Separation and Purification Technology 144 (2015) 139–145

Contents lists available at ScienceDirect

Separation and Purification Technology

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

Effective interfacial area and liquid-side mass transfer coefficients in a rotating bed equipped with baffles

Ching-Yi Tsai, Yu-Shao Chen *

Department of Chemical Engineering, Chung Yuan University, Chung-Li 320, Taiwan

A R T I C L E I N F O

Article history:
Received 23 June 2014
Received in revised form 6 February 2015
Accepted 7 February 2015
Available online 21 February 2015

Keywords:
Rotating packed bed
Baffle
Mass transfer coefficient
Effective interfacial area

A B S T R A C T

This study examines the mass transfer characteristics of a rotating bed that is equipped with static baffles. The volumetric liquid-side mass transfer coefficient (k_La) and the effective gas–liquid interfacial area were determined using a deoxygenation system and a chemisorption of CO_2 in NaOH solution, respectively; the local liquid-side mass transfer coefficient (k_L) was thus calculated. The effects of liquid flow rate, rotational speed, baffles and type of packing on these mass transfer parameters were investigated. Experimental results show that the bed with baffles had a higher interfacial area and lower k_L than that without baffles. Adding baffles to the bed did not significantly affect the k_La values. Additionally, the packing with a larger specific interfacial area yielded higher values of k_La mainly because the effective interfacial area was higher.

1. Introduction

A rotating packed bed (RPB) is commonly introduced as a gas–liquid contactor with a high mass transfer efficiency as it replaces gravity with a centrifugal force. The liquid that flows through the high-speed rotor undergoes high acceleration, yielding thin liquid films, tiny liquid droplets and chaotic flow. Accordingly, the mass transfer and mixing efficiency can be substantially increased in an RPB. An RPB typically has a mass transfer coefficient that is one to two orders of magnitude higher than that of a conventional packed column. The considerable reduction in size and capital that are provided by the RPB have made it important in the field of process intensification. Applications of the RPB in absorption [1–4], stripping [5], distillation [6,7], transesterification [8] and the production of particles [9,10] have been widely explored.

The characteristics of fluid flow within an RPB have been investigated by observation with a camera [11,12], electro-conductivity measurement [12] and CFD analysis [13]. One of the unique flow behaviors in an RPB is the synchronous rotation of fluids with the rotor, which is caused by the drag of the packing, and is supposed to be an important factor that limits the improvement of mass transfer efficiency. As the liquid enters the rotor, it is accelerated by the packing over a very short distance and then rotates synchronously with rotor. Strong mass transfer occurs in the zone close to the inner radius of the rotor because of the tangential velocity of the liquid relative to the packing is high. Outside this region, the relative velocity is very small, causing a severe mal-distribution of liquid in the packing [11,12]. Consequently, some of the packing becomes un-wetted and the gas–liquid interfacial area is reduced. On the other hand, synchronous rotation of the gas in the rotor was observed [14]. Some studies have revealed that the gas-side mass transfer coefficient (k_G) is similar to that in a conventional packed column because of the lack of tangential velocity of the gas as it passes through the rotor [15,16]. The increase in the effective gas–liquid interfacial area is responsible for most of the increase in K_Ga that is caused by the centrifugal force in a gas-side resistance-controlled process.

Recently, several novel designs that improve the hydraulic performance and mass transfer efficiency of RPBs were proposed. These designs have focused on limiting the synchronous rotation of fluids and enhancing the velocity of the fluids relative to the packing. Chandra et al. [17] developed an RPB with split packing and found that it exhibited enhanced tangential slip velocity. Reddy et al. [18] reported that K_Ga values in an RPB with split packing were two orders of magnitude higher than those in a conventional packed column. Wang et al. [19] presented a rotating zigzag bed for an ethanol–water distillation system and showed that the volume of the equipment could be made an order of magnitude smaller than that of a conventional packed column. Luo et al. [20] studied the mass transfer in an RPB with blades inside the rotor; their results revealed that the rotor with blades considerably increased the effective interfacial area and k_L.

Our earlier work developed a rotating blade bed with static baffles, whose pressure drop and overall mass transfer coefficient were examined using an isopropyl alcohol absorption process

---

* Corresponding author. Tel.: +886 3 2654131; fax: +886 3 2654199.
E-mail address: yschen@cycu.edu.tw (Y.-S. Chen).

http://dx.doi.org/10.1016/j.seppur.2015.02.008
1383-5866/

Nomenclature

a	gas–liquid interfacial area (1/m)
C_{CO_2}	concentration of carbon dioxide in liquid stream (mol/L)
$C^*_{CO_2}$	concentration of carbon dioxide at the gas–liquid interface (mol/L)
$C_{L,i}$	concentration of solute in the inlet liquid stream (mol/L)
$C_{L,o}$	concentration of solute in the outlet liquid stream (mol/L)
C_{NaOH}	concentration of sodium hydroxide (mol/L)
$C_{Na_2CO_3}$	concentration of sodium carbonate (mol/L)
D_{CO_2}	diffusion coefficient of carbon dioxide in liquid (m^2/s)
$D_{CO_2,w}$	diffusion coefficient of carbon dioxide in water (m^2/s)
E	enhancement factor of the gas–liquid flux due to chemical reaction (–)
H	Henry's constant [(mol/L)/(mol/L)]
H_{CO_2}	Henry's constant [(mol/L)/atm]
Ha	Hatta number defined in Eq. (4) (–)
I	ionic strength of solution (mol/L)
k_1	reaction rate constant (L/s)
k_2	reaction rate constant (L^2/mol s)
k_2^∞	reaction rate constant in infinite dilution (L^2/mol s)
k_G	gas-side mass transfer coefficient (m/s)
k_L	liquid-side mass transfer coefficient (m/s)
K_Ga	overall volumetric gas-side mass transfer coefficient (1/s)
k_La	volumetric liquid-side mass transfer coefficient (1/s)
m	exponent in Eq. (15) (–)
n	exponent in Eq. (15) (–)
N_{CO_2}	CO_2 gas–liquid flux (mol/m^2 s)
P_{CO_2}	partial pressure of CO_2 in the gas phase (atm)
p	exponent in Eq. (16) (–)
q	exponent in Eq. (16) (–)
Q_G	gas flow rate (m^3/s)
Q_L	liquid flow rate (m^3/s)
r_{CO_2}	rate of reaction (mol/s)
r_i	inner radius of the packed bed (m)
r_o	outer radius of the packed bed (m)
S	stripping factor defined as $S = \frac{HQ_G}{Q_L}$ (–)
T	temperature (K)
z	axial height of the packing (m)

Greek letters

ε	porosity of the packing (–)
ω	rotational speed (rpm)

[21]. Experimental results demonstrated that adding the static baffles in the rotating blade bed reduced the pressure drop by 53% and improved K_Ga by 117%. These results indicated that installing static baffles inside the rotating blade bed effectively disturbed the rotation of the gas, reducing the centrifugal pressure drop and increasing the tangential slip velocity of the gas flow. Additionally, adding the baffles made the liquid flow behavior in the device very different from that in a conventional RPB because the liquid is repeatedly accelerated between the blades and the baffles. Consequently, the liquid-side mass transfer coefficients (k_La and k_L) and the effective interfacial area of the proposed device were investigated in present study.

Many works have presented experimental data and empirical equations for the volumetric liquid-side mass transfer coefficient in an RPB [22]. Oxygen–water stripping or absorption processes are typically conducted to obtain k_La because the gas-side mass transfer resistance is negligible in these processes. Moreover, several investigations have demonstrated the measurement of the effective gas–liquid interfacial area in an RPB using a CO_2–NaOH absorption process. Munjal et al. [23] obtained the effective interfacial area of glass beads and commercial high-porosity packing in an RPB. Their experimental results showed that the interfacial area was proportional to the rotational speed to a power of 0.42 for glass beads and 0.28 for the high-porosity packing, respectively. Yang et al. [24] measured the effective interfacial area in an RPB with rotors of different radii. Higher interfacial area was observed with rotors with smaller outer radii, revealing a significant end effect in the RPB. Rajan et al. [25] measured the interfacial area in a split-packing RPB and found that counter-rotation of the packing yielded a higher interfacial area than co-rotation. Luo et al. [26] evaluated the interfacial area in RPBs that were packed with various types of wire mesh. They proposed that the effective interfacial area was proportional to the centrifugal acceleration raised to the power of 0.12. Guo et al. [27] investigated the effect of the shell zone on the interfacial area in an RPB; their results revealed that the interfacial area in the shell zone can reach 30% of that in the whole RPB. In our previous work, the rotating bed with baffles showed a high values of K_Ga. However, the fundamental characteristics of mass transfer in this device are not clear and a systematic study on the individual mass transfer coefficients and the effective interfacial area is required. Therefore, this study further investigated the liquid-side mass transfer coefficients and the effective interfacial area to understand the mechanism of mass transfer of the proposed device. An oxygen-stripping process and a CO_2 absorption process were utilized to determine k_La and the effective gas–liquid interfacial area, respectively, in a rotating bed with baffles. The k_L values were also calculated. The effects of rotational speed, liquid flow rate, baffles and type of packing on these mass transfer parameters were examined.

2. Experimental

Fig. 1 displays the structure of a rotating blade bed with baffles. The device herein comprised mainly of a rotating disk and a static disk. Three sets of blades, each has eight, 16 and 16 blades, were installed in the annular packing regions of the rotating disk, shown as Fig. 1(b). Each blade, which was covered by a layer of stainless steel mesh, had a radial width of 1.2 cm and an axial height of 1.8 cm. The inner and outer radii of the rotor were 1.8 and 7.8 cm, respectively, and the specific surface area and porosity were 163 1/m and 0.99, respectively. Between packing regions, two sets of baffles were fixed on the static disk, shown as Fig. 1(c). The baffle was made of a stainless steel sheet which was not perforated. It had a radial width and an axial height of 0.6 and 1.5 cm, respectively and was designed to be removable to enable the effect on mass transfer to be determined. The structure and number of the blades and baffles were discussed in our previous work [21]. The wire-mesh packing was also investigated by replacing the blades with stainless steel wire mesh in the annular packing regions. The specific surface area and porosity of the wire-mesh packing were 397 1/m and 0.98, respectively. The bed was operated from 600 to 1800 rpm, which provided a centrifugal force of 19 to 174-fold gravitational force. Consequently, the effect of gravity on the flow of fluids in the rotor can be neglected. The liquid entered the bed from a liquid distributor at its center; was sprayed toward the inner edge of the packing region, and was moved outward by the centrifugal force. Some of the liquid was captured by the static baffles and it would flow down along