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Experimental study on hold-up, characteristic and slip velocities in a horizontal pulsed sieve-plate column and uranium reactive extraction condition in aqueous phase



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ABSTRACT

The uranium extraction efficiency from sulfate leach liquor and the hydrodynamic behavior of the reactive extraction system was studied in the horizontal pulsed sieve-plated column. The effects of operating parameters and reactive condition were investigated. The obtained results showed that an increase in pulse intensity caused the decrease of dispersed phase hold-up and increase slip velocity. The slip velocity in the reactive uranium extraction situation was greater than that of the system without the reactive extraction due to the faster upward movement and more buoyancy of drops. The uranium extraction efficiency has a direct relationship with increasing pulse intensity and the dispersed phase flow rate, whereas has an indirect relationship with increasing continuous phase flow rate. Also, with comparison between experimental results and several empirical correlations for characteristic velocity, the Pratt model was chosen for prognostication of this parameter. The experimental results compared with the proposed correlations obtained from the previous studies demonstrated that the previous correlations have any reasonable accuracy to prognosticate the hold-up as well as the characteristic and slip velocities in this column. Therefore, the semi-empirical correlations were determined for prediction of hydrodynamic parameters as functions of the physical properties of systems and operating conditions. It can also be concluded that the horizontal pulsed sieve column is suitable for extraction of uranium from the sulfate liquor by Alamine 336 with extraction efficiency of approximately 99%. Therefore, it is a good alternative in radioactive processes, especially in places with height limitation.

1. Introduction

Uranium is an essential element in the nuclear fuel cycle. This vitally important element is found in nature in very limited ores. The extraction and separation of uranium from the sources are important processes because of chemical toxicity and radioactivity this metal can induce on ground and surface water (Kumar et al., 2011). The use of solvent extraction as a major technique on the industrial scale to recover uranium from the sulfuric acid leaching process is a known practice. Solvent extraction has various advantages because of its ease of handling, low cost for setup, high production capacity, zero waste generation and high product purity (Benedict et al., 1981).

The reported literature shows a large diversity of extractants based amines used for uranium separation from ores (Behera et al., 1993; Goldenberg and Abbruzzese, 1983). Tertiary amine extractants are the preferred reagents to the other compounds for uranium extraction from sulfate medium. Therefore, Alamine 336 is an effective extractant for uranium from the sulfuric acid liquor (Lapka et al., 2009; Quinn et al., 2013; Ramadevi et al., 2012).

Solvent extraction is a successful technique in the industry; therefore, recently a large number of extractors have been developed and extensively investigated (Godfrey and Slater, 1994). The interfacial area and system turbulence degree are directly proportional to increasing the mass transfer performance and efficiency of the liquid-liquid extractor (Jaradat et al., 2011; Samani et al., 2014). Generally, the pulsed columns are more suitable than the mixer-settlers because of their safety and economic perspective. The main advantages of the pulsed columns are: these columns do not have any moving parts, so its design is very simple; they have the least leakage, therefore, the cost of repair and maintenance in such columns is low. The contactors that have a minimal number of moving parts reduce the operating costs. Similarly, solvent extraction contactors must be efficient to reduce the

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Nomenclature		Greek letters	
AARE	Average absolute relative error $(-)$	ρ	density (kg m $^{-3}$)
VPSPC	Vertical pulsed sieve-plate column (-)	μ	viscosity (Pa s)
HPSPC	Horizontal pulsed sieve-plate column (-)	σ	interfacial tension between two p
af	Pulse intensity (m s^{-1})	arphi	Hold-up (—)
Q	Volumetric flow rate $(m^3 s^{-1})$	α	Fractional free area $(-)$
d ₃₂	Sauter mean drop diameter (m)	х	uranium concentration of the aqu
d_i	Drop diameter (mm) (mm)	у	uranium concentration of the org
n _i	number of droplets of mean diameter di $(-)$		
d	Column diameter (m)	Subscriț	ot
а	Specific interfacial area $m^2 m^{-3}$		
Α	Column cross-sectional area m ²	с	continuous phase
V	Velocity (m s^{-1})	d	dispersed phase
U	Superficial velocity (m s^{-1})	aq	aqueous phase
V _{slip}	Slip velocity (m s^{-1})	org	organic phase
V _{ch}	Characteristic velocity (m s^{-1})		

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anic phase mg L^{-1}

с	continuous phase
d	dispersed phase
aq	aqueous phase
org	organic phase

capital costs associated with shielding and containing process equipment (Melnyk, 1992). The extraction efficiency in the pulsed columns is high because of the increasing breakage and random inter-droplet coalescence and decreasing axial mixing (Lorenz et al., 1990; Yadav and Patwardhan, 2008). According to advantages cited above, the pulsed columns were applied in biochemical, petrochemical, metallurgical, chemical and nuclear industries (Hussain et al., 1988). The pulsed columns for liquid-liquid extraction are classified as: vertical and horizontal types. The vertical types are suitable for industries that have surface area restrictions and the horizontal types are appropriate for industries that have height limitation (Hussain et al., 1988; Logsdail and Thornton, 1959; Melnyk, 1992). One solvent extraction contactor developed for the nuclear industry is the vertical pulsed column. Although these contactors meets most of the required criteria for this application, a horizontal configuration would have additional advantages. The major advantage is a substantial reduction in building height, resulting in lower shielding costs. Additional advantages associated with a horizontal pulsed column include improved process control and a possible reduction in radioactive contamination of process equipment. Therefore, in the nuclear industry, the horizontal type can be replaced with vertical type for the separation of heavy metals (Melnyk, 1992). The advantages of the vertical type surpass the merits of the horizontal type; and yet the horizontal pulsed extraction column has gained much attention in recent times in the nuclear industry because of the height limitation, especially in indoor applications and availability of quick and easy column in the radioactive processes.

The design of solvent extraction columns requires determination of the height needed to attain an appropriate cross-sectional area for flow and a specified degree of mass transfer performance (Godfrey and Slater, 1991). The essential parameters for design and scale up of the mentioned horizontal pulsed column are information of the mean drop size, hold-up of dispersed phase, characteristic and slip velocities. The extraction column diameter is measured by determination of the holdup of the dispersed phase and slip velocity. The dispersed phase holdup variations in solvent extraction columns is necessary for the calculation

of residence time distributions in the analysis of interphase mass transfer rates (Sehmel and Babb, 1963). The slip velocity and interfacial area are calculated by the hold-up behavior in the extraction column; the calculation being indicative of the beginning of flooding. In transferring a solute between the aqueous and organic phases, the especially important parameter leading to the estimation of the mass transfer coefficients as well as the controlling of the mass transfer performance is determination of the slip velocity. Knowing the maximum column capacity and the flooding time requires the determination of the characteristic velocity as an important hydrodynamic parameter (Godfrey and Slater, 1991; Khajenoori et al., 2015).

The hold-up is specified by the fraction of the dispersed phase to total phase volumetric as follows (Treybal, 1963):

$$\varphi = \frac{Q_d}{Q_d + Q_c} \tag{1}$$

In pulsed sieve-plate extraction columns and the countercurrent two-phase flow condition, the slip velocity is defined as follows (Kumar and Hartland, 1994):

$$V_{slip} = \frac{U_d}{\varphi} + \frac{U_c}{1-\varphi}$$
(2)

The superficial velocities of the two phases are achieved by the each phase flow rate as follows:

$$U = \frac{Q}{A} \tag{3}$$

There are several equations for characteristic velocity have been summarized by Slater and Godfrey (Godfrey and Slater, 1991). This parameter is as a function of the slip velocity and dispersed phase holdup, which is defined as follows:

$$V_{slip} = V_{ch} f(\varphi) \tag{4}$$

Some of the equations for determination of the characteristic velocity have been listed in Table 1.

Table 1

The empirical equations for determination of the characteristic velocity.

1 1			
Model	Equation	Comments	Reference
Gayler & Pratt	$V_{slip} = V_{ch}(1 - \varphi)$	$\varphi < 0.2$	(Gayler and Pratt, 1951)
Richardson & Zaki	$V_{slip} = V_{ch}(1-\varphi)^m$	$0 < \varphi < 0.3$	(Richardson and Zaki, 1954)
Slater	$V_{slip} = V_{ch}(1-\varphi)^m + a\varphi^n$	$\varphi > 0.5$	(Slater, 1984)
		coalescence behavior shows by term $a\varphi^n$	
Letan & Kehat	$V_{slip} = V_{ch} \exp(-b\varphi)$	$-10 < \alpha < 10$, for RDC and ARDC columns	(Letan and Kehat, 1965)
Misek	$V_{slip} = V_{ch} (1 - \varphi) \exp(-\alpha \varphi)$	$\alpha\cong 0,$ if mass transfer occurs from the $c{\rightarrow}d,$ because of negligible coalescence.	(Misek, 1963)

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