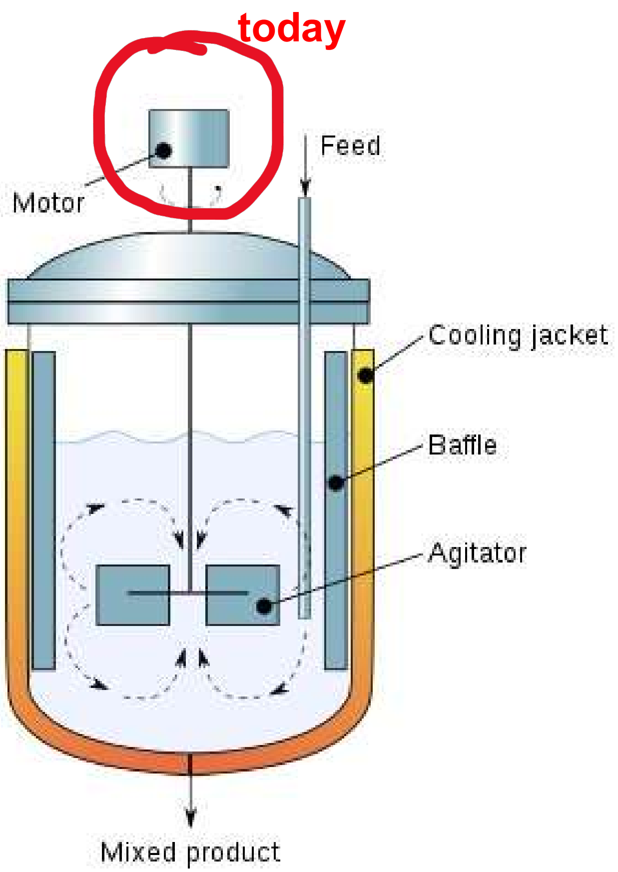


Image from Wikipedia

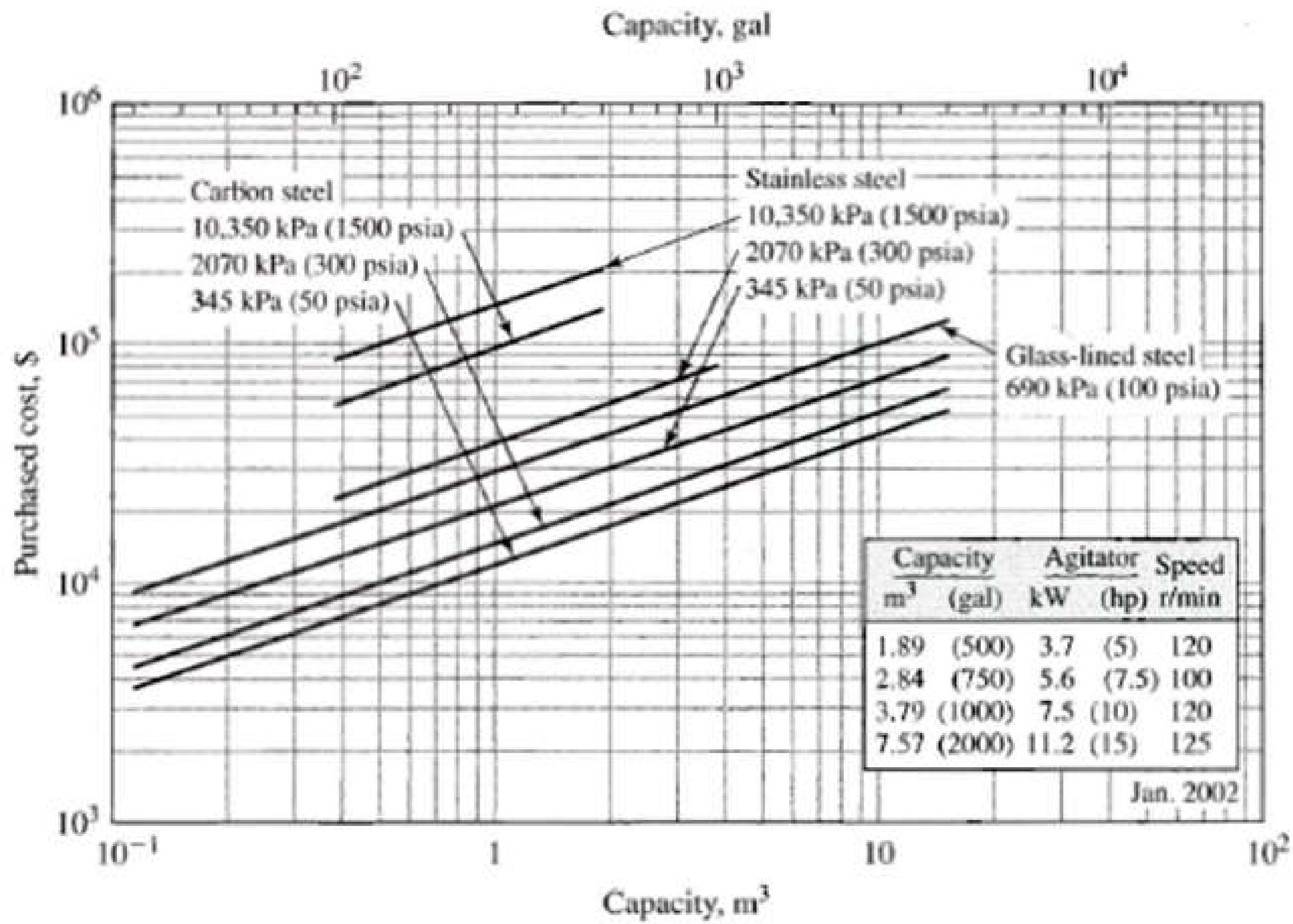


Figure 13-15
Purchased cost of jacketed and stirred reactors

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

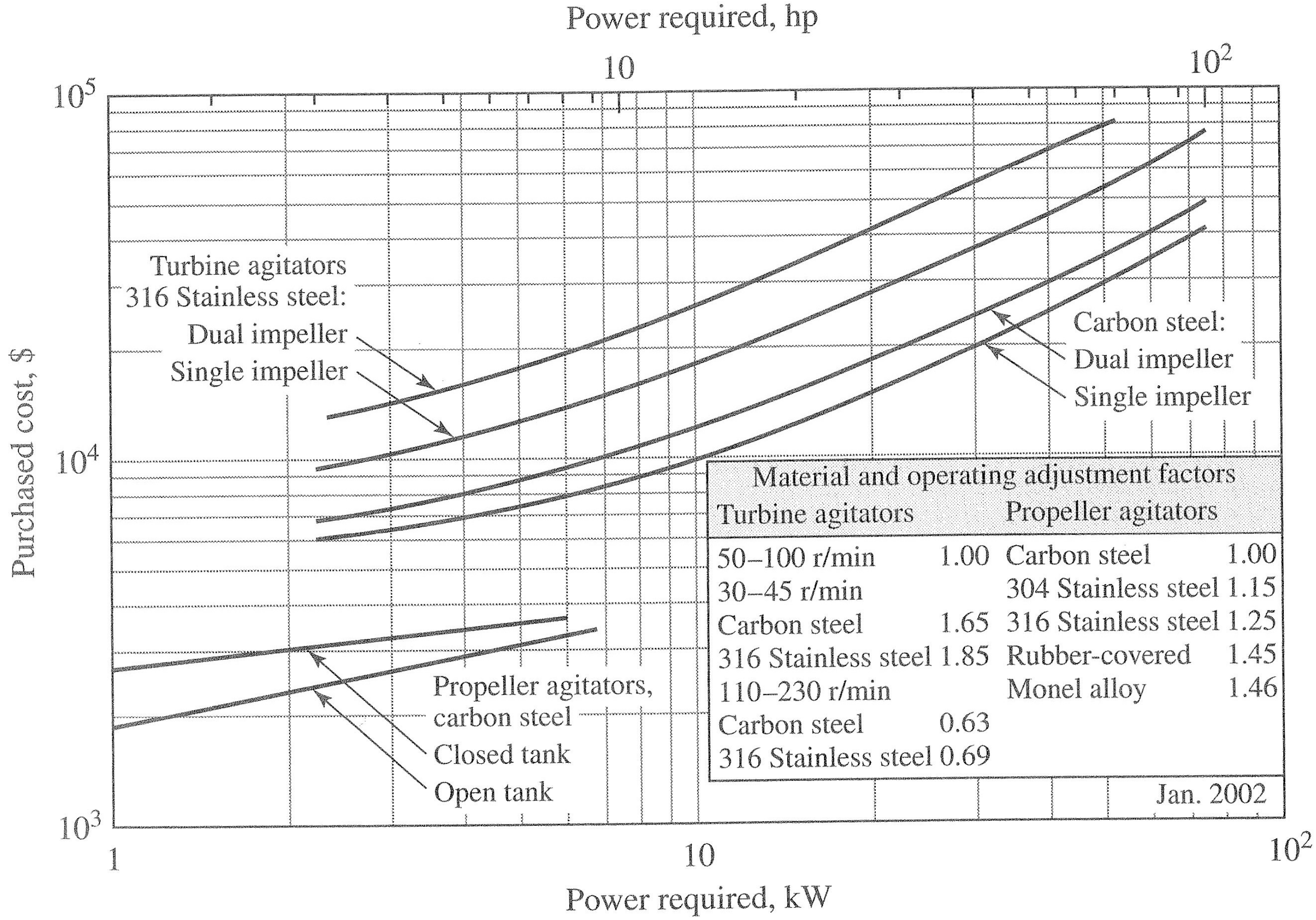


Figure 12-42
Purchased cost of turbine and propeller agitators

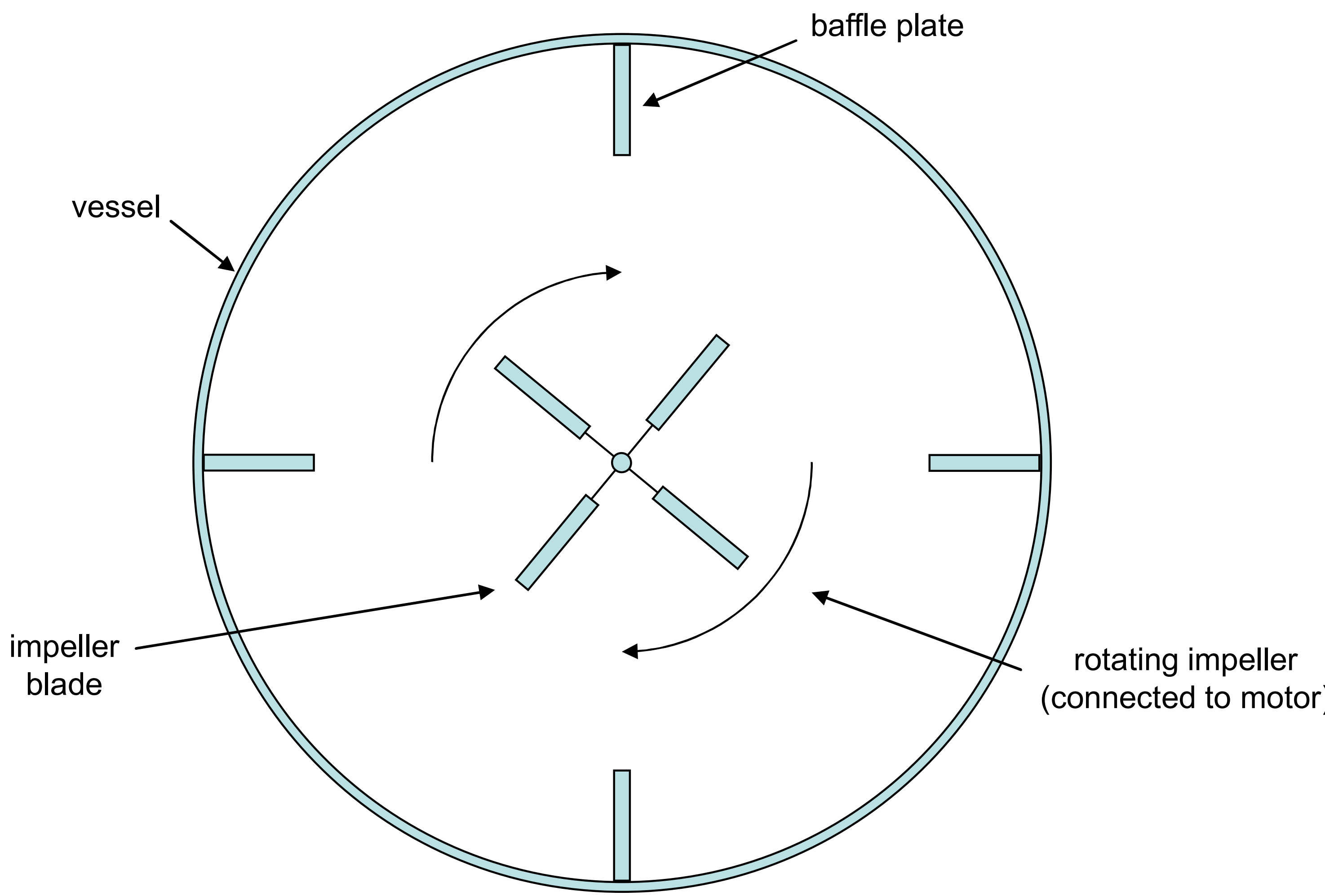
Other designs - Figs. 12-41 through 12-49, pages 545-549

Part II

Agitator Design – Method 1

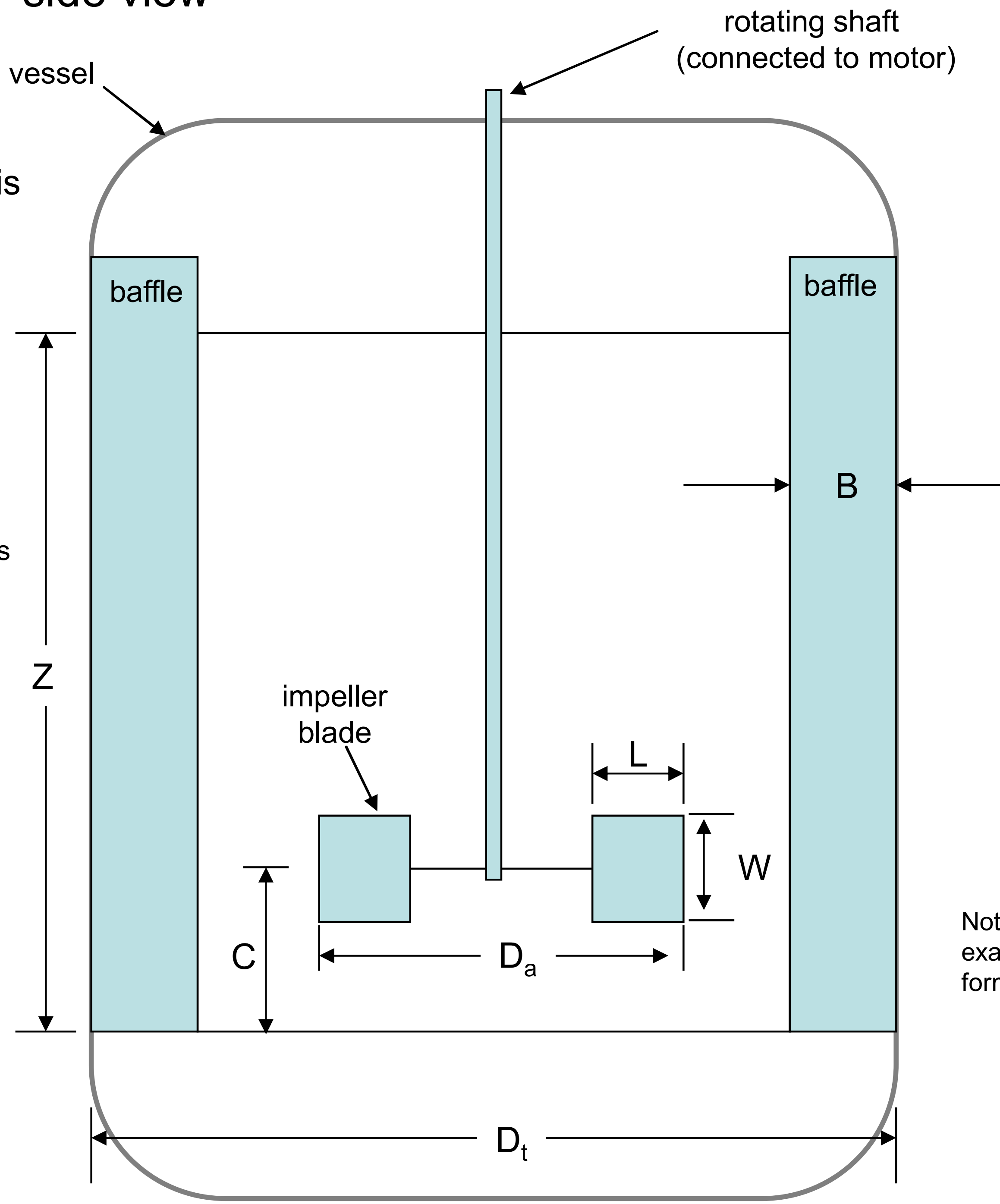
(Stirred Tank Impeller Agitators)

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.

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

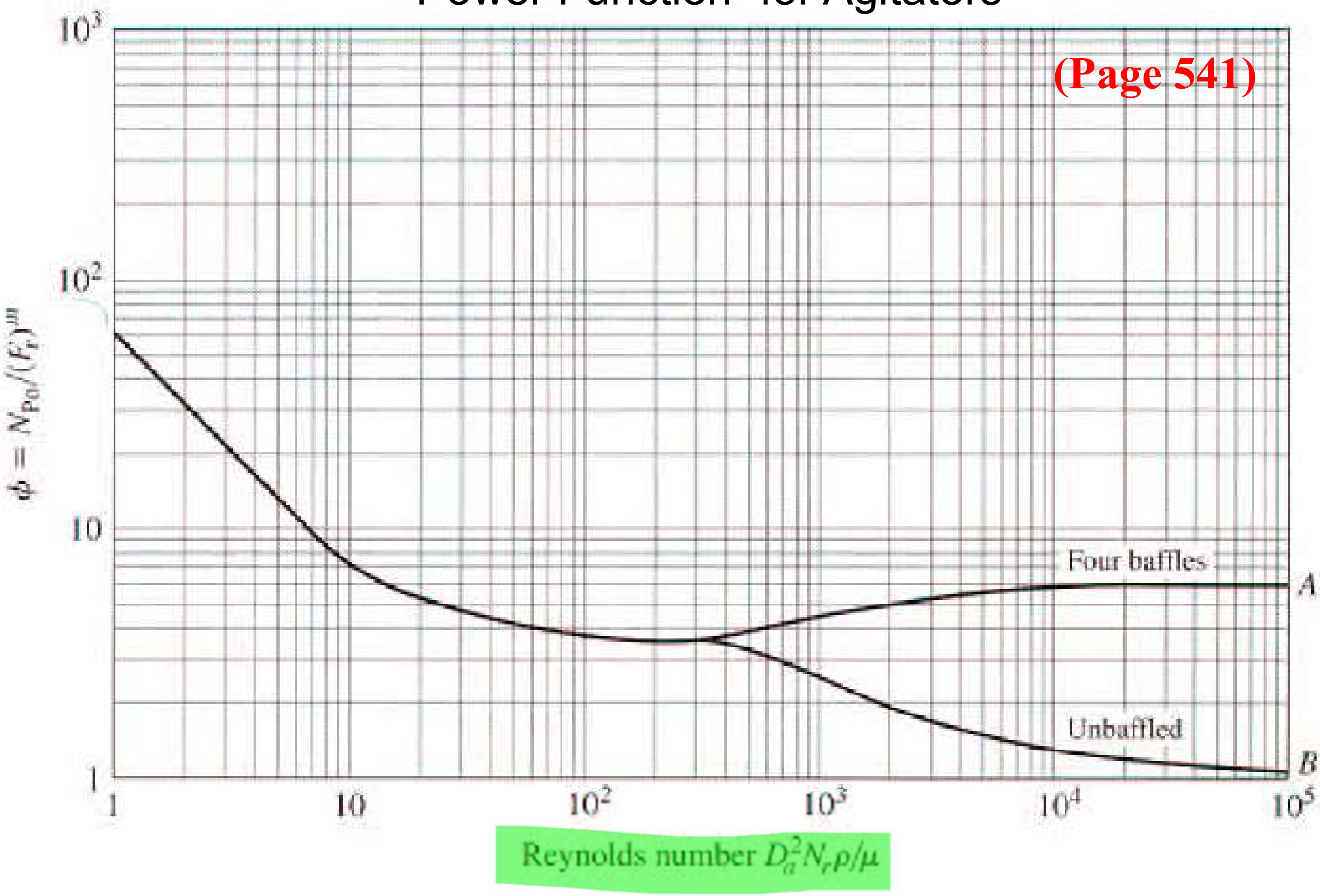
(eq 12-41)

(p. 540)

$$N_{Po} = f(Re,\ Fr,\ S_1,\ S_2,\ S_3,\ S_4,\ S_5,\ S_6) \Rightarrow N_{Po} = \phi \cdot Fr^m \qquad \phi = f(Re,\ S_i)$$

$$Re = \frac{D_a^2 N_r \rho}{\mu} \qquad Fr = \frac{D_a \cdot N_r^2}{g} \qquad m = \frac{1 - \log_{10} Re}{40} \qquad N_{Po} = \phi \cdot Fr^m \qquad N_{Po} = \frac{P}{N_r^3 \cdot D_a^5 \cdot \rho}$$

"Power Function" for Agitators



shape parameters:

$S_1 = D_t/D_a = 3.0$

$S_2 = C/D_a = 1.0$

$S_3 = L/D_a = .25$

$S_4 = W/Da = .20$

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

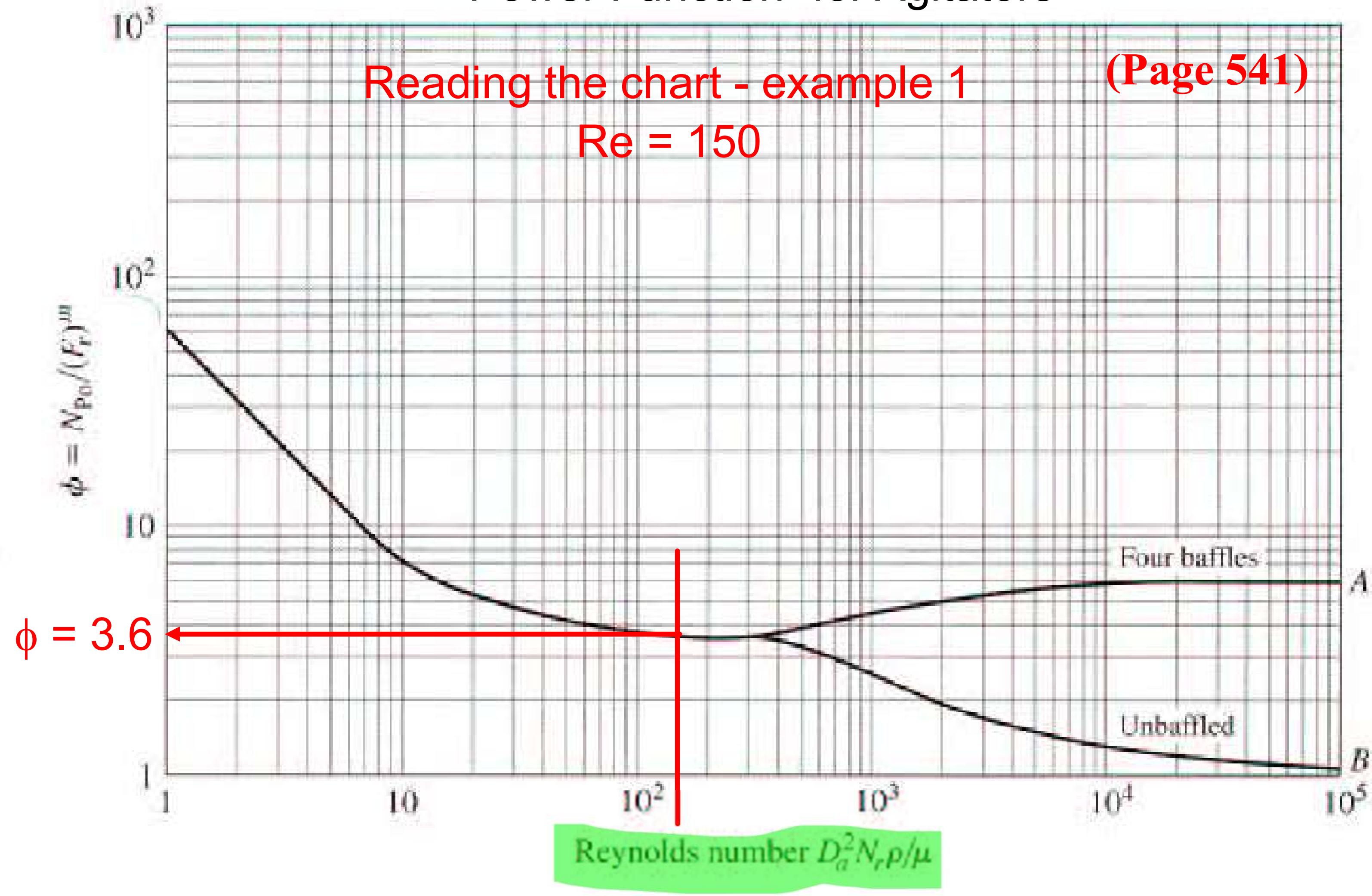
$S_6 = Z/D_t = 1.0$

(these shape factors go with this chart)

Figure 12-40
Relation between the power function ϕ 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.

$$Re = \frac{D_a^2 N_r \rho}{\mu} \qquad Fr = \frac{D_a \cdot N_r^2}{g} \qquad m = \frac{1 - \log_{10} Re}{40} \qquad N_{Po} = \phi \cdot Fr^m \qquad N_{Po} = \frac{P}{N_r^3 \cdot D_a^5 \cdot \rho}$$

“Power Function” for Agitators



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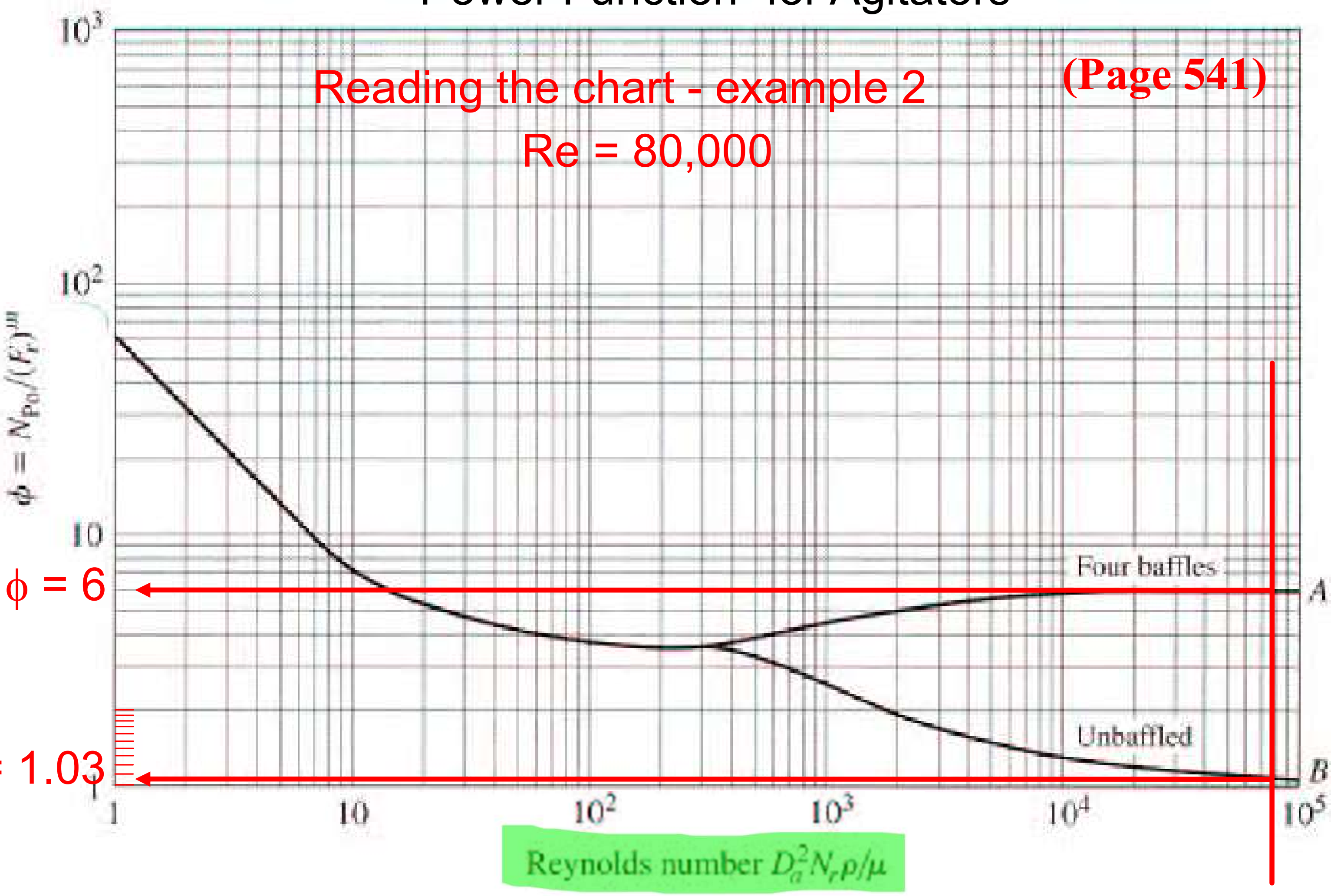

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Figure 12-40
Relation between the power function ϕ and the Reynolds number for a six-blade turbine mixer. Constants *a* and *b* in Eq. (12-41) for this mixer have been evaluated as 1.0 and 40.0, respectively.

Mixing Time (θ) 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 m^3
P = power in watts
μ = viscosity in kg/(m·s)

Important for CSTR design:

Compare θ to τ (space-time)

Generally, $\theta << \tau$

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 ϕ

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

7. Calculate Mixing Time (Slide 11)

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.

This method is for baffled tanks only.

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

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 manual - no K_L.

4. Calculate Reynolds Number

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

   5a. Laminar (Reynolds <10)

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

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

$$N_{Po} = K_T$$

6. Calculate Mixing Time (Slide 11)

Questions?