

# Jet mixing design and applications

Jet mixing creates fluid motion and shear by pumping the fluid through nozzles within the mixing vessel. This may require less energy than does mechanical agitation, especially in mixing large volumes of low-viscosity liquids.

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□ Jet mixing differs from most types of liquid/liquid and liquid/solid mixing in that the driving force is hydraulic rather than mechanical. Instead of shearing fluid and propelling it around the mixing vessel, as a mechanical agitator does, a jet mixer uses a centrifugal pump to force fluid through nozzles within the tank, creating high-velocity jets that entrain other fluid. The result is shear and circulation, which mix the tank contents efficiently.

Solids suspension, liquid blending and gas/liquid contacting may all be accomplished via jet mixing, but the technique is most likely to have a cost advantage over mechanical agitation in large-volume (over 1,000 gal) and low-viscosity (under 1,000 cP) applications. One general advantage is that a jet mixer has no moving parts submerged—the centrifugal pump is located outside the vessel.

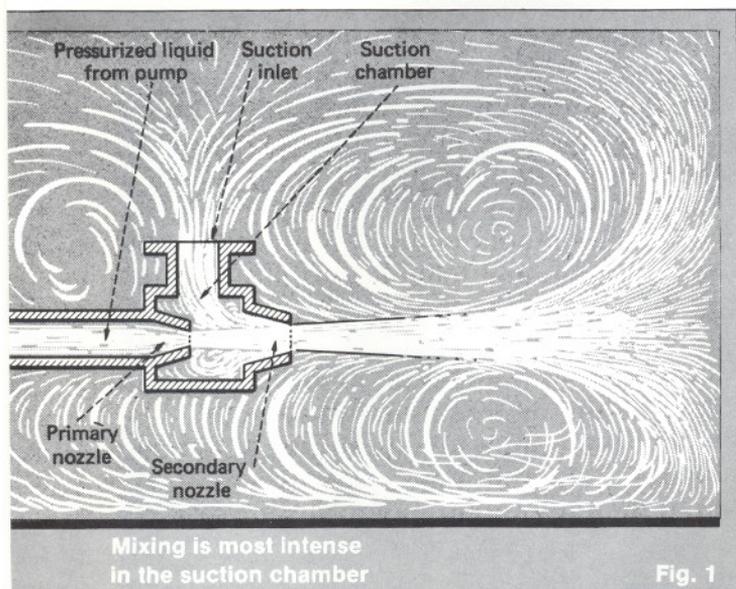
Engineers should consider jet mixing as an alternative to mechanical agitation for a variety of process applications. To aid in evaluating this technique, this

article tells how jet mixing works, where it is used, and how an engineer can develop preliminary design estimates for typical applications.

## Intense mixing within the jets

An individual jet, as in Fig. 1, has two concentric nozzles with a suction chamber between them. As the pressurized fluid flows through the primary nozzle and into the chamber, it creates a suction because of its high velocity—typically 6–10 m/s for low-shear mixing and 10–20 m/s for high shear. This suction draws fluid from the tank into the chamber, where the large velocity difference causes intense mixing. Within the jet, typical velocity gradients are on the order of 6,000/s, which means that velocity could go from 0 to 20 m/s across a distance of 1/300 m.

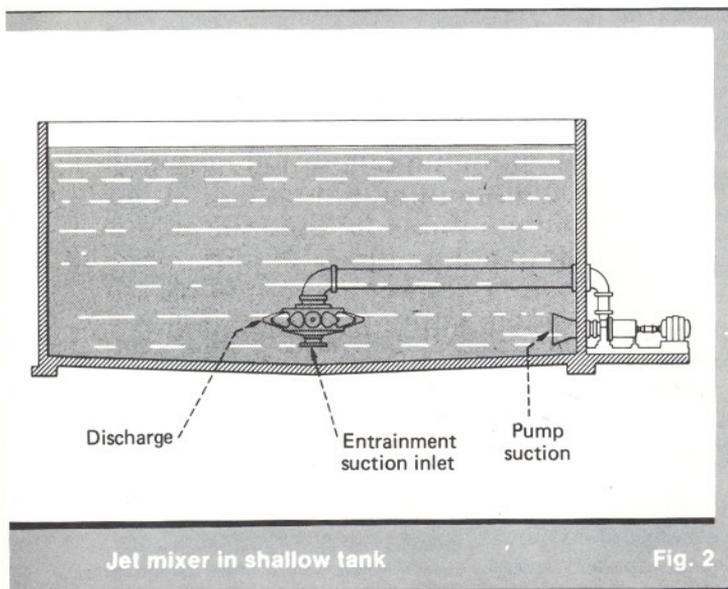
The mixed fluid is then expelled from the jet through the secondary nozzle. This forms a cone that entrains the surrounding liquid, and a plume that spreads horizontally before rising to the surface. The plume imparts



most of its energy to the fluid in its path, causing circulation and mixing throughout the tank. Mixing in the tank is less intense than in the suction chamber, with typical velocity gradients of 30–1,000/s.

Fig. 2 shows a typical jet-mixing system having 12 jets arranged radially in a cluster in the center of the mixing tank. The cluster of jets is called an eddy-jet mixer. The tank contents are pumped through the top of the mixer to the primary nozzles. Then, after passing through the common suction chamber, the 12 streams of fluid are discharged into the tank through the secondary nozzles.

A single eddy-jet mixer may have 4–24 jets, but 8–12 (as shown in Fig. 2) is the usual configuration. Likewise, a single tank may have 1 or more eddy-jet mixers, though 1 is most usual. Since a typical plume is about 5 m long (length depends on the pump discharge pressure), tanks more than 10 m dia. may require more than one cluster of jets (we will show an example later).



## Typical applications

Jet mixing is normally used for liquids and slurries having viscosities below 1,000 cP; a mechanical agitator is generally more efficient for higher-viscosity fluids. A single jet mixer can mix tanks of 200,000-gal (760 m<sup>3</sup>) and greater capacity, but jet mixers are usually not cost-effective for tanks smaller than 1,000 gal because such applications can use off-the-shelf mechanical agitators. In the photo at the beginning of the article (p. 89), a 1.35-m-dia. jet mixer having 12 jets is shown in a partially empty 240,000-gal tank. Usually, the mixer is submerged under several meters of fluid, but it can be operated at varying fluid levels.

Applications for jet mixing include: solids suspension (e.g., leaching or crystallization); liquid blending (e.g., neutralization or extraction); and gas/liquid mass transfer (e.g., aeration, reaction or stripping). In general, jet mixers tend to be used in situations that require turbulence, rapid approach to homogeneity, and high local shear rates.

Jet mixers can handle solid particles up to about 55 mm dia. For a given jet-mixing system, one must take care that the largest particles are smaller than the diameter of the primary nozzles, because plugging may otherwise occur. Jet mixers for abrasive or corrosive fluids are generally made of fiberglass-reinforced plastic, but may also be made of: carbon steel, stainless steel, high-alloy steel, rubber-lined steel, polyvinyl chloride (PVC) or PVC copolymers.

## Jet mixers vs. mechanical agitators

Fig. 3 shows a jet mixer and a top-entering turbine mixer in typical mixing vessels. What are the important differences in how they handle a given task? We have already discussed the volume and viscosity limits on jet mixing, so let us look at other aspects:

**Metal fatigue.** The rotating parts in a mechanical agitator are subject to reversing stresses that cause metal fatigue and, often, failure of shafts, seals and agitator blades—especially in certain corrosion/temperature environments. A jet-mixing system is not subject to reversing stresses.

**Mechanical components.** A mechanical agitator has a shaft and gears, and may even have immersed bearings if the shaft is very long, but a jet mixer has no such parts. A jet-mixing system does have a centrifugal pump with a motor, while a mechanical agitator has just a motor. A mechanical-agitator system may have a feed pump, however.

**Structural supports.** A jet mixer is usually anchored to and supported from the bottom of the tank, but may be supported from the walls or top if the tank is very deep. A top-entering agitator requires support at the top of the tank, which may mean specifying thicker walls or stronger materials.

**Location in tank.** A jet mixer is typically located about 0.5 m above the bottom of a tank, which saves energy in achieving off-bottom solids suspension because the mixing energy is provided where it is needed. A top-entering agitator typically requires about one impeller diameter of clearance at the bottom.

**Multilevel mixing.** In a tall tank, mixing at several levels may be necessary. One can install a top-entering

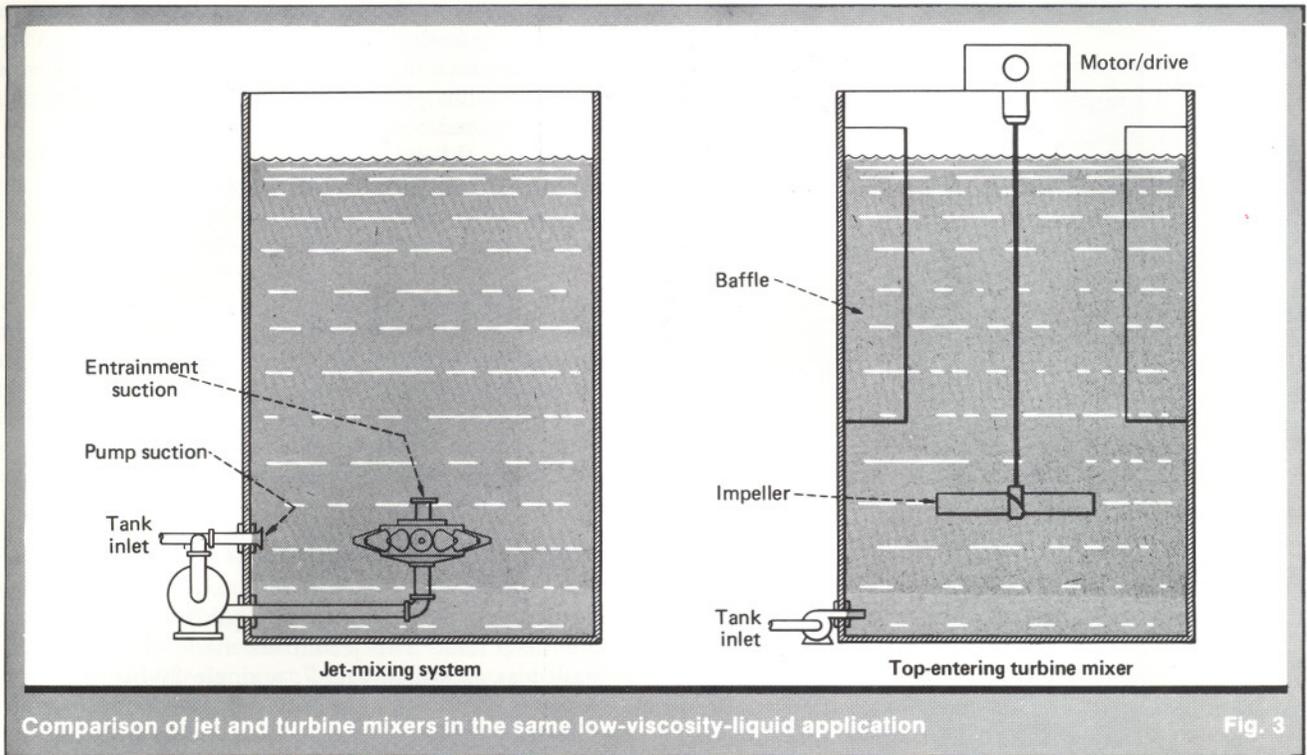


Fig. 3

agitator with two or more impellers on one shaft, or multiple side-entering agitators; or one could install two or more jet mixers at different levels. We will see an example of such a system later (in Fig. 7).

**Materials of construction.** Jet mixers may be built of plastic if necessary, while mechanical agitators for full-scale applications typically cannot.

**Baffles.** Top-entering mechanical agitators typically require a baffled tank, while jet mixers do not because the radial flow pattern eliminates vortex formation. However, a jet mixer will work well in a tank that already has baffles.

**Mixing partly-full tanks.** In most cases, a jet mixer can mix the contents of a tank even if the tank is only one-third or less full, but a mechanical agitator cannot.

**Manholes.** A jet mixer may require a larger manhole in the top of the tank, because it may have a greater diameter than a typical mechanical agitator for the same application.

**Tank geometry.** A jet mixer generally leaves fewer dead spots in a shallow or rectangular tank than does a mechanical agitator.

### Jet-mixer efficiency

Energy requirements in mixing depend on the task to be done. If it is simply to turn over the tank contents at a certain rate, the most energy-efficient approach is probably a center-mounted, top-entering agitator having a low rotational speed and high impeller diameter (such as 0.6 tank diameter). But a jet mixer is often more efficient when other mixing requirements, such as shear, are imposed.

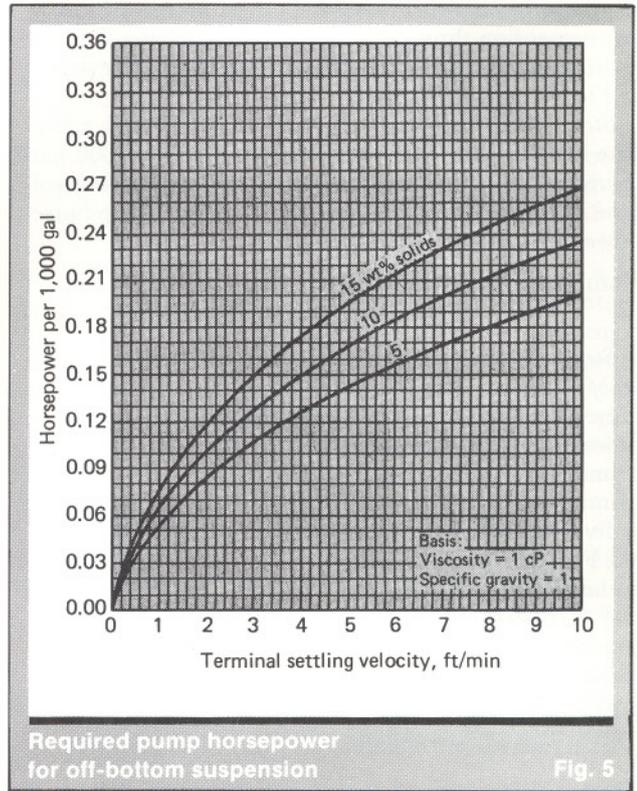
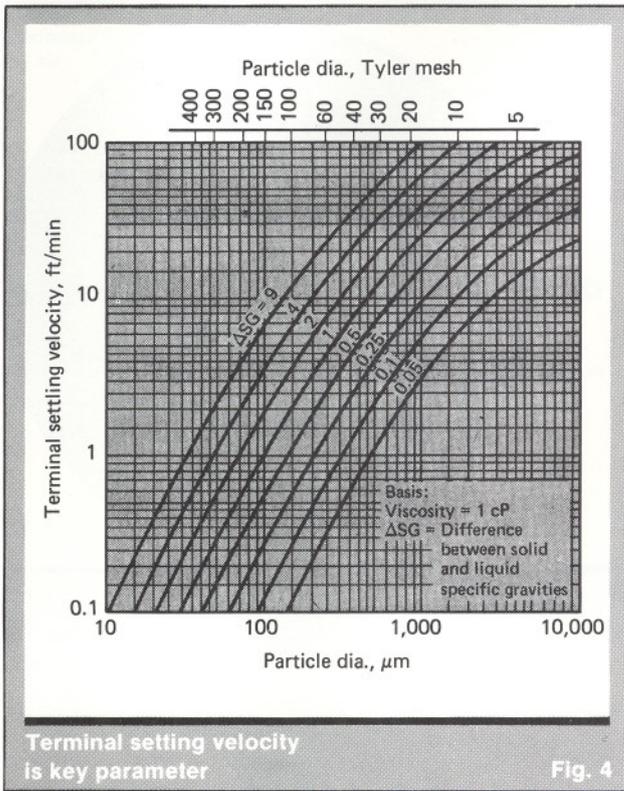
In general, a jet mixer uses less energy (typically 20–40% less) than a mechanical agitator for off-bottom solids suspension and for gas/liquid contacting. A me-

chanical agitator generally uses less energy for liquid blending in tanks smaller than 3 m dia. Before we discuss design parameters, let us look briefly at efficiency in three applications:

**Solids suspension.** Jet mixers use 20–40% less energy than do mechanical agitators in achieving on-bottom motion or off-bottom suspension. This is because a jet plume provides energy near the tank bottom (0.5-m clearance) while a mechanical agitator typically needs one impeller diameter of clearance. The energy saving diminishes as requirements for suspension increase toward uniform suspension throughout the tank, and the two types of mixers use roughly the same amount of energy for suspension above 35% of the fluid level.

**Gas/liquid contacting.** Eddy-jet mixers are very efficient gas/liquid contactors because they produce bubbles of about 0.2–0.6 mm dia., smaller than the bubbles produced by conventional sparger/agitators. Because of the greater bubble surface area and shear, the jet contactor typically achieves mass-transfer coefficients 20–50% greater for a given power input. Therefore, one can either use the same power and save gas, or use less power for the same amount of gas input and mass transfer. The optimal approach depends on the value of the gas versus the power cost.

**Liquid/liquid blending.** Experience has shown that a mechanical agitator requires about 25% less energy for blending liquids in tanks smaller than 3 m dia. In larger tanks, jet mixers and mechanical agitators use about the same amount of energy. To get the best results with a jet mixer, one of the fluids to be blended can be introduced at the pump suction. When the fluids have different densities, blending is enhanced by having a top-and-bottom piping arrangement such that the less-dense fluid is drawn into the pump at the top of the



tank and discharged through the jet mixer at the bottom (Fig. 8 shows an example).

**Design: Solids suspension**

Jet-mixing systems are used for solids-suspension applications such as crystallization, dissolution, flocculation and leaching. The following design technique allows the engineer to size and evaluate jet mixing for a particular application. This method works only within the following limits, which fit more than half of the jet-mixing applications in solids suspension: tank diameter (or width if square tank) of 3–12.2 m (10–40 ft); liquid level of 0.6–9.1 m (2–30 ft); total tank volume up to 1,360 m<sup>3</sup> (360,000 gal); and viscosity up to 30 cP. Jet mixing may be applied outside these limits, but other design techniques are required.

*Step 1: Determine terminal settling velocity.* This is the

basic parameter needed for the design. Fig. 4 shows terminal settling velocity in a 1-cP fluid as a function of particle diameter (microns or mesh size) and solid/liquid specific-gravity difference ( $\Delta SG$ ); one can also use a published technique\* or experimental data.

*Step 2: Determine required pump power.* Fig. 5 shows required pump horsepower per 1,000 gal for off-bottom suspension in a fluid of 1-cP viscosity. Terminal settling velocity and percent solids (by weight) are the parameters. For higher viscosities (to 30 cP), one can use standard viscosity-correction factors for centrifugal pumps—about 5% greater power would be typical for 30 cP. But note that settling velocity will be lower for a higher-viscosity fluid. For intermediate suspension (through about one-third of the fluid), jet mixing will

\*Perry's "Chemical Engineers' Handbook," 5th ed., McGraw-Hill, New York, 1973, p. 5-61.

**Jet-mixer design data**

Nominal pump hp	Pump capacity		Total pumpage		Primary nozzle area, cm <sup>2</sup>	Number of nozzles	Area per nozzle, cm <sup>2</sup>
	m <sup>3</sup> /min	gal/min	m <sup>3</sup> /min	gal/min			
3	0.75	200	3.75	1,000	12	12	1
6	3	800	15	4,000	50	8	6.25
8	4.5	1,200	22.5	6,000	75	12	6.25
11	6	1,600	30	8,000	100	8	12.5
16	9	2,400	45	12,000	150	12	12.5
21	12	3,200	60	16,000	200	8	25
31	18	4,800	90	24,000	300	12	25

Basis: Fluid viscosity = 1 cP; specific gravity = 1

require a pump with twice the power shown in Fig. 5. For suspension throughout 95–99% of the tank volume, jet mixing will require about ten times the power shown in Fig. 5.

*Step 3: Calculate nominal pump horsepower for tank volume.* The horsepower determined in Step 2 is per 1,000 gal; therefore, one must multiply this by the operating volume in 1,000-gal units to find the nominal pump horsepower needed for a particular tank:

$$\text{Nominal pump hp} = (\text{hp per 1,000 gal}) (\text{Volume}/1,000 \text{ gal})$$

*Step 4: Determine primary-nozzle area, pump capacity, number of nozzles, and area per nozzle.* Given the nominal pump horsepower, read from the table the next-highest horsepower. Then read in the same row the pump capacity, primary nozzle area required, recommended number of primary nozzles for the jet mixer (this is the number of individual jets), and the required area per primary nozzle. For solids suspension, 8 or 12 jets are usually recommended. Most primary nozzles have flow areas of 1–25 cm<sup>2</sup> (1.13–5.6 cm dia.).

*Step 5: Calculate actual motor horsepower.* The nominal pump horsepower must be corrected for the specific gravity of the fluid:

$$\text{Actual hp} = (\text{Nominal hp}) (\text{Specific gravity})$$

This is the horsepower used to size the motor. Note that figuring power consumption yet requires the actual motor size and efficiency.

## Design: Liquid blending

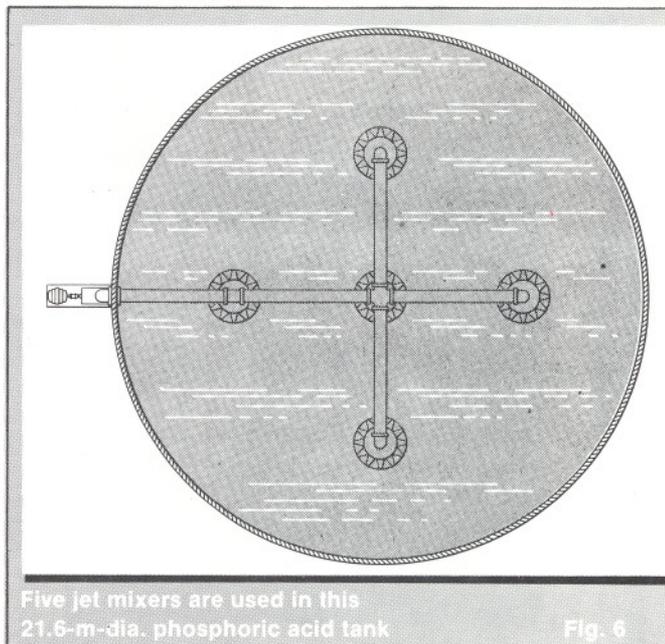
Jet-mixing systems for liquid blending are usually designed based on the rate at which liquid circulates within the tank. The following design technique, like the last one, has limits: tank diameter up to 15 m (50 ft); liquid level of 0.6–7.6 m (2–25 ft); total tank capacity up to 1,750 m<sup>3</sup> (460,000 gal) and usually above 7.6 m<sup>3</sup> (2,000 gal); and viscosity up to 30 cP. Jet mixing is not limited to these ranges, but applications outside of these may require different designs (e.g., multiple mixers) and design techniques.

Fig. 3 shows the usual bottom-suction jet-mixing system, which is adequate for most liquid-blending applications. At greater capital cost (about 10% greater), one can instead use a system with two pump suction, the second being near the top of the liquid. This provides better mixing, and should be considered when the ratio of liquid depth to tank diameter is 3 or greater; when the liquid depth is greater than 5 m (16 ft); and when low-density liquid would tend to collect at the surface. Our design technique applies to both types of systems:

*Step 1: Determine required turn time.* Turn time is the time required to turn the tank contents over once. For a jet mixer, the turn time is simply the liquid volume divided by the pumpage; pumpage is typically five times the pump output, because of entrainment. The engineer estimates turn time based on the intensity of mixing required:

- For mild agitation, typically 3–60 min. Applications include dye-blending, neutralization, and storage-tank agitation.

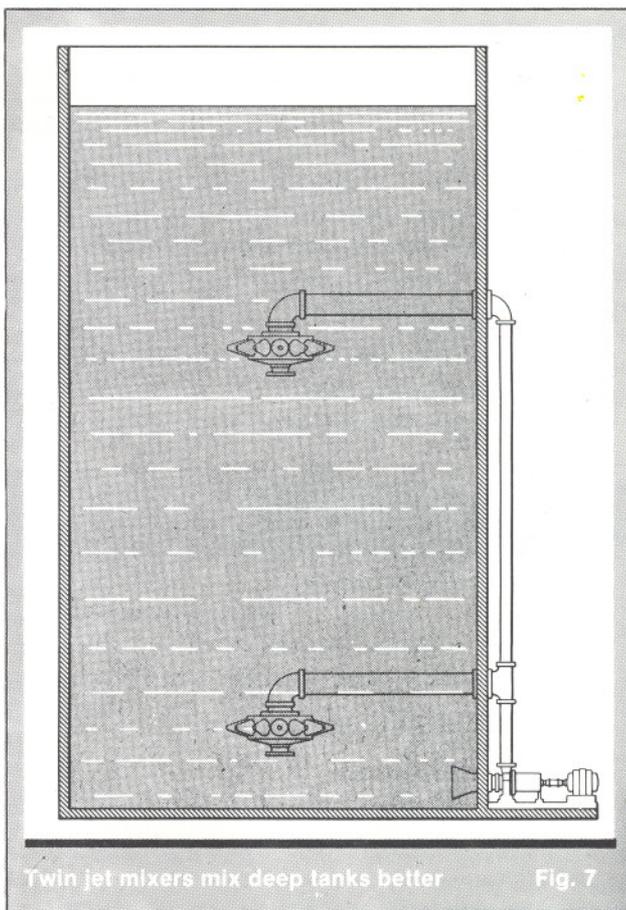
- For medium agitation, typically 30 s–3 min. Ap-

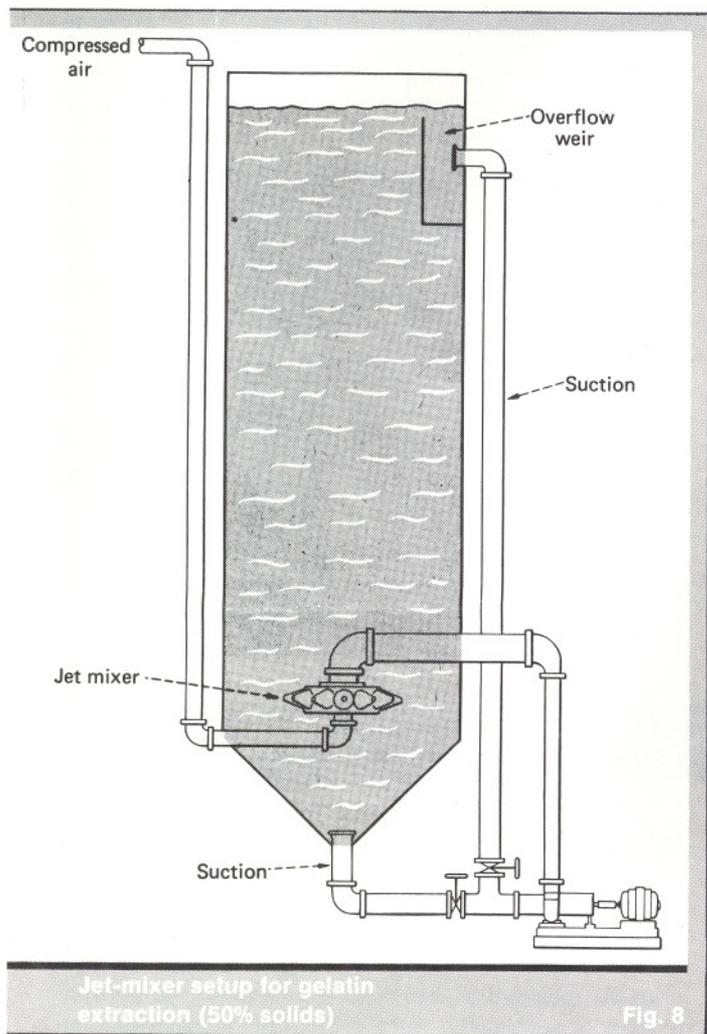


lications include pH control and batch mixing (as well as solids suspension and heat transfer).

- For violent agitation, typically 10–30 s. Applications include flash mixing, disinfection and pigment blending (as well as gas/liquid contacting).

*Step 2: Calculate pumpage requirement.* Dividing the max-





imum liquid volume by the required turn time tells the required pumpage:

$$\text{Pumpage} = (\text{Maximum volume}) / (\text{Turn time})$$

*Step 3: Determine pump capacity, nominal pump horsepower and other parameters.* Convert the pumpage to  $\text{m}^3/\text{min}$ , then go to the table and find the pumpage figure that equals or exceeds what is required. Then read in the same row the pump capacity, nominal pump horsepower, total primary nozzle area, number of primary nozzles, and area per nozzle. Note that the table assumes that pumpage is five times the pump capacity; this is based on 1-cP fluid viscosity, but is fairly accurate to 30 cP.

*Step 4: Calculate actual motor horsepower.* As for solids suspension, the nominal pump horsepower must be corrected for fluid specific gravity.

Designing jet mixers for gas/liquid contacting is beyond the scope of this article.<sup>†</sup> Let us now look at some applications to see what jet mixing can accomplish.

### Application: Phosphoric acid storage

A large tank (21.6 m dia. and 12.2 m depth) storing 54% phosphoric acid had phosphorus pentoxide ( $\text{P}_2\text{O}_5$ )

<sup>†</sup>A reference on gas-liquid contacting is: Prakash Bathija and Mikkel G. Mandt, "Jet fluid gas/liquid contacting and mixing," AIChE Symposium Series No. 167, Vol. 73, 1978, pp. 15-22.

solids settling at the bottom. This caused nonuniform acid concentration at the discharge and required frequent shutdown for cleaning the tank bottom. In addition, the solids plugged the discharge nozzles, causing some extended outages.

To solve the problem, five jet mixers made of fiberglass-reinforced plastic (FRP) were installed in the tank as shown in Fig. 6. A single 60-hp centrifugal pump (with stainless-steel wetted parts) provided the flow.

After installation, solids settling was cut to a minimum, discharge concentration was consistent, long shutdowns were eliminated, and tank-cleaning frequency was reduced. The same jet-mixing system was also installed in other tanks handling phosphoric acid at the same location. In this case, side-entering propellers or top-entering turbines could also have achieved the necessary off-bottom suspension, but the jet mixer was more efficient.

### Application: Neutralization in a deep tank

A chlorine plant had low-pH waste that had to be neutralized (by adding a liquid) in a 3-m-dia., 9-m-deep tank. Two jet mixers made of FRP were installed as shown in Fig. 7; a single 20-hp centrifugal pump made of titanium provided flow for both mixers. The result? Dye studies indicated that neutralization was complete in 45 min.

### Application: High-solids suspension

In the manufacture of gelatin from animal hides, the hides had to be soaked in high-pH water for 30 days (with no mixing) before the gelatin could be extracted. Mixing in such an application is difficult because solids concentration is high (50%) and the solids are large (50 mm square by 3 mm thick).

Fig. 8 shows a jet-mixer setup that achieves solids suspension throughout the tank. For this 4-m-dia. by 16-m-deep tank, a 40-hp centrifugal pump provides adequate flow. Some air is injected to speed the soaking.

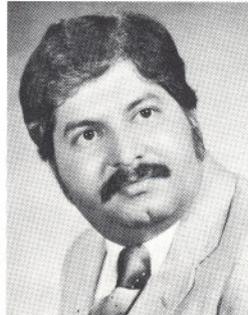
With the jet mixer, soak time is reduced to 6 days from the original 30 days. The payoff is in greater throughput per unit of soak-tank volume.

*Mark Lipowicz, Editor*

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