

Liquid–liquid mass transfer property of two inline high shear mixers



Junjie Gu^a, Qin Xu^a, Hongbin Zhou^b, Wei Li^a, Jinli Zhang^{a,*}

^a School of Chemical Engineering and Technology, Tianjin University, Tianjin 300072, PR China

^b Fluko Co., Ltd., Shanghai 201802, PR China

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ABSTRACT

The liquid–liquid mass transfer properties of two inline high shear mixers (HSMs) were investigated by the liquid–liquid extraction (LLE) method using the water–benzoic acid–kerosene system. The characteristic parameters of the extraction efficiency (E) and volumetric mass transfer coefficient ($K_L a$) were measured under different conditions involving the rotor speed, two liquid phase flow rates, and surfactant concentration. The results indicate that both E and $K_L a$ increase with the rotor speed and aqueous-phase flow rate. The value of E decreases sharply but $K_L a$ increases slightly with the organic-phase flow rate. Both E and $K_L a$ increase first and then decrease with the surfactant concentrations. Dimensionless correlations for the Sherwood number were obtained to provide guidance on the optimization and scale-up design of these kinds of inline HSMs.

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1. Introduction

Mass transfer property among immiscible liquids is fundamental to many chemical processes involving solvent extraction [1], aromatics nitration [2], polymerization [3], etc. The mixers with high stirring rate are considered as the useful tool to enhance the mass transfer property through generating small size dispersed droplets in the liquid–liquid (L–L) system. High shear mixers (HSMs), with the advantages of very high shear rates and locally intense turbulence, have already been adopted as one of the most promising process intensification equipment in dispersion and mixing process in the fields of chemical, pharmaceutical and food-manufacturing industry, etc. For example, Jasinska et al. [4] used a HSM and paddle impeller respectively to study the L–L mass transfer property with chemical reaction in a batch operation, and found that the high shear rotor–stator mixer can generate smaller droplets but poor bulk mixing contrasting to the paddle impeller.

Comparing with the batch HSMs, the inline HSMs have the advantages of continuous operation and high throughput, which has shown the superior mass transfer capacity in the gas–liquid system [5–7]. It is reported that the inline HSMs for emulsification processes can generate small droplets with a Sauter mean diameter (d_{32}) of less than 10 μm [8,9], but so far no report has

been found on whether or not the inline HSMs can enhance effectively the mass transfer property in the L–L extraction system.

In this article, the L–L mass transfer characteristics in two kinds of inline HSMs were studied by adopting the water–benzoic acid–kerosene extraction system. The characteristic parameters of E and $K_L a$ were measured to assess the L–L mass transfer property intensified by the inline HSMs. The effects of rotor speed, two liquid phase flow rates and surfactant concentration were investigated. Dimensionless correlations for the Sherwood number were obtained to guide the optimization and scale up of these kinds of inline HSMs.

2. Experimental

The L–L mass transfer properties in the inline HSMs were studied using the water–benzoic acid–kerosene extraction system. The extraction efficiency (E) and the volumetric mass transfer coefficient ($K_L a$) were determined using the Eq. (1). [10]:

$$E = \frac{\text{Amount transferred}}{\text{Maximum transferable}} = \frac{C_{\text{ORG},i}^{\text{TOT}} - C_{\text{ORG},o}^{\text{TOT}}}{C_{\text{ORG},i}^{\text{TOT}} - C_{\text{ORG},o}^{\text{TOT}*}} \quad (1)$$

where $C_{\text{ORG},i}^{\text{TOT}}$ and $C_{\text{ORG},o}^{\text{TOT}}$ are respectively the inlet and outlet benzoic acid concentrations in the organic phase, both of them are determined by the acid base titration method; $C_{\text{ORG},o}^{\text{TOT}*}$ represents the equilibrium concentration of benzoic acid in the outlet organic phase corresponding to the benzoic acid concentration in the

* Corresponding author. Fax: +86 22 27890643.
E-mail address: zhangjinli@tju.edu.cn (J. Zhang).

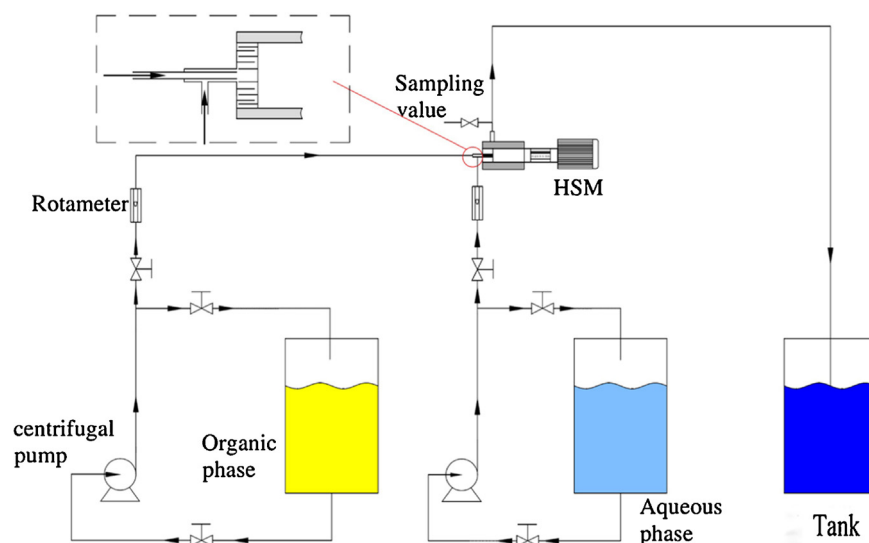


Fig. 1. Schematic flow diagram of the experimental process.

outlet aqueous phase, which can be calculated by the partition coefficient of benzoic acid between the two phases.

The volumetric mass transfer coefficient ($K_L a$) was determined using Eq. (2).

$$Q_{\text{ORG}} \frac{dC_{\text{ORG}}^{\text{TOT}}}{dV} = -K_L a (C_{\text{ORG}}^{\text{TOT}} - C_{\text{ORG}}^{\text{TOT}*}) \quad (2)$$

where Q_{ORG} is the organic phase flow rate, V is the contacting volume, $C_{\text{ORG}}^{\text{TOT}}$ is the benzoic acid concentration in the organic phase, and $C_{\text{ORG}}^{\text{TOT}*}$ is the pseudo-equilibrium concentration of benzoic acid in the organic phase corresponding to its concentration in the aqueous phase ($C_{\text{AQ}}^{\text{TOT}}$). $C_{\text{AQ}}^{\text{TOT}}$ can be calculated by the component mass balance:

$$Q_{\text{ORG}} C_{\text{ORG},i}^{\text{TOT}} + Q_{\text{AQ}} C_{\text{AQ},i}^{\text{TOT}} = Q_{\text{ORG}} C_{\text{ORG}}^{\text{TOT}} + Q_{\text{AQ}} C_{\text{AQ}}^{\text{TOT}} \quad (3)$$

When the inlet concentration of the aqueous phase $C_{\text{AQ},i}^{\text{TOT}} = 0$, in combination with Eq. (3), $C_{\text{ORG}}^{\text{TOT}*}$ can be expressed by Eq. (4).

$$C_{\text{ORG}}^{\text{TOT}*} = K_P^{\text{OBS}} C_{\text{AQ}}^{\text{TOT}} = K_P^{\text{OBS}} \frac{Q_{\text{ORG}} (C_{\text{ORG},i}^{\text{TOT}} - C_{\text{ORG}}^{\text{TOT}})}{Q_{\text{AQ}}} \quad (4)$$

where K_P^{OBS} is the partition coefficient of the benzoic acid between the organic and aqueous phase. Upon $C_{\text{ORG}}^{\text{TOT}*}$ is determined, the overall volumetric mass transfer coefficient $K_L a$ can be calculated by the numerical integration of Eq. (2) from the inlet to the outlet concentration, i.e., by Eq. (5).

$$K_L a = \frac{Q_{\text{ORG}}}{V_r} \int_i^o \frac{dC_{\text{ORG}}^{\text{TOT}}}{-(C_{\text{ORG}}^{\text{TOT}} - C_{\text{ORG}}^{\text{TOT}*})} \quad (5)$$

where i and o represents the inlet and outlet of the HSMs, respectively.

2.1. Experimental apparatus

Fig. 1 shows the schematic diagram of the experimental process. The aqueous and organic phase did not contact with each other before reaching the mixing head by a casing pipe, which sent the organic phase directly to the mixing head so as to avoid the effect of a premixing section. The two kinds of inline HSMs with the basic structure of the dual rows ultrafine-toothed and the single-

row blade-screen, of which the configurations are displayed in Fig. 2, are the custom-built pilot-scale unit of FDX series provided by FLUKO. Originally, the mixer is a rotor-stator teathed design, where the rotor consists of two rows of 52 teeth (axially straight; with outer diameters of the inner and outer teeth rows of 47 and 59.5 mm) with 1 mm slots; while the stator has two rows of 30 teeth (15° backward inclined; with outer diameters of the inner and outer teeth rows of 53.5 and 66 mm) with 2 mm slots. The shear gap width (i.e., the annular space between the assembled rotor and stator) is 0.5 mm; and the tip-to-base clearance (i.e., the axial space from the rotor tip to the stator base or that from the stator tip to the rotor base) is 1 mm.

Alternatively, the mixer can be assembled into a blade-screen configuration, where the rotor has a single row of 6 blades (15° backward inclined; with the same rotor outer swept diameter of 59.5 mm) while the single-row stator screen (with the same stator outer swept diameter of 66 mm) has two rows of 3 mm × 3 mm square holes with 30 holes in each row. The shear gap width and tip-to-base clearance are kept the same as those of the teathed design, i.e., 0.5 mm and 1 mm, respectively. The opening areas are calculated as both 23.6% of the outer circular face for the teathed and screen stators.

2.2. Materials

The aqueous phase was the deionized water solution of the surfactant Tween 80 (Tianjin Guangfu Fine Chemical Research Institute, China), while the organic phase was the kerosene (the analytical grade purity, Tianjin Damao chemical reagent factory, China) solution of 0.2% (wt) benzoic acid (the analytical grade purity, Tianjin Guangfu Fine Chemical Research Institute, China). The benzoic acid concentration in the kerosene solution was low enough to avoid any change in the physiochemical properties of the feed. In all the experiments, the aqueous phase was the continuous phase and the organic phase was the disperse phase.

Table 1 lists the physical properties of the working fluids including the densities, viscosities and interfacial tension. The densities were measured by the pycnometer method, the viscosities of the two phases were measured separately by a viscometer (LVDV-II+Pro, Brookfield), the interfacial tensions between the water and oil phase were determined by an automatic surface tensiometer (JK99B, Powereach Co., Ltd.). It is indicated

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