RESEARCH NOTES

A Study on a Gas Agitated Extractor with Static Mixer

Ren Xiaoguang(任晓光)* **and Song Yongji**(宋永吉)
Department of Organic Chemical Engineering, Liaoyang Petrochemical Engineering Institute, Liaoyang 111003, China

Liu Changhou(刘长厚)
Department of Chemical Engineering, Dalian University of Technology, Dalian 116012, China

1 INTRODUCTION

Many chemical engineering operations involve the mass and heat transfer between two liquid phases in reactions. Mechanically agitated liquid-liquid extractor can be one of the examples for such operations. It has been well developed and used in the nuclear energy, petrochemical and other chemical industries. However, not much attention has been paid to the gas agitated liquid-liquid extractor. The air-agitated mixer-settlers has been used in the atomic energy setups for the recovery and purification of the uranium and plutonium from the spent fuel[1]. Gas agitation employed in liquid-liquid extraction offers certain advantages as the absence of mechanical moving parts. There is no sealing problem and very little maintenance is required. In the case of gas-liquid-liquid contactors, the advantages of using gas agitation have been well recognized [2−5]. A number of studies have been made in this respect[6,7].

However, there is practically little information in the published literature on the holdup of phase and mass transfer coefficients, which are essential for the rational design of these units. In this work we attempt to study the hydrodynamics and mass transfer characteristics for the gas-liquid-liquid system in a gas agitated extractor with static mixer. The gas bubbles passing through the liquid phase can promote the turbulence in the liquid and make the droplets of dispersed phase smaller. It is expected that using the gas agitation and static mixer will improve not only the throughput of the solvent but also the contact efficiency.

2 DESCRIPTION OF THE TESTING APPARATUS

The extraction apparatus is shown in Fig.1. The testing section of the column is made of glass. The diameter of the column is 50 mm. Its overall height is 2740 mm and the test section used for mass transfer studies is 2050 mm. The top phase separation section is approximately 300 mm long and 150 mm in diameter. The bottom calming section is 200 mm long and 150 mm in diameter. A SL type static mixer is inserted in the column in three sections. Each section is 250 mm long.

The static mixer shown in Fig. 2 is a simple device, providing uniform resistance to the three-phase flow. A homogeneous dispersion of fine droplets and air bubbles in water is possible.
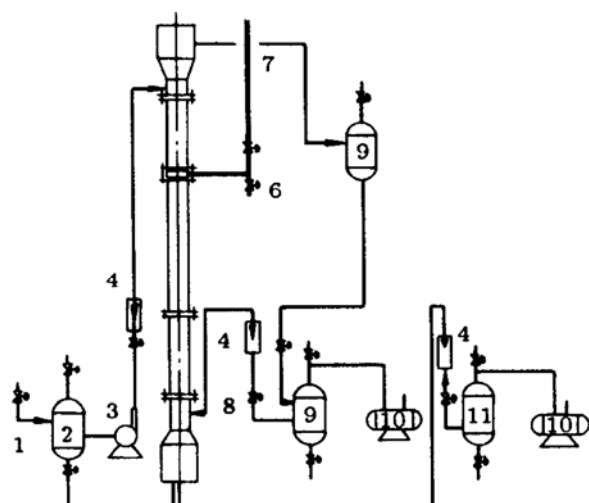
Figure 1   Sketch of the testing apparatus
1—water supply; 2—water tank; 3—water pump;
4—rotameter; 5—column; 6—sample suction slot;
7—manometer; 8—control valve; 9—oil tank;
10—compressor; 11—air buffer tank

Because of the distribution of local porosity, the static mixer can be expected to provide a solid surface on which the droplets are accelerated by the up-flowing air. The bubbles should collide among one another, leading to the breaking down of droplets, hence providing greater contact surface areas. The large open area of the static mixer offers low resistance to the counter-current streams, thereby maximizing the column's operation capacity. The static mixer may enhance the radial mixing of the individual phase and reduce the undesirable axial mixing of the column. The ranges of variables covered in this study are as follows: The continuous phase (water), dispersed phase (kerosene) and gas phase (air) velocities are 0—$10\,\text{mm·s}^{-1}$, 0—$5\,\text{mm·s}^{-1}$ and 0—$30\,\text{mm·s}^{-1}$, respectively.

Figure 2   Structure of the SL type static mixer

3 EXPERIMENT AND DATA TREATMENT

The gas holdup in the entire column was obtained by an "instantaneous closing down method", *i.e.* closing down the gas inlet valve, the liquid inlet valve and the liquid outlet valve at the same time, and recording the liquid level in the column before and after closing down the valves. Gas holdup in the three-phase section can be estimated from the following equation

$$h_g = v_g/v_o \quad or \quad h_g = v_g/(v_g + v_d + v_c) \tag{1}$$

The dispersed phase (kerosene) holdup in liquid phase (two-phase) in the test section was determined by a rapid suction withdrawal of a kerosene-water mixture from the middle part of the extracting section in the column, and then the sample was allowed to settle. The calculation of the holdup of the dispersed phase can be obtained from the following equations

$$h'_d = h_d/(h_d + h_c) \tag{2}$$
$$h_d = (1 - h_g)h'_d \tag{3}$$

where, h'_d is the holdup of dispersed oil in the sample.

For mass transfer measurements, a series of experimental runs were made with kerosene as well as benzoic acid solution. The temperature was reasonably constant throughout a run. When steady state was reached, sample solutions were taken at the outlets of liquids and also at the inlet of the kerosene. The acid concentration was determined by titration with $0.01\,\text{mol·L}^{-1}$ NaOH solution. The overall mass transfer coefficient based on continuous phase concentration changes can be calculated by using the logarithmic mean concentration difference.

$$N_{OG} = \int_{y_{E,\iota}}^{y_{E,b}} \frac{\mathrm{d}\,y_E}{y_E^* - y_E} \qquad (4)$$

N_{OG} can be calculated by using Simpson method.
Then,

$$H_{OG} = \frac{H}{N_{OG}} \qquad (5)$$

where H is effective height of the extractor.

The volumetric mass transfer coefficient can be obtained from the following equation

$$K_y a = \frac{V}{H_{OG} A} \qquad (6)$$

4 RESULTS AND DISCUSSION

4.1 Effects of gas velocity

The superficial gas velocity exerts a great effect on the holdup of the gas, the holdup of the dispersed phase and the mass transfer coefficient. The results are shown in Figs.3—6. Increases in u_g lead to promote the turbulence of liquid phase. Such intensified turbulence will in turn help to break up the dispersed phase into small droplets. The residence time of kerosene droplets in the extractor is then extended. Therefore, h_d is increased as shown in Fig. 3 and Fig. 4. It is found that the effect of u_g on $K_y a$ is also very evident. The reason is that the area between the two phases becomes greater with increasing superficial gas velocity u_g.

However, excessive mixing of the liquid in extractor may lead to emulsification. This phenomenon had been observed in the experiment. At higher gas velocity, $K_y a$ remains constant or even tends to decrease with increases in the gas velocity(see Fig. 5 and Fig. 6).

4.2 Effects of continuous phase superficial velocity

The continuous phase superficial velocity, i.e. the velocity of water u_c, has certain effects on h_d and $K_y a$. The results are shown in Fig. 4 and Fig. 6. Increase in continuous phase velocity will reduce the superficial velocity of kerosene droplets, resulting in an extension of the residence time of the kerosene droplets in the extractor. It follows that the holdup of dispersed phase and mass transfer coefficient will increase with increase in continuous phase velocity.

4.3 Effects of dispersed phase superficial velocity

The holdup of the dispersed phases depends on dispersed phase superficial velocity u_d. Increasing the dispersed phase superficial velocity u_d will increase the number of kerosene droplets in the extractor. Therefore, h_d increase with the increase of u_d. It is apparent that increasing u_d will lead to increases in h_d and will enhance the liquid phase mass transfer coefficient $K_y a$, as shown in Fig.3 and Fig.5.

4.4 Effects of static mixer

Static mixer can provide a uniform resistance to the component fluid flow and increase the intensity of turbulence of the fluids in the extractor. At the same time, a homogeneous dispersion
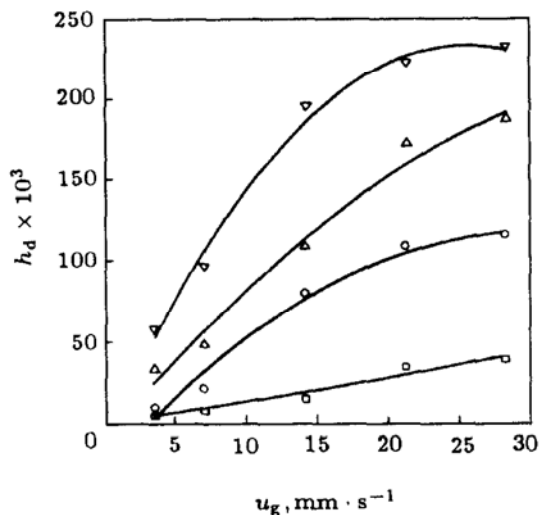
Figure 3   Effect of u_g and u_d on h_d
$(u_c=7.074\,\text{mm·s}^{-1})$
u_d, mm·s^{-1}: □ 0.321; ○ 1.283; △ 2.406; ▽ 4.011
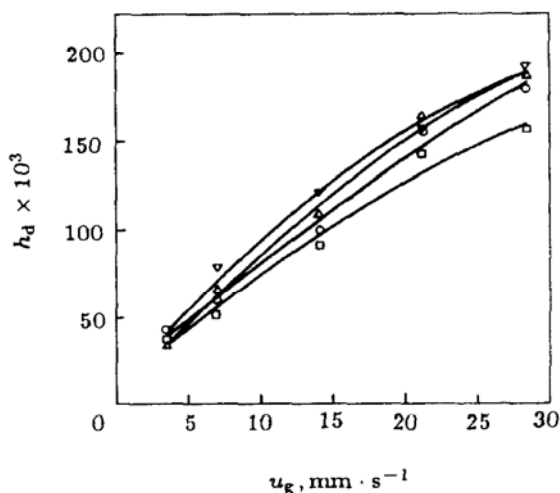
Figure 4   Effect of u_g and u_c on h_d
$(u_d=2.406\,\text{mm·s}^{-1})$
u_c, mm·s^{-1}: □ 1.415; ○ 4.244; △ 7.074; ▽ 9.903
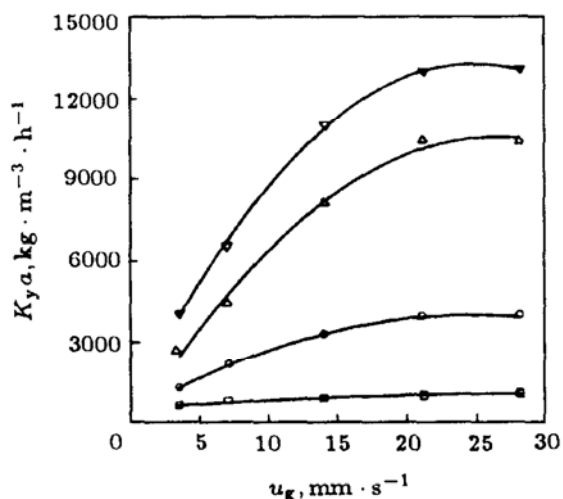
Figure 5   Effect of u_g and u_d on K_ya
$(u_c=4.244\,\text{mm·s}^{-1})$
u_d, mm·s^{-1}: □ 0.321; ○ 1.283; △ 2.406; ▽ 4.011
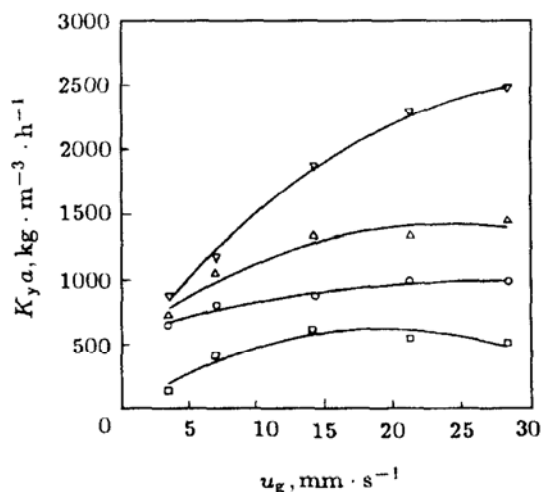
Figure 6   Effect of u_g and u_c on K_ya
$(u_d=0.321\,\text{mm·s}^{-1})$
u_c, mm·s^{-1}: □ 1.415; ○ 4.244; △ 7.074; ▽ 9.903

of fine droplets and air bubbles in water is possible. Therefore, the mass transfer coefficient K_ya increases due to the installation of the static mixer in extractor. The results are shown in Fig.7.

5 CONCLUSIONS

(1) A gas agitated extractor with static mixer can be successfully used for liquid-liquid extraction.

(2) Using gas agitation in an extractor equipped with a static mixer promotes turbulence in the liquid phase. The turbulence of liquid can effectively break up the stream of the dispersed phase into smaller droplets and increase K_ya.

(3)Increases in gas velocity can improve mass transfer in the extractor. However, excessive mixing of the liquids in the extractor may lead to emulsification and extension of the separation time of the liquid phases.
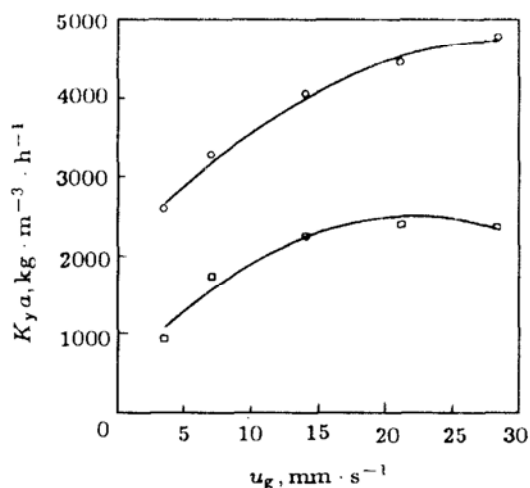
Figure 7 **Effect of SL static mixer on K_ya**
($u_c = 1.415 \, \text{mm·s}^{-1}$, $u_d = 2.406 \, \text{mm·s}^{-1}$)
□ without static mixer;
o with SL static mixer

NOMENCLATURE

A	cross-sectional area of column, m^2
H	height of extractor , m
H_{OG}	height of transfer unit, m
h	holdup, %
K_ya	mass transfer coefficient, $\text{kg·m}^{-3}\cdot\text{h}^{-1}$
N_{OG}	number of transfer unit
u	superficial velocity, m·s^{-1}
V	flow rate of water, kg·h^{-1}
v	volume of fluid phases in extractor, m^3
y	mass ratio of benzoic acid to water, kg·kg^{-1}
y^*	equilibrium mass ratio of benzoic acid to water kg·kg^{-1}

Subscripts

b	bottom
c	continuous phase
d	dispersed phase
E	extraction
g	gas phase
o	overall
t	top

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