

Short communication

Mass transfer performance in a coalescence–dispersion pulsed sieve plate extraction column

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Abstract

In order to improve the mass transfer characteristics, a coalescence–dispersion sieve plate was designed. Mass transfer experiments were carried out in a coalescence–dispersion pulsed sieve extraction (PSE) column of 150 mm in diameter with a working system of 30% TBP (in kerosene)–nitric acid–water. Mass transfer direction was from the continuous phase to the dispersed phase, namely from the aqueous phase to the organic phase. The mass transfer characteristics were evaluated by a dynamic tracer method. Three parameters, the ‘true’ height of the transfer unit, the height of the dispersion unit and the apparent height of the transfer unit, were estimated from the dynamic response curve. Compared with that in a standard PSE column, the mass transfer performance in the coalescence–dispersion PSE column was greatly improved. © 2000 Elsevier Science S.A. All rights reserved.

Keywords: Pulsed sieve extraction column; Coalescence–dispersion; Mass transfer; Dynamic tracer method

1. Introduction

Liquid–liquid extraction columns have played and will play important roles in many industries. In this field, great effort has been made to improve mass transfer characteristics. If drops of a dispersed phase can be coalesced and dispersed continuously while flowing through a column, the mass transfer can be greatly enhanced [1]. Therefore, special sieve plates (called coalescence plates), which can enhance the coalescence of drops, are inserted into a pulsed sieve extraction (PSE) column to supplant standard sieve plates. This new structure is called a coalescence–dispersion PSE column. The mass transfer performance in a 40 mm column has been studied [2]. The results indicate that, compared with that of a standard plate PSE column, the throughput of this new structure column can be increased by 50%, and the mass transfer efficiency by 20%. However, no information is available on the mass transfer characteristics in large diameter columns containing this new structure. In this work, a study of the mass transfer characteristics was carried out in a coalescence–dispersion PSE column of 150 mm in diameter.

2. Experimental details

Experiments were carried out in an air pulsed glass column of 150 mm in diameter and effective height of 2 m equipped with 31 sieve plates of standard type and 10 coalescence sieve plates. One coalescence sieve plate was installed every four plates. The coalescence sieve plates shown in Fig. 1 were made from poly(tetrafluoroethylene) (PTFE); the geometric structure is given in Table 1.

A switch valve was installed in the feed line for introducing the tracer acid and a sampling port was located just below the bottom plate for collecting the raffinate samples while the dynamics process experiments were performed [3–5]. The dispersed phase holdup was estimated by the volumetric replacement method. The experimental set-up is shown in Fig. 2.

TBP and nitric acid were of chemical grade. All the materials were purchased from Beijing chemical plant. Water was deionized. The materials were used directly without any purification.

3. Results

The Eqs. (1) and (2) for the dynamic process were established over differential elements of the column with

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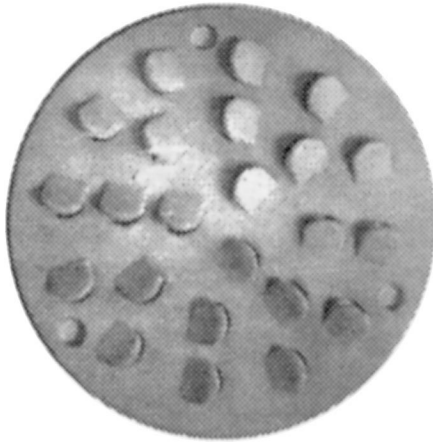


Fig. 1. Coalescence sieve plate.

Table 1
Geometric structure of the coalescence sieve plate

Material	PTFE
Thickness of the plate (mm)	2.0
Open angle	35°
Open free area	23%

cross-sectional area S and total effective height H , based upon the diffusion model and material balance, while operating under constant superficial velocities u_c and u_d at any given pulse amplitude and frequency.

$$\begin{aligned} \tau_x \frac{\partial x}{\partial t} + \frac{\partial}{\partial z} \left(x - \frac{1}{\text{Pe}_c} \frac{\partial x}{\partial z} \right) + N_{oc}(x - x^*) &= 0, \\ \tau_y \frac{\partial y}{\partial t} - \frac{\partial}{\partial z} \left(y - \frac{1}{\text{Pe}_d} \frac{\partial y}{\partial z} \right) + N_{oc}(x - x^*) \frac{u_c}{u_d} &= 0 \end{aligned} \quad (1)$$

$$\begin{aligned} \tau_x \frac{\partial x}{\partial t} + \frac{\partial}{\partial z} \left(x - \frac{1}{\text{Pe}_c} \frac{\partial x}{\partial z} \right) + N_{oc}(x - x^*) &= 0, \\ \tau_y \frac{\partial y}{\partial t} - \frac{\partial}{\partial z} \left(y - \frac{1}{\text{Pe}_d} \frac{\partial y}{\partial z} \right) + N_{oc}(x - x^*) \frac{u_c}{u_d} &= 0 \end{aligned} \quad (2)$$

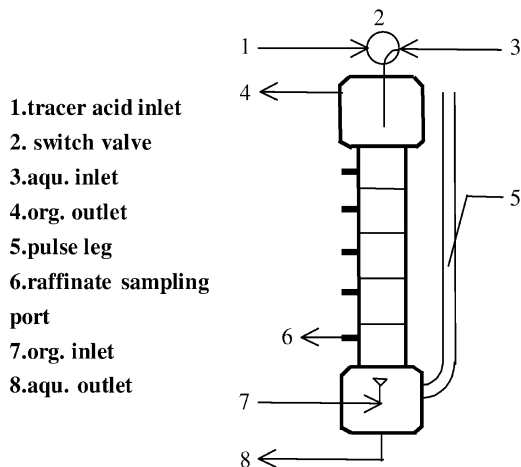


Fig. 2. Sketch of the experimental set-up.

where

$$\begin{aligned} \tau_x &= \frac{H(1-\phi)}{u_c}, \quad \tau_y = \frac{H\phi}{u_d}, \quad \text{Pe}_x = \frac{Hu_c}{E_c}, \\ \text{Pe}_y &= \frac{Hu_d}{E_d}, \quad z = \frac{h}{H}. \end{aligned}$$

Note that in Eqs. (1) and (2), $N_{oc} = (K_{oc}aH)/u_c$ represents $(\text{NTU})_{oc} = H/(\text{HTU})_{oc}$.

For solution of these equations, a difference scheme in mean implicit form was applied with suitable time and distance steps. A set of difference equations was obtained, and parameters Pe_c , Pe_d and N_{oc} were evaluated by Marquardt optimization [6] with the measured raffinate response data. Eqs. (1) and (2) were applied to the steady state, while $dx/dt \rightarrow 0$ and $dy/dt \rightarrow 0$ and the measured concentration profiles were used for the evaluation of the three parameters. For the steady state method, the outlet concentration of the two phases can be obtained directly. However, it must be calculated from the three evaluated parameters and the dynamic diffusion mass transfer model for the dynamic response method.

The apparent and diffusional height of the transfer unit are defined by

$$(\text{HTU})_{oc} = \frac{u_c}{K_{oc}a} = \frac{H}{(\text{NTU})_{oc}} \quad (3)$$

$$(\text{NTU})_{ocp} = \int_{x_r}^{x_f} \frac{dx}{x - x^*} \quad (4)$$

$$(\text{HTU})_{ocp} = \frac{H}{(\text{NTU})_{ocp}} \quad (5)$$

$$(\text{HTU})_{ocd} = (\text{HTU})_{ocp} - (\text{HTU})_{oc} \quad (6)$$

3.1. 'True' height of the transfer unit $(\text{HTU})_{oc}$

In the present work, the influence of the operating conditions, such as Af , on the 'true' height of the transfer unit $(\text{HTU})_{oc}$ is systematically studied in the coalescence–dispersion PSE column, and the results are plotted in Fig. 3.

It can be seen that $(\text{HTU})_{oc}$ depends strongly on the pulse intensity, Af . With an increase in pulse intensity, the $(\text{HTU})_{oc}$ is decreased while all other experimental conditions are unchanged. When the pulse intensity condition is $Af > 2.0 \text{ cm s}^{-1}$, compared with the condition of $Af = 1.5 \text{ cm s}^{-1}$, the $(\text{HTU})_{oc}$ is decreased dramatically. There exists a turning point in the pulse intensity. If the intensity is less than the value of this point, the break up of the dispersed phase drops is negligible, the holdup of the dispersed phase is less, and so $(\text{HTU})_{oc}$ is not obviously changed with changes in the pulse intensity. If the intensity is larger than this value, the coalescence and break up of the drops are obvious, and the holdup of the dispersed phase is increased markedly with changes in the pulse intensity, which greatly enhances the mass transfer.

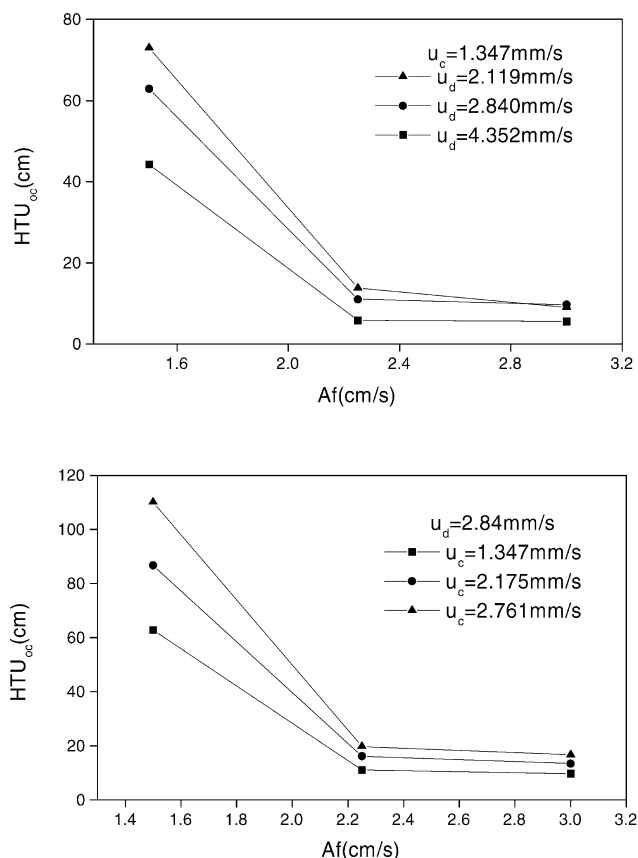


Fig. 3. Influence of operating conditions on $(HTU)_{oc}$.

It can be seen from the plots in Fig. 3 that the $(HTU)_{oc}$ also depends on the dispersed phase flow rate. When the dispersed phase flow rate is increased, the $(HTU)_{oc}$ will decrease. This is because the dispersed phase holdup is increased. From Fig. 3, it can also be clearly shown that the $(HTU)_{oc}$ is increased with an increase in velocity of the continuous phase.

In order to confirm the ability of the new column to enhance the mass transfer performance, the mass transfer results in the new column were compared with these in the same diameter column equipped with standard cartridge sieve plates. Fig. 4 shows a comparison of $(HTU)_{oc}$ between the coalescence–dispersion PSE column and standard PSE column [7].

From Fig. 4, we can see that the $(HTU)_{oc}$ decreases as the pulse intensity and dispersed phase velocity increase, and as the continuous phase velocity decreases for both columns. At low pulse intensity ($Af=1.5 cm s^{-1}$), the values of the $(HTU)_{oc}$ are almost the same for the two kinds of column under the same operating conditions. The mass transfer characteristics in the standard PSE column are better than those in the new column. The most probable reason is that the drop size of the dispersed phase at low pulse intensity is much larger than that at high pulse intensity and there are more chances of coalescence in the new column, so that the holdup of the dispersed phase is less than that

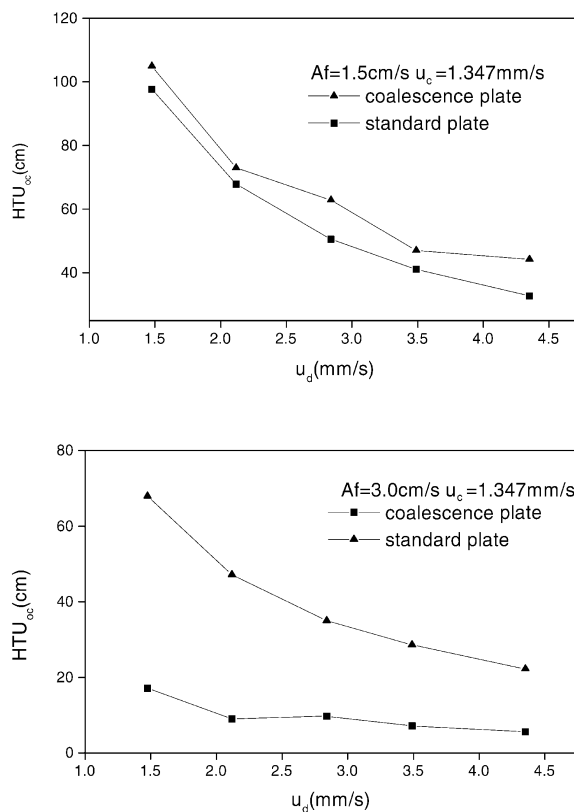


Fig. 4. Comparison of $(HTU)_{oc}$ between the coalescence–dispersion PSE column and standard PSE column.

in the standard PSE column. However, at higher intensity ($Af>2.0 cm s^{-1}$), the true height of the mass transfer unit is decreased dramatically. This is because, at high pulse intensity in the coalescence–dispersion PSE column, the drops of the dispersed phase periodically coalesce under the coalescence plates, and then break up. This greatly enhances the mass transfer.

3.2. Diffusion height of the transfer unit $(HTU)_{ocd}$

The influence of the operating conditions on $(HTU)_{ocd}$ is plotted in Fig. 5. It can be seen that $(HTU)_{ocd}$ depends on the two phase flow rates and the pulse intensity. With an increase in pulse intensity, the diffusional height of the mass transfer unit increases. At low dispersed phase flow rate, the increase is very marked, but at high dispersed phase flow rate, the increase is very slow. With an increase dispersed phase flow rate $(HTU)_{ocd}$ will decrease quickly. The influence of the continuous phase flow rate on $(HTU)_{ocd}$ is not obvious. The reason is that, when the pulse intensity is increased, the degree of axial mixing is increased, but the dispersed phase holdup will increase at the same time. These two effects determine that $(HTU)_{ocd}$ will not change seriously at high dispersed phase flow rate as the pulse intensity is increased. When the dispersed phase flow rate is increased, the holdup will increase quickly, the axial

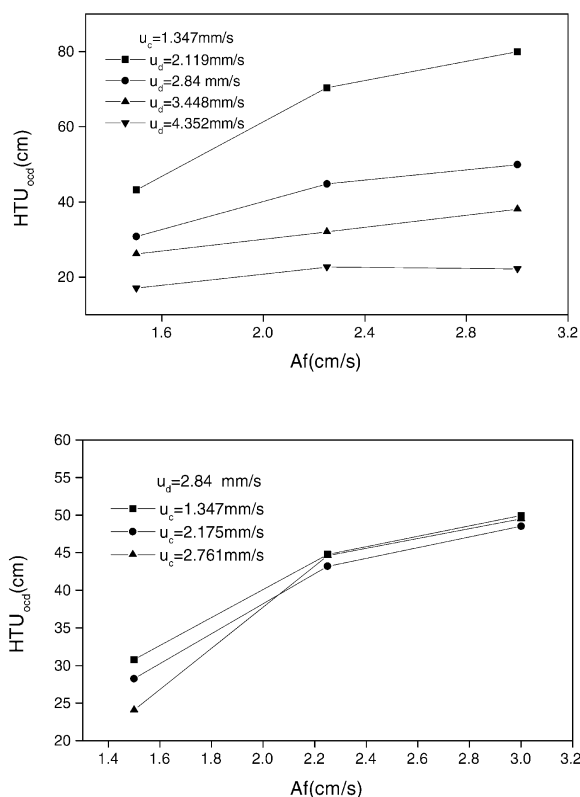


Fig. 5. The influence of the operating conditions on $(HTU)_{ocd}$.

mixing coefficient will decrease, and $(HTU)_{ocd}$ will decrease quickly.

The comparison of $(HTU)_{ocd}$ between the coalescence–dispersion PSE column and standard PSE column [8] is shown in Fig. 6. It can be seen that, compared with the standard PSE column, at low pulse intensity, the diffusion height of the mass transfer unit of the coalescence–dispersion PSE column is much smaller. At high pulse intensity, the diffusion height of the mass transfer unit of the coalescence–dispersion PSE column changes very little.

3.3. Apparent height of the mass transfer unit $(HTU)_{ocp}$

The comparison of $(HTU)_{ocp}$ between the coalescence–dispersion PSE column and the standard PSE column is shown in Fig. 7. From this figure we can see that, compared with the standard PSE column, the apparent height of the mass transfer unit of the coalescence–dispersion PSE column is decreased. At low pulse intensity ($Af < 1.5 \text{ cm s}^{-1}$), the decrease is not large and the rate of decrease slowly decreases as the dispersed phase flow rate is increased. At high pulse intensity ($Af > 2.0 \text{ cm s}^{-1}$), the decrease is obvious, and the rate of increases as the dispersed phase flow rate is increased. This is because, at high pulse intensity conditions in the coalescence–dispersion PSE column, the drops of the dispersed phase periodically coalesce under the coalescing plates, and then break up. This greatly enhances the mass transfer.

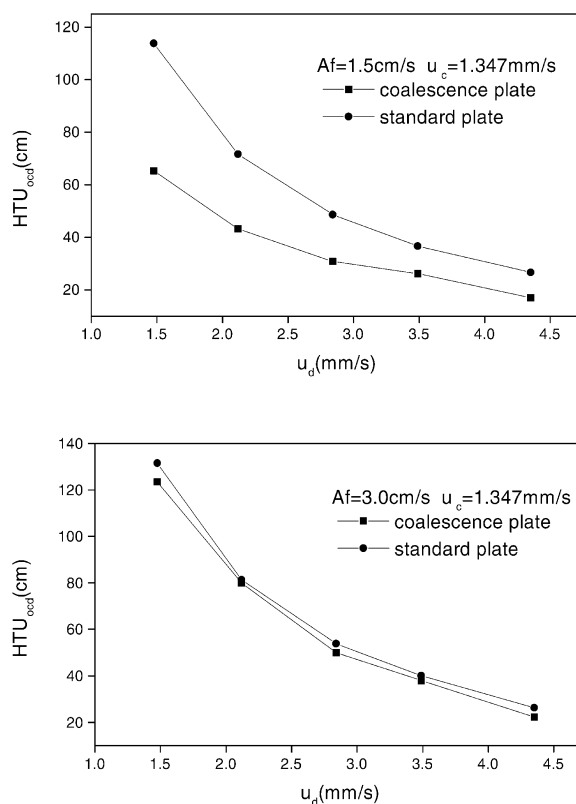


Fig. 6. Comparison of $(HTU)_{ocd}$ between the coalescence–dispersion PSE column and standard PSE column.

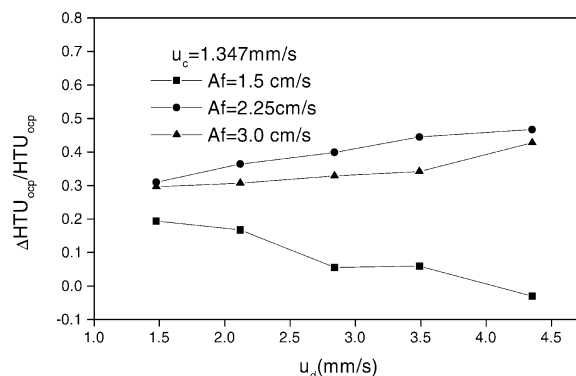


Fig. 7. Comparison of $(HTU)_{ocp}$ between the coalescence–dispersion PSE column and the standard PSE column.

4. Conclusion

Compared with the standard PSE column, the mass transfer performance in the coalescence–dispersion column changes little at low pulse intensity ($Af = 1.5 \text{ cm s}^{-1}$) and greatly increases at high pulse intensity ($Af > 2.0 \text{ cm s}^{-1}$). The periodic coalescence and break up of drops in the column can greatly enhance the mass transfer performance. If the coalescence–dispersion column operates at high pulse intensity ($Af > 2.0 \text{ cm s}^{-1}$), the mass transfer efficiency can be increased by more than 30%.

5. Nomenclature

a	interfacial area ($\text{m}^2 \text{m}^{-3}$)
A	pulse amplitude (cm)
E_c	diffusion coefficient of solute in continuous phase ($\text{m}^2 \text{s}^{-1}$)
E_d	diffusion coefficient of solute in dispersed phase ($\text{m}^2 \text{s}^{-1}$)
f	pulse frequency (s^{-1})
$(\text{HTU})_{oc}$	true height of mass transfer unit (cm)
$(\text{HTU})_{ocd}$	diffusional height of mass transfer unit (cm)
$(\text{HTU})_{ocp}$	apparent height of mass transfer unit (cm)
K_{oc}	overall mass transfer coefficient based on continuous phase (m s^{-1})
$N_{oc}, (\text{NTU})_{oc}$	number of 'true' transfer units
$(\text{NTU})_{ocp}$	number of apparent transfer units
Pe_c	Peclet number of continuous phase
Pe_d	Peclet number of dispersed phase
u_c	superficial velocity of continuous phase (mm s^{-1})
u_d	superficial velocity of dispersed phase (mm s^{-1})
x	solute concentration in continuous phase (mol l^{-1})

x^*	equilibrium concentration of solute in continuous phase (mol l^{-1})
x_f	feed solute concentration (mol l^{-1})
x_r	raffinate solute concentration (mol l^{-1})

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