

AGITATED VESSELS**JGS 210-120-1-64E**

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1. SCOPE

- (1) This standard practice provides the guidelines of selection and design of agitated vessel in refinery and chemical plants.
- (2) Specific instructions in the Project Specifications given by the client or licensor shall take precedence over the requirements in this standard practice.

2. WORK PROCEDURE

2.1 Input to the Design

The data to be used for the agitator design are as follows:

- (1) The classification of the agitation problem

Applications of agitators in the process plants involve one or more of the following objectives:

 - (a) Bulk mixing : Combining process liquids of dissimilar composition and properties.
 - (b) Chemical reaction : Distributing reactants and products to promote desired reaction.
 - (c) Heat transfer : Increasing convective motion adjacent to the transport surfaces.
 - (d) Mass transfer : Promoting contact between separate phases and different compositions.
 - (e) Phase interaction : Suspending solids or dispersing gases and immiscible liquids.
- (2) Operating Conditions
 - Fluid name
 - Temperature
 - Pressure
 - Physical properties such as density, viscosity, suspended solids concentration
 - Flow rate
 - Operation mode (Batch or continuous)
- (3) Construction data
 - Material selection data
 - Corrosion and, or erosion information

2.2 Output from the Design

The agitator design should ensure the system performance of desired condition with the following output.

- (1) Skeleton of vessel
- (2) Data sheet of agitator
- (3) Estimated utility requirement
- (4) Time table of operation cycle, if necessary
- (5) Information of P & ID Preparation

2.3 Work Steps

The followings are the guidelines of work steps of agitator design.

- (1) Confirmation on the client or licensor's requirements
- (2) Classification
 - Blending
 - Suspending solids in liquids
 - Dispersing gas into liquids
- (3) Sizing of vessels and selection of agitator
- (4) Preparation of skeleton of vessel
- (5) Preparation of agitator data sheet for issuing to vendors
- (6) Estimation of utility consumption
- (7) Preparation of time table if necessary
- (8) Evaluation of vendor's design results
- (9) Reflection on P & ID drawings

2.4 Computer Program

Software of FMP (Fluid Mixing Processes) ^[2] can be used. The softwares are listed in the Technical Report.

3. DESIGN

Various conditions shall be considered before design of agitator.

3.1 Selection of Agitator

3.1.1 Purposes of Agitation

The purposes of agitation shown below shall be determined before commencing design.

(1) **Liquids Blending**

The design procedure for liquids blending applies to agitation problems where fluids behave as a single phase and where a predictable level of fluid motion shall occur. The procedure indicated here may be used for the design of agitators in applications ranging from storage vessels requiring very little agitation to critical reactors needing great deal of it.

(2) **Suspended Solid**

The presence of a two-phase, solid-liquid system classifies an agitation problem as a solid-suspension one. In such problems, the suspension of solid particles having settling velocity greater than 0.25cm/s within a continuous liquid phase is the purpose of agitation.

(3) **Dispersing Gas into Liquid**

Turbine-agitated gas-liquid systems are basically contacting devices, which create large interfacial surface area between the gas and liquid phases. A common application involves mass transfer of a sparingly soluble gas into a liquid where a reaction may occur.

3.1.2 Types of Agitators

Agitators used in common are the following types.

(1) **Edged turbine**

(2) **Propeller**

(3) **Turbine**

(4) **Paddle**

(5) **Anchor**

The basic configurations of agitators are indicated in Fig. 3.1.2 for reference, and also the Table 3.1.2 shows the typical shape of agitators and their performance.

3.1.3 Major Heat Transfer Systems

Major heat transfer systems used for agitation vessel are shown in Fig. 3.1.3.

3.2 Agitator Sizing

3.2.1 Liquid Volume

For batch operation : $V = \text{unloading rate} = (\text{Batch/unit time}) \cdot (\text{Agitating time})$

For continuous operation : $V = (\text{Feed rate}) \cdot (\text{Residence time})$

Here, $V = \text{Liquid Volume (m}^3\text{)}$

3.2.2 Vessel Dimension

Standard dimensions are as follows.

(1) $T = Z$

(2) $Z = 0.8 H$ (general)

$Z = (0.6 \sim 0.7) H$ (for dispersing gas system)

(3) The shape of bottom head is 2:1 ellipse.

$$V_s = \frac{\pi}{4} \cdot T^2 \cdot Z(\text{shell})$$

$$V_b = \frac{\pi}{24} \cdot T^3 (\text{bottom})$$

$$V = V_s + V_b = \frac{7}{24} \pi T^3$$

$$T = \left(\frac{24V}{7\pi} \right)^{\frac{1}{3}} = Z$$

$$H = Z / 0.8$$

3.2.3 Impeller Dimension

$$D = (D/T) \cdot T$$

(D/T) should be selected by using Table 3.2.3

3.2.4 Power Input (P/V)

For the purpose of estimation, power of agitator (P) may be obtained using power input (P/V) from Fig. 3.2.4

$$P = (P/V) \cdot V \quad (\text{kw})$$

3.2.5 Power Number (P_O)

P_O (dimensionless parameter) defined as power number is a function of N_{Re} , N_{Fr} , and shape of vessel, impeller, baffles etc.

In turbulent flow ($N_{Re} > 10^4 \sim 10^5$), P_O becomes free from the change in N_{Re} .

P_O is shown in Fig. 3.2.5 (rearranged from FMP data).

$$N_{Re} = D^2 (n / 60) \cdot \rho \cdot (1000 / \mu)$$

For the impeller speed 'n', reference is made to the next section (3.2.6)

3.2.6 Impeller Speed

In general, the following equation is established.

$$P = 0.001 P_O \cdot \rho (n / 60)^3 \cdot D^5$$

Thus, the following equation is obtained.

$$n = 60 \{ 1000P / (P_O \cdot \rho \cdot D^5) \}^{1/3}$$

3.2.7 Standard Agitator Assembly

Other supplementary details are shown in Table. 3.2.3.

3.3 Heat Transfer Coefficients for Agitated Vessels ^[1]

The typical equations for heat transfer of agitated vessel are listed in this paragraph.

3.3.1 General

The overall heat-transfer coefficient can be calculated by the following equations:

- (1) $1/U = 1/h_i + ff_i + \chi/\kappa + ff_j + 1/h_j$ (Jacketed vessel)
 (2) $1/U_o = 1/h_i + ff_i + (\chi/\kappa)(d_{co}/d_{cm}) + (1/h_{ci})(d_{co}/d_{ci}) + ff_j$ (Internal-coil vessel)
 (3) $N_{Nu} = h_i \chi / \kappa$

3.3.2 Inside Coefficient at Jacket Vessel**(1) Flat Blade Turbine**

(a) $N_{Re} < 400$

$$N_{Nu} = 0.54 A (N_{Re})^{0.67} (N_{Pr})^{0.33} \left(\frac{\mu}{\mu_o} \right)^{0.14} \text{-----(1)}$$

(b) $N_{Re} > 400$

$$N_{Nu} = 0.74 (N_{Re})^{0.67} (N_{Pr})^{0.33} \left(\frac{\mu}{\mu_o} \right)^{0.14} \text{-----(2)}$$

Note : Both equations apply to vessels of "Standard" geometry that is $Z/D=1.0$ and $T/D=1/3$,
 and $T_w = t_j - \{ (t_j - t_b) / [1 + (h_j \cdot A_o / h_i \cdot A_i)] \}$

(2) Retreating-blade turbine

(a) Mixing in a jacketed vessels (6-blades)

$$N_{Nu} = 0.68 (N_{Re})^{0.67} (N_{Pr})^{0.33} \left(\frac{\mu}{\mu_o} \right)^{0.14} \text{-----(3)}$$

(b) Glass-steel impeller (3-blades)

$$N_{Nu} = 0.68 (N_{Re})^{0.67} (N_{Pr})^{0.33} \left(\frac{\mu}{\mu_o} \right)^{0.14} \text{-----(4)}$$

(c) Alloy impeller (3-blades)

$$N_{Nu} = 0.37 (N_{Re})^{0.67} (N_{Pr})^{0.33} \left(\frac{\mu}{\mu_o} \right)^{0.14} \text{-----(5)}$$

(3) Paddle

(a) $20 < N_{Re} < 4000$

$$N_{Nu} = 0.415 (N_{Re})^{0.67} (N_{Pr})^{0.33} \left(\frac{\mu}{\mu_o} \right)^{0.24} \text{-----(6)}$$

(b) $N_{Re} > 4000$

$$N_{Nu} = 0.36 (N_{Re})^{0.67} (N_{Pr})^{0.33} \left(\frac{\mu}{\mu_o} \right)^{0.24} \text{-----(7)}$$

(4) Helical Ribbon

(a) $N_{Re} < 130$

$$N_{Nu} = 0.248(N_{Re})^{0.5} (N_{Pr})^{0.33} \left(\frac{\mu}{\mu_{\omega}} \right)^{0.14} \left(\frac{e}{D} \right)^{-0.22} \left(\frac{i}{D} \right)^{-0.28} \quad (8)$$

$$\text{Where, } e = \frac{T - D}{2}$$

(b) $N_{Re} > 130$

$$N_{Nu} = 0.238(N_{Re})^{0.67} (N_{Pr})^{0.33} \left(\frac{\mu}{\mu_{\omega}} \right)^{0.14} \left(\frac{i}{D} \right)^{-0.25} \quad (9)$$

(5) Anchor

(a) $30 < N_{Re} < 300$

$$N_{Nu} = 1.0(N_{Re})^{0.67} (N_{Pr})^{0.33} \left(\frac{\mu}{\mu_{\omega}} \right)^{0.18} \quad (10)$$

Note : Anchor-to-wall clearance of less than 1 inch.

(b) $300 < N_{Re} < 4000$

$$N_{Nu} = 0.38(N_{Re})^{0.67} (N_{Pr})^{0.33} \left(\frac{\mu}{\mu_{\omega}} \right)^{0.18} \quad (11)$$

Note : Anchor-to-wall clearance of less than 1 inch.

(c) $4000 < N_{Re} < 37000$

$$N_{Nu} = 0.55(N_{Re})^{0.67} (N_{Pr})^{0.25} \left(\frac{\mu}{\mu_{\omega}} \right)^{0.14} \quad (12)$$

3.3.3 Outside Coefficients at Jacket Vessel (Annular Jacket with Spiral Baffling)(1) $N_{Re} < 2100$

$$N_{Nu} = 1.86[(N_{Re})(N_{Pr})(D_e/L)]^{0.33} \left(\frac{\mu}{\mu_{\omega}} \right)^{0.14} \quad (13)$$

(2) $N_{Re} > 10000$

$$N_{Nu} = 0.027 \cdot (N_{Re})^{0.8} (N_{Pr})^{0.33} \left(\frac{\mu}{\mu_{\omega}} \right)^{0.14} [1 + 35(D_e/D_c)] \quad (14)$$

(3) In the transient region, $2100 < N_{Re} < 10000$, obtain h_j from the greater result of the equations (13) and (14).Note : (1) $N_{Re} = D_e V_p / \mu$ (2) $N_{Nu} = h_j D_e / \kappa$

3.3.4 Inside Coefficients at Internal Coils

(1) Flat-blade turbine

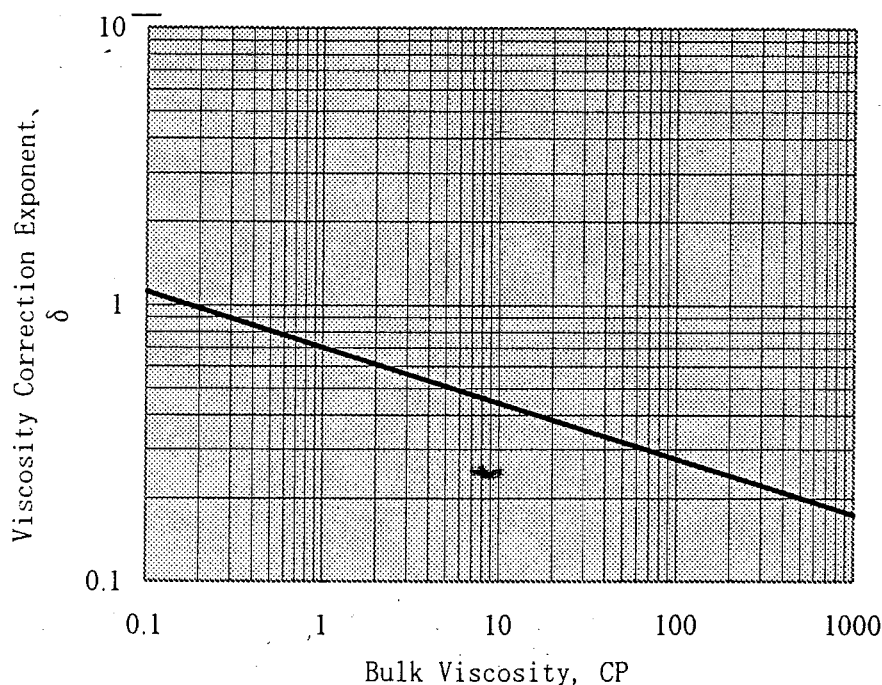
(a) Six blades at $400 < N_{re} < 1.5 \times 10^6$

$$\frac{h_i d_{co}}{\kappa} = 0.17(N_{Re})^{0.67}(N_{Pr})^{0.37}\left(\frac{D}{T}\right)^{0.1}\left(\frac{d_{co}}{T}\right)^{0.5}\left(\frac{\mu}{\mu_\omega}\right)^\eta \quad (15)$$

Note : For η , reference is made to Fig. 3.3.5.(b) Four-bladed turbine and vertical tubes as baffles at $1300 < N_{re} < 2.0 \times 10^6$

$$\frac{h_i d_{co}}{\kappa} = 0.09(N_{Re})^{0.65}(N_{Pr})^{0.3}\left(\frac{\mu}{\mu_\omega}\right)^\eta \quad (16)$$

FIG. 3.3.5 Viscosity Correction Applies to All Tanks



(2) Retreating-blade turbine with internal helical coils and impeller of six retreating blades.

$$\frac{h_i T}{\kappa} = 1.40(N_{Re})^{0.62}(N_{Pr})^{0.33}\left(\frac{\mu}{\mu_\omega}\right)^{0.14} \quad (17)$$

(3) Propeller

$$\frac{h_i d_{co}}{\kappa} = 0.078(N_{Re})^{0.62}(N_{Pr})^{0.33}\left(\frac{\mu}{\mu_\omega}\right)^{0.14} \quad (18)$$

(4) Paddle-(For mixing with a paddle)

$$\frac{h_i T}{\kappa} = 0.87(N_{Re})^{0.62}(N_{Pr})^{0.33}\left(\frac{\mu}{\mu_\omega}\right)^{0.14} \quad (19)$$