Measurement 91 (2016) 440–450

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

The effect of various designs of six-curved blade impellers on reaction rate analysis in liquid–liquid mixing vessel

Reza Afshar Ghotli [a], Abdul Aziz Abdul Raman [a,*], Shaliza Ibrahim [b]

[a] Department of Chemical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 12 March 2015
Received in revised form 6 March 2016
Accepted 19 April 2016
Available online 20 April 2016

Keywords:
Liquid–liquid mixing
Curved blade impeller
Rushton turbine
Reaction rate
Stirred vessel

ABSTRACT

The mixing efficiencies of impellers vary according to their designs. In this work, the effects of 6-curved-blade impellers of different curvature angles and central disk sizes on the reaction in a stirred vessel were investigated and the results were compared to that of a Rushton turbine. The impeller efficiency was defined by the ratio of reaction rate to power consumption, (r_A/P). The experiments were performed at the rotational speeds of 5, 6 and 7 rps. The interaction among the experimental parameters was investigated using Response Surface Methodology. The r_A/P values were found to decrease with increasing curvature angles. The lowest r_A/P value was obtained for the impeller with curvature angle of 140°. The result showed that the results for Rushton turbine was relatively low compared to curved-blade impellers and increase in central disk size did not significantly affect r_A/P. In conclusion, curved-blade impellers were more economically efficient than Rushton turbine.

1. Introduction

Immiscible and miscible liquid–liquid dispersions in mixing tanks are the key processes in various industries such as chemical, biotechnological, pharmaceutical, and food processing industries [1,2]. Mixing generates essential interfacial areas to support mass and heat transfer between phases [3,4]. Sufficient mixing of the mixtures is essential for chemical reaction in stirred vessels. The efficiency of liquid–liquid mixing can be determined through measurement of several parameters such as minimum agitation speed, mixing time, circulation time, power consumption, drop size distribution, break-up and coalescence, interfacial area and phase inversion [2]. However, changes in the input parameters such as impeller type; impeller power number, impeller flow pattern, number of impellers, dispersed phase volume fraction and physical properties of phases (viscosity and density) can also affect the liquid–liquid mixing efficiency. Apparently, hydrodynamics in a stirred vessel have a strong influence on mixing efficiency [5]. Investigation of agitation hydrodynamics is critical in order to minimize the investment and operating costs while increasing the productivity to increase profits [6]. Generally, mixing of liquids by mechanical agitation in a stirred vessel is explained by the momentum transfer from impeller to liquid [7]. There are different types of mixing systems available in the market for efficient mixing in stirred vessels [8,9]. Selection of impeller depends on a number of factors such as fluid viscosity, operating conditions and system flow regime [6]. Several researches on the mixing efficiency of various types of impellers for liquid-liquid mixing in stirred tanks have been conducted. Skelland and Lee [10], studied the minimum impeller speeds for nearly uniform liquid–liquid dispersion in stirred vessels and described the influences of impeller type, speed, size, location, and liquid properties on the degree of mixing. Pacek et al. [11] and Musgrove et al. [12], determined the effectiveness of several impellers via drop size measurement and drop size distributions. Szalai et al. [13], focused on the performance of multiple Ekato Intermig impellers system, considering both the flow pattern and mixing properties. Modified impellers such as curved-blade impellers, SCABA or hydrofoil impellers have been developed in the last two decades, to improve the performance of conventional impellers [14]. The existing studies reveal that 6-flat-blade Rushton turbine is the most commonly used impeller for liquid–liquid dispersions [11,12,15].

Table 1 illustrates some of the previous liquid–liquid experiments with different impeller types. The literature shows that flat-blade Rushton turbine produces high-speed and low-pressure trailing vortexes at the back of each blade. Dispersion in the mixing tanks is influenced by the turbulence produced by the vortexes. On the other hand, the trailing vortexes result in high power number

---

[*] Corresponding author.

E-mail addresses: Afsharghotli_reza@yahoo.com (R. Afshar Ghotli), azizraman@um.edu.my (A.A. Abdul Raman), shaliza@um.edu.my (S. Ibrahim).

http://dx.doi.org/10.1016/j.measurement.2016.04.044

Nomenclature

T	tank diameter (m)
C	impeller clearance (m)
D	impeller diameter (m)
H	tank height (m)
H_L	liquid height (m)
P	power consumption (kg m^2 s^{-3})
P_0	impeller power number (dimensionless)
r_A	reaction rate (kg m^{-3} s^{-1})
r_A/P (r_{AS})	specific reaction rate (s^2 m^{-5})
τ	torque (N m)
N	agitation speed (rps)
x_i	coded value
X_i	actual value
X_0	actual value at the center point
ΔX	Value of step change
Y_1 and Y_2	responses (specific reaction rate (s^2 m^{-5}))

under un-aerated conditions which lead to high torque and operating cost [16]. Therefore, high power consumption and considerable power reduction under aerated conditions are among the weaknesses of Rushton turbine [16,17].

It is essential to find an alternative for Rushton turbine. 6-curved-blade impellers were employed in 1976 by van't Riet et al. [18] as an alternative for 6-blade Rushton turbine. A considerable lower power number values were found for the he curved blade power number than the Rushton turbine [9,17,19]. Warmoeskerken and Smith [20], Bakker et al. [21], Paul et al. [6], Chen and Chen [17] and Cooke and Heggs [22] reported that curved-blade impeller yielded 20–30% higher mass transfer than Rushton turbine without significant loss of power during the gas–liquid dispersion processes. These new curved-blade impellers also reduced the cavity size on the rear side of each blade [17] and trailing vortex [23]. Furthermore, Mishra and Joshi [24] revealed that the pumping capacity of a semi-circular-blade impeller was much higher than that of a Rushton impeller. Besides, previous experiments on semi-circular-blade impeller have proven that this type of impeller consumes less power compared to Rushton turbine in liquid–liquid systems [25]. Generally, curved-blade impellers are known to have smaller power consumption, better gas handling capacity and higher mass transfer for gas–liquid dispersion [7,9,20] compared to Rushton turbine but its application in liquid–liquid mixing is not well established. There is therefore a need to investigate the use of curved blade impellers as an alternative to Rushton turbine for liquid–liquid mixing.

The main objective of this work is to investigate the influence of different types of 6-curved-blade impellers on hydrolysis reaction in immiscible liquid–liquid systems. This work aims at investigating the effects of curvature angle, central disk size and speed to explain the suitability of curved-blade impellers for liquid–liquid mixing [26].

Response Surface Methodology (RSM) is normally used to design the experiments and develop statistical models to investigate the interactions and significance of the affecting parameters [9,27–29]. There is no literature available on modeling of the interactions between curvature angles, central disk size and power consumption with reaction rate. Hence, in the present work, Response Surface Methodology (RSM) in combination with central composite design (CCD) was used to study the effects of blade curvature angles and central disk sizes on the reaction rate (r_A) at different rotational speeds in stirred vessels and to develop a model using the experimental data.

2. Experimental

2.1. Materials

The palm oil used in this work was purchased from Sik Cheong Edible Oil SDN. BHD, Malaysia. Lipase (Type-VII) from *Candida rugosa* was obtained from Sigma Chemical Co., Japan. Isopropanol of analytical grade and potassium hydroxide were procured from Merck Chemicals Co., Germany. The buffer solution of pH 7.0

Table 1
Some of previous liquid–liquid works carried out in mixing tanks.

System	Impeller type	Vessels	Inner dia. (m)	Ref.
• Benzaldehyde + water • Ethyl acetate + water • Dow corning 200 silicone fluids + water	• Three-blade propellers • 6-pitched-blade turbine • 6-flat-blade RT • 6-curved-blade turbine	Cylindrical flat bottom baffled vessel	0.2135	[10]
• Chlorobenzene + dionised, distilled water • Sun flower oil + dionised, distilled water	• 6-flat-blade RT • 6-flat-blade disc turbine • Axial flow hydrofoil chemineer HE3 • Ultra high shear chemineer CS2, CS4	Cylindrical flat bottom baffled vessel	0.150 0.125	[11]
• Silicone oil (dow corning) + water	• 6-flat-blade RT • Pitched blade turbine	Standard baffled cylindrical torispherical based tank (closed top)	0.17 0.29	[12]
• Glycerine + water	• Four Ekato Intermig	Standard baffled cylindrical tank	0.3048	[13]
• Sun flower oil + water	• 6-flat-blade RT	Glass cylinder with 4 stainless steel baffles	0.1	[48]
• Silicon oil + water	• 6-flat-blade RT	Cylindrical flat bottom baffled vessel	0.157	[4]
• Toluene + water	• 6-flat-blade RT	Cylindrical flat bottom baffled vessel	0.15	[49]
• Palm oil + water	• Propeller stirrer	Stirred bio reactor Glass cylinder Propeller stirrer	0.1	[50]
• n-Tetradecane + water • Diesel fuel + water	• 6-flat-blade RT	Standard baffled cylindrical tank (closed top)	0.232	[51]
• Silicon oil + water surfactant solution	• Sawtooth • 4-pitched-blade turbine	Standard ESCO mixer (ESCO labor AG)	0.2	[52]