CHAPTER 9. AGITATION AND MIXING

ABRAHAM ROGELIO MARTIN GARCIA

PRESENTATION OUTLINE

-Definitions
-Purposes of agitation
-Devices to produce agitation
-Power consumption of agitators
-Blending and Mixing
-Suspension of solid particles
-Dispersion Operations
-Agitator selection and Scale up

DEFINITIONS

- Agitation: It refers to the induced motion of a "homogenous" material in a specified way
- Mixing: It is the random distribution, into and through one another, of two or more initially separate phases

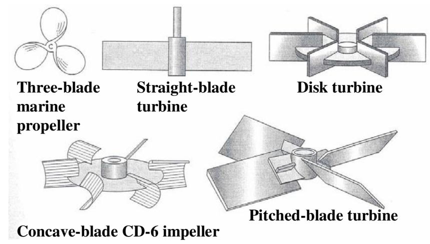
PURPOSES OF AGITATION

- Suspending solid particles
- Blending miscible liquids
- Dispersing a gas through the liquid
- Dispersing a second liquid to form an emulsion or suspension
- Promoting heat transfer

DEVICES TO PRODUCE AGITATION

IMPELLERS

- Propellers (high-speed, low viscosity)
- Turbines (Moderate viscosity)
- High-efficiency impellers



Source: McCabe et al. 2001

DESIGN OF TURBINES

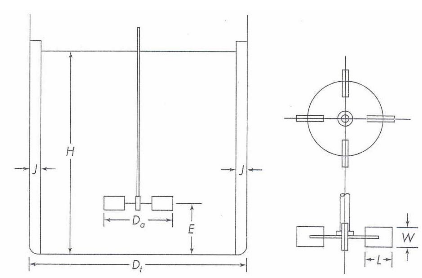


FIGURE 9.3
Measurements of turbine. (*After Rushton et al.*[45])

$$\frac{D_a}{D_t} = \frac{1}{3} = S_1$$

$$\frac{E}{D_t} = \frac{1}{3} = S_2$$

$$\frac{H}{D_t} = 1 = S_3$$

$$\frac{W}{D_a} = \frac{1}{5} = S_4$$

$$\frac{J}{D_t} = \frac{1}{12} = S_5$$

$$\frac{L}{D_a} = \frac{1}{4} = S_6$$

Source: McCabe et al. 2001

POWER CONSUMPTION OF AGITATORS

It is a function of the volumetric flow rate and the kinetic energy

$$q = K\left[(\pi D_a n(1-k)\tan\beta)(\pi D_a W)\right]$$
$$q \propto n D_a^3$$
$$N_Q = \frac{q}{n D_a^3} \quad \text{(Flow number)}$$

Values of N_Q

Impeller	N_Q
Marine propellers (square pitch)	0.5
Four-blade 45° turbine (W/D_a)=1/6	0.87
Disk turbine	1.3
HE-3 high-efficiency impeller	0.47

$$E_k = \frac{\rho (V_t)^2}{2} = \frac{\rho}{2}(\alpha \pi n D_a)^2$$
$$P = q \cdot E_k$$
$$P = \rho n^3 D_a^5 \left(\frac{\alpha^2 \pi^2}{2} N_Q\right)$$
$$\frac{P}{\rho n^3 D_a^5} = \frac{\alpha^2 \pi^2}{2} N_Q \qquad N_p = \frac{P}{\rho n^3 D_a^5} \quad \text{(Power number)}$$

$$N_p = \psi(\mathrm{Re}, Fr, S_1, S_2, \ldots, S_n)$$

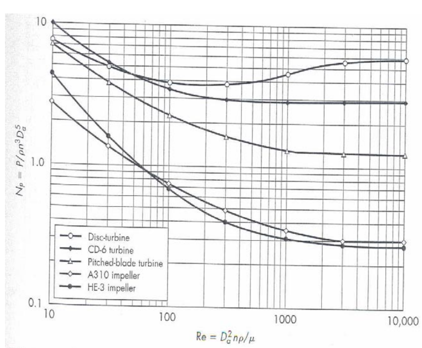


FIGURE 9.13
Power number N_P versus Reynolds number Re for turbines and high-efficiency impellers.

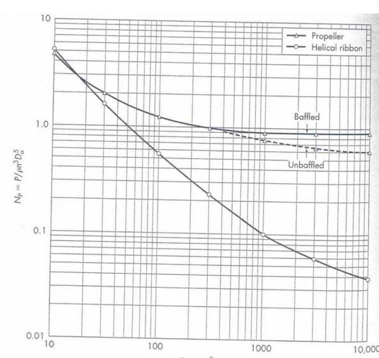


FIGURE 9.14
Power number N_P versus Reynolds number Re for marine propellers (pitch = 1.5:1) and helical ribbons.

Source: McCabe et al. 2001

$P = N_p n^3 D_a^5 \rho$

For Re < 10

$P = K_L n^2 D_a^3 \mu$

For Re > 10000

$P = K_T n^3 D_a^5 \rho$

TABLE 9.2

Values of constants K_L and K_T in Eqs. (9.19) and (9.21) for baffled tanks having four baffles at tank wall, with width equal to 10 percent of tank diameter

Type of impeller	K_L	K_T
Propeller, three blades		
Pitch 1.0[43]	41	0.32
Pitch 1.5[37]	48	0.87
Turbine		
Six-blade disk[37] ($S_3 = 0.25$, $S_4 = 0.2$)	65	5.75
Six pitched blades[42] (45°, $S_4 = 0.2$)	—	1.63
Four pitched blades[37] (45°, $S_4 = 0.2$)	44.5	1.27
Flat paddle, two blades[43] ($S_4 = 0.2$)	36.5	1.70
HE-3 impeller	43	0.28
Helical ribbon	52	—
Anchor[37]	300	0.35

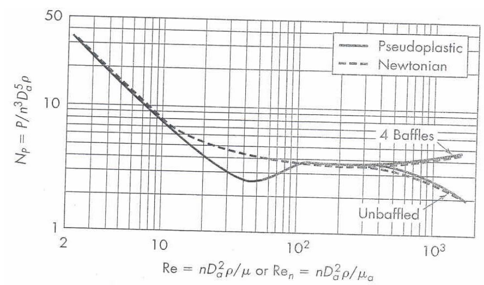


FIGURE 9.15
Power correlation for a six-blade turbine in pseudoplastic liquids.

Source: McCabe et al. 2001

BLENDING AND MIXING

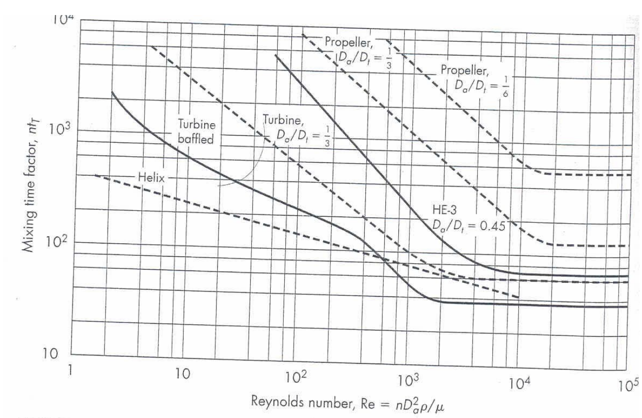


FIGURE 9.16
Mixing times in agitated vessels. Dashed lines are for unbaffled tanks; solids lines are for baffled tanks.

Source: McCabe et al. 2001

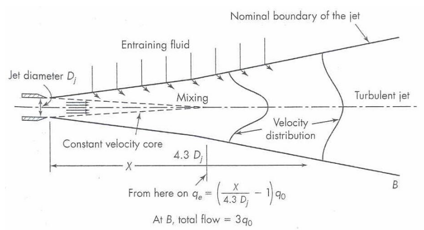


FIGURE 9.18
Flow of a submerged circular jet. (*After Rushton and Oldshue.*[46])

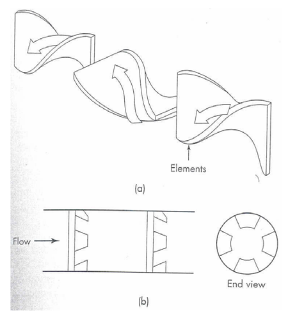


FIGURE 9.19
Static mixers: (*a*) elements of a helical-element mixer; (*b*) turbulent vortex mixer.

Source: McCabe et al. 2001

SUSPENSION OF SOLID PARTICLES

$$n_c D_a^{0.85} = S \nu^{0.1} D_p^{0.2} \left(g \frac{\Delta\rho}{\rho} \right)^{0.45} B^{0.13}$$

Shape factor S

Impeller type	D_t/D_a	D_t/E	S
Six-blade turbine $D_a/W=5$ Np=6.2	2 3 4	4 4 4	4.1 7.5 11.5
Two-blade paddle $D_a/W=4$ Np=2.5	2 3 4	4 4 4	4.8 8 12.5
Three-blade propeller Np=0.5	3 4 4	4 4 2.5	6.5 8.5 9.5

DISPERSION OPERATIONS

$$\frac{\bar{D}_S}{D_a} = 0.058(1 + 5.4\psi)\left(\frac{\rho_C n^2 D_a^3}{\sigma}\right)^{-0.6}$$

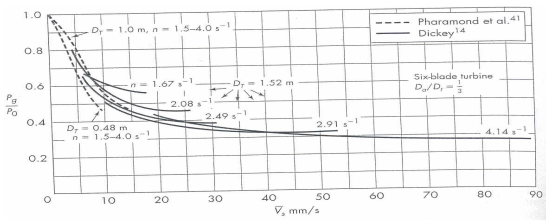


FIGURE 9.21
Power consumption in aerated turbine-agitated vessels.

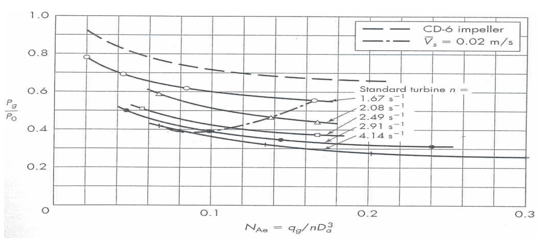


FIGURE 9.22
Relative power consumption in agitated vessels versus aeration number N_{Ae}.

Source: McCabe et al. 2001

AGITATOR SELECTION AND SCALE UP

AGITATOR SELECTION

- Depends on the viscosity of the liquid
- For specific time of mixing, the best mixer is the one that mixes in the required time with the smallest amount of power

SCALE UP

- Maintaining constant power per unit volume and geometric similarity

$$\frac{n_2}{n_1} = \left(\frac{D_{a1}}{D_{a2}}\right)^{\frac{2}{3}}$$