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A comparative study of liquid-liquid extraction in different rotating bed contactors

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ABSTRACT

This study examines the influence of the internal structure of the rotor of rotating bed contactors on mass transfer characteristics in liquid-liquid extraction. Experiments were carried out in rotating spiral bed, rotating zigzag bed, and rotating packed bed. The system studied was removal of hexavalent chromium from an aqueous solution using Aliquat336 (dissolved in kerosene) as the extractant. The stage efficiency in all the rotating contactors increased with rotational speed and flow rates but decreased with feed concentration. The rotating spiral bed extractor (RSB) provides significant improvement over other rotating packed bed (RPB). The stage efficiency attained in RSB was ~99% within a bed of radial depth ~0.06 m at aqueous and organic flow rates of $13.34 \times 10^{-6}\,m^3s^{-1}$and $3.34 \times 10^{-6}\,m^3s^{-1}$respectively. The overall volumetric mass transfer coefficient is over twenty five times higher than that in conventional extractors like mixer settler and fixed bed.

1. Introduction

Liquid-liquid extraction (LLE) is extensively used in various industrial applications [1] such as removal or recovery of heavy metals from waste water, pharmaceutical and hydrometallurgical industries, and biochemical separations. This technique is considered to be better than other conventional purification processes due to simplicity in its operation, high efficiency and loading property [2].

There has been continuous attempt to develop new types of extractors to improve the mass transfer efficiency over traditional ones like mixer settler, spray column, packed bed, etc. In recent years, HIGEE (acronym for high gravity) technology has received considerable attention for intensification of mass transfer rates in gas-liquid operations such as absorption and distillation [3–5]. Rotating packed bed (RPB) contactor has been widely studied for implementation of the technology. In this device, the phases are contacted between two rotating co-axial disk (rotor). The space within the rotor is filled with packing material. The liquid flows radically outward within the rotor under centrifugal acceleration that is hundreds of times the terrestrial gravity. As a result, the volumetric mass transfer coefficients achieved is much higher than those obtained in traditional contactors. This makes it possible to reduce the physical size of the equipment along with capital and operating costs.

The application of HIGEE technology to the processes involving liquid-liquid extraction is very limited. Modak et al. [6] studied solvent extraction of methyl red using xylene in rotating packed bed contactor. They reported that the overall volumetric mass transfer coefficient in RPB for the system varied approximately between $0.02\,s^{-1}$ and $0.2\,s^{-1}$ for the operating conditions investigated. These values are higher compared to other extractor designed to operate in a centrifugal field such as annular centrifuge [7] and rotating spray column [6], and over an order greater than in conventional extractors.

Besides packed bed, several other variations of the internal structure of the rotor [8] such as split packing, zigzag bed, spiral bed, helical, wave-form disk have been reported in the literature. In rotating zigzag bed [9], liquid is dispersed as droplets in the space between adjacent concentric baffles, and as film on the walls of the baffles. The liquid flow in the spiral channels of rotating spiral bed (RSB) may be considered to be akin to liquid film falling over wetted wall towers [10] whereas it flows as rivulet, films or drops over the packing in RPB [11]. Both theoretical and experimental gas-liquid mass transfer studies have been reported in rotating zigzag bed [8,9,12–14], and rotating spiral bed contactors [10,15–17].

The mass transfer efficiency of extractors generally depends on the degree of mixing and the interfacial area [18,19]. These parameters would vary in the rotor designs due to difference in the liquid flow texture. Selection of appropriate rotor design therefore requires knowledge of the mass transfer rates. Investigators have reported the significant difference in performance between zigzag bed [8,9,14], spiral bed [16], split packing [20] and rotating packed bed for gas-

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Nomenclature

a	Effectiveinterfacial area per unit volume (m^2m^{-3})
C	concentration($mmolm^{-3}$)
C_D	distribution ratio
D	Diffusion coefficient ($m^2\ s^{-1}$)
d	Disk diameter (m)
h	axial distance between the rotating disks (m)
$K_L a$	overall volumetric mass transfer coefficient (s^{-1})
m,n	constant in Eq. (1)
p	constant in Eq. (4)
Q	flow rate (m^3s^{-1})
r	radial distance (m)
V	velocity ($m\ s^{-1}$)

Subscript

a	aqueous phase
ex	extractant
o	organic phase

Superscript

e	exit
i	inlet
n	constant in Eq. (1)
u	constant in Eq. (7)
v	constant in Eq. (7)
x	constant in Eq. (7)
y	constant in Eq. (7)
z	constant in Eq. (7)
*	equilibrium

Greek symbols

$\alpha_1 - \alpha_{10}$	constants of Eq. (6)
ω	rotational speed(rpm)
η	stage efficiency
ρ	density ($kg\ m^{-3}$)
ν	Kinematic viscosity ($m^2\ s^{-1}$)
γ	Interfacial Tension ($N\ m^{-1}$)
ϕ	ratio of Cr(VI) concentration in the solution at radial distance r to that in the feed

liquid mass transfer. However, similar studies are not available for liquid-liquid systems.

In this study, liquid-liquid extraction was carried out in three different rotors with internal structure similar to RPB, RZB and RSB having different flow hydrodynamics. The performance of these devices was compared for the removal of hexavalent chromium (Cr (VI)) from aqueous solution using Aliquat 336 as the extractant (kerosene as the diluent).

2. Materials and methods

2.1. Materials

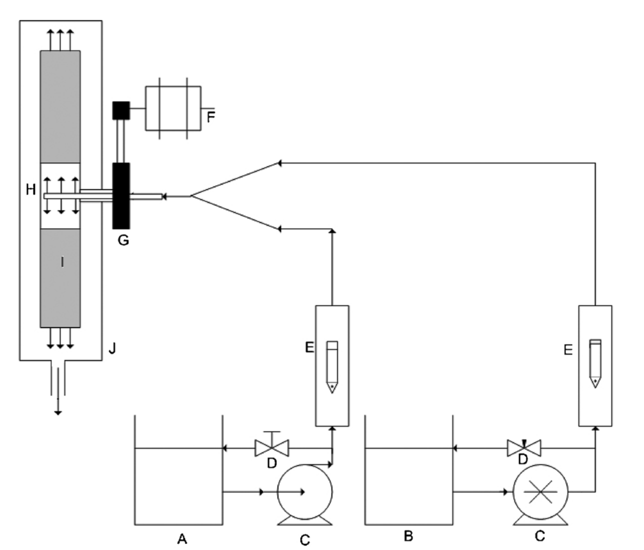
Potassium dichromate was used as the model solute. Commercially available Aliquat336 (Methyltrialkyl ammonium chloride) was selected as the extractant. It was dissolved in kerosene (non-polar diluents) procured from the local market and used without further purification. Modifier, 1-decanol was added to the kerosene to prevent solid phase formation of the complex in the organic phase. All reagents including hydrochloric acid (purity 37%), 1–5 diphenylcarbazide, sulfuric acid (purity 98%), and acetone used were of analytical grade and procured from Merck.

2.2. Experimental set up

The schematic diagram of the experimental set up used for liquid-liquid extraction experiments is shown in Fig. 1. Fig. 2 shows the internal sketches of the three different rotors. All the rotors consisted of a pair of stainless steel circular disk of 0.160 m diameter fastened coaxially, and separated by an axial distance of 0.02 m. The two disks were rotated vertically around a horizontal shaft by a motor. The whole rotor arrangement was housed inside a cylindrical casing of 0.20 m diameter and 0.05 m axial length. The liquid is fed into the rotor through a stationary distributor at the eye of the rotor. The diameter of the distributor was 0.034 m and provided with 24 holes of 1 mm diameter.

The internal features of rotor *A*, *B* and *C* is similar to rotating spiral bed, rotating zigzag bed and rotating packed bed respectively. Rotor *A* featured spiral baffles of height 0.02 m and 0.01 m spiral channel width on each of the rotating disk. The width of the spiral channel reduced to ~0.005 m, when the disks were brought together to constitute the rotor. Each of the spiral channels made approximately 6 revolutions with length 1.9 m. A series of circular concentric baffles were fitted onto the two rotating disks of Rotor *B*. The baffles were of height 0.017 m and were separated by a distance of 0.01 m. When the disks were brought together, the gap between successive baffles was 0.005 m. The space between the disks in Rotor *C* was filled with glass beads having average diameter ~3 mm.

Experiments were also carried out in a fixed bed contactor and mixer settler. The former was a glass column of diameter 0.05 m and packed with glass beads. The solution in the latter was mechanically agitated. The packed bed volume and liquid volume in these contactors was identical to that of rotating contactors.



A: Aqueous phase tank, B: Organic phase tank, C: Pump, D: Valve, E: Rota meter, F: Electric driven motor, G: Rotating shaft, H: Liquid distributor, I: Rotating bed, J: Stationary casing

Fig. 1. Schematic diagram of experimental set up for liquid-liquid extraction.

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