Optimize Mixing by Using the Proper Baffles

It is common knowledge that baffles promote better flow in an agitated vessel, but how to apply them and what kind to use take some ingenuity.

Agitated vessels are used throughout the chemical engineering industries (CEI) for diverse applications including storing, blending and reacting materials. Agitator design requires specification of the motor, drive and impeller system that will satisfy both process (1, 2, 3) and mechanical (4) requirements. In addition, most agitated vessels are baffled, and the design of the baffle system must also economically satisfy process objectives.

Why use baffling?

During agitation of a low-viscosity liquid, the rotating impeller imparts tangential motion to the liquid. Without baffling, this swirling motion approximates solid-body rotation in which little mixing actually occurs. Think about stirring a cup of coffee or a bowl of soup: The majority of the mixing occurs when the spoon is stopped or the direction of stirring is reversed. The primary purpose of baffling is to convert swirling motion into a preferred flow pattern to accomplish process objectives. The most common flow patterns are axial flow, typically used for blending and solids suspension, and radial flow, used for dispersion. However, baffling also has some other effects, such as suppressing vortex formation, increasing the power input and improving mechanical stability.

A common agitation objective is suspending settling solids in a low-viscosity liquid, and Figure 1 illustrates the effect of baffling on this. In the unbaffled vessel on the left, the swirling flow field is ineffective at dispersing the solids that are grouped in a rotating pile below the pitched-blade impeller. Also, a large surface vortex is visible at the top of the shaft. In the vessel on the right, the baffles are visible on the left and right sides of the vessel and as a thin gray strip that bisects the impeller and shaft. The presence of baffles produces axial flow, in which the discharge flow produced by the impeller impinges on the base of the vessel, flows radially to the vessel wall, then up the wall, returning to the impeller from above. This flow pattern can be inferred from the solids that are distributed rather uniformly throughout the liquid. All parameters (impeller, speed, solids, etc.) are the same in the two vessels in

Figure 1. Agitation in an unbaffled vessel (left) leads to swirling flow with surface vortex formation and poor solids distribution, while standard baffling (right) with a pitched-blade turbine promotes axial flow that results in good solids distribution.
The only difference is the presence of baffles. However, note that baffles do lead to a difference in power input. This point will be discussed later.

Why consider baffling alternatives?

As evidenced by Figure 1, in most applications, the key to successful agitation is providing the proper flow field to achieve process objectives. In some instances, particularly the most challenging ones, selection of the proper baffling system is critical to providing the optimal flow field.

Standard baffling

Many agitated vessels, including the one on the right in Figure 1, use standard baffling, which consists of four flat vertical plates, radially-directed (i.e., normal to the vessel wall), spaced at 90 deg. around the vessel periphery, and running the length of the vessel’s straight side. Standard baffle width is 1/10 or 1/12 of the vessel dia. \((T/10\) or \(T/12\)) (5). Sometimes, baffles are flush with the vessel wall and base, but, more often, gaps are left to permit the flow to clean the baffles. Recommended gaps are equal to 1/72 of the vessel dia. \((T/72)\) between the baffles and the vessel wall, and 1/4 to one full baffle width between the bottom of the baffles and the vessel base.

Why use standard baffling?

The decision to use standard baffling is often an easy one. First, standard baffling typically provides near-optimal performance, and because of the symmetric placement of the baffles around the vessel periphery, standard baffling provides a high degree of mechanical stability. In addition, in turbulent operation, many impeller characteristics, such as the power and pumping numbers \((P_{gc}/N^3D^5\rho\) and \(N_Q = Q/ND^3\), respectively), are essentially independent of the impeller Reynolds number when standard baffling is used. Fully turbulent agitation occurs for impeller Reynolds numbers \((N_{Re} = ND^2\rho/\mu)\) greater than about 10,000. In contrast, in under-baffled vessels, the impeller power number continually decreases with increasing Reynolds number, introducing an additional complication to the design process (5).

And last, but far from least, because of its widespread use, the choice of standard baffling is supported by extensive design and scaleup data. It is the lack of such data and the potential sacrifice in mechanical stability that are the primary cautions when considering the use of non-standard baffles.

Baffling effects

Figures 2 and 3 illustrate how baffling in turbulent operation affects two primary agitator characteristics. Figure 2 shows that the impeller power number increases...
es as the number of standard width baffles \((T/12)\) is increased. Data are presented for three impeller styles: radial-flow impellers, such as straight-blade and Rushton turbines, mixed-flow impellers, such as pitched-blade turbines, and axial-flow impellers, such as high-efficiency impellers. All data in this figure are normalized with respect to the unbaffled condition, with each impeller style being normalized individually, rather than with respect to a common reference. “Normalized” means that, if the unbaffled radial-flow power number is 2.5 and the unbaffled high-efficiency impeller number is 0.2, then all of the radial-flow impeller data are divided by (normalized) 2.5 and all of the high-efficiency impeller data are divided by 0.2.

The power number of radial-flow impellers is most strongly influenced by the extent of baffling, continually increasing with the number of baffles. The mixed-flow and axial-flow impeller power numbers are affected to a lesser extent, approximately doubling for a single baffle compared to an unbaffled system, but increasing only marginally as the number of baffles is further increased.

It may seem counterintuitive to want to increase the power input to an agitated vessel. Why not operate at a lower power input in an unbaffled vessel? The reason for using baffles is that the higher power input is often necessary to achieve process objectives. Figure 3 illustrates that at equal power input with surface addition of the material to be incorporated, the turbulent blend time of an unbaffled vessel is substantially greater than that of a baffled system. In this instance, all impeller styles are affected in a similar manner, with the addition of a single baffle significantly decreasing the blend time, but the addition of further baffles having minimal effect. Again, all data have been normalized with respect to the unbaffled condition for each particular impeller style.

**Non-standard baffling applications**

Despite the popularity of standard baffling, there are many instances in which non-standard baffling is commonly used. In fact, there are situations in which no baffling is used. Baffles are rarely used with side-entering agitators or with close-clearance impellers, such as gates, anchors and helical ribbons, for which the impeller-to-tank dia. ratio is typically greater than 90\% \((D/T > 0.90)\). Baffles are also generally not used in rectangular or square tanks that prevent swirl by providing some natural baffling in their sharp corners as illustrated in Figure 4. The flow field in the unbaffled square vessel in this figure is quite similar to that of the baffled cylindrical vessel in Figure 1 (all conditions, such as speed, impeller and solids, are the same in Figures 1 and 4: only the vessel has been changed).

For impeller Reynolds numbers less than about 50, the viscous action of the liquid at the vessel wall causes a natural baffling effect, eliminating the nearly solid-body rotation that can occur during agitation of low-viscosity liquids in unbaffled vessels. Thus, no baffles or narrow baffles might be used \((6)\). Simply for convenience, small agitated vessels, less than a few hundred gallons, also may not be baffled. In these systems, angled and/or off-center mounting of the agitator can be used to eliminate excessive swirling. Mechanical complications and the associated costs generally preclude the use of angled and off-center mounting with larger agitators.

The flow patterns produced by off-center mounting in unbaffled vessels are shown in Figure 5. In the vessel on the left, the impeller is mounted vertically, but midway between the vessel centerline and wall, rather than on the vessel centerline. This reduces, but does not eliminate swirl. Although the solids are somewhat dispersed through the liquid, they are still grouped in a loose swirling pile at the center of the vessel base.

In the vessel to the right, in addition to mounting the...
impeller off the vessel centerline, the agitator is angled at approximately 10 deg. to the vertical. This combination in an unbaffled vessel approximates the flow field produced in a fully-baffled tank. When using angled mounting with an axial-flow impeller, the discharge flow produced by the impeller should oppose the swirling motion produced by the impeller’s rotation (5).

Baffles might not be used in vessels that require sterility or in which material hang-up during draining is problematic. Although choosing not to use baffles makes vessel cleaning easier, it can make optimal agitator design difficult. Some agitated vessels do not use baffles per se, but contain internals such as heat-exchanger tube-bundles that provide sufficient baffling to accomplish process objectives. In fact, some reactors that are used to carry out highly exothermic or endothermic reactions contain so many heat exchanger tubes that the vessel is over-baffled, making it difficult for the agitator to promote sufficient flow.

Flat-plate baffles are the norm because of their ease of manufacture and installation and the associated economy. A potential problem with them is that material can hang up or become trapped in stagnant regions near them, particularly in more viscous or non-Newtonian liquids, or in the presence of filamentous materials. This leads to the use of profiled baffles, often triangular or semicircular in shape, attached flush to the vessel wall that eliminate stagnant regions. The use of profiled baffles is limited to critical applications such as polymerization reactors and clean-in-place reactors, which are commonly used in the pharmaceutical industry. Another option is using baffles that are not mounted normal to the vessel wall, but that are angled away from the direction of impeller rotation.

**Glass-lined vessels**

Use of a limited number of baffles, one or two, is usually avoided because it does not provide adequate mechanical stability. However, there is one notable ex-
ception. To ensure the integrity of the vessel lining, rather than being mounted on the vessel wall, baffles in glass-lined vessels hang from flanges in the vessel’s top head. Typically, due to the limited space in this head, no more than two baffles are used in glass-lined tanks.

Figure 6 demonstrates that use of a single baffle is an improvement over an unbaffled system, but the flow is still highly tangential (note the small surface vortex at the top of the impeller shaft). The flow field in a vessel equipped with two standard baffles very closely approximates that in a fully-baffled vessel.

There are two primary challenges for baffling in glass-lined vessels. First, the surface of the baffle must be contoured because sharp corners cannot be coated with glass. As a result, the most common type of baffle used in glass-lined vessels consists of a pipe flattened to yield an elliptical cross section. This type of baffle is commonly referred to as a beavertail (Figure 7, left). The second challenge is that glass-lined vessels are under-baffled, and it can be difficult to provide sufficient power input to achieve process objectives. To overcome both of these challenges, a patented concave baffle has been developed (7, 8) (photo at the right of Figure 7, shown without the glass coating).

The data of Figure 8, taken with a retreat-curve impeller, the most commonly used impeller in glass-lined vessels, illustrates that the concave baffle increases power input relative to the beavertail baffle and that two concave baffles approach the power input of four standard baffles. Studies with the concave baffle confirm that the higher power input associated with this design leads to process improvements, such as more uniform distribution of settling or floating solids and enhanced gas dispersion. An additional benefit of the concave baffle is that it prevents surface vortex formation, and is therefore more effective at avoiding gas entrainment at high power inputs in under-baffled vessels.

**Surface incorporation**

In some applications, it is actually critical that the impeller draw in material — gas, floating liquid or solids — from the surface. In these instances, standard baffling may not be the best approach. Partial lower baffling is often used for drawdown of material from the vessel headspace. In these instances, four baffles of standard width are used, but they extend only about half way up the vessel’s straight side, leaving the upper portion un-

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pared to the two-baffle one is greater mechanical stability and better mixing in the lower portion of the vessel. The right-most data set of Figure 9 is for a narrow set of four baffles that is recommended for solids drawdown (9). This system uses four baffles that run the length of the vessel’s straight side, but the baffles are narrow, having a width equal to approximately 2% of the vessel diameter (typically $T/50$ to $T/40$, rather than the standard of $T/10$ or $T/12$). This system provides symmetry, and an associated degree of mechanical stability, as well as very low drawdown power requirements, good solids distribution throughout the liquid, and limited surface vortexing.

Additionally, the drawdown power requirement of the narrow baffle system is relatively unaffected by impeller submergence, a distinct advantage for processes in which the liquid level varies. The superior solids drawdown performance of the narrow baffle system is shown on the right of Figure 10.

In some instances, it is necessary to simultaneously satisfy a number of process objectives. Figure 11 shows how a dual-impeller system in a vessel equipped with partial lower baffles can be used to simultaneously draw down floating solids and suspend settling solids. The lack of baffles in the upper portion of the tank permits sufficient swirl to incorporate the floating solids, while the baffles in the lower portion promote axial flow that is effective at suspending the settling solids.

For some applications, partial upper baffling is the preferred approach. In pulp-and-paper agitation, the baffles may not extend below the impeller to prevent material hang-up and stagnant regions. A second example is high-solids-loading slurries that can be difficult to agitate, particularly if settled solids must be resuspended. Full baffling can cause the impeller and solids to bind, while removing the lower portion of the baffles allows tangential motion that can improve solids suspension performance (10). Partial upper baffles have also been shown to be somewhat effective for drawdown of floating solids (11, 12).

Concluding remarks

When agitating low-viscosity liquids, standard baffling typically provides near-optimal performance and good mechanical stability. In addition, standard baffling is backed up by extensive design and scaleup data. However, as described here, there are situations in which standard baffling may not be the best choice. The guidelines presented here are intended to identify the baffle system modifications that can be used to improve performance and the situations in which these modifications should be considered.

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