Experimental Study of the Effect of Impeller Geometrical Parameters on Fluid Hydrodynamics in Copper Solvent Extraction Mixer

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Abstract: Dynamic mixers are widely used in hydrometallurgical processes. Improvement in mixers' efficiency is one of the greatest challenges in this research. The geometrical factors of the impeller are of the most important elements affecting hydrodynamics and efficiency. Type, diameter, speed and off-bottom clearance of impeller are investigated in this work. These factors are validated by experimental setup. Mixing time is assumed fixed. Materials composition is set according to solvent extraction unit of Sarcheshmeh copper complex, Iran. The setup is manufactured according to the mixer dimensions in industrial unit. The hydrodynamic behavior of mixture is visualized by using an advanced imaging and lighting system. The effect of impeller speed in the range of 75 to 275 rpm on the position of eddies and fluid hydrodynamics are investigated. According to the results, at impeller speeds more than 200 rpm dead zones around the baffles are intend to be vanished. Furthermore, the effect of off-bottom clearance on hydrodynamics is studied. Optimum clearance to tank diameter ratio are determined 0.4 and 0.33 for 100 and 200 rpm, respectively. Results shows Rushton impeller with 6 vertical blades and impeller to tank diameter of 0.33 is optimum.

Keywords: Dynamic mixer, Hydrodynamics, Impeller geometry, Impeller speed, Off-bottom clearance, Solvent extraction

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1 INTRODUCTION

Several chemical engineering processes such as solvent extraction involve mixing of two immiscible liquids [1]. In the solvent extraction process, the dispersion should be fine enough in order to guarantee sufficient mass transfer, and at the same time, the dispersion must be coarse enough to provide rapid separation of the phases. Commonly, mixer-settler systems can utilize finer dispersions than solvent extraction columns [2]. Mixers, especially dynamic mixers have a wide range of application such as hydrometallurgical, chemical, mineral, and petroleum industries [3], [4]. Flow patterns are the main factor affecting the mixer efficiency and sensitive to impeller geometry, the number of impellers and their position in the vessel [5].

Some researchers studied the effect of impeller speed and showed the mixing percentage as a function of impeller speed for an inlet velocity of 0.1 m/s. Because of exchanging momentum between two fluids through the flow layer in the mixing process of the primary and secondary fluid, mixing increases with impeller speed increment [6]. Cyclohexane/water hydrodynamic was studied in a dynamic mixer with Rushton turbine impeller in batch system, experimentally and with CFD simulation. Baffles was not used in the mixer [7]. One of the most important elements that affect mixing is agitation speed. Results has been stated that with increasing agitation speed, the mixing time decreased. The dispersion quality of oil phase has been changed in different impeller speeds [8].

Three types of impellers had been used commonly in solvent extraction mixers. They are disc turbine (DT), pitched blade down-flow turbine (PBDT) and pitched blade up-flow turbine (PTUT) [9]. Mixing time data for mechanically agitated contactors (MAC) using different impeller designs have been reported. The results of these data showed that the more energy efficient impeller type was pitched bladed down flow turbine [10], [11]. Likewise, the turbulent kinetic energies caused by three different impellers (Rushton turbine, four bladed PBTD and Lightning A310) have been investigated. Radial fluctuations for Rushton turbine and axial fluctuations for PBTD and A310 had been observed by laser Doppler anemometer [12]. The comparison of four different impellers (RDT, HCDT, PBTU and PBTD) was done by the dispersed oil phase.

The results has been showed that in spite of higher shear and turbulence levels for RDT and axial flow pattern of PBTD, PBTD is favourable for macro mixing [13]. The preference of commercial hydrofoils Chemineer HE-3 and Prochemmaxflo T impellers in producing the circulating flow at equal power input had been compared. In spite of the similarity of axial and radial flows, there was a drastic difference in their magnitudes [14]. The flow efficiency of three commercially common impellers was investigated. The mixer TT was found to show the efficiency of 70.9% while Rushton turbine and Lightnin A310 had flow efficiency of only 52.7% and 46.2% respectively [15].

D/T is the ratio of impeller diameter to tank diameter that is in the range of 0.25 to 0.4. The lower value at the end of this range is applied for water like viscosities and D/T is increased by increasing the mixture viscosity. Areas would be remained unmixed by smaller D/T [16]. Clearance plays a crucial function in overall flow pattern of mixing. T/6 impeller position shows lower circulation zone. So only an upper loop exists and an axial flow pattern occurs. As the clearance from the tank bottom increases from T/6 to T/3, the double loops flow structure is produced and thus the radial flow is strengthened and the mixing time becomes increased [8]. Physical, geometrical and operational parameters are governing the performance of dynamic mixers.

Since the function of mixers is based on conservation of continuity, momentum and energy laws, impeller geometrical parameters, organic and aqueous phases' property are the main important factors affecting the mixer hydrodynamics and efficiency. Since researches had been done before mainly used chemical oils and acidic solution or water instead of organic and aqueous solutions, in this work organic and aqueous solutions of copper industries has been used. Therefore, the effects of metallic ions (especially copper) and typical extractant have been considered. In this study, speed, type, diameter and bottom clearance of the impeller of an experimental mixer setup are investigated in copper solvent extraction condition. For this purpose, a laboratory scaled mixer was manufactured and professional imaging and lighting system have been used.

2 EXPERIMENT

In this study the effecting parameters (speed, impeller type, diameter and off-bottom clearance of impeller) had been changed in a laboratory pyrex mixer. The aqueous and organic phases charged the vessel according to the mixers Sarcheshem copper complex. Finally, imaging and lighting system were used to observe the hydrodynamic results in mixer vessel.

2.1. EXPERIMENTAL SETUP

According to Fig. 1, the optimum geometry ratios for mixer dimension are obtained [17], [18]. The Pyrex mixer was manufactured with 2 inlets and one outlet according to the schematic situation in Fig. 1. Mixer setup is equipped with four symmetric baffles that they are perpendicular to mixer wall. Rushton turbine with 6 blades are used in the mixer impeller.

As shown in Fig. 2, two magnet pumps are used for transferring the aqueous and organic phase from their storage to the mixer inlets. Acid proof sealing system is used in the mixer structure. For recording the hydrodynamics behaviour of fluids, Casio EX-10 with 1000 fps filming, 60 fps imaging and shutter speed of 1/12800 is used. Two 1000W projector with monochrome lens is used for lighting system.

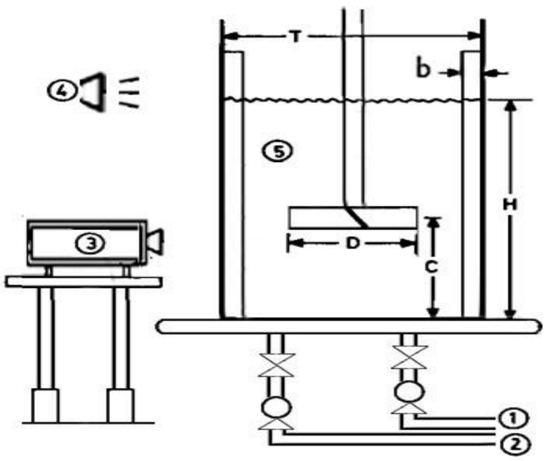

Fig. 1 Mixer setup schematic and geometry relations (H=1.2T=10b=3D=3C) (1,2: organic and aqueous inlets, 3: camera, 4: lighting system, 5: mixer vessel) (H: effective tank height, T: tank diameter, b: baffle width, D: impeller diameter, C: impeller off-bottom clearance)

Fig. 2 Mixer laboratory scale setup (1: mixer, 2: mixer vessel 3: outlet, 4: organic and aqueous inlets, 5: mixer controller 6: flash projector, 7: reflecting surface)

2.2. MATERIALS AND METHODS

Materials used in mixer are provided from solvent extraction unit of Sarcheshmeh copper complex, Iran, containing aqueous (1.6g Cu/l, pH=2) and organic phase (kerosene containing 10 g/l DEHPA). Major physical properties of aqueous and organic phases are mentioned in table 1. Hydrodynamics of fluids inside the mixer is investigated using filming, imagining and lighting systems.

Table 1 The physical properties of aqueous and organic phases used in experimental setup

Aqueous viscosity (mPa.S)	Organic viscosity (mPa.S)	Aqueous density ($kg.m^{-3}$)	Organic density ($kg.m^{-3}$)	Interfacial tension ($mN.m^{-1}$)
2.3	3.3	1100	806	26.1

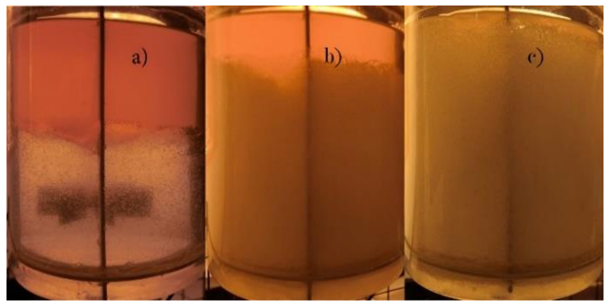

Fig. 3 Mixing region for off-bottom clearance of 7 cm and baffle width of 21 mm a) impeller speed of 100 rpm, b) impeller speed of 150 rpm, c) impeller speed of 200 rpm.

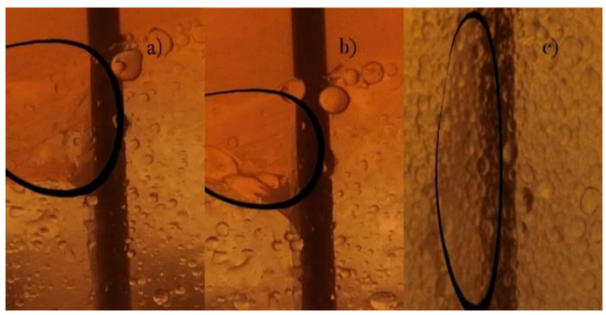

Fig. 4 Dead zone after baffle a) impeller speed of 100 rpm, b) impeller speed of 150 rpm, c) impeller speed of 200 rpm.

3 RESULTS AND DISCUSSIONS

Type of impeller, impeller diameter, impeller speed and off-bottom clearance of impeller are investigated and their effect on mixing characteristic is studied in this section. For each parameter, 2 images are selected and discussed. Films are used to explain the fluid behaviour and hydrodynamics.

3.1. INFLUENCE OF IMPELLER SPEED

Impeller speed is one of the most important parameters affecting the mixing efficiency of mixers. As shown in Fig. 3, by increasing impeller speed from 100 to 200 the mixing region is increased. Besides, from the transparency of the fluids it is found that phase inversion occurs in impeller speed range between 100 and 150 rpm. Off-bottom clearance was fixed at 7 cm. According to the Fig. 4, with increasing impeller speed, dead zones regions around the baffles decreased sensibly and stuck to the mixer wall.

3.2. INFLUENCE OF IMPELLER TYPE

For investigating impeller type, three common impeller types are investigated as follows:
pitched blade up-flow turbine (PTU), Rushton turbine (RT) and pitched-blade down-flow turbine (PTD). Should be noted that, RT impeller has 6 blades and PTU and PTD have 4 blades according to their popularity in copper industry. As shown in Fig. 5 suction region in Rushton (RT) blades is very big in comparison to other blades, thus mixing with Rushton blade is more efficient.

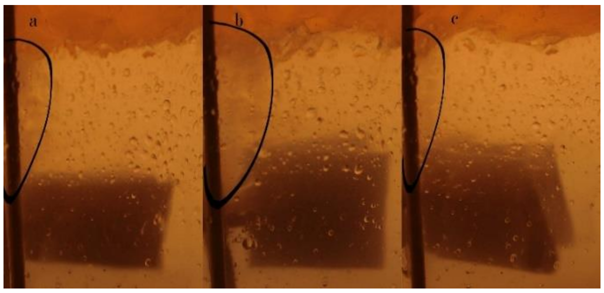

Fig. 5 Suction region in 3 different impeller type; a) PTU, b) RT, c) PTD

According to the Fig. 6 turbulent flow around the baffle for Rushton impeller is more sever, thus mixing is improved in the similar situation if Rushton impeller is used.

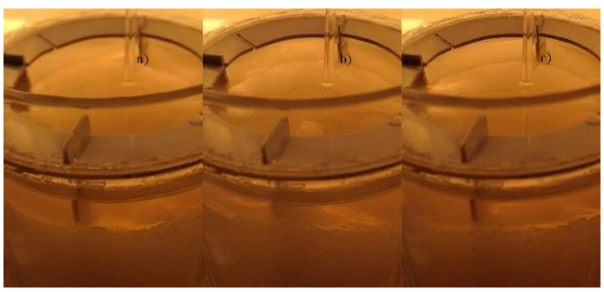

Fig. 6 Turbulence around baffle for 3 different impellers a) PTU, b) RT, c) PTD

3.3. INFLUENCE OF IMPELLER DIAMETER

As mentioned in literature, impeller diameter is related with geometrical ratios like d/D and D/T. As shown in Fig. 7, changing impeller diameter in the laboratory mixer from 6 to 8, does not have any sensible effects on the mixing region height, but with increasing impeller diameter, the amount of dispersed phase increased and in another work, that will be published by the authors it was observed that the volume of fluid that is affected by the impeller, spread thus the droplet size is decreased.

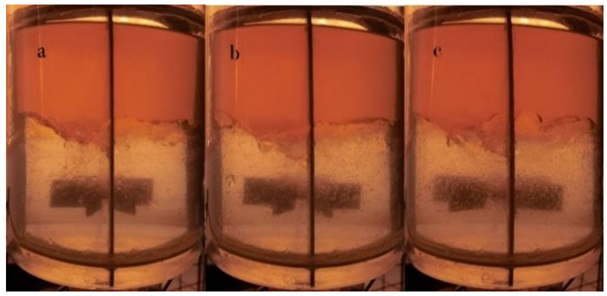

Fig. 7 Mixing region in impeller speed of 100 rpm a) impeller diameter of 6 cm, b) impeller diameter of 7 cm, c) impeller diameter of 8 cm.

According to the Fig. 8, dead zone around the baffles with increasing impeller diameter is intended to vanish. Because of increasing impeller diameter, the distance between impeller and baffles decreased thus shear stresses around the baffles are amplified.

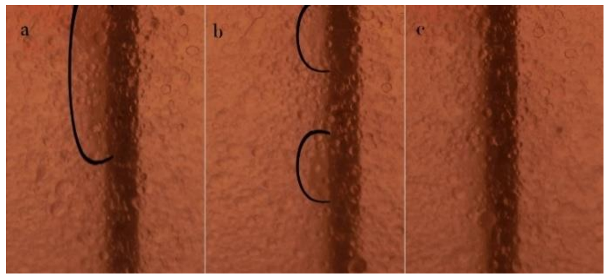

Fig. 8 Dead zone after baffles in impeller speed of 200 rpm a) impeller diameter of 6 cm, b) impeller diameter of 7 cm, c) impeller diameter of 8 cm.

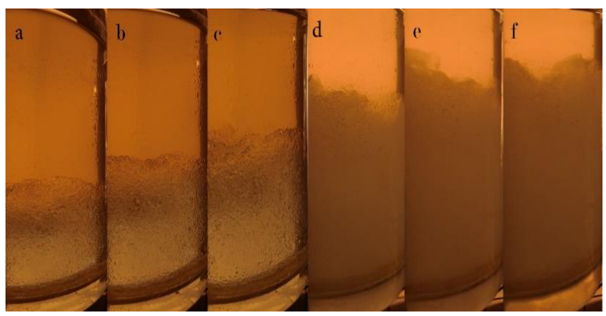

Fig. 9 Mixing region and flow hydrodynamics in impeller speed of 150 rpm, a) clearance of 5 cm b) clearance of 6 cm c) clearance of 7 cm d) clearance of 8 cm e) clearance of 9 cm e) clearance of 10 cm

3.4. INFLUENCE OF OFF-BOTTOM CLEARANCE

As a result of analysing Fig. 9 it was found that the increasing off-bottom clearance has straight forward effect on the mixing region. Mixing height has been increased around 1.5 cm because of increasing 1 cm of clearance. But it should be mentioned that in low clearance, vortex created by the impeller increased and in high speed of impellers, aeration occurred. Besides it is obvious from the figures that phase inversion occurred in off-bottom clearance between 7 and 8 cm.

4 CONCLUSION

Increasing impeller speed leads to improving eddy flow size. The effect of increasing impeller speed is different in the top and bottom of the impeller. In the top region of the impeller, the mixing volume enhanced but in the bottom region of impeller, flow speed increased. Optimum impeller speed in the setup condition is 200 rpm. In this speed, mixing volume is approximately equal to the mixer vessel volume (approximately 7.3 litter). With increasing impeller speed, turbulent flows increased, dead zones after baffles intend to be vanished and at impeller speeds more than 250 rpm dead zones omitted. In three mentioned common impeller types, Rushton impeller with 6 vertical blades shows efficient mixing. Increasing impeller diameter results in improvement of mixing flows and diminish dead zones after baffles, but with different impeller diameters, the mixing height remains fixed approximately. In impeller speed of 200 rpm, mixing volume is approximately independent of impeller diameter. According to the results in impeller speed of 200 rpm, optimum impeller to tank diameter is 0.33. Increasing clearance leads to increasing mixing region in the mixer. But mixing efficiency decreased because of aeration decrement. Thus, according to the images and filming results, it seems that in impeller speed of 200 rpm and baffle width of 21 mm, optimum clearance to tank diameter is 0.33. Furthermore, phase inversion of organic and aqueous phases is occurred as the result of changing impeller speed or off-bottom difference.

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