DESIGN AND UTILIZATION OF INTERNAL FITTINGS FOR MIXING VESSELS

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THE purpose of this paper is to make available to design engineers concerned with agitation in vessels, the best current practice for design, location and utilization of internal tank fittings, such as coils, baffles, draft tubes, steady bearing supports, compartmentation septums, spargers, feed pipes, and thermometer wells. Since many operations and processes require the presence of one or more of these elements within the tank system, it is desirable that they be utilized for the best results with agitation. In most cases the improper location of any one of these elements will defeat the entire purpose of the agitator, or at least, require additional horsepower for the agitator drive to obtain the results which could have been obtained with a smaller powered agitating device used in conjunction with properly designed internal fittings.

Fluid-Flow Requirements

One general requirement of agitation is to produce mass shuffling or constant interchange of the agitated material in all parts of the tank. Such an interchange is primarily a function of the pattern of fluid flow resulting from the rotating impeller and its environment. The mechanical factors which determine the fluid regime in a mixing tank are the tank shape, impeller, and any stationary object in the liquid. To produce the necessary interchange of particles in the shortest time, it is essential that currents of flow cause vertical motion from top to bottom and horizontal motion from center to tank wall. Such flows can be produced in differing relative intensities by various combinations of tank shape, impeller, and stationary objects.

Sometimes intense vertical currents are desired, when for example, heavy solids are to be suspended in liquids. At other times intense lateral or horizontal flows are required as is the case when gases are dispersed through liquids, or when miscible liquids of approximately the same density are to be blended. To obtain the effect best fitted to the particular operation it is necessary to know how each of the three mechanical factors (tank, impeller, and stationary objects) exert their influence on the fluid-flow pattern.

The type of flow which will insure vertical and lateral mixing is produced by any combination of impeller and its position relative to the tank sides, bottom, and baffles which will result in the elimination of vortices at the liquid surface. For large installations this condition is most easily achieved by the use of baffles of one form or another. For smaller and portable installations such flow conditions are attained by using "off-centering" without baffles, as well as by the use of baffles.

Whenever the combination of tank, impeller, and stationary objects results in deep vortices, liquid swirl will predominate in various degrees and will result in the minimum of vertical and lateral currents of flow. Swirling liquid produces laminar circular flow. Particles of like densities traveling in such streams stay stratified and will move vertically and horizontally only by virtue of their own relative diffusivities. Dense particles in swirling streams move away from the center of the motion by centrifugal force and will stay away from the central portion of the mass. This may result in separation, or classification and thickening, rather than suspension and mixing.

Vertical cylindrical tanks with dished-out bottoms are preferred for mixing operations, although agitating devices can be applied satisfactorily in spherical, rectangular or almost any other shape. The surface conditions of the tank wall should be relatively smooth within the limits of the materials used, and no sharp corners should be present. Fillets should be provided at the bottom and side walls of rectangular tanks whenever solids are present and are difficult to suspend. (*See* Figure 1.) It is usually desirable to operate with liquid depth equal to or greater than tank diameter. A depth of one and one-half diameters is a usual limit for a single impeller operation. In unavoidable situations shallow batches must be used and in such cases the recommended limitations for liquid depth, and tank diameter are as shown in Table 1. The effects of tank proportions on mixing requirements have been discussed elsewhere. (*1*)

Impeller Shapes

When any impeller, whether a paddle, a turbine, or a propeller, rotates in a vertical cylindrical tank without any stationary objects in the liquid, the flow pattern will be essentially a swirl. A deep vortex will form and the minimum of agitation and mixing will result from the energy supplied. One important exception to this is the off-center positioning of an axial-flow propeller.

Off-centering and Side-entering

Top off-center positioning is illustrated in Figure 2. The propeller shaft enters the top surface of the liquid to one side of the centerline and passes down through the liquid at an angle to the vertical. The exact position and angle of the shaft depend upon size of tank and depth of liquid, to secure agitation without forming a vortex. The position is critical and a variation of shaft angle, propeller depth, or lateral placement will allow swirling to take place. When properly installed the

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downward flow from the propeller is strong and excellent top-to-bottom movement of the liquid can be obtained without the use of baffles.

Top-entering off-center axial-flow propeller mixers are used in sizes up to ten horsepower units. They are usually applied to low-viscosity liquids; the propeller is immersed at least one diameter below the liquid level and operates at relatively high speeds. The shafts are almost always overhung, since steady bearings are to be avoided whenever possible. Their use and application will, however, be discussed in a later section. Steady bearings are often sources of corrosion and erosion difficulties in addition to the purely mechanical problems of alignment. In large tanks it is difficult to align any type of bearing. Tanks are usually made of thin metal and the shape often changes sufficiently with the amount of liquid in the tank to cause serious misalignment of bearings and supports. Wooden tanks swell and change shape between dry and wet conditions and bearings thus cannot be aligned with precision. Temperature changes and position of welds often result in distortion of tank walls and bottoms so that holes used for alignment and fastening will change position relative to the mixer shaft. Troubles have even been encountered in movement of bearing supports in a 3000-gal. tank, 8 ft. in diameter made of a concrete base and walls 16 in. thick.

Using overhung shafts makes it imperative that both the impeller shaft and bearings be adequately designed for the overhung stresses, and that the shafts are not allowed to operate above their critical speeds. Therefore there is a limit to shaft length for safe operation at a given power input. For these reasons ten horsepower is usually the upper limit with ordinary off-center top-entering mixers.

Another off-center position shown in Figure 3, which will also result in the elimination of swirl without the use of stationary objects, is the side-entering position. The shaft is horizontal but enters the side wall at least one and one-half propeller diameters below the liquid surface and is offset on a line parallel to a diameter of the tank. The exact positioning for proper performance is dependent on tank size and proportions, but the position is not quite so critical as that required for the top-entering off-centering. The location for clockwise rotation is given in Figure 3.

Side-entering mixers can be used in deep and very large tanks. Shaft lengths can be short since it is not necessary to locate the propeller very far from the tank wall. Thus greater power inputs can be handled by the same shaft and bearing sizes than for the corresponding top-entering sizes. Side-entering mixers are applied successfully up to twenty-five horsepower units.

Baffles or Swirl Breakers

In all vertical shaft and centrally located agitating devices, regardless of whether they are axial-flow propellers or radial-flow paddles or turbines, baffles or swirl breakers of some kind are an absolute necessity in order to secure the top-to-bottom interchange of particles necessary for the accomplishment of almost any agitating duty or service. Any stationary object located off the center-line of the tank will act as a baffle. Obviously, small objects give very little baffling effect. In low-viscosity liquids, baffles will result in greater power consumption by the impeller than when no baffles are present.

Necessity for such baffles is greater for low-viscosity than for high-viscosity liquids for equivalent power absorption. High-viscosity liquids offer internal fluid resistance which produces proportionally less swirl and more vertical flow currents for the same applied power than do low-viscosity liquids.

In liquids whose viscosities are several thousand centipoises or more an impeller will draw the same power regardless of whether baffles of any type are used or not. (*4*) Thus in most cases, no additional power is necessary to increase vertical flow currents when baffles or other stationary objects are used with high-viscosity liquids.

The number of baffles and the ratio of baffle width to tank diameter is more or less arbitrary and according to the manufacturers' ideas differ

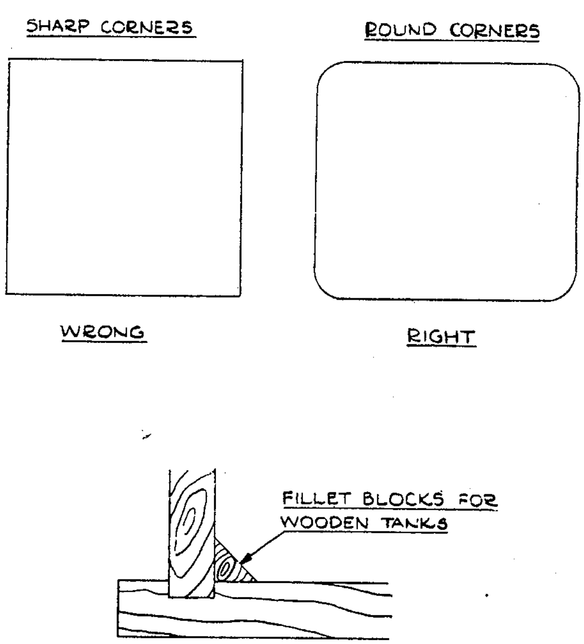

FIG. 1. SQUARE AND RECTANGULAR TANKS

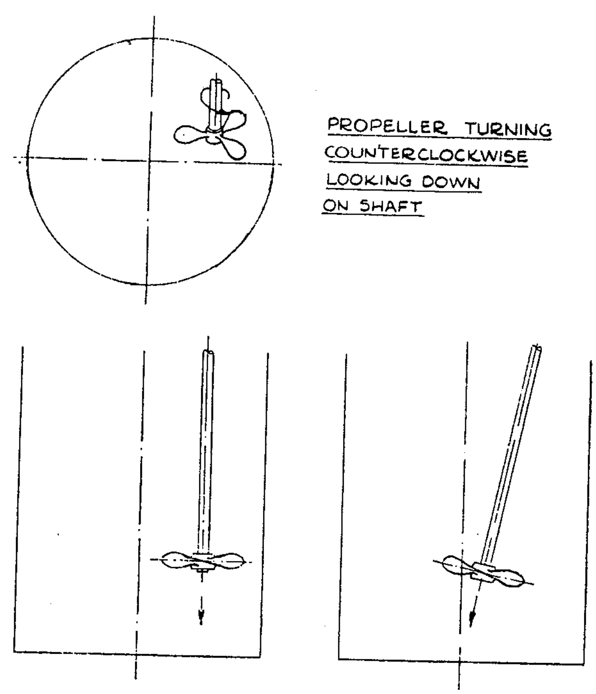

FIG. 2. OFF-CENTER TOP-ENTERING PROPELLER POSITION

on amount of vertical flow or turnover required. One manufacturer of mixers recommends four equally spaced baffles extending the full length of the straight vertical sides, and whose width is one-twelfth of the tank diameter. This arrangement results in the optimum power absorption consistent with adequate vertical and horizontal fluid-flow requirements. Power absorption is dependent upon the size and number of baffles for low-viscosity fluids. However, four baffles each extending one-twelfth tank diameter toward the center of the tank, will absorb almost the maximum amount of power possible with this type of baffle. Table 2 shows typical power data for a four-blade turbine (*5*) whose diameter was one-third tank diameter, and rotated on the center-line of a vertical cylindrical tank containing water. Note that for any given baffle width, the addition of baffles beyond four results in relatively little power increase. Similarly for any given number of baffles, an increase of width from one-twelfth to one-tenth has relatively little effect. For marine-type propellers a baffle width of 1/18 (or 0.055) tank diameter will absorb the same power at the same Reynolds number * as 1/12-width required for turbines. It should be emphasized that strong (and usually desirable) vertical currents can be produced by baffles at the expense of power-in low-viscosity liquids. Therefore baffles should not be added to existing nonbaffled installations without reference to the manufacturer of the agitator, to be certain that the agitator motor will not be overloaded under the proposed baffled conditions.

Baffles may either be welded or bolted directly to the tank wall. If solids or fibrous material is being handled, or for any reason it is necessary to clean the walls between batches, it is common practice to set the baffles out from the tank wall a distance of one-half to one and one-half inches. This "set-out" space is not considered a part of the baffle width. Thus a baffle width of one-twelfth tank diameter would be used whether the baffle was attached to the wall or set-out this small distance.

For simplicity in design and for instructions to the tank builder, baffles ordinarily should be installed to extend the full straight side of the tank. However, if light floating solids are to be added to the surface of the liquid, it is frequently desirable to cut off the upper part of a baffle so that it ends from two to six inches below the liquid level. This will prevent accumulations of solid at the lee side of the baffle, and will allow a slight surface swirl and small vortex down which surface particles can flow to the impeller.

In cone bottom tanks where agitation is required during draw-off, it is often necessary to extend baffles well down into the cone. When turbines are used it is very important that baffle area always be available directly opposite the turbine blades.

In many cases it is extremely difficult to provide wall baffles in existing tanks. This is a serious problem in connection with rubber-lined, lead-lined, and in the case of glass-coated and ceramic-lined equipment. At present most manufacturers of glass-lined tanks have made provisions for introducing glass-coated baffles which are adjustable in position by handles or stems passing through stuffing boxes in the head of the mixing vessel. Another form of baffle is the stator ring.

A stator ring is composed of a number of blades mounted on one or two rings whose inner diameter is slightly larger than the turbine to be used with it. The outside diameter of the ring is usually much less than one-half tank diameter. Blade width is a little greater than turbine-blade width and the ring is mounted in the plane of the turbine so that the ring blades are like fixed-position extensions of the turbine blades. Such stator rings are frequently provided instead of wall baffles. Sometimes they offer a satisfactory solution to the problem of breaking swirl and getting proper interchange of particles from top to bottom. They are often applied to glass-lined, lead-lined, or rubber-lined tank operations, where the tank-lining cannot be disturbed or changed.

The effect of a stator ring on the discharge flow from a turbine is basically different from that of baffles at or near a tank wall, in that it deflects and thus offers resistance to flow just after the liquid leaves the turbine blades rather than after the flow has reached the tank wall. Regardless of whether baffles are at the tank wall or close to a turbine (as in a stator ring), they function by providing deflection to flow streams and resistance to flow, causing vertical components of flow and formation of turbulent eddy currents at the expense of flow velocity. If baffles are at a distance from a turbine the high-velocity flow from the blades de-

TABLE 1.—MAXIMUM TANK DIAMETERS

Liquid Depth ft.	Maximum Tank Diameter ft.
1	2
3	8
5	16
8	30
10	45
12	55
15	80
20	140

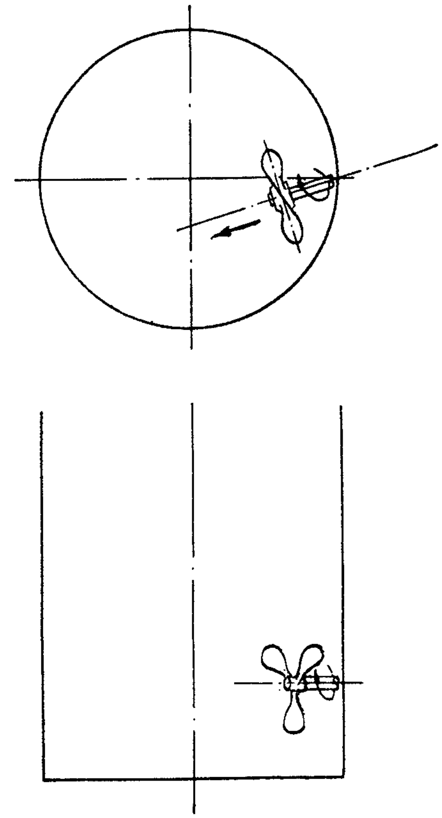

FIG. 3. SIDE-ENTERING OFF-CENTER PROPELLER LOCATION CLOCKWISE ROTATION

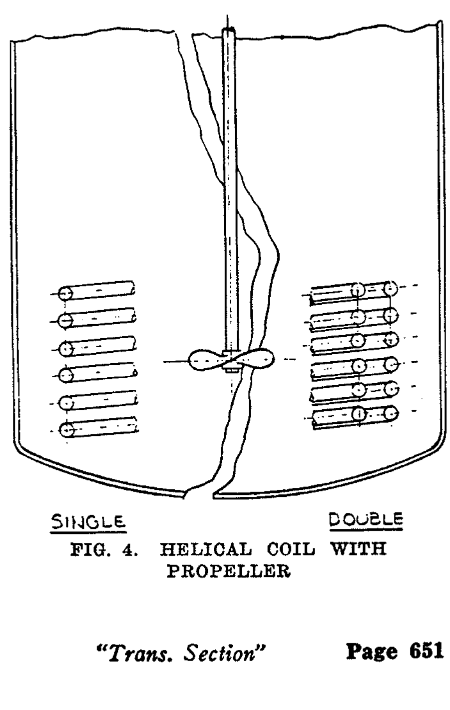

FIG. 4. HELICAL COIL WITH PROPELLER

* This refers to the usual modification of Reynolds number, applying to an impeller in a mixing tank, and is $N_{Re} = D^2N\rho/\mu$ where D is impeller diameter, N is revolutions of impeller per unit time, ρ is fluid density, and μ is fluid viscosity. (*4*)

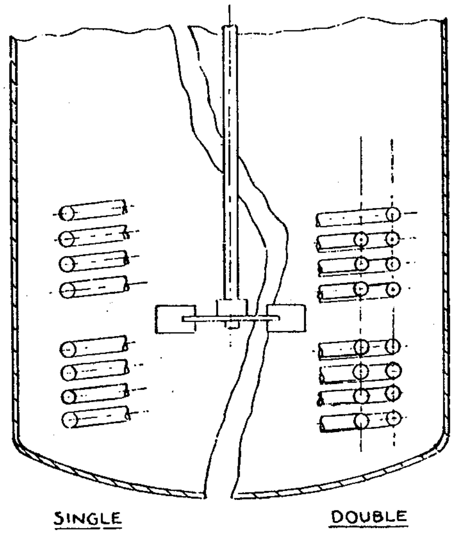

FIG. 5. HELICAL COIL WITH TURBINE

creases gradually as it approaches the wall and it then meets the baffle and wall resistance and the over-all flow pattern is set up. In this case the turbulence is carried throughout the liquid by the highest possible steam velocities. When baffles are placed in a stator ring the high-velocity liquid stream meets resistance before traversing to the tank wall and most of the energy is absorbed from the high-velocity streams, giving rise to turbulent eddy currents near the center of the tank rather than at the tank wall. With this arrangement a maximum of turbulence may result in a localized area only, because the fluid stream by which it is carried throughout the liquid may be of low velocity. Thus the choice between the two methods of baffling depends on whether it is desired to project streams with relatively high velocity to the tank walls and then produce additional turbulence by wall and baffle friction, or whether it is desired to produce the maximum of turbulence adjacent to the turbine and thereby have relatively low-velocity streams remaining to distribute such turbulence. Emulsions which are difficult to prepare and operations requiring disintegrating and breaking up of agglomerates, may sometimes be accomplished more readily by the use of stator rings where very high local turbulence is essential, than by the use of wall baffles. For most operations, including heat exchange, suspension of solids, and similar duty requirements, it is desirable to maintain high-stream velocities in order to distribute the eddy currents formed at the impeller blades and at the baffles, over as long a path as possible and to provide the high velocities at remote portions of the tank necessary to overcome the terminal velocity of fall of suspended particles. Baffles at the tank wall give such conditions.

Everything that can be accomplished by stator rings can usually be done with baffles. Baffles should not be considered standard design elements to be used on every occasion. Preliminary design, however, should always include the baffles at the tank wall, to be furnished by the manufacturer of the tank, unless off-center agitation is desired. In most cases this will reduce the over-all cost of the equipment, since the furnishing of baffles as part of the tank will always cost less than the furnishing of stator rings with their complicated supports and braces.

Ordinarily any vertical elements in the tank can be used as baffles or swirl breakers if properly located. Such elements are thermometer wells, downcomers or feed pipes, and coil supports. For operations involving heat transfer it is sometimes practicable to use vertical return bend-heating or cooling coils as baffles thus taking advantage of high heat-transfer coefficients resulting from the turbulence produced at the pipe baffle. Other heat-transfer elements which might be used as baffles are bayonet-type heaters, direct-fired flues, and anything else capable of being located in a vertical position a few inches from the tank wall.

Coils and Heat-Exchange Devices

Omitting consideration of the jacketed vessel for heat-transfer work, (since this paper is concerned only with internal tank fittings) probably the most commonly met heating or cooling device is the single bank helical pipe coil. The over-all heat-transfer performance of even this simple element, however, is greatly affected by its design and location. If the coil is placed too close to the tank wall, it is evident that the flow of liquid between coil and wall necessary for high liquid-film coefficients cannot be attained. A satisfactory position for such coils (¾-in. to 3-in. pipe size) is to allow a space of three pipe diameters (O.D.) between the coil and tank wall, but never less than 2 in. For double-banked coils the spacing between the outer coil and

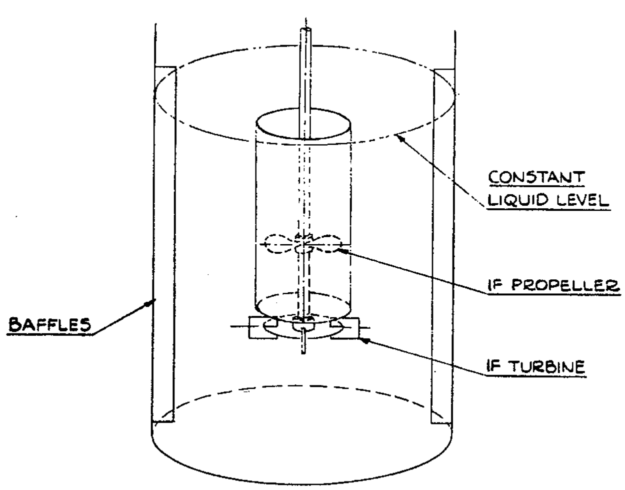

FIG. 6. DRAFT TUBE AND BAFFLES

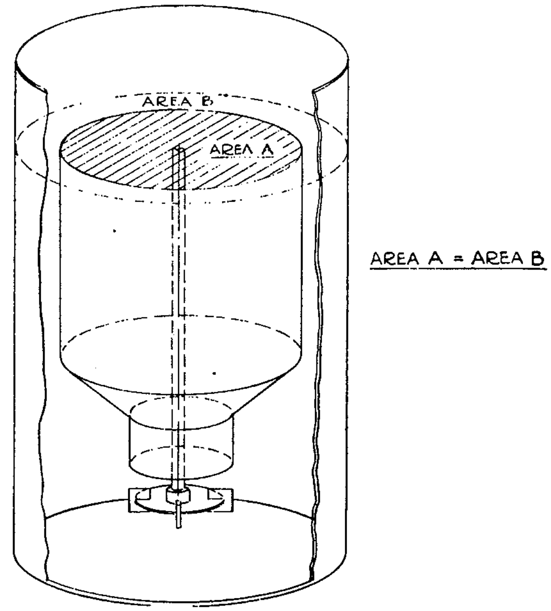

FIG. 7. UNIFORM VELOCITY BY USE OF DRAFT TUBES

the tank wall should be increased to about four times the pipe diameter, and the spacing between the inner and outer helix should be approximately two pipe diameters. Turns of the inner coil should not be staggered in horizontal planes with respect to the outer coil. (*See* Figure 4.)

Clearance between pipes in a helix need not be great and if liquid viscosity is less than 500 centipoises the clearance between layers may be as little as one-third pipe diameter.

Where very large coil surfaces are desired, a triple or even quadruple bank may be necessary. In this case the inner coil may be wound tightly to form a draft tube and the impeller should either operate within this coil, if an axial-flow propeller, or immediately below if a turbine is used.

When a propeller is used, driving liquid down to the bottom of the tank, the lowest turn of the helix is placed several pipe diameters above the tank bottom to allow the liquid to flow upward between tank wall and the coil. When a turbine is used and it is desired to assure flow between the tank wall and the coil sufficient in velocity to suspend any solids which may be present, the coil is split into lower and upper parts. The space between the two parts should be approximately equal to turbine-blade width, and the space should be directly opposite the turbine blades so that flow can pass to the wall of the tank with the minimum of resistance from the coil. (*See* Figure 5). If suspension of solids is not a problem then the helical coil can extend from three pipe diameters from the bottom to the surface of the liquid without interruption.

The position of either a propeller or a turbine is one impeller diameter off bottom for most mixing operations including those involving heat transfer. In large-sized vessels turbines are more frequently used, and when depth of liquid is equal to or greater than tank diameter, it is advisable to use several impellers on the same shaft so that more uniform flow patterns can be attained and all parts of the heating coils will have about the same flow environment.

Data are available (*2*) on heat-transfer coefficients for a helical coil in a paddle agitated vessel. The paddle acts like a turbine and thus the data show the same characteristics as for a turbine or any other radial-flow impeller. The paddle used in the data referred to was placed closer to the bottom of the tank than in many heat-transfer operations and due allowance should be made for its position relative to the coil height and liquid depth. For it is probable that too low an impeller position would not give the highest coefficients attainable for a given power input.

Pancake coils, closely conforming with the shape of the bottom of the tank, are practical for cone-bottom, dish-bottom, and flat-bottom tanks, when solids are not present to accumulate. If solids or suspensions are present, pancake or bottom coils should not be used.

The so-called hairpin coil or return-bend coil is frequently used on the bottom of large tanks. Location of such a coil may seriously interfere with agitation, permit the accumulation of high-density components where blending is to be accomplished, and will always encourage the accumulation of solids. In addition, such an element is relatively expensive to install and maintain, and interferes with the cleaning of the tank.

Baffles with Coils

In all cases coil supports can be utilized as baffles whether the coils are supported from the wall or from the bottom. Helical coils themselves give a limited baffling effect regardless of their pitch with respect to propeller rotation. Extra baffling is almost always necessary beyond that supplied by vertical-coil supporting members. Tables 3 and 4 give typical power-consumption data on effect of baffles and their position with respect to a helical coil. The effect is correlated by comparison with the power consumed by the same impeller rotating in the same tank but without the coil and with four equally spaced baffles each a 1/12-tank diameter. This arrangement has been described before as giving optimum results and is often termed "fully baffled condition." The power drawn by the impeller divided by the power at fully baffled conditions multiplied by 100 is the per cent of reference power shown in the last column. (Tables 3, 4.)

These data show that for maximum power absorption consistent with a desirable fluid-flow regime, coils should be of smaller diameter than that of the tank and the baffles should be placed between the coil and the tank wall. Such baffles could well be made as support for the coils, but they should offer baffle surface between the coil and the wall. With the coil turns spaced from 1½- to 2-tube diameters, for a turbine, it is necessary to use baffles sized 1/12-tank diameter when placed between coil and wall. Larger baffles are required when the baffle is placed inside the coil to achieve the same power absorption. For a propeller, less baffle surface is required to produce equivalent power and a desirable flow regime. Note that a 1/18-tank diameter (5.5%) baffle is equivalent to a 1/12-tank diameter (8.3%) baffle. As for a turbine the baffles should be placed between the helical coil and the tank wall. Similarly, greater baffle area is required for the same power when the baffles are located inside the coil.

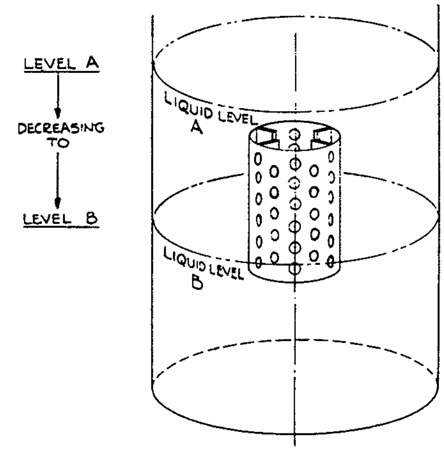

FIG. 8. PERFORATED DRAFT TUBE FOR VARYING LIQUID LEVELS

Securing Cross Flow of Fluid Over Coil Surface

In all the illustrations that have been discussed the recommended ar-

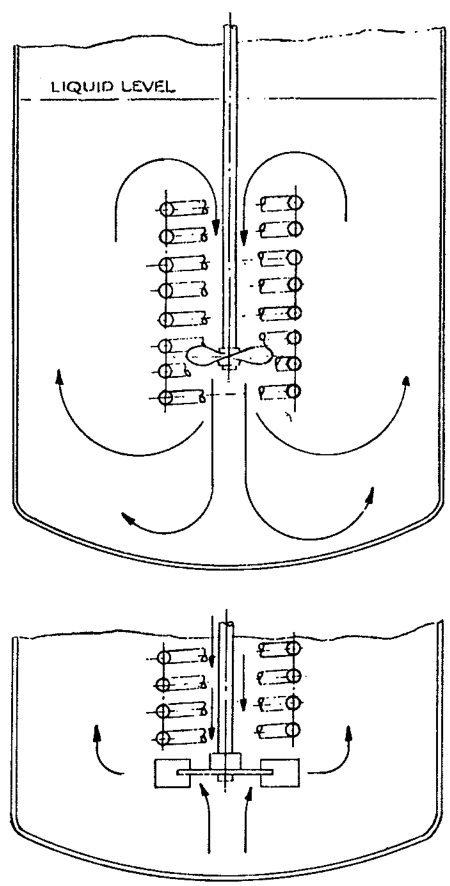

FIG. 9. COIL USED AS DRAFT TUBE

Table 2.—Relation of Power Absorption to Number and Width of Baffles

Per cent power based on four full-length baffles each one-twelfth tank diameter in width. Turbine Reynolds Number of 5×10^4. Turbine one diameter off bottom.

Baffle Width % Tank Diameter	% Power for One to Six Baffles					
	1	2	3	4	5	6
2	30	52	63	72	76	78
5.5 (1/18)	40	64	78	87	92	94
8.3 (1/12)	50	78	92	100	102	104
10.0 (1/10)	58	82	95	103	105	106

rangement will allow the maximum amount of cross flow over heat-exchange surfaces. In cross flow the principal component of the fluid flow will take place at right angles to the axis of the pipe instead of parallel with it. In any new design, or in the use of heating elements of shapes different from those illustrated and discussed here, the designer should attempt to locate the coils so as to obtain the high heat-transfer characteristics inherent in cross-flow heat transfer. Some data on coil heat-transfer coefficients are available *(2)* *(3)* and apply in most cases to coil arrangements and impeller shapes and positions which are not recognized as best practice. Thus, care must be exercised in applying such data to the commercially available impellers operated at positions recommended for best mixing performance. Sufficient data correlating fluid velocity, or a Reynolds number, to coil coefficients for coils of different pitches, diameters, and positions, are not as yet available so that heat-transfer coefficients cannot be predicted for arrangements other than the precise ones for which the present data apply.

Draft Tubes

Draft tubes are used with both axial-flow propellers and radial-flow turbine-type impellers. The proper function and use of draft tubes are not commonly understood, and they are often misapplied.

Two facts that should be kept in mind about the effect of draft tubes on the power requirements and on the fluid-flow pattern are: first, regardless of the position of the draft tube, for a given energy input to the impeller there will result less fluid discharge from the impeller than without the draft tube. This is due to the fact that fluid-flow resistance is increased whenever a draft tube (or any other fixed position object) is placed in a mixing tank, and second, the draft tube is useful to direct the liquid feed to an impeller if such direction is necessary or desirable. The discharge stream from an axial-flow propeller is cylindrical in shape *(5)* and persists so for a considerable distance. Thus the confining or directing influence of a draft tube is not needed on the discharge side of a propeller. However, the inflow to a propeller approaches that which develops in a Borda tube with the result that liquid approaches the feed side of a propeller from all directions.

Feed to a paddle- or turbine-type radial-flow impeller approaches from many angles both above and below the blades, whereas the discharge from the blades is sharply defined in direction and width of flow path. Therefore, draft tubes are useful on the *inlet* or *feed* side of impellers where it is desired to create a definitely directed, limited cross-sectional area, high average velocity inflow.

Unless it is essential to direct the inflow to an impeller it is ordinarily not necessary to use a draft tube. There are some mixing problems which require high "suction heads" to be developed and draft tubes confine inflow fluid streams thus producing high flow heads over limited flow areas. For example, when low density or hard-to-wet solids are added to the surface of a liquid, they can be drawn down to the impeller by the higher velocity downward flowing streams which flow from very near the liquid surface. (*See* Figure 6.) Such solids would usually accumulate on the surface if no draft tube were used and if a deep vortex were avoided.

When an impeller is placed very low in a deep liquid, a draft tube can be used to insure against short-circuiting of liquid in the lower part of the tank, because feed can be drawn down through the tube from the upper part of the liquid. Actually for ordinary mixing and blending operations for the same expenditure of power, a properly positioned impeller, or multiple impellers on the same shaft, will almost always accomplish a better result than by the use of a draft tube.

Propellers and turbines with draft tubes should be located as illustrated

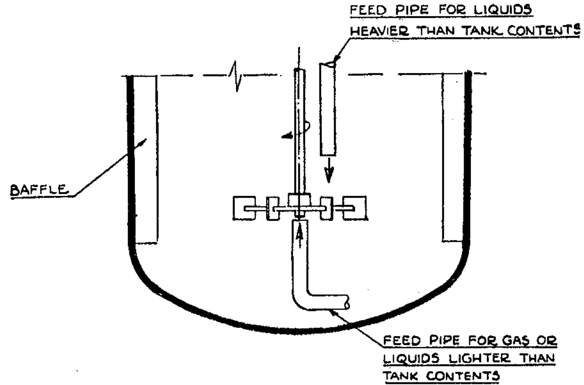

FIG. 10. FEED OF LIQUIDS AND GASES TO TURBINE

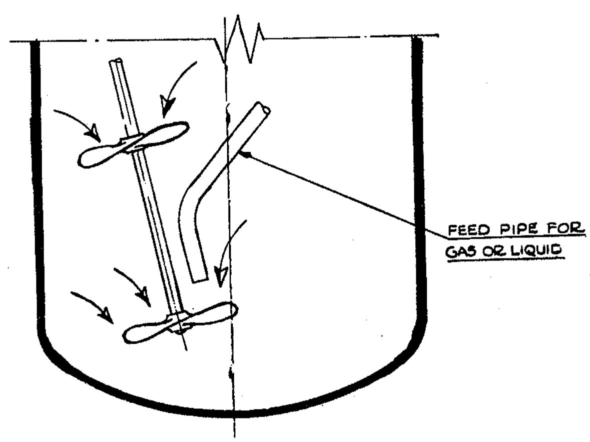

FIG. 11. FEED OF LIQUIDS AND GASES TO DUAL PROPELLERS

in Figure 6. Arrangement for the propeller results in positive flow upward through the annular space between draft tube and tank wall and results in high liquid velocities at the surface of the liquid toward the center of the tank. The propeller can be located at the lower end of the tube or a little distance above the end. If it is desired to maintain the same fluid velocity upward and downward, the cross-sectional area of the draft tube can be made equal to the annular area between tube and tank wall. This would result in a draft-tube diameter equal to 71% of the tank diameter. Since propellers (and other impellers) are usually sized at 33% of tank diameter, it is necessary to use a restriction at the bottom of the draft tube as shown in Figure 7, so that all flow to the impeller is brought down from the top and short-circuiting eliminated within the tube. When a draft tube is used with a radial-flow impeller, like a turbine, the impeller should be placed directly below the tube and should be of the same diameter as that of the tube, or of the throat of a larger tube.

If draft tubes are used without baffles in the tank or tube, swirl and vorticity will result. If swirl is to be eliminated, baffles should be used in the tank and also in the draft tube. The draft tubes are often made of sheet metal and are usually rather short so that they may be moved up or down to provide greater or lesser surface fluid velocity. High-surface velocities are often necessary in processing floatable solids and substances which tend to accumulate and agglomerate on the surface or in the body of the liquid. Sometimes draft tubes are made of sheet metal perforated with slots or holes so that they will feed even with falling liquid level. (*See* Figure 8.) Occasionally, a tightly wound helical heating or cooling coil is placed as in Figure 9 to act partially as draft tube.

TABLE 3.—RELATION BETWEEN BAFFLES AND HELICAL COILS ON POWER CONSUMPTION WITH A TURBINE

4-in. diameter 4-blade turbine rotated counterclockwise except as noted.

Tank diameter 13.5 in. Reference horsepower is that absorbed using no coils and four full-length equally spaced baffles each 1/12 (8.3%) tank diameter. Reynolds Number 5×10^4. Baffle widths are exppressed as per cent of tank diameter.

Baffles				
Outside Coil		Inside Coil		% of Reference Horsepower
Number	Width	Number	Width	
Coil made of 3/8-in. tube, coil spacing 3/4-in. single clockwise helix, 10 3/4-in. O.D.				
0	....	0	....	36
4	5.5	0	....	82
0	....	4	5.5	60
0	....	4	10.0	78
4	5.5	4	5.5	84
4	5.5	4	10.0	90
4	8.3	0	....	100
4	10.0	0	....	100
4	8.3	0	....	108*
Coil spacing 9/16-in.				
4	8.3	0	....	100
Coil diameter 13 1/2-in. O.D., 9/16-in. spacing				
0	....	0	....	30
0	....	4	5.5	76
0	....	4	11.2	86
0	....	4	22.2	100

* Rotation is clockwise.

Spargers and Feed-Pipe Location with Reference to Impellers

When any component of a mix must be dispersed rapidly, to prevent undesirable reactions if allowed to contact the other components in concentrated form, it should be led directly to the mixer impeller, as close as possible to the center of the im-

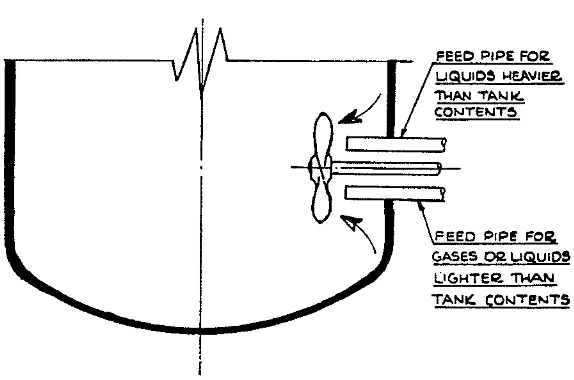

FIG. 12. FEED OF LIQUIDS AND GASES TO SIDE-ENTERING PROPELLER

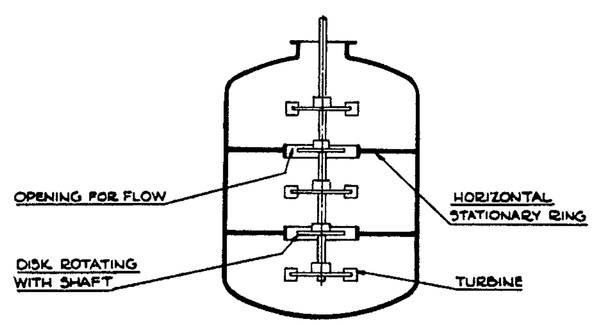

FIG. 13. VERTICAL TANK, COMPARTMENTED

TABLE 4.—RELATION BETWEEN BAFFLES AND HELICAL COILS ON POWER CONSUMPTION WITH A PROPELLER

4-in. diameter 3-blade marine-type propeller, discharging downward and rotating counterclockwise, one diameter off bottom.

Tank diameter 13.5 in. Reference horsepower is that absorbed using no coils and four full-length equally spaced baffles each 1/12 (8.3%) tank diameter. Reynolds Number 5×10^4. Baffle widths are exppressed as per cent of tank diameter.

Baffles				
Outside Coil		Inside Coil		% of Reference Horsepower
Number	Width	Number	Width	
Coil made of 3/8-in. tube, coil spacing 3/4-in. single clockwise helix, 10 3/4-in. O.D.				
0	....	0	....	76
4	5.5	0	....	98
0	....	4	5.5	90
4	5.5	4	5.5	101
0	....	4	11.2	98
Coil diameter 13 1/2-in. O.D.				
..	....	0	....	58
..	....	4	5.5	88
..	....	4	11.2	98
..	....	4	22.2	100

peller. This also applies to the addition of gas and air when they are to be dispersed. Figures 10, 11, and 12, show the desired location of the sparger or feed pipe for ordinary conditions. If a liquid is added which has a higher specific gravity than the average tank contents, it should be fed directly above the impeller. If the material to be added is a gas or a liquid lighter than the average contents of the tank, it should be added immediately below the center of the impeller. Open-type sparging is recommended with the proper speed and type of impeller, instead of porous ceramic spargers which produce fine bubbles but cause difficulty in cleaning and maintenance. A ring-type sparger should not be used unless the ring is less than one-third the diameter of the turbine with which it is used, and placed as close to the impeller as possible. Open-type turbines should not be used for gas dispersion due to the escape of the gas bubbles through the relatively slow moving central part of the turbine.

In the case of dual propeller installation, gas or liquid feed should enter between the impellers and just above the bottom propeller. (*See* Figure 11.)

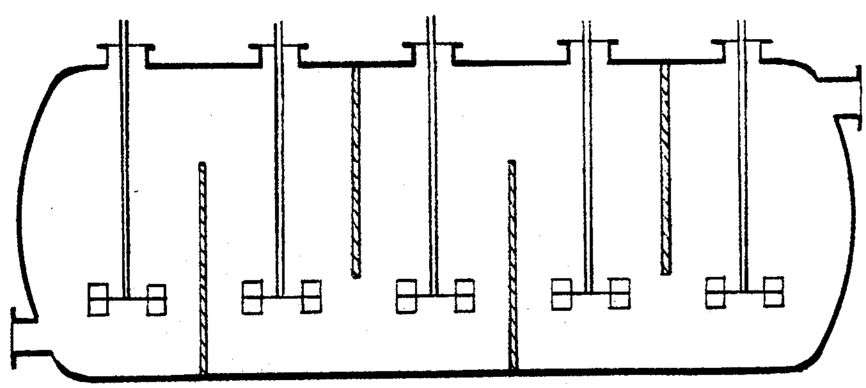

FIG. 14. HORIZONTAL TANK, COMPARTMENTED

Compartmentation of Vessels

Vessels are sometimes compartmented in order to accomplish the same results as the use of a number of vessels in series. A number of compartments may be required to reduce the percentage of material short-circuited through the system or to accomplish a series of different reactions in continuous flow. Compartmented vessels are used for continuous rather than batch operations. In a vertical cylindrical vessel the simplest design for installation and maintenance is to provide a nozzle opening large enough to pass the entire shaft and impeller assembly. If the compartments are formed by using horizontal stationary rings, the opening in each horizontal ring is partially closed by a disk of appropriate size attached to the shaft and rotating with it. (*See* Figure 13.) This makes it possible to control the size of openings, between compartments, which are generally sized to be just large enough to prevent undue resistance to flow through the system. Each compartment should be baffled in the usual manner as described here.

In the case of horizontal cylindrical tanks the compartmentation is usually affected by means of vertical septums staggered so as to provide over- and underflow. (*See* Figure 14.) In many cases manways are provided for access to each compartment. It is obvious, of course, that the compartments can be made of different size, and the size of impellers and the number of blades on the turbine can also be varied so as to give different degrees of intensity of agitation in any compartment. For example, it may be desirable to have a high degree of agitation, resulting in violent turbulence, in the first compartment while in later compartments less agitation may be necessary.

In a horizontal cylindrical tank it is also possible to have agitation in one compartment and to allow settling without agitation in the adjoining compartment. Settled material can be made to flow back into the first compartment by tilting the tank slightly and providing an opening at the bottom of the septum so that the feed end is lower than the effluent liquid end. However, the flow within the agitating compartment must be such as to allow gravity flow of the settled material under the septum wall and into the agitating compartment. This can be accomplished only by having liquid flow down the septum wall and across the bottom from wall to compartment center. Such flow can be achieved by the use of turbine impellers.

In the same category as compartmentation, as far as agitation is concerned, there are also such design elements as false bottoms, dissolving baskets, etc. False bottoms are used where large chunks or lumps of soluble material are placed in the tank, the false bottom being used to absorb the shock when the heavy materials are charged to protect the agitating device, and also to hold dense solids off the bottom so that they may be more readily contacted by fresh solute. If the solids to be handled in this manner are heavier than the liquid, the false bottom should be placed as close to the bottom of the tank as possible and still leave room for an impeller between the two. The depth of liquid underneath the false bottom should not be less than one-half the tank diameter. In the case of floating solids, such as large blocks of ice, the false bottom should be placed as close to the top as possible while permitting the floating chunks to move about freely. Such installations usually require 30 to 50 per cent more power than would be the case if the solids are broken up into smaller lumps. Small lumps are preferred to prevent damage to the impeller.

Dissolving baskets can be made in a square cross section and can run the full straight side of the tank. By using several of these, they may take the place of the conventional baffles if presenting the proper area. The dissolving baskets may be charged at the top in this case without danger of damaging the impeller. Conventional dissolving baskets or bags of materials hung over the rim of the tank do not require any special consideration, for if adequate baffles are being used, the additional resistance of the bags is not important.

Where solids must be handled and it is not possible to use a false bottom or dissolving basket, proper guards or bars must be provided around the impeller. These generally require special consideration. The use of fine mesh screen or hardware cloth around the impeller should be avoided since it would reduce velocity of stream flow through the tank.

Auxiliary or Steady-Bearing Application

One of the most frequent sources of trouble in the operation of mixers and agitating equipment is the tendency of the shaft carrying the impeller to "whip" or vibrate excessively, either while operating in air or during the period when the liquid level is passing through the plane of the impeller, which occurs when the tank is being filled or emptied. Shaft vibration usually results from operation at or near the critical speed, which is a function of the shaft length and size and the weight of the impeller. For overhung shafts (or those supported only by the mixer bearings and stuffing box) that operate satisfactorily in air, excessive vibration during the filling or drawing-off phases can usually be corrected by attaching a suitable stabilizing device attached to the impeller. (*See* Figure 15 for a turbine stabilizer.)

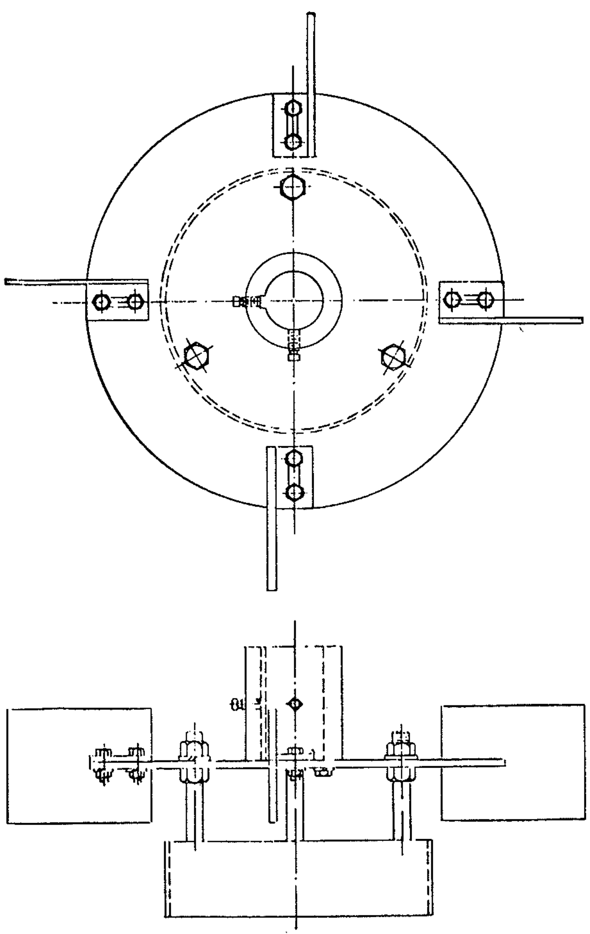

FIG. 15. TURBINE WITH STABILIZER

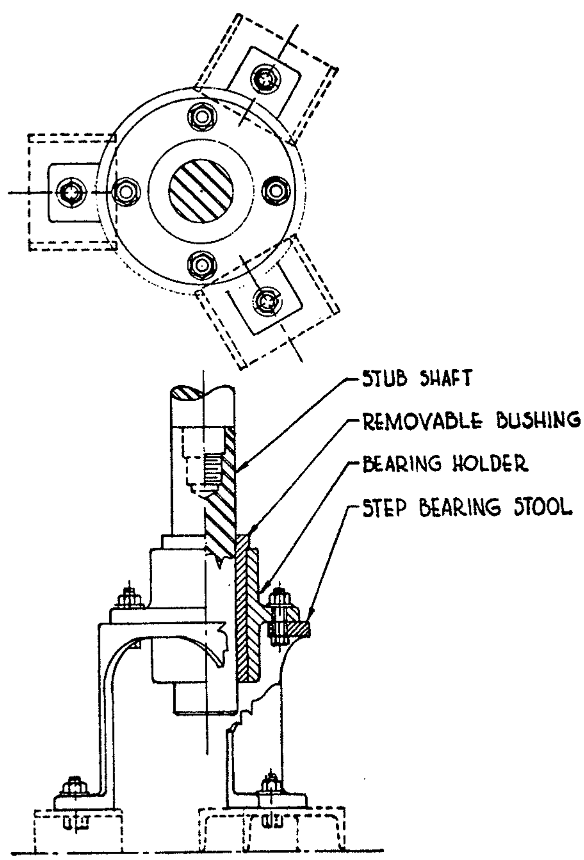

FIG. 16. STEADY BEARING

Propellers can be provided with fins for stabilizing. Development of critical speed theory and the formulation of actual test data obtained from laboratory research permit the application of overhung shafts with lengths of twelve feet without stabilizers, and with lengths up to sixteen feet with stabilizers, for safe operation through all conditions of filling and drawing-off, as well as satisfactory operation in either the air or the submerged phases.

In deep tanks, where very long shafts must be used, excessive shaft vibration may be ameliorated or eliminated by providing an auxiliary or steady bearing at the lower end of the shaft. The satisfactory operation of a bearing of this character is complicated by problems of corrosion and abrasive conditions in the tank contents, and the lack of good bearing qualities characteristic of most anticorrosive metals. Servicing an auxiliary bearing involves shutting down the equipment as well as the expense of removing and replacing the steady bearing itself, and the consequent loss of production should be given careful consideration by the designer of the tank. In many instances it may be desirable or expedient to specify two or more vessels of moderate depth with overhung impeller shafts in preference to a single very deep tank requiring a bottom steady bearing for the shaft. Installations of the former character will often show long-term savings in the form of continuous service, uninterrupted production, and freedom from maintenance.

If bottom steady bearings are necessary, the need for service and maintenance must be borne in mind by the designer. If the bearing is to be installed from the interior of the vessel, the coil spacing and the location of baffles or other internal equipment must be such that a mechanic can have ready access to the unit. One commonly used form of steady bearing (Figure 16) consists of a three- or four-legged bearing frame, welded to the bottom of the tank, to which is bolted a bushing carrier or adapter; the adapter is furnished with oversize bolt holes to permit adjustment for shaft alignment. The adapter carries a separate bushing so that replacement can be effected without disturbing the initial alignment. Another form of steady bearing consists of a simple pillow block with a replaceable bushing, bolted to a vertical clip bracket welded to the bottom of the tank. Either of these constructions will permit cleaning, and will eliminate the use of a structural steel member, such as an *I* beam or channel, extending across the tank. Members of this character should be avoided, since they allow corners for solids to accumulate.

If the vessel compartmentation, or the diameter of interior coils, is such that insufficient room is available for servicing the steady bearing from the interior of the vessel, it is necessary to provide a bearing which will be accessible from the outside of the tank. In such instances, the obvious (although sometimes overlooked) factor of providing sufficient room below the bottom of the tank to service the unit must be kept in mind and incorporated into the layout of the vessel and its auxiliaries. The steady bearing itself can be made accessible from below by providing a nozzle of suitable size in the bottom of the tank, directly under the end of the mixer shaft. If the bearing frame is mounted on a blind flange serving as a closure for the nozzle, the original alignment of the steady bearing must be made from the interior of the tank. Where this is undesirable or impossible, the bearing frame carrying the adapter and bushing should be attached to a ring mounted between the flange nozzle and the closure plate. The ring should be separately doweled for alignment.

Servicing of the steady bearing may then be accomplished by removing the closure plate and the ring; since the latter is doweled in place, it can readily be replaced with its original alignment after replacing the bushing and the shaft sleeve or stub shaft. Bottom steady bearings are sometimes, although erroneously, called "step" bearings. (The latter term refers literally to a bearing-carrying axial or thrust loads.) It is worthy of emphasis that a bearing submerged in a tank should provide radial restraint only, unless the liquid within the vessel has excellent lubricating qualities. For the usual operating conditions, any axial load induced by the shaft and impeller weights, or by virtue of any thrust caused by the impeller of the flow currents within the vessel, must be cared for by the bearings of the mixer itself. This is particularly important since the conventional step bearing is more difficult to lubricate than a sleeve or radial bearing, and especially so in submerged installations, where the only possible lubricant is the material within the vessel.

In some instances, tank designers specify or suggest an intermediate steady bearing, either in conjunction with a bottom steady bearing, or as a replacement for the latter. Intermediate steady bearings are even more undesirable than bottom steady bearings, particularly when the liquid depth is variable and there is danger of the bearing operating dry or above the liquid level, at some time during the mixing cycle. Intermediate bearings should be of the split pillow-block type, with split bushings, in order to avoid disassembly of the shaft and one or more impellers when the wearing parts require replacement. The usual stub-shaft construction cannot be employed, and a separate sleeve mounted on the impeller shaft is the only feasible method of providing for the inevitable shaft wear. Intermediate steady bearings are usually more difficult to support than bottom steady bearings, and require the use of a structural member extending across the tank, and will act as a baffle.

When an intermediate bearing is used in conjunction with a bottom bearing, it is difficult to obtain sufficiently precise alignment of the two tank bearings with each other and with the mixer bearings and the stuffing box. These difficulties are aggravated when shafts three or four inches in diameter are used, since it is difficult to obtain large diameter shafts sufficiently straight to eliminate undesirable flexure and excessive wear.

Proper attention to critical speed conditions, and careful design analysis, will permit the use of shafts with lengths of thirty feet or more, furnished with only a well-designed steady bearing at the lower end. Therefore, the application of intermediate steady bearings can and should be, restricted to those extreme and occasional circumstances that inevitably occur in practice.

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