CHEMICAL ENGINEERING RESEARCH AND DESIGN 90 (2012) 1417–1424

Contents lists available at SciVerse ScienceDirect

Chemical Engineering Research and Design

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

Flow dynamics in perforated plate liquid extraction columns

*R.S. Ettouney**, *M.A. El-Rifai*

Chemical Engineering Department, Faculty of Engineering, Cairo University, Giza, Egypt

ABSTRACT

A linearized unsteady state flow model is developed for two counter-currently flowing liquids in an un-agitated perforated plate liquid–liquid column contactor. The model is based on the simultaneous solution of dynamic conservation equations and linearized hydrodynamic constitutive equations relating pressure drops and dispersed phase holdups to flow rates. Analytical expressions are obtained for the dynamic responses of inter-stage continuous and dispersed phase flow rates, inter-stage holdups, and level of the top interface to changes in the light liquid and heavy liquid inflow rates to the column. The system's dynamic behavior is vividly demonstrated through a set of typical frequency and transient response computations. Owing to the interaction between the dynamics associated with the flow of the two liquids, the frequency responses of the flow rates and holdups of the two phases are characterized by resonance peaks and non-minimum phase behavior.

Keywords: Extraction; Perforated plate columns; Hydrodynamics; Transient response; Frequency response

1. Introduction

Various approaches have been suggested for modeling the fluid dynamics of liquid–liquid extraction equipment featuring complicated flow patterns such as pulsed or mechanically agitated columns. They are intended to account for the effects of dispersed phase droplets size distribution, coalescence, and re-dispersion, and for axial mixing in the continuous phase. These include non-equilibrium cell models with inter-stage back flow (Mjalli, 2005), models incorporating the effect of forward mixing (Korchinsky, 1992) and its reflection on drop size distribution (Tang et al., 2004), as well as drop population balance models (Al Khani et al., 1989) enabling the generation of hold up profiles (Tsouris et al., 1994). The bivariate droplet population balance model (Attarakih et al., 2006) and its numerical solution (Kronberger et al., 1995) enable the incorporation of the effects of mass transfer on viscosities, densities, and interfacial tension (Bart, 2003). The complexity of such models may be somewhat simplified by incorporating the results of single drop experiments (Schmidt et al., 2006). Simpler hydrodynamic models assuming rigid spherical droplets of constant average diameter are suitable for control purposes (Weinstein et al., 1998) and have been used to recommend modification of the conventional method for interface level control at the column exit for stirred liquid extraction columns (Hufnagl et al., 1991).

Un-agitated perforated plate liquid–liquid extraction columns have the advantage of high liquid handling capacity, and relatively low capital, maintenance, and operating costs. Compared to mechanically powered pulsed and agitated column contactors, the hydrodynamic characteristics of un-agitated columns are relatively simple to analyze. Continuous phase mixing is confined to the region between individual trays rather than spreading throughout the column length. Also, the establishment of a concentration gradient within the dispersed phase droplets is avoided because drops coalesce beneath the plates and are reformed when entering the next plate (Garner et al., 1953). However, jet breakup mechanisms (Skelland and Johnson, 1974) and perforated plate hydrodynamics may limit the admissible range within which the phase flow rates are allowed to fluctuate around the nominal average design value.

Fairly reliable empirical correlations describing perforated plate hydrodynamics and mass transfer are well detailed in the literature (Mewes and Pilhofer, 1979). This makes such columns amenable to a straightforward modeling approach. Existing correlations address both plate design (Koch and Vogelpohl, 2001) and estimation of the hydrodynamic

* *Corresponding author*. Tel.: +20 122 3149352; fax: +20 23 330 3528.
E-mail addresses: ettouney@thewayout.net, rettouney@hotmail.com (R.S. Ettouney).

Received 6 October 2011; Received in revised form 26 December 2011; Accepted 24 February 2012
0263-8762/$ – see front matter © 2012 The Institution of Chemical Engineers. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.cherd.2012.02.014