Journal of the Taiwan Institute of Chemical Engineers 63 (2016) 33–38

Contents lists available at ScienceDirect

Journal of the Taiwan Institute of Chemical Engineers

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

Micromixing in a rotating packed bed with blade packings

Chia-Chang Lin*, Cheng-Hua Tsai

Department of Chemical and Materials Engineering, Chang Gung University, Taoyuan, Taiwan, R.O.C

A R T I C L E I N F O

Article history:
Received 22 November 2015
Revised 5 March 2016
Accepted 8 March 2016
Available online 6 April 2016

Keywords:
Rotating packed bed
Micromixing
Magnesium hydroxide
Nanoparticles

A B S T R A C T

The micromixing efficiency of a rotating packed bed (RPB) with blade packings, which is determined by a parallel competing reaction system, is related to the rotational speed, the total liquid flow rate, the outer radius of the blade, the inner radius of the blade, the number of blades, and the liquid viscosity. Experimental results show that increasing the rotational speed, the total liquid flow rate, and the number of blades effectively increased the micromixing efficiency. Increasing the outer radius of the blade and the liquid viscosity did not almost affect micromixing efficiency. The inner radius of the blade had a particular effect on micromixing efficiency: the micromixing efficiency firstly decreased and then increased as the inner radius of the blade was increased. Although the micromixing efficiency in the RPB with blade packings was lower than that in the RPB with structured packings, the mean size of the magnesium hydroxide nanoparticles that were prepared using the RPB with blade packings was close to that of those prepared using the RPB with structured packings. Accordingly, the RPB with blade packings is a promising reactor for preparing nanoparticles with high micromixing efficiency.

1. Introduction

In 1981, Ramshaw and Mallinson [1] first proposed the intensification of the gas–liquid mass transfer by increasing dramatically the rate of regeneration of the interface between gas and liquid phases. Hence, they used centrifugal force to produce contact between gas and liquid under high centrifugal acceleration by rotating doughnut-shaped packings. Therefore, a rotating packed bed (RPB) was developed to increase mass transfer in distillation and absorption processes. This novel technology was called “Higee” technology, which referred to “high gravity”. In an RPB, thin films and tiny droplets that are generated by the high centrifugal acceleration promote gas-liquid mass transfer. The RPB can be operated at higher gas and/or liquid flow rates than a conventional packed bed owing to its lower tendency to flood. Accordingly, the gas–liquid mass transfer is typically 10∼100 times high and the size of the equipment is much lower, reducing both capital and operating costs [2].

The RPB has been extensively utilized for various gas–liquid processes, including distillation [3], VOCs absorption [4], CO_2 absorption [5], O_3 absorption [6], ozonation [7], reactive precipitation [8], and stripping [9]. In 2004, Chen et al. [10] studied for the first time micromixing in an RPB. Their results revealed that the micromixing efficiency in an RPB can be increased by centrifugal acceleration. Therefore, an RPB can be utilized in liquid–liquid process, and especially in precipitation for the preparation of nanoparticles [11,12]. In 2007, our group became the first to use an RPB with blade packings to absorb volatile organic compounds (VOCs), as displayed in Fig. 1 [13]. The results thus obtained convinced us that the RPB with blade packings exhibited superior operating characteristics, such as a low pressure drop and a high mass transfer. Although micromixing in RPBs with various packings has been examined [14–20], micromixing in an RPB with blade packings has seldom been discussed. Therefore, the main goal of this investigation is to study the characteristics of micromixing in an RPB with blade packings and the effects of rotational speed, total liquid flow rate, outer radius of the blade, inner radius of the blade, number of blades, and liquid viscosity thereon.

Precipitation is a very important process in the chemical industry. It has been found to be significantly influenced by mixcromixing, because the reaction time of precipitation is of the same order of magnitude as the characteristic time for micromixing [15]. Marcant and David [21] developed a simple mixing model to predict qualitatively the effect of micromixing on precipitation. They proposed that increasing the mixing efficiency increased the crystallization rate and reduced the particle size in primary nucleation. In this investigation, magnesium hydroxide ($Mg(OH)_2$) nanoparticles were prepared by precipitation in an RPB with blade packings.

* Corresponding author. Tel.: +886 3 2118800x5760.
E-mail address: higee@mail.cgu.edu.tw (C.-C. Lin).

http://dx.doi.org/10.1016/j.jtice.2016.03.012
1876-1070/

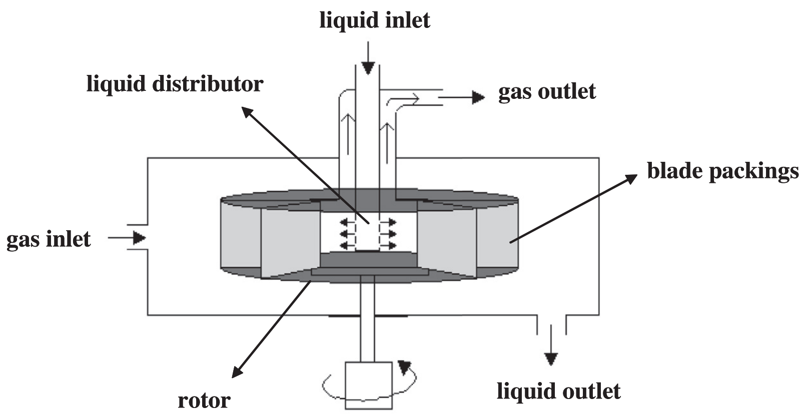

Fig. 1. RPB with blade packings.

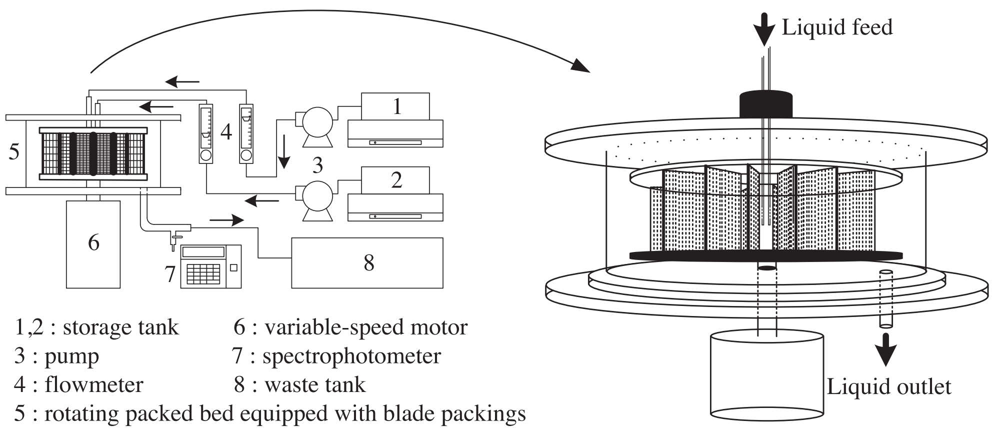

Fig. 2. Experimental setup for measuring micromixing efficiency.

2. Experimental

2.1. Estimation of micromixing

In 1996, Fournier et al. [22] developed a parallel competing reaction system in which dilute sulfuric acid was fed into an aqueous solution of $H_2BO_3^-$, I^-, and IO_3^- in a mixing device. The parallel reactions, which were acid–base neutralization, described by Eq. (1), and the Dushman reaction, described by Eq. (2), compete with each other.

$$H_2BO_3{}^- + H^+ \leftrightarrow H_3BO_3 \qquad \text{(quasi-instantaneous)} \tag{1}$$

$$5I^- + IO^-{}_3 + 6H^+ \leftrightarrow 3I_2 + 3H_2O \qquad \text{(fast)} \tag{2}$$

Since the first reaction can be regarded as instantaneous, all hydrogen ions react with excess $H_2BO_3^-$ if the mixing is perfect. If the mixing is not perfect, iodine will be generated and further react with I^- to form I_3^-, according to Eq. (3).

$$I_2 + I^- \leftrightarrow I_3^- \tag{3}$$

The micromixing efficiency is quantified by the segregation index (X_S), which is defined as

$$X_S = \frac{Y}{Y_{ST}} = \frac{(C_{I_2} + C_{I_3^-})(6C_{IO_3^-,0} + C_{H_2BO_3^-,0})(Q_H + Q_I)}{3C_{H^+,0}C_{IO_3^-,0}Q_H} \tag{4}$$

$$Y = \frac{2(n_{I_2} + n_{I_3^-})}{n_{H^+,0}} = \frac{2(C_{I_2} + C_{I_3^-})(Q_H + Q_I)}{C_{H^+,0}Q_H} \tag{5}$$

$$Y_{ST} = \frac{6C_{IO_3^-,0}}{6C_{IO_3^-,0} + C_{H_2BO_3^-,0}} \tag{6}$$

where Y is the ratio of the number of moles of acid that is consumed in the Dushman reaction (Eq. (2)) to the total number of moles of acid that are introduced into the system, and Y_{ST} is the value of Y under total segregation. Detailed discussion and calculation of X_S can be found in the literature [10,15,22]. $X_S = 0$ represents perfect micromixing, and $X_S = 1$ represents complete segregation. Therefore, a smaller X_S indicates higher micromixing efficiency. As noted by Fournier et al. [22], these reactions are fast enough that the micromixing efficiency in stirred reactors can be measured, even in fast mixing devices. Therefore, this particular reaction system has been used to estimate the micromixing efficiency of the RPB [10,14–20].

Fig. 2 schematically depicts the experimental setup for measuring micromixing in the RPB with blade packings. Tank 1 contained solution I of $H_2BO_3^-$, I^-, and IO_3^-. To obtain solution I, boric acid and sodium hydroxide were firstly added to deionized water, and then potassium iodate and potassium iodide were introduced. This sequence ensured the coexistence of the iodide and iodate ions in a basic solution and prevented the formation of iodine. The initial concentration of $H_2BO_3^-$ was 0.09 mol/L; that of I^- was 1.2×10^{-2} mol/L, and that of IO_3^- was 2.3×10^{-3} mol/L. Tank 2 contained solution H of H^+. To form solution H, sulfuric acid was added to deionized water. The initial concentration of H^+ was 0.1 mol/L. Solutions from both tanks 1 and 2 at 25 °C were introduced into the RPB by the liquid distributors at different flow rates, which were maintained using flowmeters. The ratio of the flow rate of solution I to that of solution H was maintained at 7.2.