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Effect of recycle-barrier location on membrane extraction in a parallel-flow rectangular module with internal reflux

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Abstract

The influence of recycle-barrier location on membrane extraction through a parallel-flow rectangular module with internal reflux has been investigated. The recycle barrier is placed in the raffinate phase to divide the flow channel into an operating subchannel and a reflux subchannel and thus, there are concurrent flow in one subchannel and countercurrent flow in another subchannel. It was found that the larger part of mass-transfer area for countercurrent-flow channel, as well as the smaller part of mass-transfer area for concurrent-flow channel, is beneficial to total mass-transfer rate. It was also noted that with the recycle-barrier location moving gradually from the centerline of the raffinate phase to create larger mass-transfer area for countercurrent-flow channel, and to decrease mass-transfer area for concurrent-flow channel, the same performance can be achieved with reducing the reflux ratio.

Keywords: Membrane extraction; Reflux; Recycle-barrier location; Parallel flow

1. Introduction

Membrane extraction is carried out in a microporous membrane device, in which the membrane is generally contacted with two immiscible fluids at two sides (phases *a* and *b*). However, if these two fluids are miscible, then the pores of the membrane is filled with another fluid (phase *c*) which is immiscible with these two fluids. The solute is extracted from phases *a* to *c* and then to phase *b*, or vice versa. This new technique overcomes the limitations of conventional liquid extraction, such as flooding, intimate mixing, limitations on independent phases flow rate variations, requirement of density difference and inability to handle particulates (Lo and Baird, 1980).

Application of the external or internal reflux to the design and operation of a mass- or heat-transfer equipment can effectively enhance the effect on mass or heat transfer, leading to improved performance (Garcia-Calvo et al., 1998; Goto and Gaspillo, 1992; Ho et al., 1988; Kikuchi et al., 1999; Korpijarvi et al., 1998; Santacesaria et al., 1999; Stenas et al., 1999; Tsai and Yeh, 1985; Yeh et al., 1986a,b, 1987). Recently, the recycle effect on solvent extraction in microporous-membrane modules has been studied both theoretically and experimentally (Yeh et al., 1999; Yeh and Chen, 2001). For solvent extraction through membrane modules, the recycle effect is suitable for the system with higher distribution coefficients where the liquid-phase mass-transfer resistances are more strongly predominant. The purpose of this work is to investigate the influence of recycle-barrier location in the raffinate phase on a solvent extraction through a double-pass parallel-plate membrane module with internal reflux.

2. Theory

A parallel-flow device has two different flow patterns for operation. Fig. 1 shows the system with concurrent flow first and then followed by countercurrent flow. On the other

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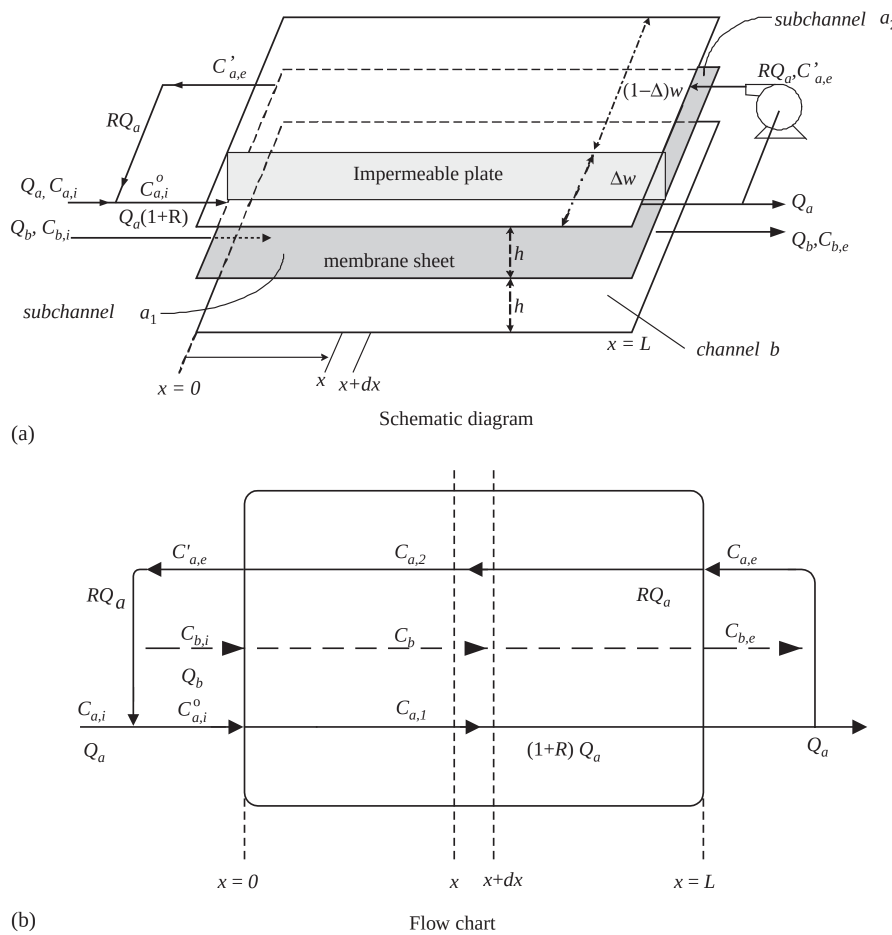

Fig. 1. (a,b) Parallel-plate membrane extractor with concurrent-flow operation and countercurrent-flow reflux.

hand, Fig. 2 illustrates the system with countercurrent flow first and then followed by concurrent flow. The total mass-transfer rate may be expressed by referring Figs. 1 and 2 as

$$W = Q_a(C_{a,i} - C_{a,e}) = Q_b(C_{b,e} - C_{b,i}). \tag{1}$$

2.1. Concurrent-flow operation with countercurrent-flow reflux

Fig. 1 shows a concurrent-flow rectangular membrane extractor with internal reflux by countercurrent flow. An impermeable plate with negligible thickness is placed in vertical to the upper plate and the membrane sheet, at a certain line of channel a (phase a) to divide the raffinate phase into two subchannels (subchannels a_1 and a_2) of widths Δw and $(1-\Delta)w$, respectively, and that a pump is installed for internal reflux. Thus, in the raffinate phase (phase a) the inlet fluid of volume rate Q_a mixed with the outlet reflux fluid of volume rate RQ_a flows steadily as well as concurrently and countercurrently within subchannels a_1 and a_2, respectively. The extract phase (phase b) with inlet volume rate Q_b flows steadily through channel b.

Referring to Fig. 1, the mass balance over the right-hand section of the membrane extractor operated, with reflux ratio R, is

$$Q_b(C_{b,e}-C_b)=(1+R)Q_aC_{a,1}-RQ_aC_{a,2}-Q_aC_{a,e} \tag{2}$$

or

$$C_b = C_{b,e} - \left(\frac{Q_a}{Q_b}\right)[(1+R)C_{a,1} - RC_{a,2} - C_{a,e}]. \tag{3}$$

Considering the mass transfer on subchannels a_1 and a_2 over the length dx

$$-(1+R)Q_a\,\mathrm{d}C_{a,1} = K_1\Delta w(H_{ac}C_{a,1} - H_{bc}C_b)\,\mathrm{d}x, \tag{4}$$

$$RQ_a\,\mathrm{d}C_{a,2} = K_2(1-\Delta)w(H_{ac}C_{a,2} - H_{bc}C_b)\,\mathrm{d}x, \tag{5}$$

where K_1 and K_2 are the overall mass-transfer coefficients in subchannels a_1 and a_2, respectively, while H_{ac} and H_{bc} are the distribution coefficients between two different phases, as defined by

$$H_{ac} = \frac{\text{Solute concentration in phase } c}{\text{Solute concentration in phase } a}. \tag{6}$$