Contents lists available at ScienceDirect

Chemical Engineering Research and Design

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

Experimental investigation of dispersed phase holdup and flooding characteristics in a multistage column extractor

Mehdi Asadollahzadeh[a,b], *Meisam Torab-Mostaedi*[b,*], *Shahrokh Shahhosseini*[a], *Ahad Ghaemi*[a]

[a] *Department of Chemical Engineering, Iran University of Science and Technology (IUST), PO Box 16765-163, Tehran, Iran*
[b] *Nuclear Fuel Cycle Research School, Nuclear Science and Technology Research Institute, PO Box 11365-8486, Tehran, Iran*

ARTICLE INFO

Article history:
Received 12 June 2015
Received in revised form 15 November 2015
Accepted 25 November 2015
Available online 8 December 2015

Keywords:
Liquid–liquid extraction
Multistage column extractor
Dispersed phase holdup
Flooding velocities

ABSTRACT

In this research work, liquid–liquid extraction via three different systems has been investigated for determination of holdup, flooding velocities and holdup at the flooding points in a multistage column extractor. The effects of various parameters including rotor speed and dispersed and continuous phase velocities were studied. The results showed that the enhancement of rotor speed and dispersed and continuous phase velocities would enhance the dispersed phased holdup. There was a significant increase in the holdup at the flooding points with an increase in the rotor speed because of the smaller drops formation. New correlations were also developed for prediction of the flooding velocities, holdup at flooding points and dispersed phase holdup in the multistage column extractor. The results of the proposed correlation were compared with the experimental data obtained from the literature and the present investigation. Findings of this study demonstrated that the proposed correlations give accurate predictions for flooding characteristics.

1. Introduction

Solvent extraction (liquid–liquid extraction) is one of the most important unit operations in the chemical industries comprising the fuel recovery unit of nuclear power plants (Bahmanyar et al., 2014; Ettouney and El-Rifai, 2011; Ghadiri et al., 2014; Torab-Mostaedi et al., 2009). Among different types of solvent extraction units, the mechanically agitated extraction columns are emerging as the best choices because of their extreme case of flow regime compared with the most commonly used mixer-settler type extraction units (Gourdon et al., 1991; Hemmati et al., 2015a).

Among the counter-current agitated differential extraction columns, the rotating disc contactor and the multistage column extractor are used widely in industrial solvent extraction processes. A wide range of liquid–liquid systems commonly encountered in industry can be processed by the use of these two extraction columns. The rotating disc contactor is appropriate for low interfacial tension liquid–liquid systems and this kind of extractor is the most important agitated extractor. However, there is little information regarding the multistage column extractor. The advantages of multistage column extractors are their higher mass transfer rate and higher number of theoretical stages than the other types of extraction columns (Komasawa and Ingham, 1978; Morís et al., 1997; Reman and Olney, 1955).

The agitation was provided via the discs mounted on the rotor shaft improving multistage column extractor

* Corresponding author. Tel.: +98 2188221117; fax: +98 2188221116.
E-mail address: mmostaedi@aeoi.org.ir (M. Torab-Mostaedi).
http://dx.doi.org/10.1016/j.cherd.2015.11.019
0263-8762/

Nomenclature

a	specific interfacial area (m^2/m^3)
A	amplitude of pulsation (m)
AARE	average absolute relative error (–)
D_c	column diameter (m)
d_R	rotor diameter (m)
d_s	stator diameter (m)
e	void fraction of packing (–)
f	frequency of pulsation (s^{-1})
g	acceleration due to gravity (m/s^2)
H	effective height of the column (m)
h	compartment height (m)
m	exponent (–)
N	rotor speed (1/s)
P/V	power per unit volume (W/m^3)
V	superficial velocity (m/s)
V_d	dispersed phase velocity (m/s)
V_c	continuous phase velocity (m/s)
V_{df}	dispersed phase velocity at flooding (m/s)
V_{cf}	continuous phase velocity at flooding (m/s)
V_k	characteristic velocity (m/s)

Greek

ρ	density (kg/m^3)
μ	viscosity (Pa s)
σ	interfacial tension (N/m)
φ	dispersed phase holdup (–)
φ_f	dispersed phase holdup at flooding (–)
ε	free cross sectional area (–)
ψ	power dissipated per unit mass (m^2/s^3)

Subscripts

c	continuous phase
d	dispersed phase

performance by breaking the disperse phase droplets, and thereby enhancing the interfacial area for mass transfer (Laitinen and Kaunisto, 1998, 1999; Oldshue and Rushton, 1952; Sarker et al., 1980; Treybal, 1963). However, the performance of extraction column can be affected by two unwanted side effects including the entrainment of small droplets and hence an increase in axial mixing (Morís et al., 1997; Sarkar et al., 1985; Tsouris and Tavlarides, 1993). Therefore, investigation of hydrodynamic parameters comprising dispersed phase holdup, characteristic velocity and flooding is vital for the scale-up and design of multistage column extractors.

In recent years, the hydrodynamic parameters of different kinds of extraction columns have been investigated by several researchers (Asadollahzadeh et al., 2011; Napeida et al., 2010; Pina and Meirelles, 2000; Rahbar-Kelishami and Bahmanyar, 2012).

Several correlations have been published for hydrodynamic parameters in various types of columns. Unfortunately, many of these correlations are based on limited experimental ranges of variables, so they only apply to the particular liquid systems or column geometries for which they were obtained. Knowledge of the dispersed phase holdup is of fundamental importance in the design and operation of liquid–liquid extraction columns, since it is essentially needed to calculate the interfacial area per unit volume. Table 1 describes the experimental dispersed phase holdup correlations for various rotating columns. However, the available correlations for the prediction of dispersed phase holdup are either approximate or not always applicable.

Sarkar et al. (1985) observed the flooding characteristic in the multistage column extractor by the complete rejection of the dispersed phase through the aqueous phase inlet line. Arnold and co-workers studied the toluene/water physically equilibrated system and they observed flooding outside the impeller Reynolds number range 1.075×10^4 to 2.15×10^4, with phase inversion occurring inside this range (Arnold et al., 1974).

The main reasons for the disagreements are the lack of reliable correlations with which data from various investigations can be compared, the complexity of the involved experimental measurements, the limitations of the methods of measurement and the complete absence of a unifying theory to predict the hydrodynamic behavior of such contactors under various operating conditions.

Unfortunately, no experimental work concerning hydrodynamic parameters of multistage column extractor for low, medium and high interfacial tension systems has been reported in the literature to date. There is thus a requirement for investigation of multistage column extractor hydrodynamic parameters and proposition of new correlation for prediction of these parameters in this type of extractor.

In the current study, the hydrodynamic behavior of a pilot scale multistage column extractor is reported. The operational parameters such as agitated speed, continuous and dispersed phases flow rate are studied in order to investigate the dispersed phase holdup and flooding characteristics using three various liquid–liquid systems. The results are discussed and compared with the predicted values from several available correlations. Finally, new correlations are proposed for determination of holdup and flooding velocities in the multistage column extractor.

2. Experimental

2.1. *Liquid–liquid systems*

The liquid–liquid systems investigated were *n*-butanol–water (low interfacial tension), *n*-butyl acetate–water (medium interfacial tension) and toluene–water (high interfacial tension). These liquid–liquid systems have been recommended by the European Federation of Chemical Engineering as official test systems for investigation of extraction (Mĭsek et al., 1985). These liquid–liquid systems cover a range from 1.75 to 36.0×10^{-3} N/m with respect to the interfacial tension.

Distilled water was used as the continuous phase and technical grade of toluene; n-butyl acetate and *n*-butanol were used as the dispersed phase. The physical properties of the chemical systems are given in Table 2.

2.2. *Experimental column*

The schematic diagram of the multistage column extractor used in the present study is depicted in Fig. 1. The column was built of a cylindrical glass section and was equipped with impellers with accurate speed control, whereas the internal parts were constructed of stainless steel. The main section is made of Pyrex glass, 113 mm I.D, and the height of the column with nine stages is 700 mm. Mixing is done by nine 6-blade impellers of 50 mm diameter located at the center of each stage and these impellers are driven by an electric motor