International Journal of Multiphase Flow 157 (2022) 104248

Contents lists available at ScienceDirect

International Journal of Multiphase Flow

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

Hydrodynamics and mass transfer studies of liquid-liquid two-phase flow in parallel microchannels

Sudhanshu Singh, U.K. Arun Kumar *

Department of Chemical Engineering, Malaviya National Institute of Technology Jaipur, Rajasthan 302017, India

ARTICLE INFO

Keywords:
Propionic acid
Solvent extraction
Parallel microchannels
Single microchannel
Liquid-liquid slug flow
Mass transfer coefficient

ABSTRACT

Parallel or multiple microchannels (PMC) are being tried for high throughput operations. Extremely fewer reports on liquid/liquid two-phase flow in PMC exists in the open literature compared to the gas/liquid flow especially utilizing the new designs. In this work, a bifurcation-based PMC was employed to study hydrodynamics and the mass transfer aspect of solvent extraction of propionic acid. Slug formation, slug volume, specific surface area, extraction efficiency and mass transfer coefficients were evaluated. PMC exhibited better results than the single microchannels (SMC), making them superior in performance than the SMC. The standard deviation for uniform flow distribution is within 2%. A maximum specific surface area was obtained in PMC than the single channels, which is 10513 m^2/m^3. Similarly, the maximum extraction efficiency of 98% is achieved in PMC at flow rates 16 times higher than the SMCs. The overall pressure drop in PMC is significantly less than in the SMCs. Thus PMC is a suitable choice for process intensification in process industries.

1. Introduction

Microchannels have occupied an inevitable place in chemical engineering research in industries and academia for process intensification (Matsumoto et al., 2003; Singh et al., 2021). One of the ways of process intensification is to replace the existing large-size equipment, making changes in the reactions and separation equipment with small size, cleaner, safer, and energy-efficient ones (Kashid et al., 2007; Ponce-Ortega et al., 2012; Kumar and Mohan, 2018). Numerous studies have proved the superiority of microchannels over the conventional ones employed in chemical engineering (Kashid et al., 2007; Raimondi et al., 2014). Interestingly, very high heat and mass transfer coefficients, extremely large specific surface area, short diffusion distance, and precise control over the bubbles or droplet size have placed them above all the existing separators or reactors (Jahnisch et al., 2004; Dessimoz et al., 2008; Jovanovic et al., 2011; Singh et al., 2020). Microchannels have been employed for gas/liquid (Yue et al., 2007; Yue et al., 2008; Yao et al., 2015; Su et al., 2010a; Yao et al., 2017), liquid/liquid (Kumar and Mohan, 2018; Darekar et al., 2014, Chin et al., 2011; Su et al., 2010b; Sahu et al., 2016; Jovanovic et al., 2011) and gas/solid (Kobayashi et al., 2004; Yu et al., 2020; Wang et al., 2011; Jeevarathinam et al., 2011) reactions and mass transfer operations. Fundamentally, in all these cases, single microchannels were used to evaluate their performances. Certainly, single microchannel-based studies are essential but can be considered preliminary and inadequate compared to the industrial scale needs. The purview of microchannel research has been enlarged from single-channel investigations to multiple or parallel channels to realize high throughput. Thus, studies related to the design of flow distributors, uniform flow distribution, and mass transfer performance characteristics in PMCs have become the recent research objectives. High throughput operations in microchannels for liquid/liquid two-phase is the current focus of this work.

Extraction in microchannels is a widely investigated process. Excellent results have been reported in the literature related to carboxylic acid extraction (also distillation) in single microchannels. Burns and Ramshaw (2001) studied acetic acid titration in kerosene using a square microchannel having a width of 0.38 mm. Khasid et al. (2007) conducted the microchannel extraction in a PTFE capillary under a slug flow regime to separate acetic acid, succinic acid and iodine. Extraction efficiency of about 90% was reported by them. Zhao et al. (2006) investigated the separation of succinic acid from an aqueous mixture employing the solvent n-butanol in a microchannel. They reported a four times higher overall volumetric mass transfer coefficient than the conventional contactors. Likewise, Sahu et al. (2016) demonstrated propionic acid extraction in a microchannel. The extraction efficiency of PA is reported to be 98%. Susanti et al. (2016) conducted reactive distillation

* Corresponding author.
E-mail address: ukarunkumar.chem@mnit.ac.in (U.K.A. Kumar).

https://doi.org/10.1016/j.ijmultiphaseflow.2022.104248
Received 2 April 2022; Received in revised form 4 August 2022; Accepted 4 September 2022
Available online 10 September 2022