# CH402 Chemical Engineering Process Design

## Class Notes L4

Agitators

# Part I

# Agitator Design – General Features

# Tank/Vessel Mixers  PTW, p. 628

**today**

Motor

Feed

Cooling jacket

Baffle

Agitator

Mixed product

Image from Wikipedia

Capacity, gal

Carbon steel
10,350 kPa (1500 psia)
2070 kPa (300 psia)
345 kPa (50 psia)

Stainless steel
10,350 kPa (1500 psia)
2070 kPa (300 psia)
345 kPa (50 psia)

Glass-lined steel
690 kPa (100 psia)

Purchased cost, $

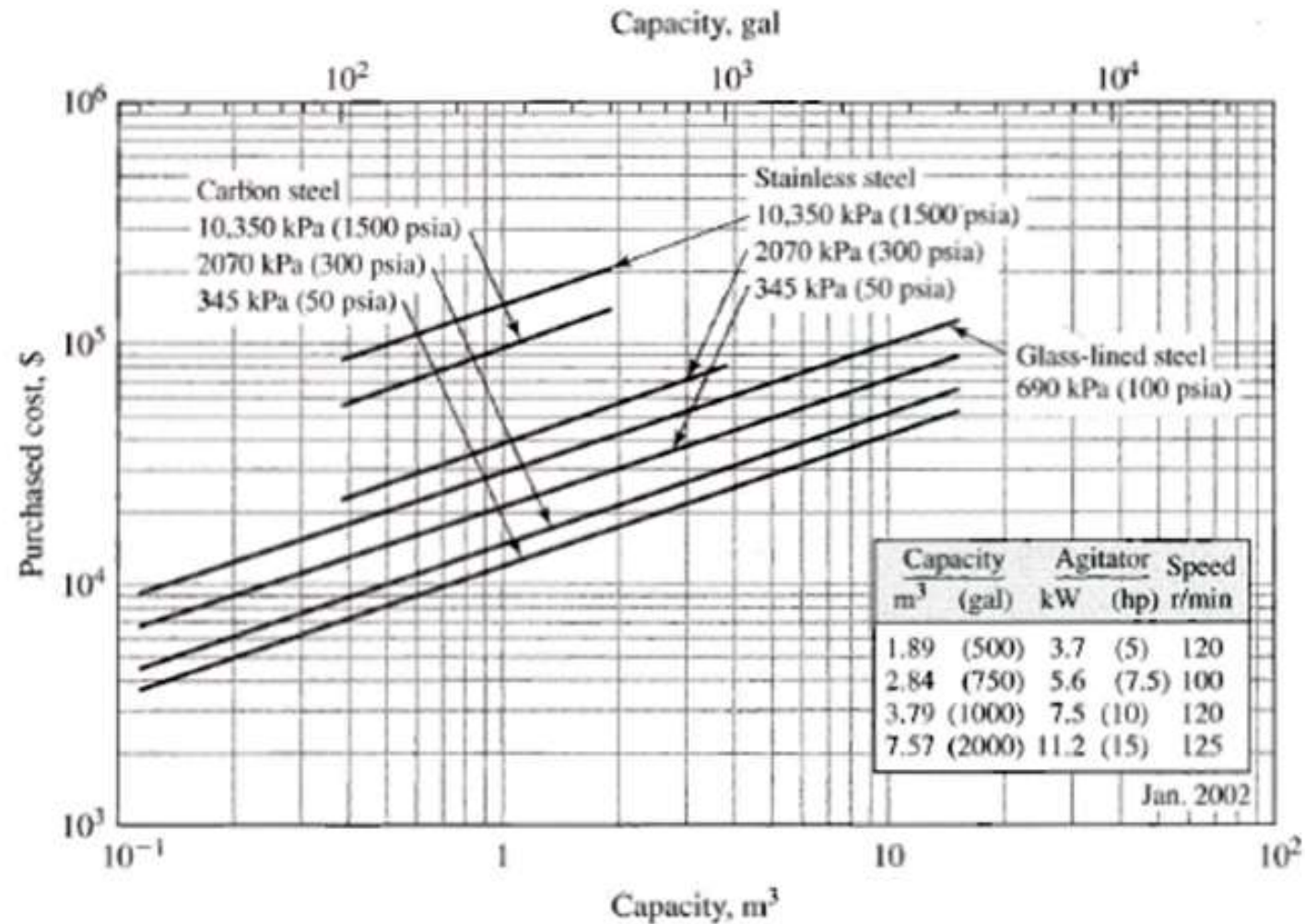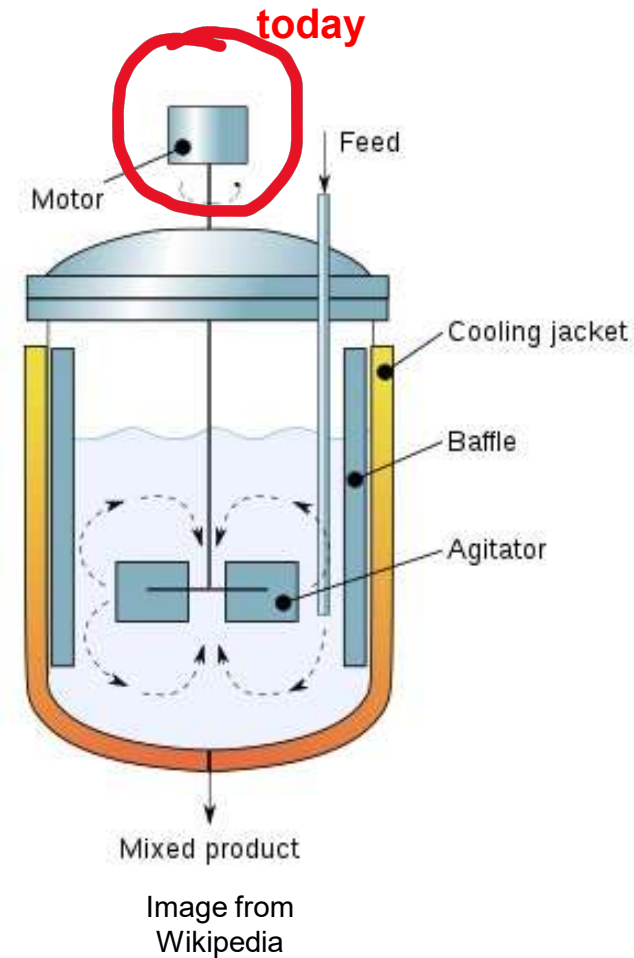| Capacity | | Agitator | | Speed |
|---|---|---|---|---|
| m³ | (gal) | kW | (hp) | r/min |
| 1.89 | (500) | 3.7 | (5) | 120 |
| 2.84 | (750) | 5.6 | (7.5) | 100 |
| 3.79 | (1000) | 7.5 | (10) | 120 |
| 7.57 | (2000) | 11.2 | (15) | 125 |

Jan. 2002

Capacity, m³

**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.



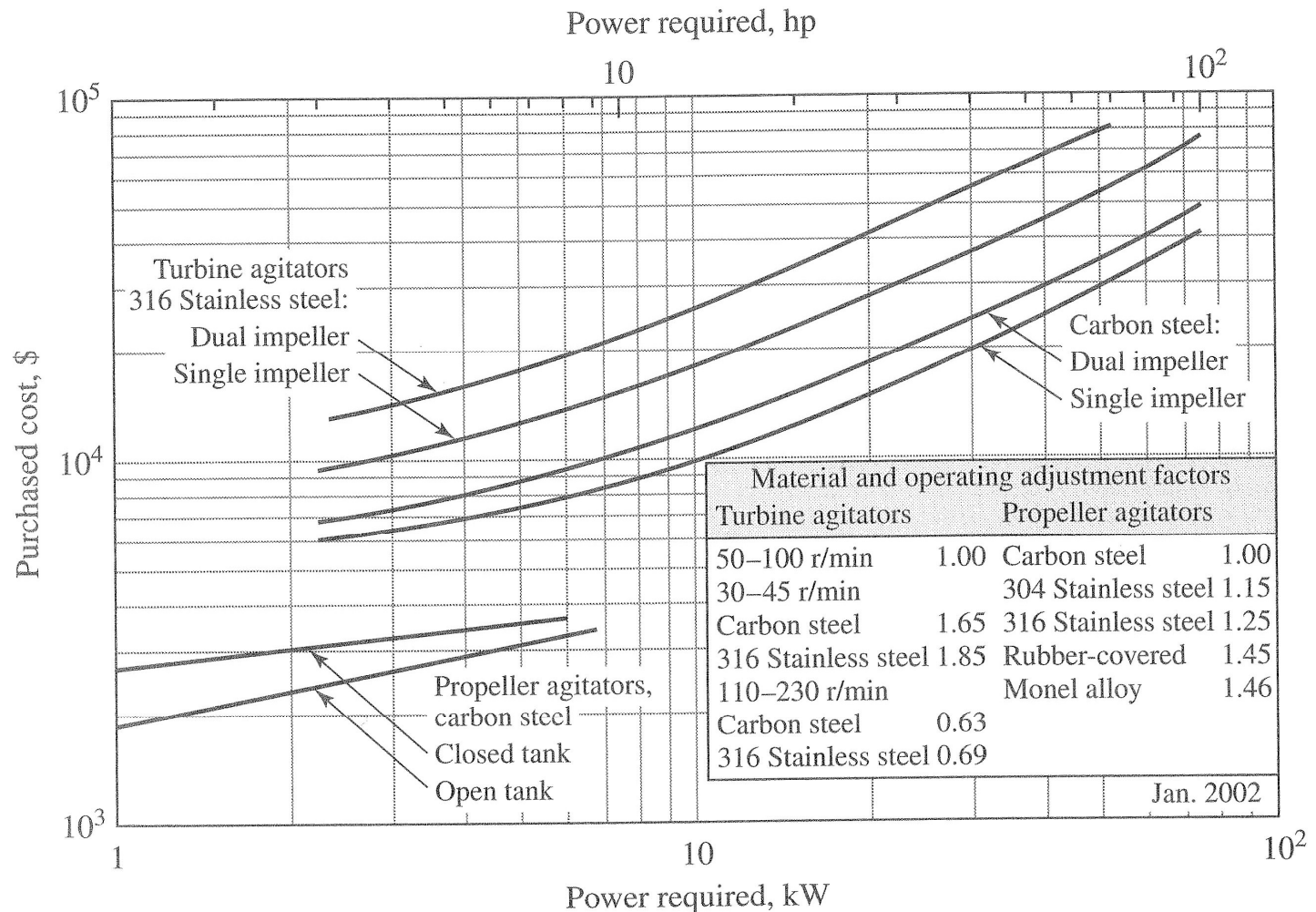http://www.gmmpfaudler.com

**Figure 12-42**
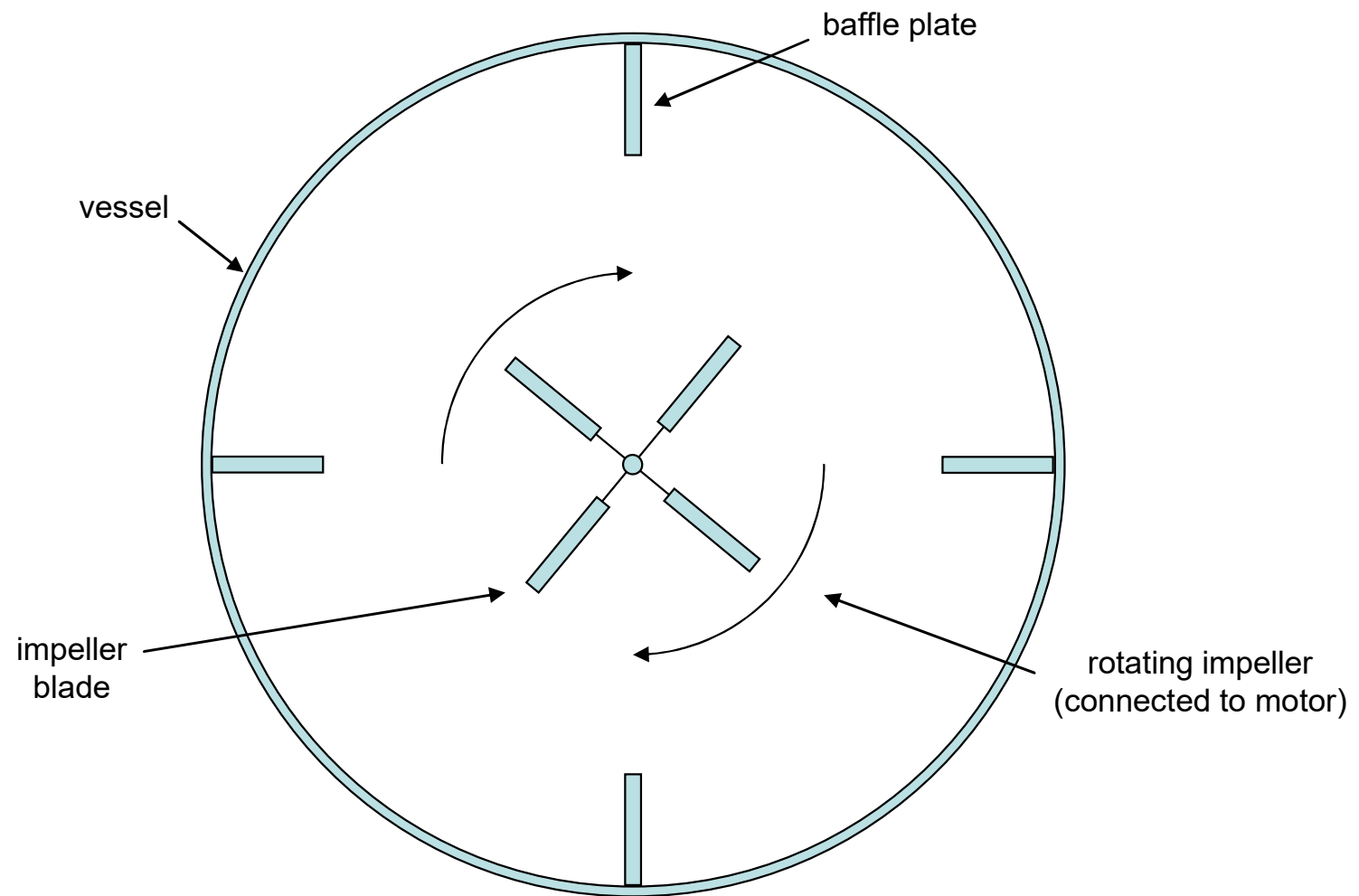Purchased cost of turbine and propeller agitators

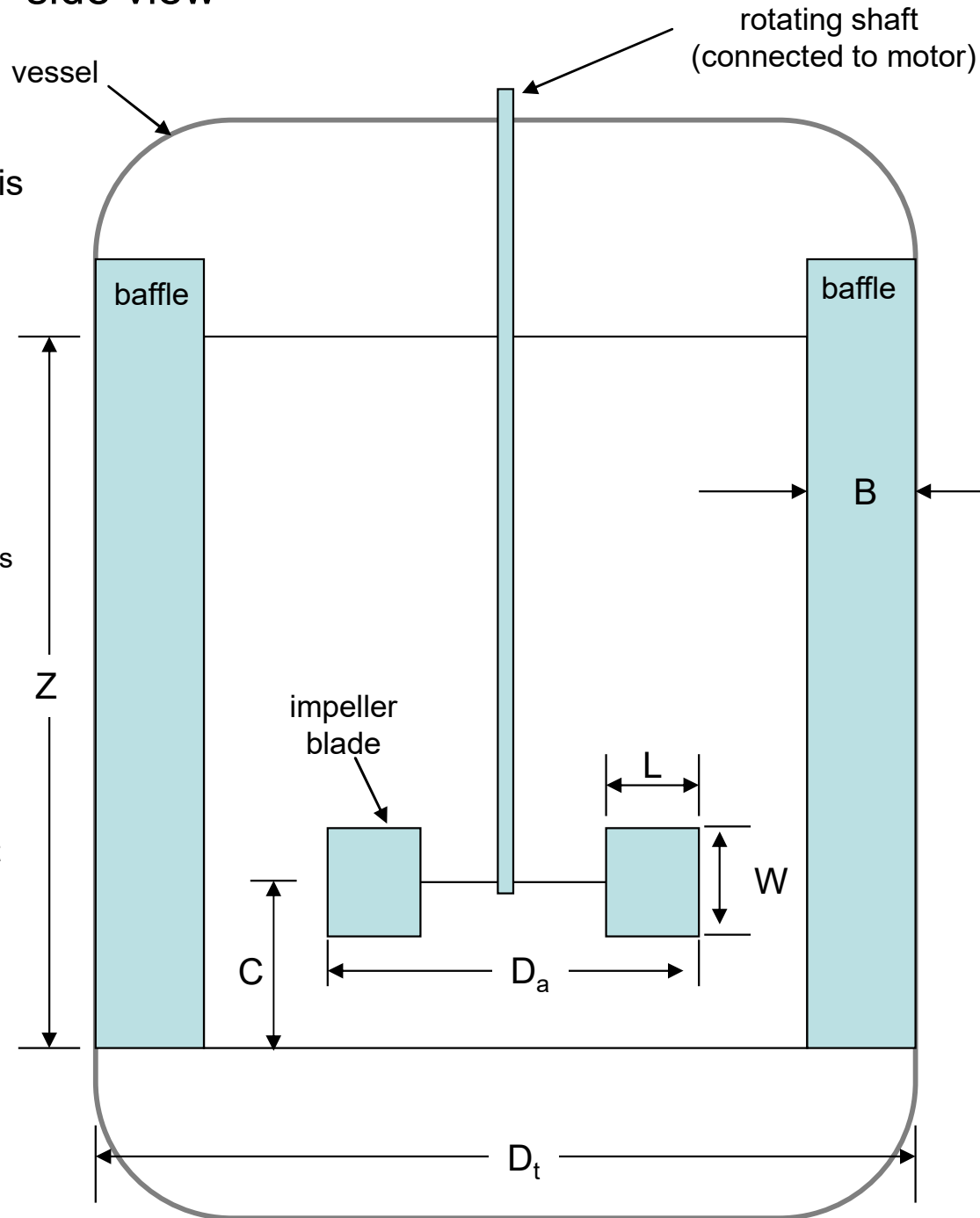Other designs - Figs. 12-41 through 12-49, pages 545-549

# Part II

# Agitator Design – Method 1

# (Stirred Tank Impeller Agitators)

# Basic Design - top view



baffle plate

vessel

impeller
blade

rotating impeller
(connected to motor)

# Basic Design - side view

rotating shaft
(connected to motor)

vessel

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

baffle

baffle

### 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

Z

B

impeller
blade

L

W

C

$D_a$

$D_t$

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)

$$N_{Po} = f(Re,\ Fr,\ S_1,\ S_2,\ S_3,\ S_4,\ S_5,\ S_6) \quad \Rightarrow \quad N_{Po} = \phi \cdot Fr^m \qquad \phi = f(Re,\ S_i)$$
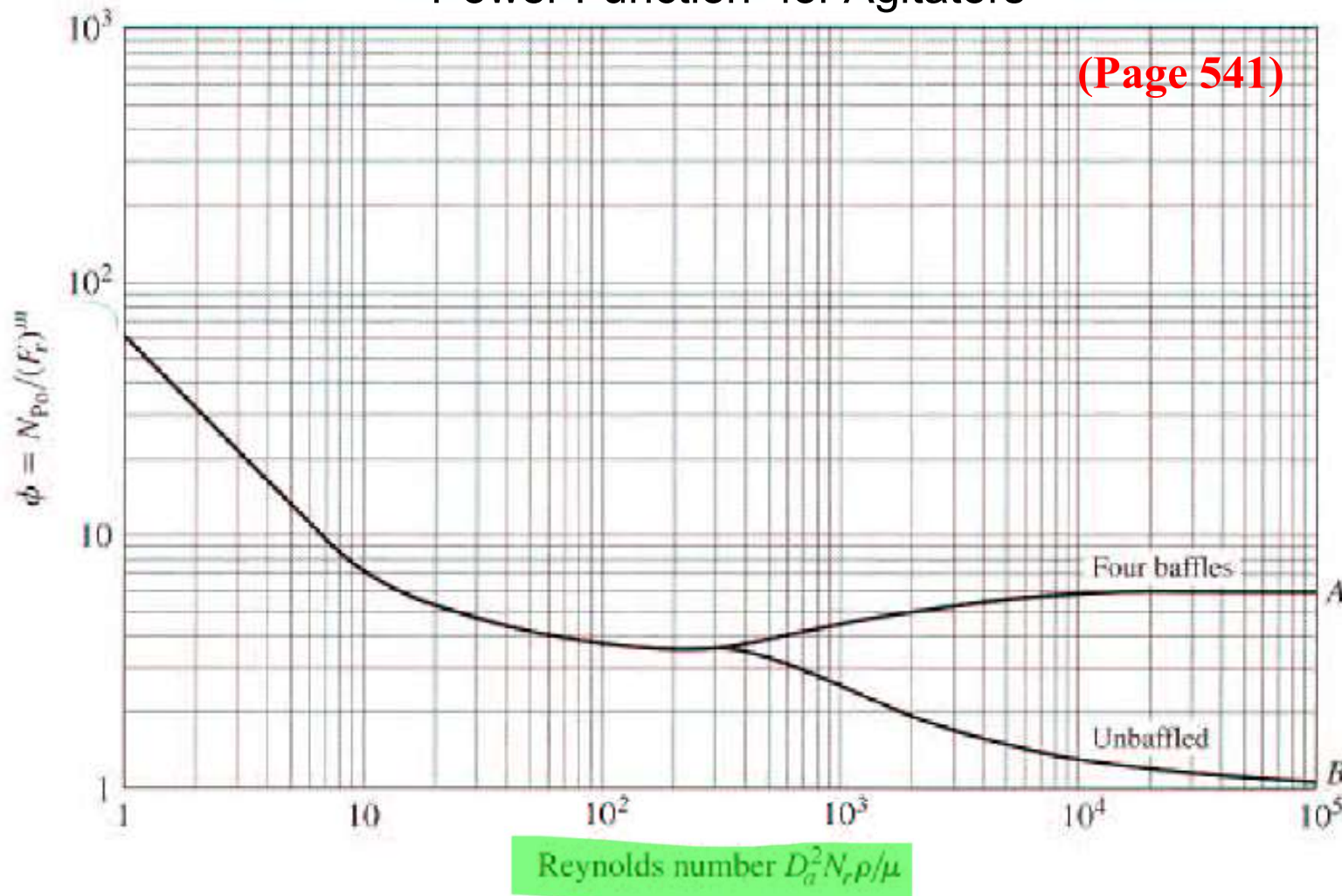
$$Re = \frac{D_a^2 N_r \rho}{\mu} \qquad Fr = \frac{D_a \cdot N_r^2}{g} \qquad m = \frac{a - \log_{10} Re}{b} \qquad N_{Po} = \phi \cdot Fr^m \qquad N_{Po} = \frac{P}{N_r^3 \cdot D_a^5 \cdot \rho}$$

## "Power Function" for Agitators



(Page 541)

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)

y-axis: $\phi = N_{Po}/(F_r)^m$

Four baffles — A

Unbaffled — B

Reynolds number $D_a^2 N_r \rho/\mu$

**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.

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

## "Power Function" for Agitators



Reading the chart - example 1
(Page 541)
Re = 150

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)

$\phi = 3.6$

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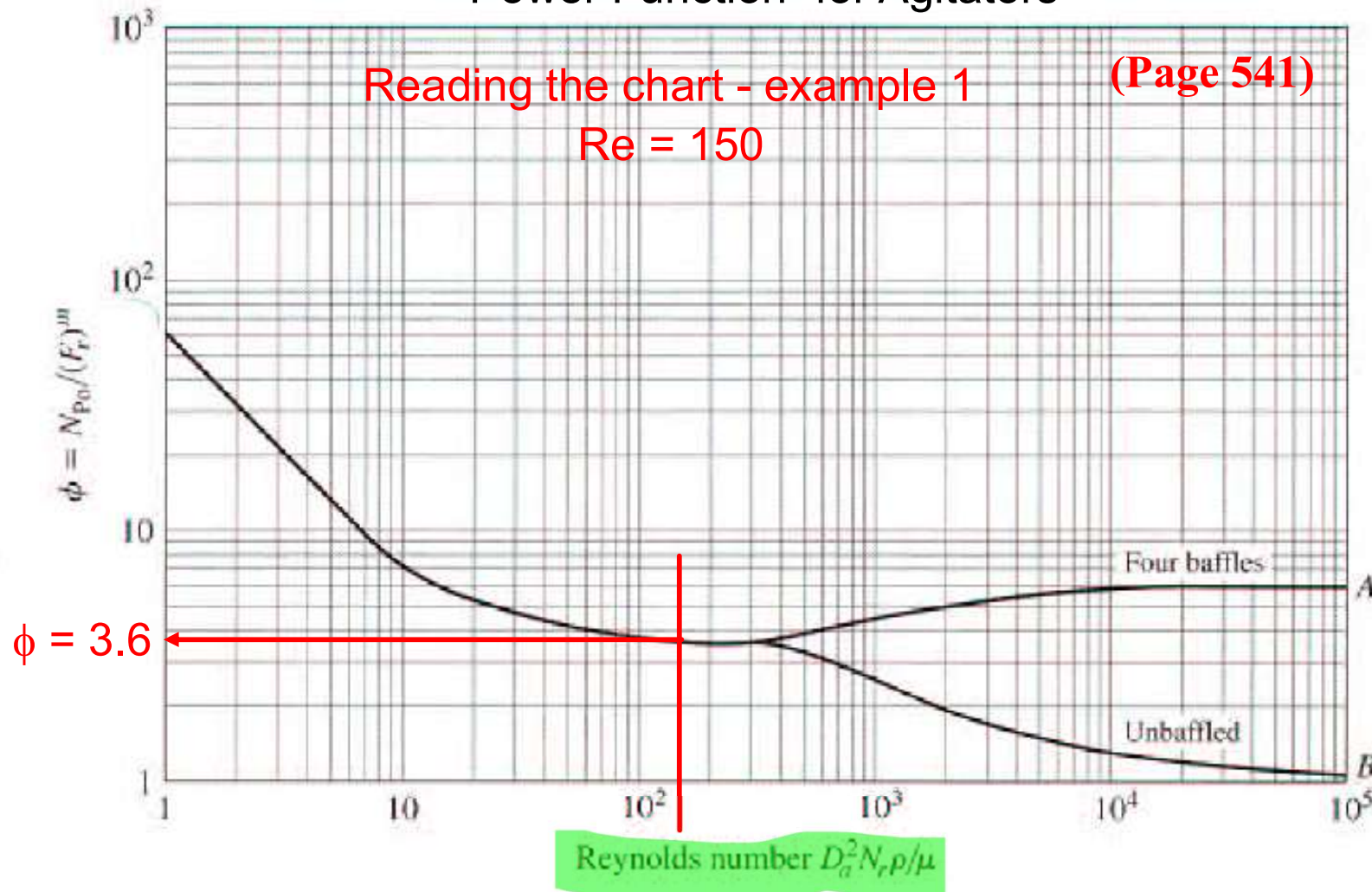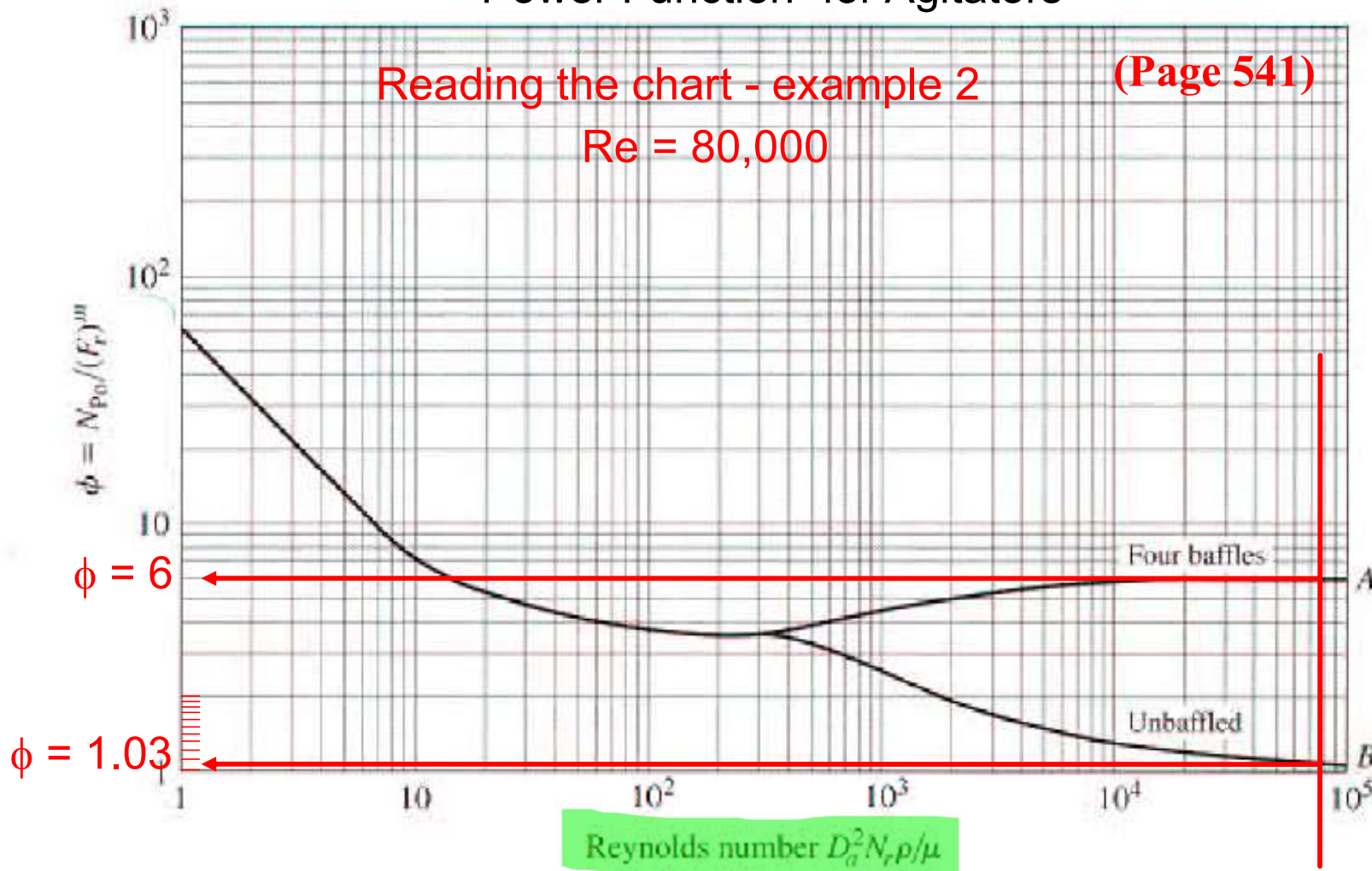
$$Re = \frac{D_a^2 N_r \rho}{\mu} \qquad Fr = \frac{D_a \cdot N_r^2}{g} \qquad m = \frac{a - \log_{10} Re}{b} \qquad N_{Po} = \phi \cdot Fr^m \qquad N_{Po} = \frac{P}{N_r^3 \cdot D_a^5 \cdot \rho}$$

## "Power Function" for Agitators



Reading the chart - example 2 **(Page 541)**

Re = 80,000

$\phi = \frac{N_{Po}}{(F_r)^m}$

$\phi = 6$

$\phi = 1.03$

Four baffles — A

Unbaffled — B

Reynolds number $D_a^2 N_r \rho / \mu$

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.

# 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 m$^3$
P = power in watts
$\mu$ = viscosity in kg/(m·s)

**Important for CSTR design:**

Compare $\theta$ to $\tau$ (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 $\phi$

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.

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 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?