Designing of Mixing Equipment, Reactors and Bioreactors

T. Jirout and D. Jiroutova

Abstract The present work deals with general description of the most common processes in the agitated batch (blending and particle suspension) and with hydrodynamic parameters and geometrical configuration of the mixing equipment (shape of vessel, baffle and impeller and their mutual arrangement) that influence the process. The optimization of the construction and arrangement of the mixing equipment were performed to ensure the specified process with minimum energy consumption.

Keywords Axial impeller • Hydrofoil impeller • Multi-stage impeller • Blending • Particle suspension

1 Introduction

A mixing of liquid media is the one of the most common operations in the chemical, biochemical, food and consumer industry. The intensification of heat and mass transfer and preparation of mixtures with required properties, e.g. suspensions and emulsions, are mixing purpose. The mixing equipment with high-speed rotary impeller, which creates forced flow in the mixing vessel, is the most frequently encountered in industry.

The homogenization of the agitated batch and ensuring the particle suspension are the most frequently encountered requirements in terms of the mixing purpose. These operations are affected by flow in the agitated batch. The primary liquid flow influencing mainly suspension of the solid phase is caused by the pumping effect of the mechanical impeller [1]. Due to the momentum transfer between the liquid flowing from the rotor area of the impeller and surrounding environment arises in the remaining volume the induce flow that affects the homogeneity of the agitated

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batch. The geometrical parameters of the mixing system, especially the shape of the impeller blade affect character of the flow in the agitated batch.

For the designing of mixing equipment, it is necessary to determine the impeller speed needed to ensure the required process taking place in agitated batch and power consumption of impeller needed for drive and gear box dimensioning. These design parameters are dependent not only on the geometrical configuration of the mixing equipment (vessel shape, baffles, type of impeller and their mutual geometric arrangement) but also on the physic-chemical properties of the agitated batch.

2 Flow in Agitated Batch

2.1 Character of the Flow in the Agitated Batch

Flow and circulation of the agitated liquid in the vessel is the primary effect of the mechanical impeller. The geometrical parameters of the high-speed rotary impellers affect axial, radial or tangential character of the flow in the agitated batch – see Fig. 1.

Mixing equipment with cylindrical vessel and centrally placed high-speed rotary impeller, which creates a forced flow in the vessel, are the most frequently encountered in the industry. In case it is necessary to suppress a tangential flow in the agitated batch and prevent the creation of axial vortex, the cylindrical vessels are

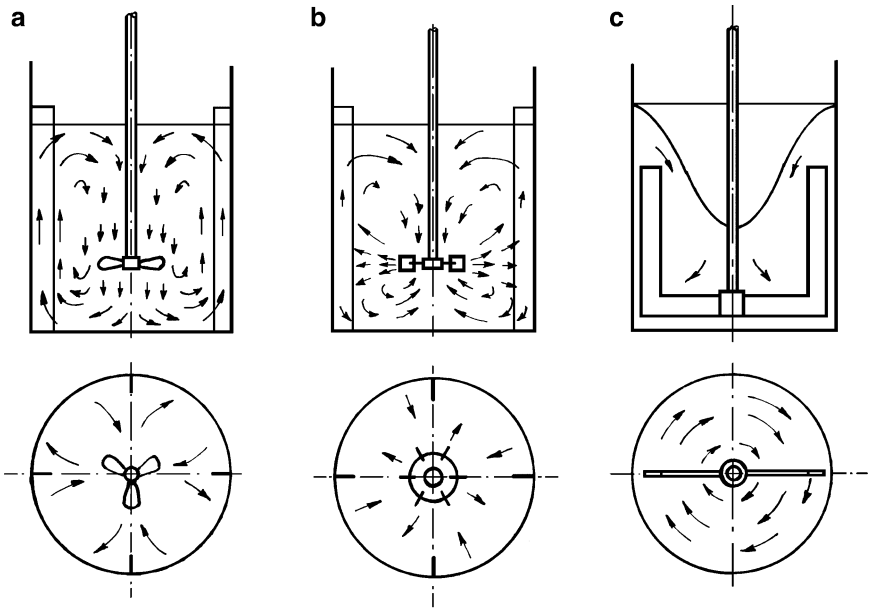

Fig. 1 Flow in agitated batch with rotary impellers [2]: (**a**) – axial-flow pattern (baffled vessel), (**b**) – radial-flow pattern (baffled vessel), (**c**) – tangential-flow pattern (unbaffled vessel)

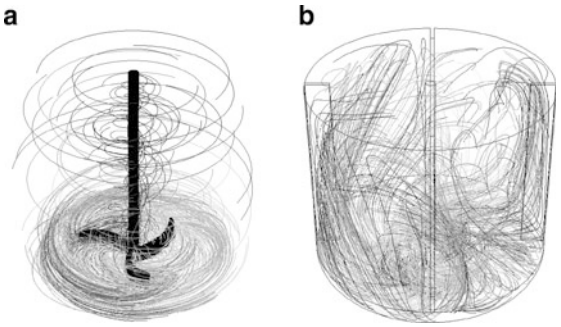

Fig. 2 Flow pattern in the cylindrical unbaffled vessel (**a**) and with two radial baffles (**b**) equipped with curved blade impeller

Fig. 3 Flow pattern in the square vessel equipped with axial impeller

equipped by differently shaped baffles (radial, tubular, special . . .). This adjustment of mixing equipment strengthens the axial flow and intensity of circulation in the agitated batch. This results in a significant improvement of the homogenization of miscible liquids, and heterogeneous mixtures in the agitated batch. Flow in the cylindrical vessel without baffles and with two radial baffles equipped with pitched blade radial impeller is shown in Fig. 2. It is not possible used vessels equipped with baffles in many applications, e.g. due to cleaning or surface finish (e.g. enamelled apparatuses). The axial flow can be enhanced by suitable impeller configuration in the case of viscous flow of agitated high viscosity liquid. Tangential flow in vessel without baffles under turbulent regime of flow can be partially suppressed by an eccentrically placed impeller in a vessel or using of impeller with special two-stage shaped blades. Square or rectangular vessel are sometimes used due to building plan or space saving. Sharp corners of vessel disrupt tangential flow and practically perform the function of baffles (Fig. 3).

Primary flow of the liquid Q_p in the agitated batch is caused by pumping effect of the high-speed impeller. Induced flow Q_i arises in the remaining volume of agitated batch due to momentum transfer between the liquid flowing from the rotor area of impeller and the surrounding environment. Primary and induced flow is shown in Fig. 4 in the velocity field of agitated batch with axial impeller.

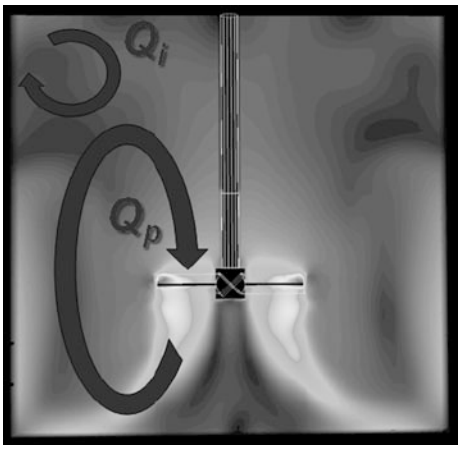

Fig. 4 Flow in agitated batch with axial impeller

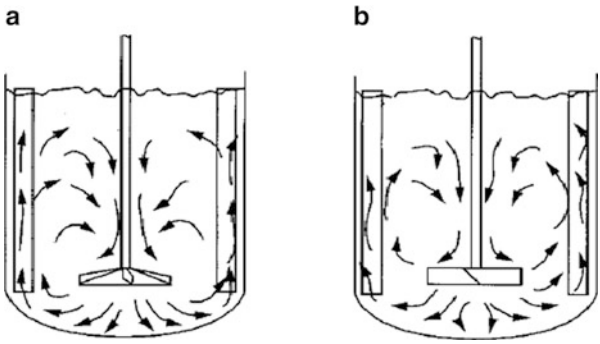

Fig. 5 Flow pattern in agitated batch equipped with axial hydrofoil impeller (**a**) and standard pitched blade impeller (**b**) [5]

2.2 Hydrofoil Impellers

The geometrical parameters of the mixing system and the shape of the impeller blade have essential effect on the velocity distribution in the agitated batch and thus affect processes of mixing [3, 4]. Currently the leading manufacturers of mixing equipment (e.g. Chemineer, Lightnin, Ekato and Czech company Techmix) uses its own developed new type of flow-optimizing impeller called *hydrofoil impellers*. The aim is design impeller with shaped blades that makes the most streamline of flow in agitated batch at achieving the highest hydraulic efficiency, i.e. the highest utilization of energy input to impeller in the form of its power consumption to initiate pumping efficiency and turbulences outside the rotor area of impeller. Comparison of flow in vessel equipped with an axial hydrofoil impeller and standard pitched blade axial impeller is shown in Fig. 5.

Design modifications of blade shape are consist in the adjustment of blade area and their bending or folding. Examples of development types of axial hydrofoil impellers are shown in Fig. 6. Basic no optimized type of impeller with pitched

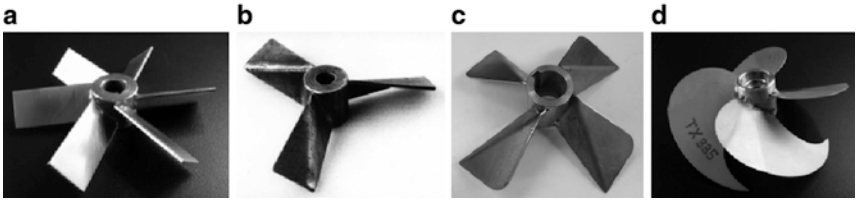

Fig. 6 Design modifications of axial impellers – from standard pitched blade to hydrofoil impeller

rectangular blades is shown in Fig. 6a. The diagonal folding of the blades is the simplest method of blade shaping (Fig. 6b). Folding of the blades results in uniform axial outflow of liquid from the impeller with almost piston velocity profile. Increasing of the blade area and adjustment of its shape its next step of design modifications. This adjustment will not only directing the flow, but also improve the process characteristics. Hydrofoil impeller proposed by author is shown in Fig. 6c [6] and hydrofoil impeller proposed by Techmix s.r.o. is shown in Fig. 6d. Shaping of blades is carried out either on the basis of working experiences or based on experimental results of process taking place in agitated batch (e.g. blending, particle suspension and dispersion) and velocity field in agitated batch (e.g. using LDA, PIV) or using CFD simulations.

The shape of the velocity profile at the outflow of the hydrofoil impeller, the streamlined flow of the batch within cylindrical vessel equipped by radial baffles and their high hydrodynamic efficiency are main qualities that predestine these impellers for enhancement homogenization [7–9] and particle suspension processes especially with regard to minimizing energy requirements. In case of the suspensions mixing in the vessel equipped by baffles where the density of particles is higher than liquid, these impellers should be placed above bottom of the vessel and pumping should be downwards the bottom [9–11]. Conversely, if the particles of the suspension are lighter than liquid, these impellers should be placed near liquid level and pumping should be upwards the level [12].

2.3 Multi-stage Impellers

To ensure homogeneity of the suspension mainly in slender vessel or for mixing of Non-Newtonian batch it is necessary to extend an intensive flow to the whole mixing batch, which can be achieved using *multi-stage axial impellers*. Generally, multi-stage impellers are commonly installed in slender vessels where individual impellers create independent circulation zones in the agitated batch. However, it is often necessary to ensure circulation in the whole mixing batch. It could be provided by the installation of multi stage impellers into standard agitated vessels with height of the liquid level approximately equal to the diameter of vessel.

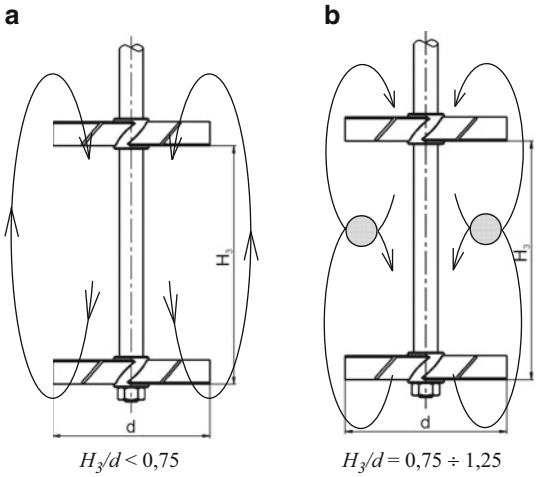

Fig. 7 Flow in vessel equipped with axial multi-stage impeller [13]. (**a**) $H_3/d < 0.75$, (**b**) $H_3/d = 0.75 \div 1.25$

The distance between impellers in a multi-stage arrangement has a strong effect on flow patterns in the mixing batch. In case of a relatively close distance between impellers i.e. at $H_3/d = 0.5 \div 0.75$, the suspension pushed out by the upper impeller is sucked by the impeller at the bottom. The multi-stage impeller creates only one circulation loop in the agitated batch (see Fig. 7a). However, for their distance higher than $H_3/d = 1.25$, the lower and upper impellers work independently that means two separate circulation loops are formed (see Fig. 7b).

The multi-stage impellers installed in the cylindrical vessel equipped by baffles are the most suitable impellers to ensure the required flow and circulation in the entire volume of the stirred batch during mixing of the concentrated, fain-grained [14] or heterogeneous suspensions [15] considering the required degree of the suspension homogeneity and energy demands of the process.

3 Special Aspects of Mixing Equipment Design

It is important during the mixing equipment design to choose mixing equipment configuration not only to minimize operating expenses, but it is necessary take into consideration choice of shape and material of functional equipment parts (impeller, shaft and vessel) with respect to their strength characteristics, corrosion resistance and mechanical wear. Mixing equipment are often exposed to aggressive environments in the chemical, food and pharmaceutical industry. It is necessary to protect mixing equipment against corrosion and wear by using of suitable surface finish, e.g. enamelling, in the aggressive environments. This equipment needs geometry modification of equipment functional parts (need to remove all sharp transitions and edges by using gradual rounding-off in case of enamelling – Fig. 8) due to machine production. These interventions to the equipment design significantly affect flow

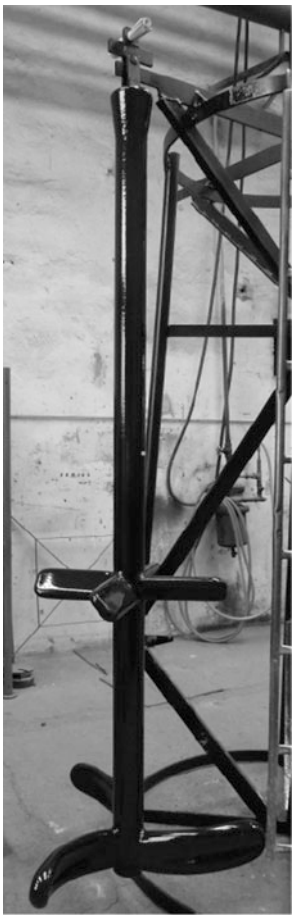

Fig. 8 Enamelled multi-stage impeller manufactured by Tenez a.s.

character and flow intensity in the agitated batch and thus also process in it. The rounded impellers have $2 \div 3\times$ higher energy requirements in comparison to no rounded impellers during blending and particle suspension. This fact must be allowed for design, e.g. enamelled mixing equipment. It is not possible used process characteristics of impellers without rounded edges to calculate the frequency and power input of enamelled impellers with rounded edges.

Environments affect the mixing equipment without adjustment against corrosion and wear and caused shaped wear or areal wear of blades. Shape wear of impeller blade results in changes of geometrical shape of the impeller. This affect decreasing of pumping efficiency and thus to change other process characteristics [16] and it can lead to deterioration of product quality. The areal wear of impeller blade results in a reduction of the blade thickness and thus their strength. It can also lead to destruction of equipment in extreme case. And this results in shut down of the mixing equipment and after that additional cost of maintenance and impeller replacement.

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