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MIXING AND AGITATION IN WATER TREATMENT SYSTEMS

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Mixing is one of the primary processes involved in water and wastewater treatment. In this article, the state of the art in mixing and impeller design is presented.

INTRODUCTION

Stirring is provided in a wide variety of processes to blend constituents or to disperse one phase into another or several other phases. In a blend-type operation, the purpose is to obtain a homogeneous mixture, whereas in the dispersion process, the goals vary widely, depending also on the nature of the phases involved:

- in gas-liquid dispersions, gas is dispersed into fine bubbles which must be distributed as evenly as possible in the vessel to take part in a subsidiary process, for example, absorption and/or reaction with a dissolved component, as in water and wastewater treatment, or flotation of hydrophobic particles, among others;
- in solid-liquid distributions, it is necessary to provide the appropriate conditions for entraining all solid particles inside the bulk of the liquid, either from the bottom of the vessel or from the free surface of the liquid;
- in liquid-liquid dispersions, fine droplets of one of the liquids have to be dispersed inside the other liquid to produce an emulsion or for a polymerization, among others.

For each of these processes, a particular type of agitator is appropriate. These have evolved from the simple paddles used during the past centuries; modern flow visualization techniques (1) have helped in designing agitator blade shapes optimized for specific processes.

In the following sections, the main types of agitators are presented, according to the processes for which they are intended; this presentation is limited to turbulent flow, which is typical in water and wastewater treatment processes, and does not describe agitators designed for viscous liquids (anchors, gates, etc.).

TYPES OF IMPELLERS

An impeller is a pump; by its rotation, it draws liquid from its neighborhood and then ejects it at a relatively high speed. It is typically mounted on a shaft connected to a motor, and the shaft-impeller structure is inserted in the stirred tank either axisymmetrically or sideways. Close to the impeller blades, the rotation induces a tangential flow. Inside the bulk of the vessel, on the other hand, the action of the impeller induces flow circulation, which follows a pattern typical of the impeller type. Thus, we distinguish mainly radial and axial impellers, depending on the direction of the flow that emerges from the impeller-swept region.

Radial impellers eject a liquid stream radially. In a typical stirred vessel where the impeller is mounted on a shaft, is vertical and is usually centrally located, the ejected liquid flows from the edge of the impeller blades toward the vessel walls. There, it separates into two streams; one flows in the upper part of the vessel and one in the lower part of the vessel, thus forming two flow loops. The liquid from these two streams circulates in the upper and the lower parts of the vessel and eventually is drawn back into the agitator-swept region; two primary circulation loops are established inside the stirred tank.

Figure 1 presents some typical radial impellers. The Rushton turbine (RT, Fig. 1a) is one of the most widely used impellers due to its efficiency in gas-liquid and liquid-liquid mixing. Its construction is simple; usually it has six flat blades mounted on a flat disk. Figures 1b (SCADA 65RT turbine or Chemineer CD-6) and 1c (Chemineer BT-6) present two variants of the Rushton turbine, where blades have a parabolic shape, which is even more efficient than the RT, especially in dispersing gas inside a stirred vessel. Finally, the Narcissus (NS) impeller (2) produces an inverse radial flow; liquid is drawn in from its side and pumped out from its upper and lower parts.

Figure 2, which is a 2-D plot of composite radial and axial velocities $U_R$—which are obtained from the vector sum of the radial ($U_R$) and axial ($U_a$) components of the local velocity vector—illustrates the typical radial flow patterns of the Rushton turbine—radial flow directed from the impeller toward the vessel walls—and of the Narcissus (NS)—radial flow directed toward the impeller. A similar double-loop circulatory flow pattern is induced by the SCABA turbine (3).

Axial impellers draw liquid mainly from one of their sides, top or bottom, and eject it from the opposite side; when liquid is ejected toward the bottom of the vessel, the impeller is said to work in the “down-pumping” mode, whereas when the liquid is ejected toward the surface of the liquid, this corresponds to the “up-pumping” mode. Often, liquid is also drawn from the side of the rotating impeller. Note that axial impellers are sometimes called “mixed-flow” impellers, too: in some cases, part of the ejected flow is directed sideways; this becomes more pronounced when the viscosity of the liquid increases (4).

Figure 3 presents some typical axial-flow impellers. The marine propeller (Fig. 3a) has been used for the propulsion of boats, and nowadays it is its sole application; far more efficient agitators have been designed for mixing liquids. Figure 3b shows the widely used pitched-blade turbine (PBT); the number of blades and their inclination usually characterizes the PBT more specifically, for example, the PBT in the illustration is referred to as a “4-45-PBT.” The Mixel TT has blades, which are wider than those of
Figure 1. Radial agitators: (a) Rushton turbine; (b) SCABA 6SRGT (or Chemineer CD-6); (c) Chemineer BT-6; (d) Narcissus.

Figure 2. Flow patterns induced by radial impellers in a stirred tank: (a) Rushton turbine (4); (b) Narcissus (NS) impeller (2).

the PBT and are profiled to be more efficient in energy consumption.

The typical 2-D flow pattern induced by all axial-flow impellers in their usual configuration—"down-pumping"—is illustrated in (Fig. 4a). As already stated, liquid is drawn from the upper part and the side of the impeller and is ejected downward. A single circulation loop is established in all cases; liquid flows upward close to the vessel walls and returns toward the impeller. The velocities in the upper part of the vessel are typically rather slow: the $U_{kz}$ vectors are much shorter than those close to the upper and lower sides of the impeller.
Therefore, the liquid in the stirred tank may be divided into two regions: the first corresponds to the primary circulation loop, which is established around the impeller; liquid flows fast and results in an intensive mixing process. The liquid in the second region, located mainly in the upper part of the vessel, circulates slowly; therefore the mixing process is less intense and effective there; it is often necessary to add a second impeller on the same shaft, to enhance circulation and mixing in the upper part of the vessel.

The inverse configuration—“up-pumping”—again yields a single primary circulation loop, located around the impeller (Fig. 4b). A smaller, secondary circulation loop is established in the upper part of the vessel, achieving better overall circulation and mixing than the “down-pumping” mode.

Several other impellers have been tested and/or marketed, based on extensive hydrodynamic performance measurements, taking into consideration some optimization criterion; some of them are variants of the pitched-blade turbine; others have blade shapes originating from hydrofoils. Figure 5 illustrates some of these impellers.

The size and location of the impeller inside the stirred vessel are dictated by the process needs and affect its performance, for example,

- to disperse gas effectively inside a stirred tank, it is necessary to use a radial agitator that has a large impeller diameter \( D \) to tank diameter \( T \) ratio, for example, \( D/T = 1/2 \), and to provide high rotational speed;
- if it is required to provide surface aeration to the stirred tank, the impeller is located close to the free liquid surface;
- if it is necessary to achieve an effective distribution of solid particles, an axial impeller having a reduced size \( D/T = 1/3 \) should be used, located closer to the bottom of the vessel, having clearance \( C \), that is,
Figure 5. Examples of advanced impellers: (a) "Medek" PBT [6,7]; (b) Chemineer HE-3 [8]; (c) Ekato MIC; (d) Lightnin A-310; (e) DeDietrich hydrofoil; (f) Lightnin A-320; (g) Prochem Maxflo; (h) APV B2.
the distance from the bottom of the vessel, close to \(T/6\) or even \(T/4\).

When mixing is applied to rectangular troughs, the axis of the impeller is horizontally located at one end of the trough, and an axial-flow agitator with hydrofoil blades is used to induce longitudinal motion of the liquid in the trough.

**PERFORMANCE DATA**

The performance of the various impellers is characterized by quantitative criteria; some of these are power consumption, the amount of flow circulation caused by the pumping action of the impeller, the ability of the impeller to cause intense circulation in the stirred tank, and the time necessary to achieve homogeneity of the tank contents, among others.

The power consumption depends upon the impeller type; it has been found that in turbulent conditions, where the dimensionless Reynolds number \(Re\),

\[
Re = \frac{\rho ND^3}{\mu}
\]

is larger than about 4000, the dimensionless power number \(P_o\),

\[
P_o = \frac{P}{\rho N^3 D^5}
\]

is approximately constant and characterizes each impeller. Table 1 presents power numbers for a variety of commonly used impellers.

Another feature of impellers is the amount of fluid being "pumped out" of the agitator-swept region; from the flow rate of this stream \(Q_o\), another dimensionless number, the flow number, \(Fl\), which also characterizes impellers may be obtained:

\[
Fl = \frac{Q_o}{ND^3}
\]

Table 1 presents typical values of flow numbers for the most common types of impellers.

One of the purposes of an impeller is to create circulation inside a stirred vessel, so one quantitative characteristic of its efficiency is the spatial mean velocity achieved in the vessel. This mean velocity, compared to the velocity at the tip of the blades \(V_{tip}\), yields the "agitation efficiency" \(I_0\) of each particular impeller (9).

Finally, the time to obtain vessel homogeneity is termed "mixing time" \(t_{mix}\); it has been found that for a wide variety of impellers it may be correlated to the power number and to the impeller-to-vessel diameter ratio (10):

\[
N t_{mix} = 5.3 (P_o)^{1/3} \left(\frac{T}{D}\right)^2
\]

**CONCLUSIONS**

Mixing is used in a multitude of processes, including water and wastewater treatment, to achieve several goals: to disperse another phase—gas, liquid, or solid—into the bulk of the liquid; to homogenize the stirred tank contents, and to assist and promote a reaction between some of the dissolved and dispersed species, among others. This is usually achieved by using rotating impellers, whose blade design has been often optimized for particular processes. Radial impellers, such as the Rushton turbine, are more suitable for homogenization and for dispersing a second phase in liquids; however, they generate high-shear flows. Axial-flow impellers are more suitable for solids dispersion and for cases where shear-sensitive material exists in the liquid, requiring benign mixing conditions.

**NOTATION**

- \(C\): clearance of impeller (from midplane to vessel bottom (m))
- \(D\): impeller diameter (m)
- \(Fl\): dimensionless flow number (-)
- \(I_0\): dimensionless agitation index (-)
- \(N\): impeller rotational frequency (Hz)
- \(P_o\): dimensionless power number (-)
- \(Re\): dimensionless Reynolds number (-)
- \(T\): vessel diameter (m)
- \(t_{mix}\): mixing time (s)
- \(U\): liquid velocity (m/s)
- \(V_{tip}\): liquid velocity at the tip of the impeller blades \(= \pi ND\) (m/s)

**GREEK LETTERS**

- \(\mu\): viscosity of liquid (Pa.s)
- \(\rho\): density of liquid (kg/m³)
INDEXES

R: radial
RZ: composite radial-axial
Z: axial

BIBLIOGRAPHY


