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Revision Memo

12/01 Minor modifications in guidelines for water suspension.



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SCOPE

This section covers the mixing of miscible fluids. This mixing can be for blending components having different physical properties or can be for ensuring the homogeneity of a single fluid. Blending operations in small tanks (up to 30 ft in diameter) is carried out using top entering mechanical agitators. For larger tanks either side entering propeller mixers or jet mixers can be used. Blending in continuous systems can be achieved with inline mixers. This section is to be used in conjunction with [Section XIII-A](#) for mechanical agitators and [Section XIII-D](#) for inline mixers. It is essentially self-contained for tank jet mixers.

REFERENCES

OFFSITES DESIGN PRACTICES

Section XXII-B Appendix B, C, D Storage Facilities

Section XXIV Blending Facilities

OTHER REFERENCES

Goldstein, A. M., *Design Guidelines for Propeller Mixing in Crude Oil Tankage*, ER&E Report No. EE.4TTR.73, June, 1973.

Tarmy, B. L., *Jet Nozzle Performance Evaluation*, ER&E Report No. EE.85E.73, August, 1973.

Fossett, H. and Prosser, L. E., *Proc. I. Mech. E.*, 160, 224 (1949).

Hicks, R. W., Morton, J. R., and Fenic, J. G., *Chemical Engineering*, April 26, 1976, p. 102 - 110.

Fasano, J. B., Bakker, A. and Penney, W. R., *Chemical Engineering*, August, 1994, p. 110 - 116.

Nazario, F., *Rollover Protection Guidelines for Refrigerated Liquefied Gas Storage Tanks*, ER&E Report No. EE.42E.83.

BACKGROUND

For the blending or mixing of miscible fluids, a criteria describing the desired approach to homogeneity must be set. Examples of such criteria are maximum allowable deviation of a fluid property (i.e., concentration, conductivity, color, temperature, etc.) at a point from the average value at that point, maximum allowable deviation of a fluid property between two or more points, etc. In addition to homogeneity criteria, blending operations can be specified on the basis of an empirical batch mixing time, ratio of mixer discharge flow to stream flow rate (or for batch systems, tank volume divided by batch time), or a mixing power per unit volume to be supplied to the contents of the mixing vessel. The application of the various criteria will be discussed in the design procedure for the various mixer types.

DEFINITIONS

The definitions given in [Section XIII-A](#) also pertain to this section. Additional terms are:

Heel - the amount of liquid in a tank before a refilling operation starts.

Roll over - the phenomena occurring when an initially dense layer at the bottom of a stratified tank becomes less dense than the fluid above it due to heat or mass transfer which then causes the layers to exchange positions and/or spontaneously mix.

Stratified - describes the situation in a storage tank when unmixed batches of fluids of differing densities form discrete layers in the tank.

Tank turn overs - describes a mixing criteria based on a ratio of total mixer discharge flow to the total volume being mixed.

EQUIPMENT TYPES AND APPLICATIONS

Miscible fluids can be blended in vessels or in inline mixing devices. Vessel mixing of miscible fluids can be done on a batch, semi-batch, or continuous basis. In a batch operation, all components are present before the mixing starts. In a semi-batch operation, mixing is underway as the components are added. The components can be added together or sequentially. For vessel mixing, three distinct configurations are in use: top entering agitators, side entering propellers, and jet mixers. Top entering mixers are used for small tanks and for tanks which have high mixing requirements such as reactors and flash mixing tanks used in wastewater treatment. Side entering propeller mixers are used in blending and storage tanks from 10 to 300 ft (3 to 90 m) in diameter. Side entering propellers are the normal mixing devices for crude oil storage tanks. Jet mixers are used in conjunction with a pump, which serves as the source of the required mixing energy. If the supply pumps have sufficient ΔP and flow capability, tank jet mixers are attractive for use in LNG, LPG, gasoline, jet, and distillate fuel storage and blending tanks.

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EQUIPMENT TYPES AND APPLICATIONS (Cont)

The inline devices are used when the components of the mixture are fed in the exactly desired proportion to the mixing device on a continuous basis. The inline device then removes any radial variations across the line cross-section. Inline devices do not provide back mixing; hence they cannot be used to smooth out fluid properties which vary with time. Inline mixers find application in gasoline and fuel oil blending operations when the line lengths after component addition are not long enough to insure the desired uniformity. The inline mixers are particularly useful upstream of analyzer sample points in computer controlled blending systems.

BASIC DESIGN CONSIDERATIONS

The basic requirements to be satisfied by the mixer are that the entire contents of the tank be mixed and that the mixing be completed within the desired time period. Consideration of the entire contents arises because if fluid batches of different densities are added to a tank, it is possible to form stable layers of the different batches. This is known as stratification. In a stratified tank, mixing accomplished by a mixer physically located in one layer does not guarantee mixing throughout the tank. The differing fluid densities, which lead to stratification, can be caused by differences in temperature or composition. In the case of refrigerated LNG and LPG, which can vary in composition, it is possible to add a dense layer to the bottom of a tank, which upon warm-up during storage can become less dense than the upper layer resulting in a "roll-over" of the tank contents. This can result in dangerously high vapor release rates, in non-pressure tanks, due to spontaneous flashing of the warm layer, which is suddenly exposed to reduced pressure at the surface of the tank. For operations where stratification can potentially occur, tank operating procedures and mixer design should be selected so that stratification will not occur. Once a tank becomes stratified, significantly higher mixing energy and longer mixing time are required to break the stratification.

VESSELS MIXED WITH TOP ENTERING AGITATORS

Top entering agitators are normally used for small tanks and for vessels having high mixing requirements. The agitator type used is dependent upon fluid viscosity as discussed in [Section XIII-A](#) (see [Table 1](#) in particular). For low and moderate viscosity applications, a pitched blade turbine or hydrofoil impellers are recommended, and the balance of this discussion will be limited to these turbines. However, design methods for achieving desired mixing objectives with other mixer types are available in the open literature, and EMRE's Chemical Engineering Technology (CET) section can be consulted for guidance in their use.

DESIGN CONSIDERATIONS AND PROCEDURE

The ultimate purpose of a turbine agitator is to achieve a desired process result. However, it is often difficult to accurately define the process result. Therefore, the mixer design is based on an appropriate dynamic response. For blending of miscible liquids, bulk fluid velocity (v_b) calculated from impeller pumping rate divided by tank cross-sectional area, represents the fundamental dynamic response. It is this velocity that is characteristic of all the velocities in the mixing tank.

Blending quality is quantified on a scale of 1 to 10 based on v_b and is described in [Table 1](#). The mixing system can then be designed by first specifying the desired scale of agitation. The required v_b , obtained from [Table 1](#) is used to calculate impeller pumping rate Q .

$$Q = \frac{\pi}{4} T^2 v_b \quad \text{Eq. (1)}$$

At this point an impeller is selected between pitched blade turbine (PBT) and hydrofoil impellers, and impeller diameter is decided based on D/T ratio between 0.25 and 0.6. The mixer speed is calculated in the pumping equation.

$$Q = N_q N D^3 \quad \text{Eq. (2)}$$

where: Q = Impeller pumping rate, ft³/min (m³/s)
 v_b = Bulk fluid velocity, ft/min (m/s)

N_q for PBT is plotted against N_{Re} in [Figure 8](#) of [Section XIII-A](#). N_q values for two hydrofoil impellers Lightnin A310 and Chemineer HE3 are given in [Table 5](#) of [Section XIII-A](#). For PBT, first turbulent conditions should be assumed for estimating N_q . The turbulent flow should be confirmed and N_q should be adjusted if needed. The calculated mixer speed should be changed to the closest standard speed using [Table 2](#) of [Section XIII-A](#). The impeller diameter should then be recalculated using [Eq. \(2\)](#). The mixer power is calculated using the method discussed in [Section XIII-A](#).

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TANKS MIXED WITH JET MIXERS

As discussed in [Section XIII-A](#), jet mixers can be used for continuously blending miscible fluids as they enter a tank or batchwise by recirculating a portion of the tank contents through the jet. The jet mixer is a stream-lined nozzle installed in the side of a tank near the bottom and discharges at an angle above the horizontal. It points diametrically across the tank at two thirds of diameter distance on the liquid surface, or preferably at the opposite corner on the liquid surface. A typical jet nozzle design is shown in [Figure 1](#) and a typical tank installation in [Figure 2](#).

DESIGN CONSIDERATIONS

Jets mix by the entrainment of the surrounding fluid into the jet. The induced flow within the tank is therefore greater than the jet flow itself and can lead to rapid mixing. The amount of fluid entrained by a jet is a function of jet Reynolds number, jet expansion angle, and jet length. Turbulent jets, i.e., jet Reynolds Number > 3000, provide the most effective mixing and thus jet mixers are designed for such operation. Entrainment is then dependent on jet expansion angle and length. Expansion angle is a function of the kinematic viscosity of the jet fluid as given by:

$$\tan \phi = 0.2 \, v^{0.133} \left(= 0.81 \, v^{0.133} \right) \quad \text{Eq. (3)}$$

where: ϕ = Jet half angle, angle between edge of expanding jet discharge and jet centerline, degrees

v = Kinematic viscosity, ft²/hr (m²/s)

Since experimental data are not available for liquids having kinematic viscosities greater than 7 centistokes, for conservative design, values for ϕ should be limited to that corresponding to 7 centistokes even for more viscous liquids.

The total flow produced by a free jet of circular cross-section (the type produced by a tank jet mixer) is given by:

$$Q_x = 2 \tan \phi \frac{x}{d} Q_0 \quad \text{for } 5 < \frac{x}{d} < 400 \quad \text{Eq. (4)}$$

where: Q_x = Total flowrate at distance, x, ft³/sec (m³/s)

Q_0 = Flow discharge rate from nozzle, ft³/sec (m³/s)

x = Downstream distance from nozzle, ft (m)

d = Nozzle exit diameter, ft (m)

The velocity of the jet decreases with increasing distance from the nozzle. The axial velocity along the jet centerline (the location of the maximum) is given by:

$$U_x = 5 \frac{d}{x} U_0 \quad \text{for } 5 < \frac{x}{d} < 400 \quad \text{Eq. (5)}$$

where: U_x = Centerline velocity at distance, x, ft/sec (m/s)

U_0 = Velocity at nozzle exit, ft/sec (m/s)

The jet centerline velocity is used to estimate the jet penetration distance above the surface at low tank liquid levels or to calculate forces on floating roof structures. The restriction of [Eqs. \(4\) and \(5\)](#) to downstream distances (x/d) of less than 400 is due to generally low velocities and lack of data beyond that point.

DESIGN PROCEDURE

Jet mixer design involves determining:

- The jet nozzle angle of inclination (θ)
- The required minimum jet nozzle diameter (d)
- The required minimum jet velocity (U_0)
- The existence of turbulent flow conditions (U_0)
- The guideline minimum number of tank turnovers (N_t)
- The time required to achieve homogeneity (t)
- The nozzle pressure drop (ΔP)

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TANKS MIXED WITH JET MIXERS (Cont)

Angle of Inclination

The jet nozzle angle of inclination is illustrated in **Figure 1**. The equation to calculate ϕ is as follows:

$$\theta = \arctan \frac{(H_s)}{(T)} \quad \text{Eq. (6)}$$

where: θ = Nozzle angle of elevation above horizontal, degrees
 H_s = Submergence of nozzle below liquid surface, ft (m)
 T = Tank diameter, ft (m)

Minimum Jet Nozzle Diameter

The nozzle exit diameter and discharge velocity are chosen to achieve adequate penetration of the jet stream across the tank. The minimum diameter to achieve this penetration is expressed by the following equation:

$$d \geq \frac{H_s}{400 \sin(\theta)}, \text{ ft (m)} \quad \text{Eq. (7)}$$

Minimum Jet Velocity

The required nozzle discharge velocity is given by:

$$U_o = \left[\frac{2 g F H_s}{\sin^2(\theta + 5^\circ)} \frac{\Delta \rho}{\rho_o} \right]^{1/2} \quad \text{Eq. (8)}$$

where: U_o = Nozzle discharge velocity, ft/sec (m/s)
 g = Acceleration of gravity, 32.2 ft/sec² (9.81 m/s²)
 F = Factor which is dependent upon the limiting design condition as discussed below, dimensionless
 ΔP = Density difference between jet liquid and tank contents, lb/ft³ (kg/m³)
 ρ_o = Density of jet fluid, lb/ft³ (kg/m³)

The factor, F , is calculated as follows:

1. To prevent stratification in an initially homogeneous tank:

$$F = 0.253 \left(\frac{\Delta \rho}{\rho_o} \right)^{-0.342} \left(\frac{H_s}{d} \right)^{0.652} \quad \text{for } \frac{H_s}{d} \leq 100 \quad \text{Eq. (9)}$$

or

$$F = 7.5 \left(\frac{\Delta \rho}{\rho_o} \right)^{-0.237} \quad \text{for } \frac{H_s}{d} > 100 \quad \text{Eq. (10)}$$

where: d = Nozzle exit diameter, ft (m)

2. To destratify an already stratified tank:

$$F = 0.586 \left(\frac{H_s}{d} \right) - 4 \ln \left(\frac{\Delta \rho}{\rho_o} \right) - 32.7 \quad \text{for } \frac{H_s}{d} > 50 \quad \text{Eq. (11)}$$