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

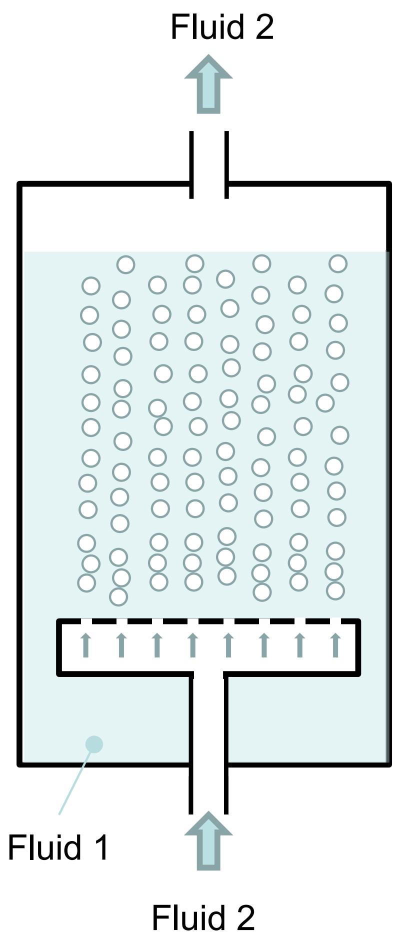
$$P = \frac{\dot{m}_G \cdot \eta \cdot \Delta p}{\rho_G}$$

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

η = compressor efficiency

Δp = compressor pressure differential

ρ_G = gas density



Motionless Mixers

advantage – no power requirement

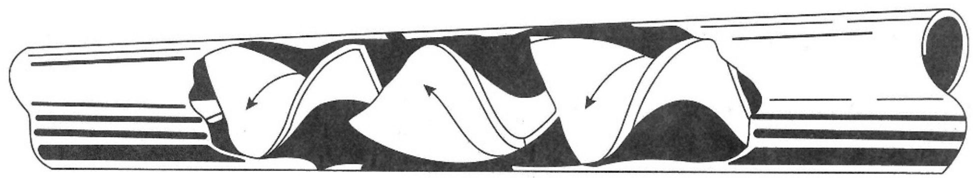


Figure 10.53. Static mixer (Kenics Corporation).

Towler & Sinnott, page 614

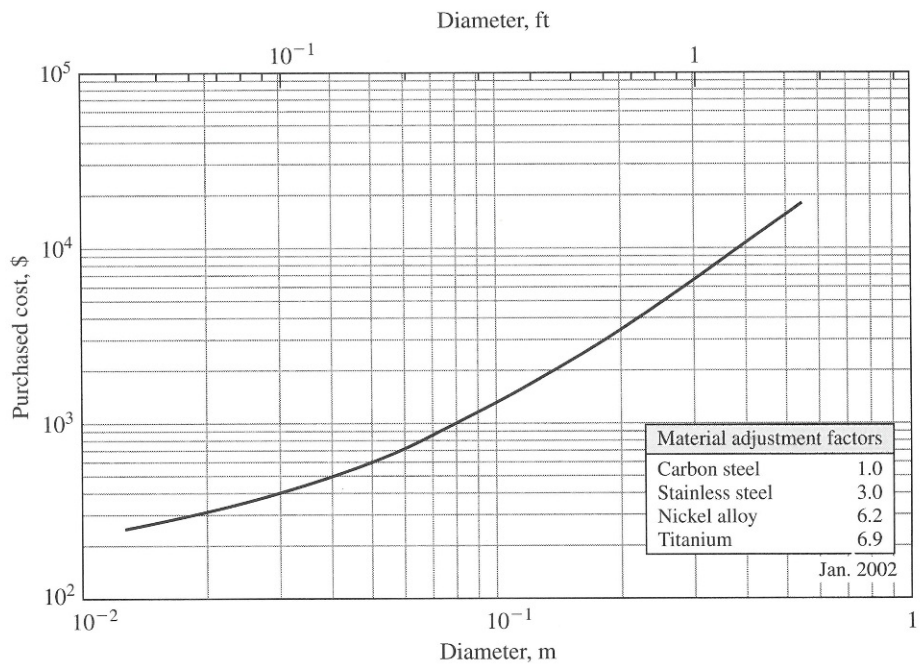


Figure 12-41
Purchased cost of motionless mixers

PTW, page 645

Tank/Vessel Mixers PTW, p. 628

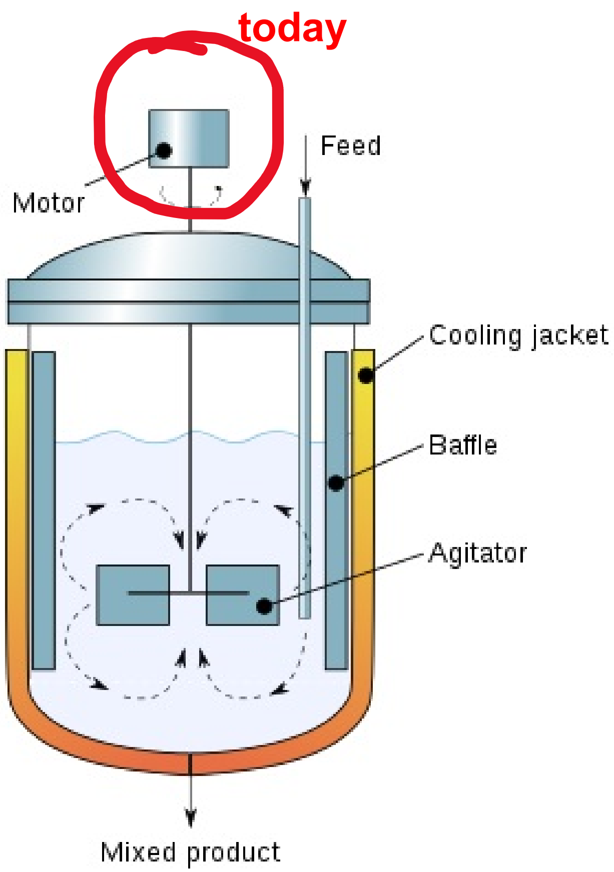


Image from Wikipedia

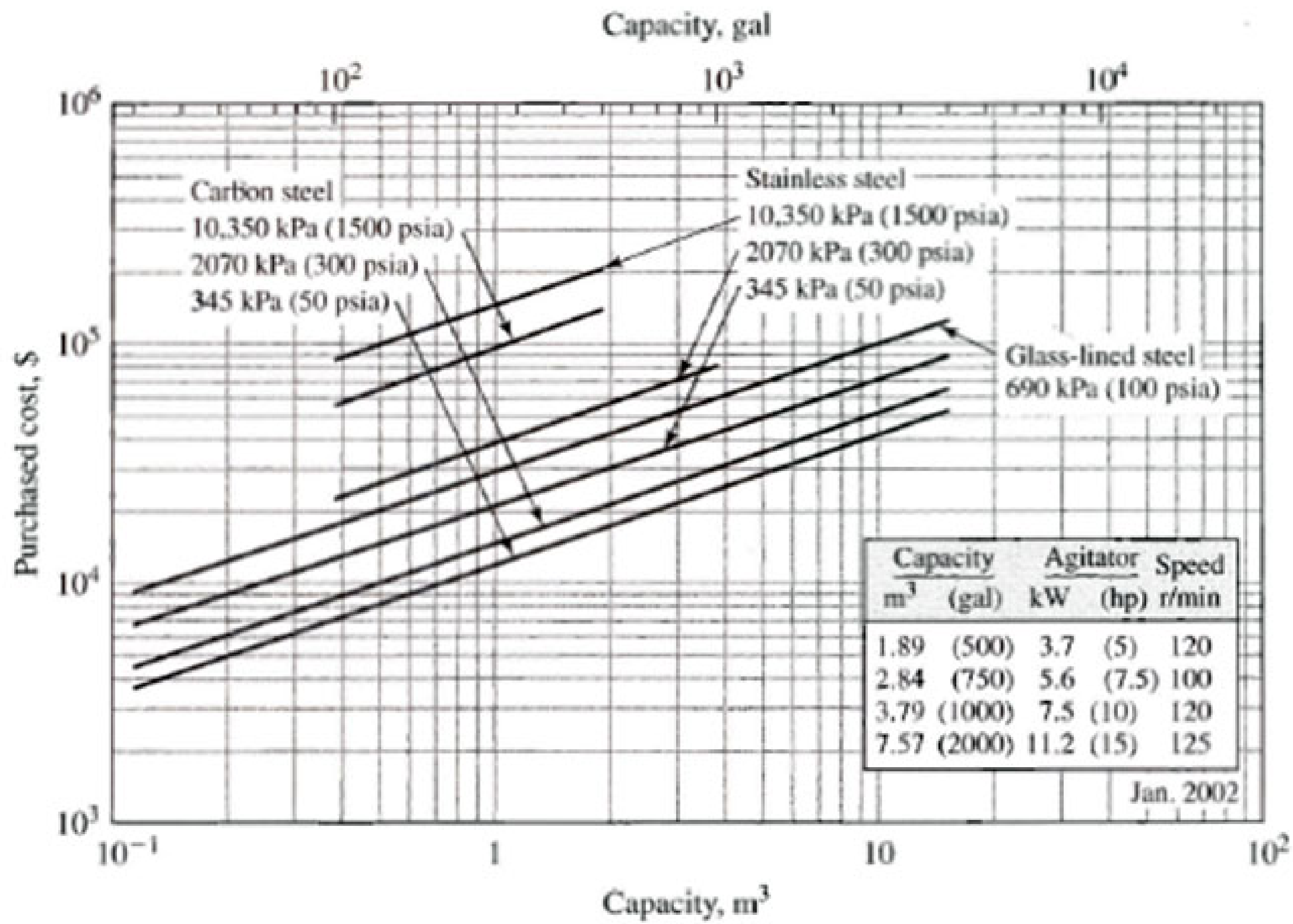


Figure 13-15
Purchased cost of jacketed and stirred reactors

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

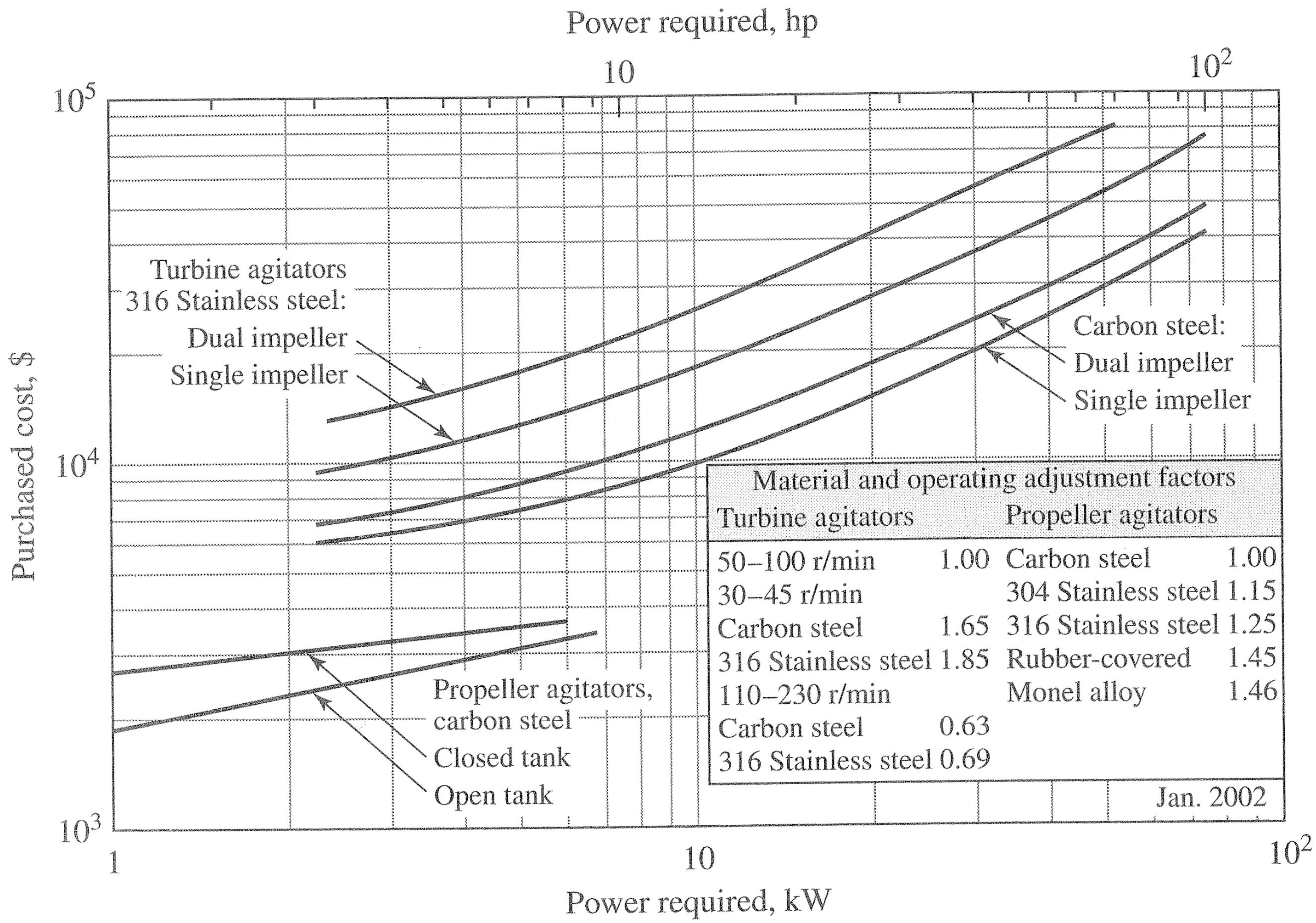


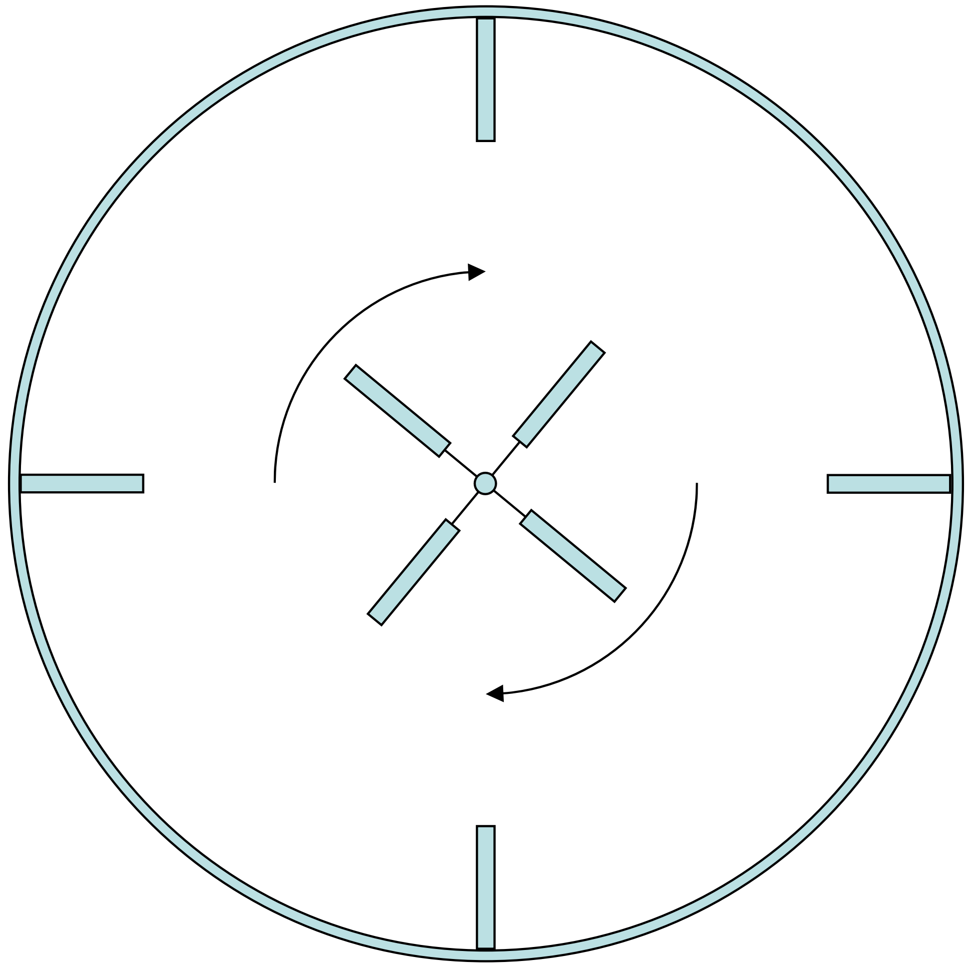
Figure 12-42
Purchased cost of turbine and propeller agitators

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

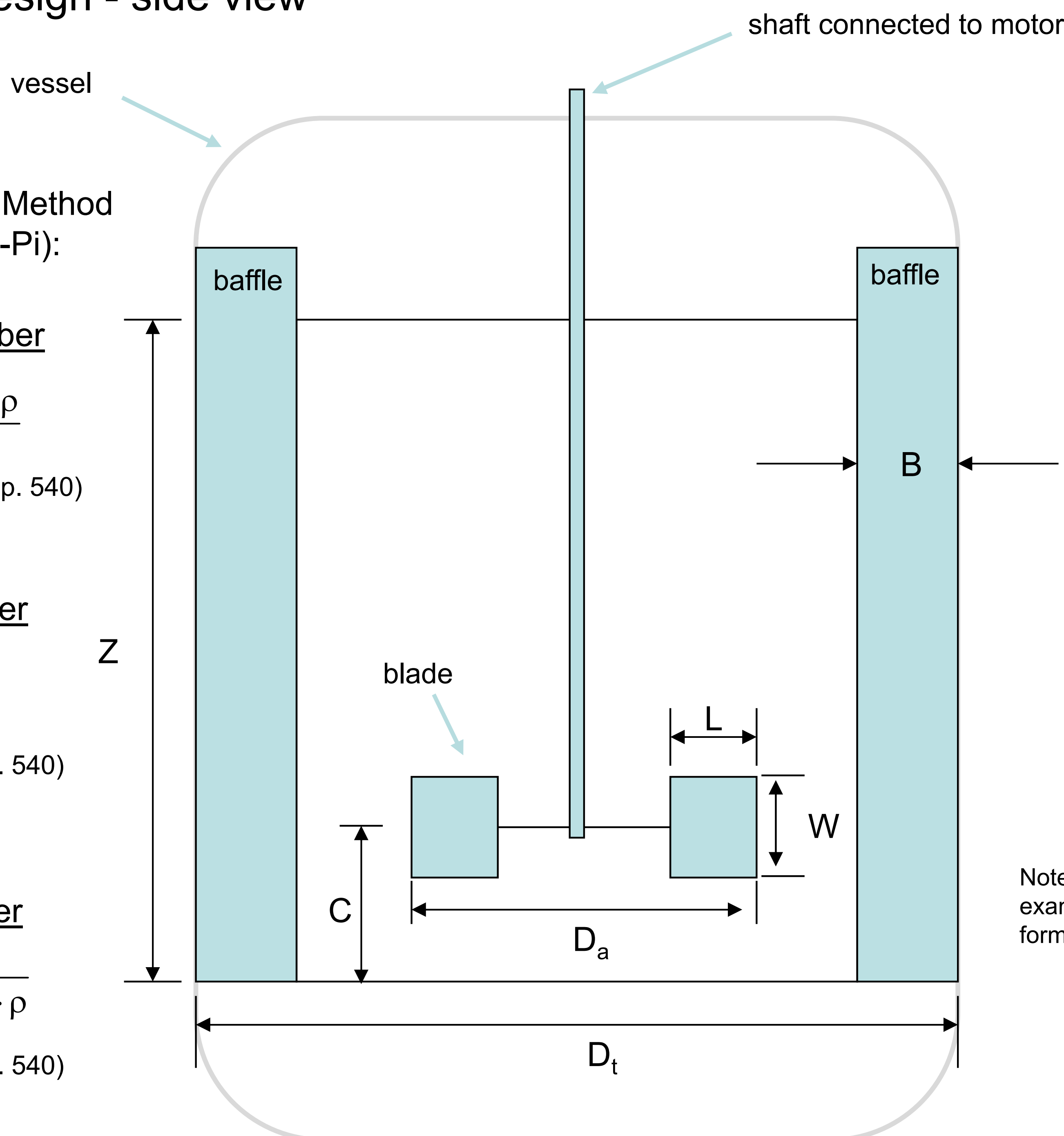
Agitator Design – Method 1

(Stirred Tank Impeller Agitators)

Basic Design - top view



Basic Design - side view



From Rayleigh's Method (Buckingham-Pi):

Reynolds Number

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

(defined in Fig. 12-40, p. 540)

Froude Number

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

(defined in para. 3, p. 540)

Power Number

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

(defined in para. 3, p. 540)

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)

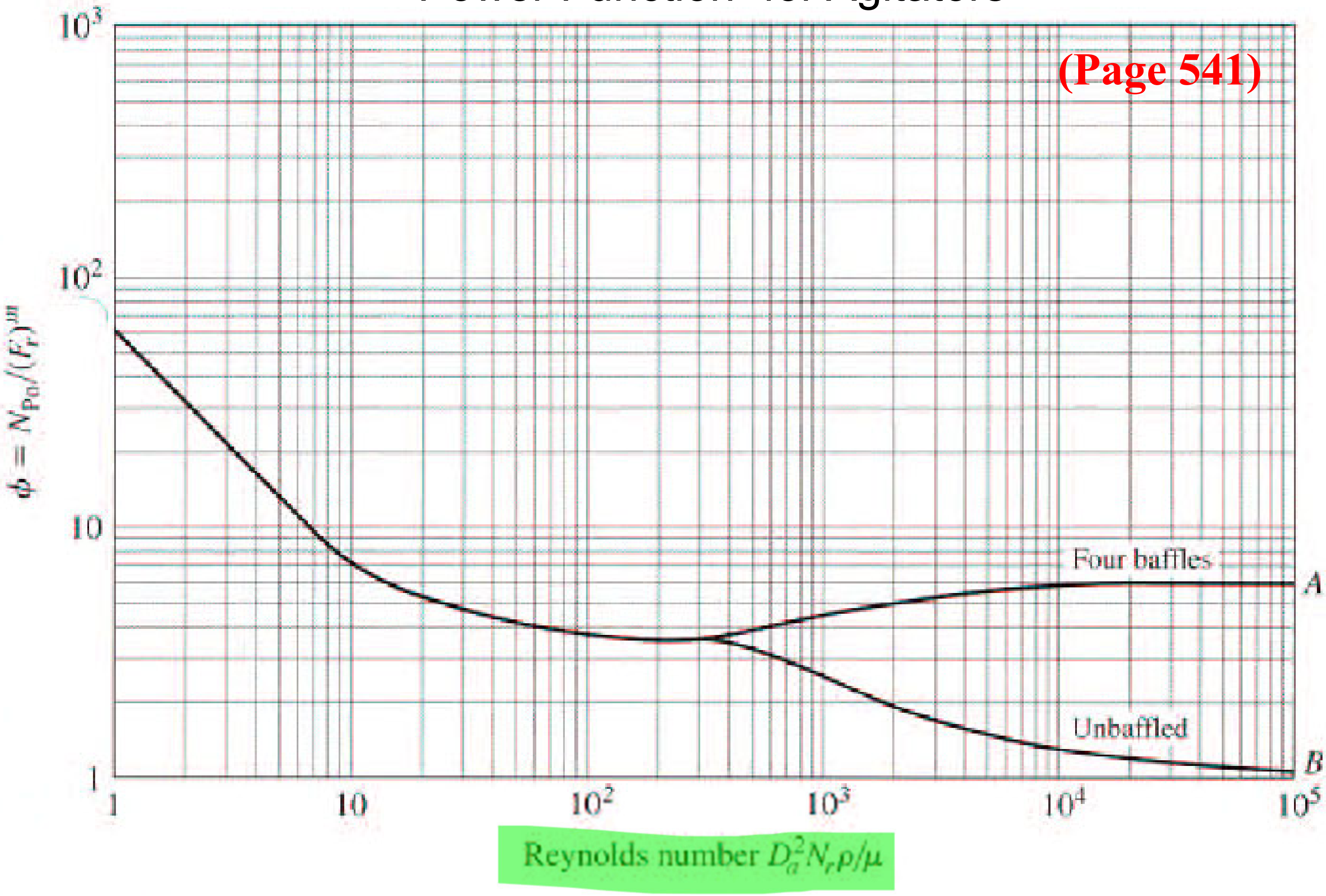
(p. 540)

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

Rayleigh method, a.k.a Buckingham Π

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

"Power Function" for Agitators



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)

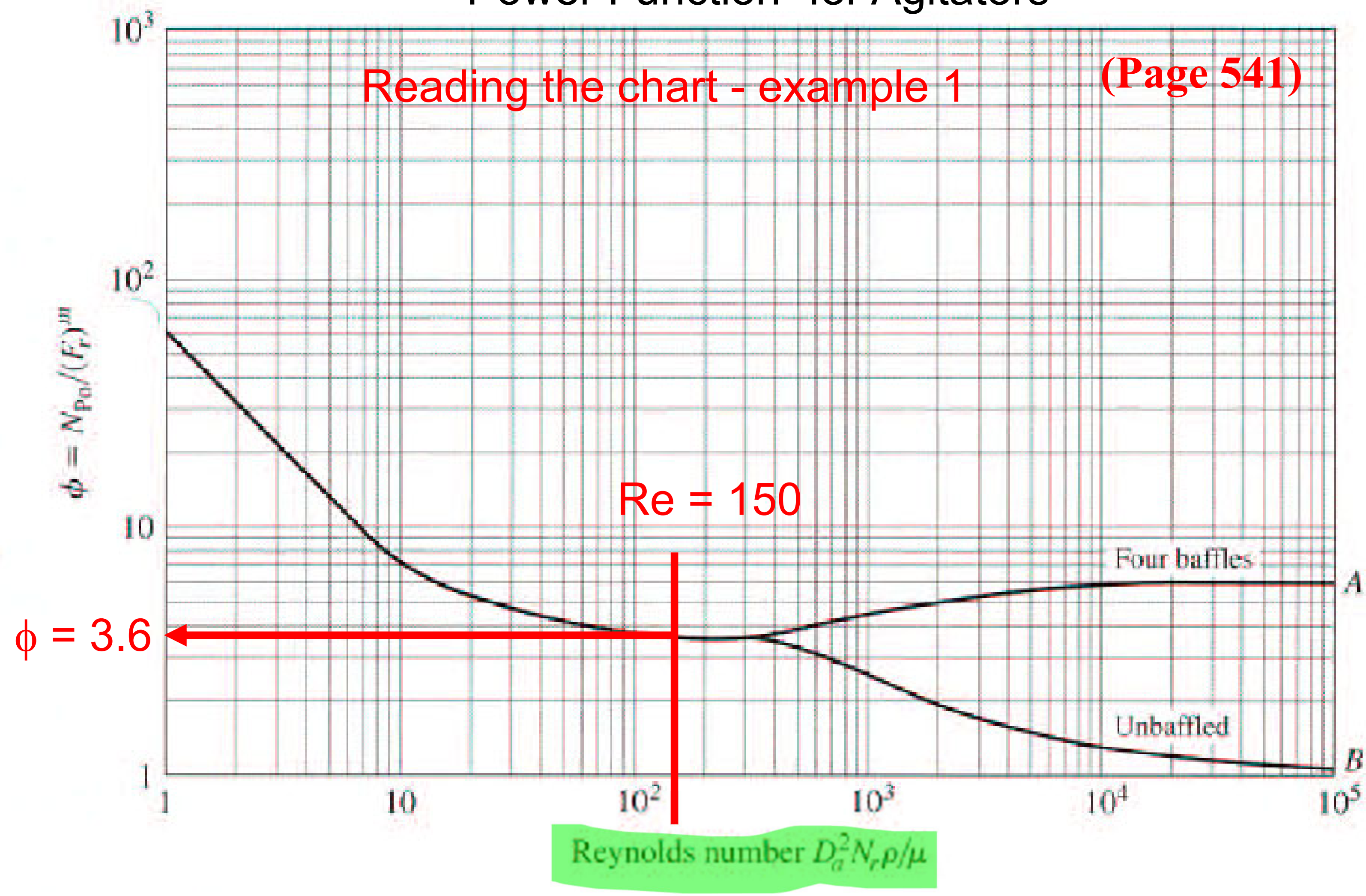
S_6 = Z/D_t = 1.0

(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.

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

"Power Function" for Agitators



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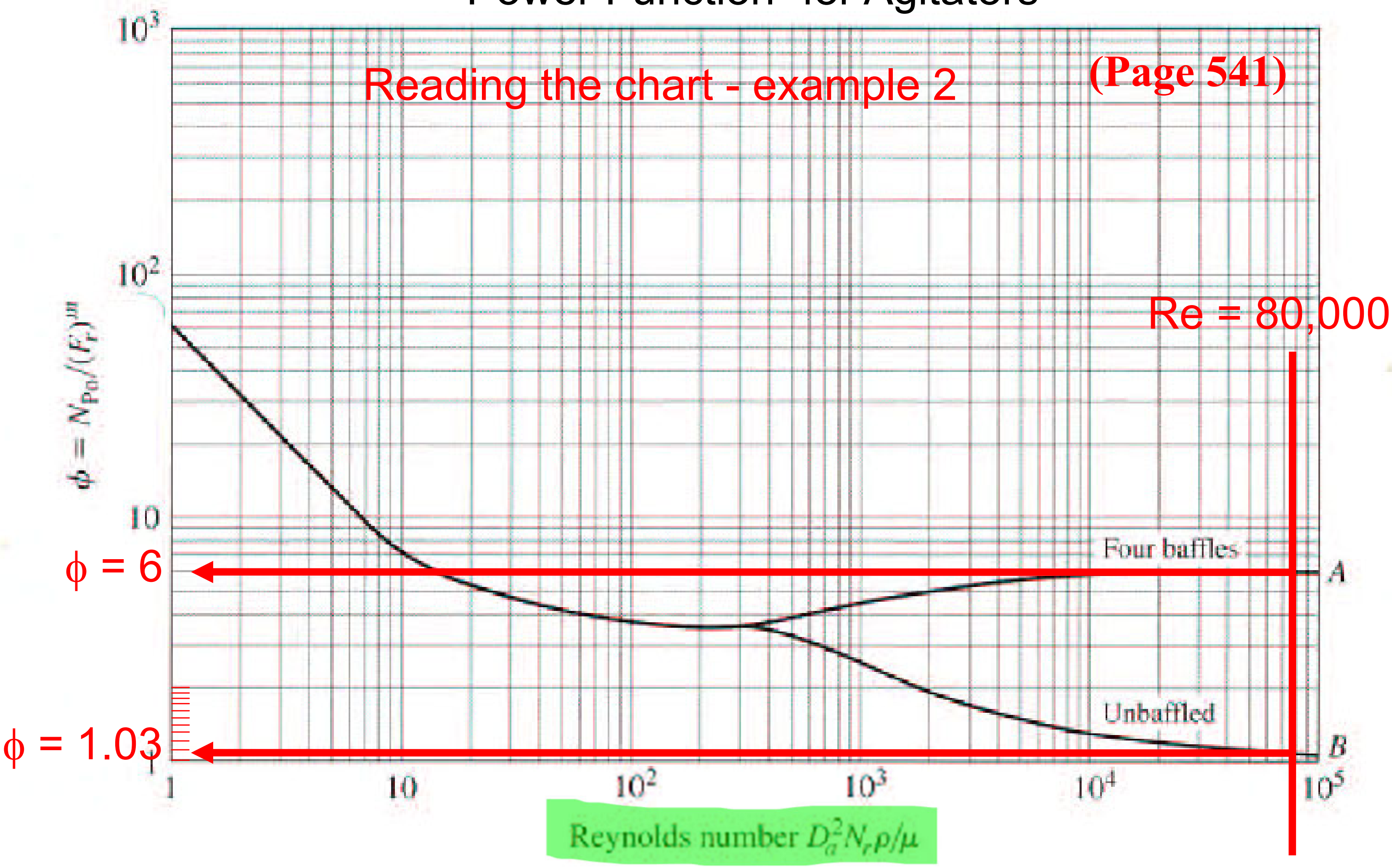
“Power Function” for Agitators



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(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.

Mixing Time (θ) for a Stirred Tank:

$$\theta = 12000 \cdot \left(\frac{\mu \cdot V}{P}\right)^{.5} \cdot \left(\frac{V}{1 \cdot m^3}\right)^{.2}$$

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:

Must compare θ to τ (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 ϕ

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

$$\boxed{\begin{gathered} Re < 10 \\ N_{Po} \cdot Re = K_L \end{gathered}}$$

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

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

$$\boxed{\begin{gathered} Re > 10{,}000 \\ N_{Po} = K_T \end{gathered}}$$

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)

   $$N_{Po} Re = K_L$$

   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^3.

Solve by methods 1 and 2

Determine mixing time by methods 1 and 2

Questions?