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Reciprocating Plate Extraction Column As a Cocurrent Mixer

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INTRODUCTION

A cocurrent mixer in a mixer-settler extraction system is inherently more efficient than a conventional mixer. In the present work data were obtained in short sections of the Karr Reciprocating Plate Extraction Column (RPEC) employed as a cocurrent mixer. With the system o-xylene-acetic acid-water, stage efficiencies close to 100% were achieved at a total flow rate of 220 $m^3/h{\cdot}m^2$ when 0.91 m of plate stack operating at an agitation intensity of 1,270 cm/min was employed. At a total flow of 2,010 $m^3/h{\cdot}m^2$ the stage efficiency was 96.7% at an agitation intensity of 1,778 cm/min.

The data on this system showed:

1. The lower the throughput the higher the efficiency for a given intensity of agitation.
2. The greater the agitation intensity the greater the efficiency.
3. The longer the plate stack the higher the efficiency.

With commercial systems, unlike the o-xylene-acetic acid-water system, it was possible to overmix, which resulted in excessive settling times. This indicates the need to optimize the agitation intensity which is readily achieved in the RPEC.

The flexibility and uniform turbulence in the RPEC should minimize the formation of emulsions while insuring a close approach to equilibrium.

At the ISEC '77 Conference in Toronto Barnea (1977), Orjans, et al. (1977) and Kennedy and Pfalzgraff (1977) showed that multiple mixers in series for use in mixer-settler extraction systems offered advantages, such as improving mixer efficiency and reducing settler volume. The logical extension of this trend is to employ a plug flow mixer, thus Godfrey and Slater (1978) and Merchuk et al. (1980) studied static mixers and packed columns operating in a cocurrent manner.

The Reciprocating Plate Extraction Column has been previously reported by Karr (1959, 1980), Karr and Lo (1971, 1976), and Karr et al. (1980) when employed in a countercurrent manner. In this paper data are presented on short sections of a Reciprocating Plate Extraction Column employed as a cocurrent mixer.

EXPERIMENTAL

The equipment used is shown in Figure 1. 25 mm diameter columns, having lengths of 0.61, 0.91 and 1.22 m were employed. The plates were made of Teflon and were spaced 50 mm apart. A drawing of the plate is shown in Figure 2. Flows were controlled via calibrated rotameters. Both aqueous and solvent streams entered at the bottom of the column. The effluent from the top of the column was run into a 44 L receiver while waiting for equilibrium conditions to be achieved. Then a sample was taken in a 2 L separatory funnel. As soon as clear layers were observed at the top and bottom of the separatory funnel the respective samples were taken for analysis.

O-Xylene-Acetic Acid-Water System

Most of the data were obtained with the o-xylene-acetic acid-water system. This system was selected because it was considered to be a relatively difficult extraction system. Xylene containing approximately 1% acetic acid was extracted with water. The volumetric xylene to water flow ratio was approximately 16 to 1 in all runs. The extraction factor was an average of 2.2 over the range of concentrations studied. The interfacial tension for the system is 26–29 dyne/cm at the exit concentrations of the xylene and aqueous phases.

Phase separation for this system was very rapid. It was nearly complete within 15 seconds and complete within 2 minutes at the highest intensity of agitation.

The results obtained are given in Table I and plotted in Figure 3. In this figure, agitation intensity, the product of stroke length and agitation speed, is plotted against stage efficiency for different lengths of plate stack and throughput. Stage efficiency is the ratio of the change of acetic acid con-

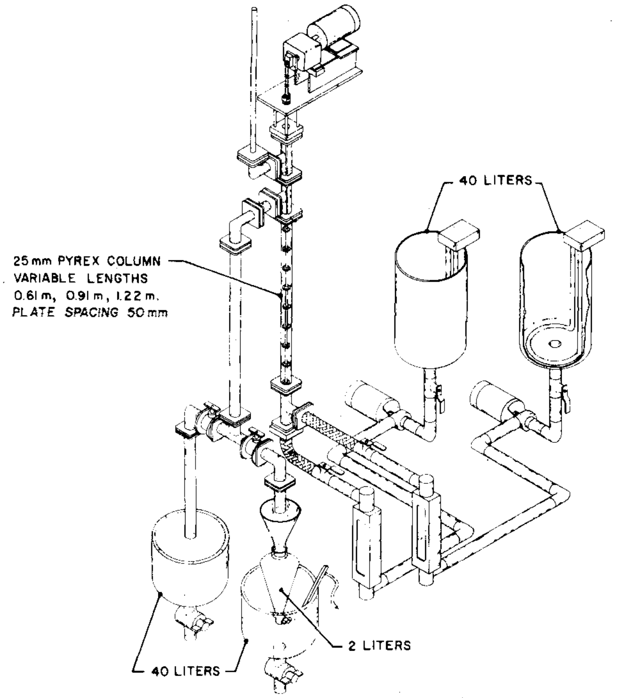

Figure 1. Reciprocating plate extraction column as cocurrent mixer.

centration in the xylene (or aqueous) phase to the change that would have occurred if equilibrium was achieved. The following conclusions can be drawn:

(1) In the configuration employed stage efficiencies approaching 100% can be achieved for throughputs up to 2,010 $m^3/h{\cdot}m^2$. We could not study higher throughputs because of limitations on the xylene pump.

(2) The lower the throughput the higher the efficiency for a given intensity of agitation.

(3) The greater the agitation intensity the greater the efficiency.

(4) The longer the plate stack the higher the efficiency.

(5) With no agitation the stage efficiency has an approximate mean value of about 63%. The 63% efficiency can be considered to be the "tare" of the system. Since we are dealing with a cocurrent flow system a better quantification of the results should be based on transfer units rather than stage efficiency.

For a given system, assuming straight operating and equilibrium lines, the number of transfer units is given by Treybal (1963).

$$N_{TOR} = -\frac{\epsilon\, ln(1 - E)}{1 + \epsilon} \tag{1}$$

If we assume the extraction factor is constant over the range of concentrations studied,

$$N_{TOR}\ \alpha - ln(1 - E) \tag{2}$$

From Eq. 2 it can be seen that the relative number of transfer units increases from 1 at a stage efficiency of 63% corresponding to no agitation, to 4.6 at a stage efficiency of 99%, corresponding to a high degree of agitation. Therefore it is possible to estimate the effectiveness of the agitation alone if it were possible to remove the "tare" from the system (inlet piping, column and stationary plates, outlet piping and valves, and sampling funnel). Thus, in the present system, an indicated stage efficiency of 99% (4.61 relative transfer units) corresponds to a stage efficiency of approximately 97% (3.61 relative transfer units) due to agitation alone.

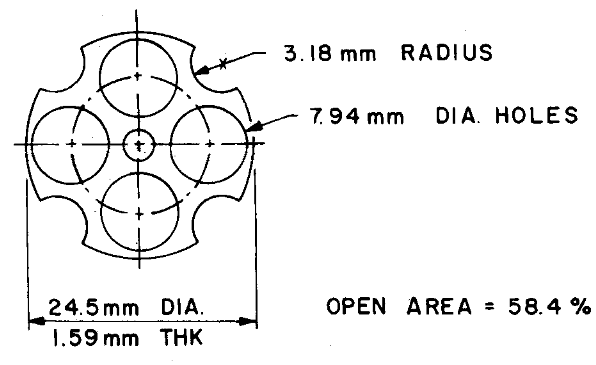

Figure 2. 24.5 mm teflon plate.

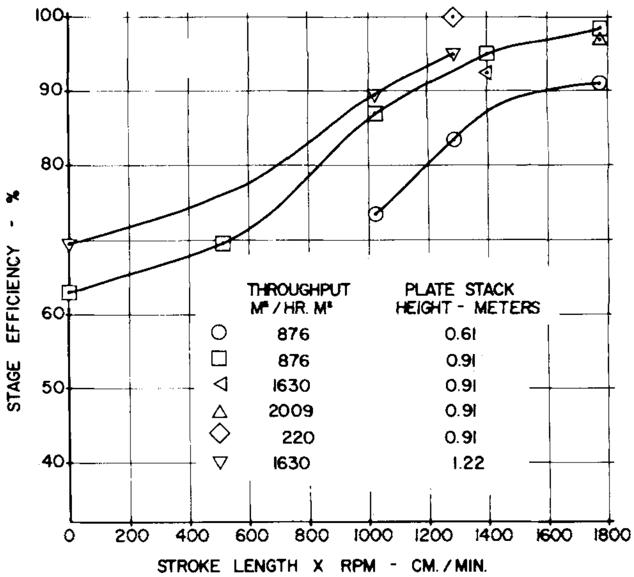

Figure 3. Cocurrent mixer performance system: o-xylene—acid—water.

Methyl Isobutyl Ketone-Acetic Acid-Water System

MIBK containing about 8% acetic acid was extracted with water at approximately a 1:1 ratio on a weight basis. The interfacial tension at equilibrium was 7 to 8 dyne/cm. With the equipment shown in Figure 1, stage efficiencies for this system were essentially 100% for all the runs made. The range of variables studied were:

- Total throughput: 1,000–2,000 $m^3/h{\cdot}m^2$
- Agitator speed: 0–400 RPM
- Stroke length: 1 in. (25 mm)
- Plate stack length: 0.91 m

100% stage efficiency was also achieved when the plate stack was removed.

These data illustrate how "easy" the MIBK-acetic acid-water system is, presumably due to the low interfacial tension and possible coalescence-redispersion effects.

Commercial Systems

Systems of commercial interest have been tested for clients in essentially the same equipment. With these systems high degrees of agitation intensity were required to achieve a close approach to 100% stage efficiency at throughputs up to 2,032 $m^3/h{\cdot}m^2$ (50,000 $gal/h{\cdot}ft^2$). However, for these systems, unlike the o-xylene-acetic acid-water system, it was possible to overmix, which resulted in excessive settling times. For example, with a system consisting of an amine and an aliphatic diluent extracting a compound from an aqueous solution, the following results were obtained:

Agitation Intensity cm/min	Stage Efficiency %	Settling Time, min
1,016	97	2
1,524	99	10+

The above typical results indicates the need to optimize the agitation intensity. Excessive agitation will result in long settling times and, therefore, require large settler volumes. In the extreme case severe emulsions can be produced with excessive agitation.

ADVANTAGES

The results discussed lead to a discussion of the advantages of the Reciprocating Plate Extraction Column as a cocurrent mixer.

TABLE 1. COCURRENT EXTRACTIONS RUNS SYSTEM: O-XYLENE—ACETIC ACID—WATER

Run No.	Total Flow $m^3/h{\cdot}m^2$	Stroke Length, cm	Agitator Speed, RPM	Stroke Length × RPM, cm/min	Height of Plate Stack, m	Stage Efficiency, %
1	876	2.54	400	1,016	0.61	74.4
2	876	4.45	400	1,780	0.61	91.2
3	876	3.18	400	1,272	0.61	84.2
4	876	—	0	0	0.91	63.1
5	876	2.54	200	508	0.91	69.4
6	876	2.54	400	1,016	0.91	85.8
7	876	4.45	400	1,780	0.91	98.6
8	876	3.49	400	1,396	0.91	94.9
9	1,630	3.49	400	1,396	0.91	92.5
10	2,009	4.45	400	1,780	0.91	96.7
11	220	3.18	400	1,272	0.91	100
12	1,630	3.18	400	1,272	1.22	94.8
13	1,630	2.54	400	1,016	1.22	89.4
14	1,630	—	0	0	1.22	69.7

High Throughput

Very high throughputs of 2,030 $m^3/h{\cdot}m^2$ and possibly higher can be achieved. Flow rates are in the pipeline velocity range. Thus, the size of the equipment is relatively small.

Flexibility of Operation

By having the flexibility of agitator speed and stroke length, the pilot plant unit can readily be optimized so as to maximize efficiency while minimizing settler volume. Furthermore, in the production unit, should the physical properties or emulsifying characteristics of the feed streams change, or if turndown is required, the ability to vary agitator speed is very useful for controlling the operation.

Uniform Turbulence

Because of the relatively uniform agitation over the cross-sectional area of the column, drop size is relatively uniform, which is advantageous in preventing the formation of emulsions while insuring a close approach to equilibrium.

Small Settler Volumes

Because of uniform turbulence and the flexibility with respect to agitation intensity settling times can be minimized. Therefore, settler volumes may be minimized compared to settlers employed with other types of mixers.

Low Overall Investment

The above advantages may lead to a low overall investment for the mixer, settler, and solvent inventory compared to that for other mixers.

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