Performance of a Reciprocating-Plate Extraction Column

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An open type of reciprocating-plate extraction column was developed, and it is proposed that the scaling up of such a column should be straightforward; that is, the height of an equivalent theoretical stage (H.E.T.S.) and the throughput per unit area should be independent of the diameter of the column.

Plates having 5/8-in.-diameter holes and 62.8% free space were selected to minimize the resistance to countercurrent flow in the column. With this design low H.E.T.S. values were achieved at throughputs much higher than those reported for other columns. Thus for two systems the present column was shown to require the lowest volume of column to accomplish a given extraction job. Data were obtained in a 3-in.-diameter column on two systems, methyl isobutyl ketone–acetic acid–water and *o*-xylene–acetic acid–water. Throughputs studied on the first system ranged from 547 to 1,837 gal./hr./sq. ft., and the corresponding minimum H.E.T.S. values achieved were 4.3 and 7.5 in. respectively. For the second system minimum H.E.T.S. values of 7.7 and 9.1 in. were attained at throughputs of 424 and 804 gal./hr./sq. ft. respectively.

Extraction column design procedures are discussed. The fabrication of the reciprocating-plate column is relatively simple, and this should encourage its use first in pilot-scale sizes and ultimately in large-scale columns.

The ideal extraction column is one which has a high capacity and a high efficiency. It should also be easy to construct and capable of being scaled up from small test sizes to commercial columns in a simple, reliable manner. The purpose of the present work was to attempt to develop an extraction column which approaches these ideal requirements. In a recent review of liquid extraction (*1*) it was emphasized that the "major difficulty in the design of extraction equipment continues to be the lack of well-correlated mass transfer rate data and reliable scale-up procedures when such data are gathered in pilot plants." It is hoped that the present work will be a significant step toward the reliable scaling up of a high-efficiency, high-capacity extraction column.

It is generally recognized today that efficient extraction columns require the application of some form of mechanical energy other than that due to the difference in the specific gravity of the countercurrent streams. Two principal classes of extraction columns utilizing added mechanical energy are now employed in the process industries:

a. Columns employing a series of rotating impellers of various designs in conjunction with different arrangements of baffles, packing, and calming zones (*2* to *8*).

b. Pulse columns in which the entire contents of the column is given a reciprocating motion by means of a pulsing mechanism located near the bottom of the columns (*9* to *16*).

Columns having rotating impellers are inherently difficult to scale up accurately, because there is as yet no sound theoretical basis for doing so. As shown by Rushton (*17*), if two fluid property forces are operative, as for example interfacial tension and viscosity, then it is not possible to obtain dynamic similarity with liquids having the same physical properties. This is true even if geometric similarity is maintained; if geometric similarity is not maintained, then dynamic similarity is impossible, by definition.

Of course empirical correlations can be obtained (*3*, *5*, *18*), but their ranges

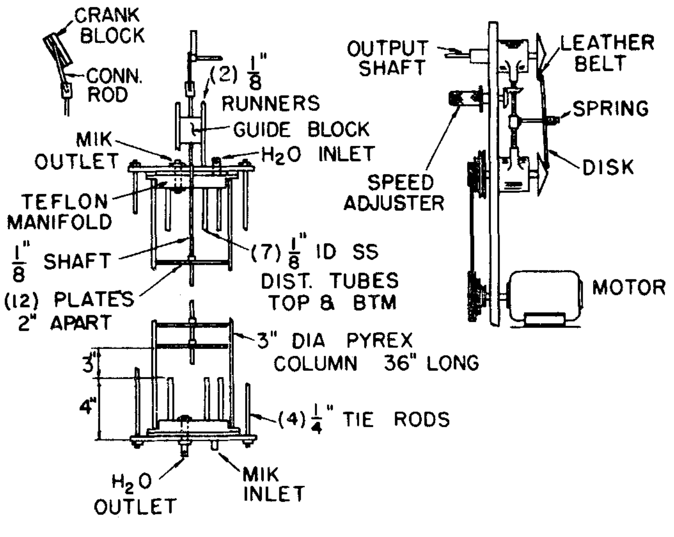

Fig. 1. Extraction-column details.

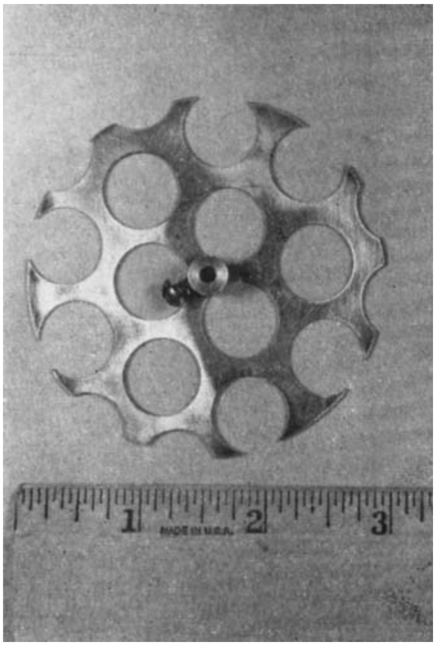

Fig. 2. Reciprocating plate.

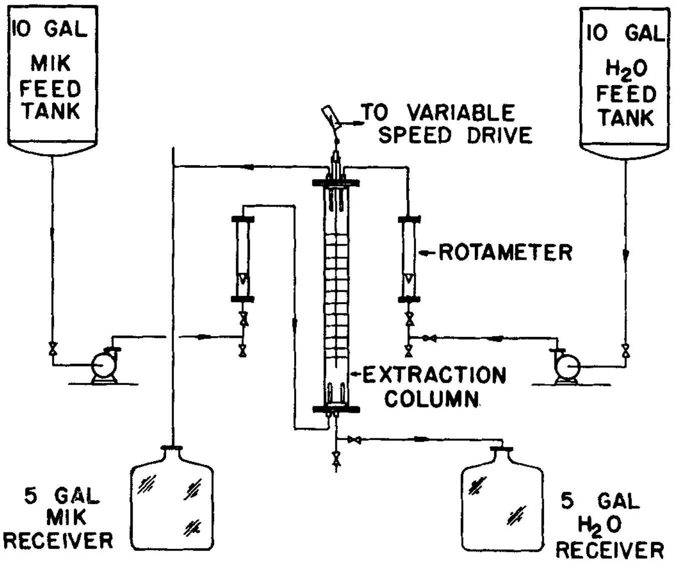

Fig. 3. Flow sheet of liquid extraction unit.

of application and extrapolation are necessarily limited.

Some data on pulsed sieve-plate extraction columns indicated that it should be possible to scale up such columns with no increase in the height of the column (*15, 19*). In other words H.E.T.S. and throughput were presumed to be independent of column diameter. However, Woodfield and Sege (*16*) showed that, as the column diameter increases, "the countercurrently flowing liquid phases display an increasing tendency to channel in some portion of the column cross section rather than to distribute evenly across it. This increasing channeling tendency brings with it increasing over-all transfer unit heights." These authors developed a redistributor which minimized the channeling effect, but throughput was thereby reduced, depending on the design of the redistributor.

DESCRIPTION OF COLUMN

The reciprocating-plate column shown in Figure 1 was employed in the present work. The column consisted of a series of plates mounted on a central shaft which was reciprocated by a simple drive mechanism at the top of the column. The amplitude could be varied between 0 and about 2 in. by simply adjusting the length of a crank arm.

The variable-speed drive shown in Figure 1 made it possible to operate over a range of speeds of 100 to 3,000 strokes/min.

The plates were made from 0.04-in. stainless steel sheet which was drilled with ⅝-in.-diameter holes on ¾-in. triangular centers. This arrangement has a free area of 62.8%. After a large section of the sheet had been drilled, the individual plates were cut out. A typical plate is shown in Figure 2. The diameter of the plates was 2 29/32 in. A 5/16-in.-diameter hub was attached to the center of the plate, and the plates were attached to the ⅛-in.-diameter shaft with set screws.

The column was made from a 36-in. section of nominal 3-in.-diameter Pyrex pipe. The plates were distributed over a height of approximately 22 to 24 in. at varying plate spacings, which left about 6 to 8 in. above and below the plates for disengaging space. An attempt was made to distribute the feed streams uniformly by means of seven ⅛-in. I.D. inlet tubes manifolded at the top and bottom of the column and extending 4 in. into the column at either end.

Pyrex pipe is not uniform in diameter, variations of ¼ in. or more in inside diameter being possible, and the clearance between the plates and pipe wall was estimated to have varied from substantially 0 to ⅛ in.

The relatively large openings and high free area in the plates were deliberately selected for this work for the following reasons:

1. It was thought that a relatively open type of plate would offer the minimum resistance to flow of the countercurrent streams and that therefore the capacity of the column would be maximized.
2. Providing a high free area of large openings would eliminate the need for close clearance between the plates and the column wall. Thus Van Dijck (*20*) described a reciprocating-plate column with relatively small perforations which required very careful sealing against the shell to prevent excessive bypassing around the perimeter of each plate. In the present work the dispersed droplets could flow freely by gravity through the large openings and did not require the upward or downward motion of the plates to force them through. Thus there is no tendency for the drops preferentially to flow toward the wall of the column, and therefore there is no need to have a tight fit between the plates and the column; it is necessary only that the plate cover substantially the entire cross section of the column, and a moderate clearance is not detrimental.

The plates employed in this work are looked upon simply as reciprocating agitators which impart energy to the counterflowing streams as they flow through the column. The higher the speed of reciprocation, the greater the energy imparted and the finer the dispersion produced. Very fine dispersions can be produced in a reciprocating-plate column.

It was pointed out above that the flow of the dispersed phase in such a column should be essentially uniform throughout the cross section of the column. There is no preferential tendency for the drops to pass around the perimeter of the plates, as long as the clearance between the column and the plates is not excessive. Even if there is a preferential tendency for the dispersed phase to wet the wall, the effect of the agitation of each plate ensures a uniform dispersion over the entire cross section of the column. At design operating speeds, the close proximity of the reciprocating plates to the wall is sufficient to ensure against a preferential wetting effect along the wall.

If it is accepted that in the reciprocating-plate column described a uniform dispersion is bound to exist throughout the cross section of the column, then the scale up of such a column should be straightforward. Large-scale columns of this design have not been built yet; therefore final proof of the proposed hypothesis of scale up is still required. It is hoped that this information will soon be forthcoming.

SYSTEMS INVESTIGATED

Data were obtained on the following two systems:

System 1. Methyl isobutyl ketone (M.I.K.)-acetic acid-water.

System 2. *o*-xylene-acetic acid-water. These systems were used, because various investigators have employed them in obtaining performance data on other columns (*4, 6, 7, 9, 10, 18*). Thus the relative effectiveness of the present column employed could be evaluated.

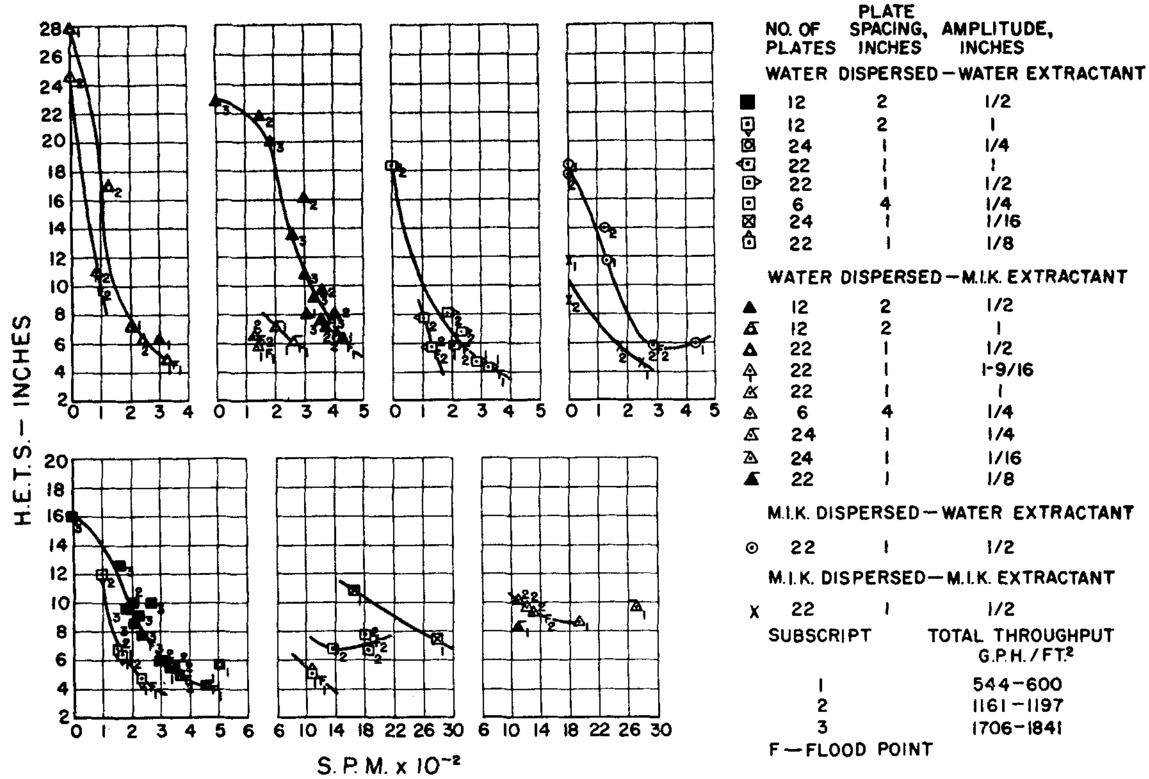

Fig. 4. Effect of reciprocating speed on H.E.T.S., M.I.K.–acetic acid–water system.

DISTRIBUTION DATA

The distribution data employed were the same as those previously reported (*3*).

OPERATING PROCEDURE

With system 1 the solute was first extracted from the aqueous solution by the M.I.K. phase. In the following run the solute was extracted from the organic phase by the aqueous phase. Four types of runs were made as follows:

1. Water dispersed–M.I.K. extractant
2. Water dispersed–water extractant
3. M.I.K. dispersed–water extractant
4. M.I.K. dispersed–M.I.K. extractant

With system 2 only one type of operation was studied, namely water dispersed–water extractant, since the H/L ratios employed for this system were of the order of 1/20.

The solvent ratios employed for both systems were mainly such that the operating line was approximately parallel to the equilibrium curve. The solvent ratios employed are given in the tables of data. The concentration of acid in the feed solutions was purposely not varied greatly in order to minimize the

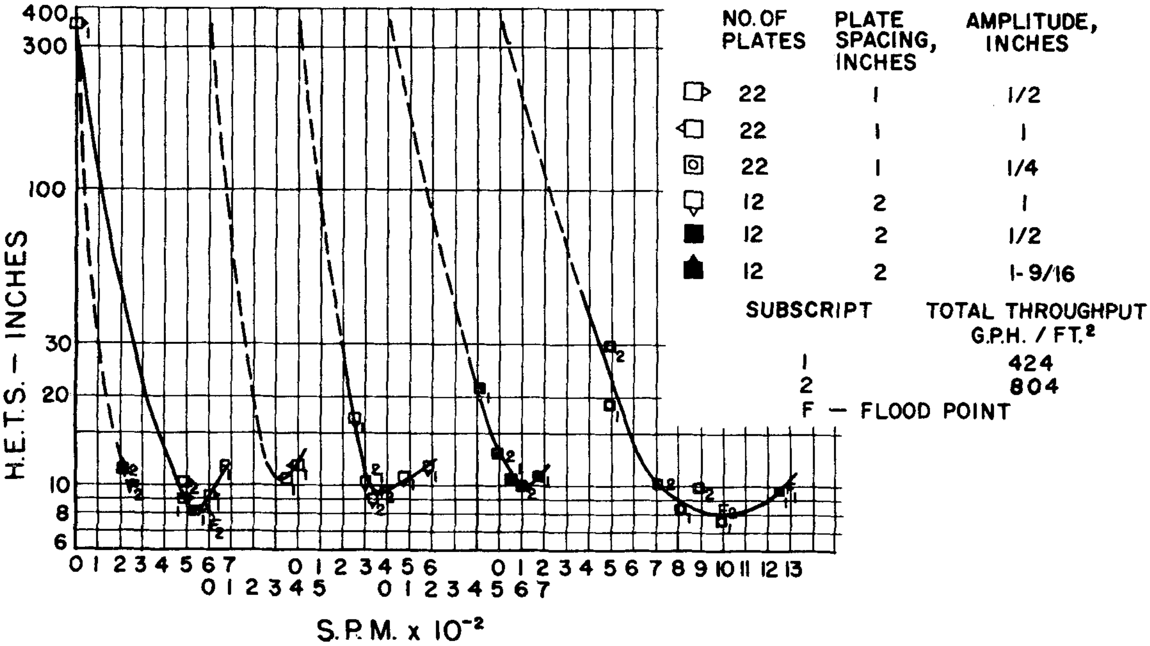

Fig. 5. Effect of reciprocating speed on H.E.T.S., o-xylene–acetic acid–water system.

effect of solute concentration on the results.

Figure 3 is a flow sheet of the liquid-extraction unit employed. The feed solutions were maintained at 25°C. and were mutually saturated in the 10-gal. stainless steel storage tanks. In the case of system 2 the aqueous feed was stored in a 1-gal. feed tank. The aqueous and organic feed streams were metered into the column by means of small centrifugal pumps via calibrated rotameters and needle valves. All lines were made of stainless steel, and care was taken to avoid contamination of the solvents by pipe dope, gaskets, and packings.

The plates were not reciprocated until the interface at either the top or bottom of the column was established. Then the flow rates were adjusted, and the desired reciprocating speed was set by means of the adjusting screw of the variable-speed drive. The interface was maintained in as constant a position as possible by setting the bottoms draw-off valve. The interface was usually maintained at about 2 in. from the top or bottom of the column, depending on which phase was dispersed.

The column came to steady conditions by the time the contents of the column had been replaced two or three times. Usually considerably more than three times the volume of the column was fed before samples of the exit streams were taken for analysis.

RESULTS

The data obtained* are shown in Table 1*a*, *b*, and *c* for the M.I.K.–acetic acid–water system and Table 2 for the *o*-xylene–acetic acid–water system. In Tables 1*a*, *b*, and *c* the quantity $(H/L)_{Rot.}/(H/L)_{M.S.C.}$ is a severe test of the material balance. It is the H/L ratio, as measures by the calibrated rotameters divided by the H/L ratio for the feed streams determined by the mix point of feed and product streams on the ternary mutual solubility diagram. A value of $(H/L)_{Rot.}/(H/L)_{M.S.C.}$ of unity would correspond to a perfect material balance. In Table 2 the material balance was calculated from the rotameter readings and analyses of the feed and product streams, neglecting the mutual solubility of the phases.

As shown in Tables 1*a*, *b*, and *c* and 2 the ranges of variables studied for the two systems were as follows:

	System 1	System 2
Number of plates	6 to 24	12 to 22
Plate spacing, in.	1 to 4	1 to 2
Amplitude, in.	1/16 to 1 9/16	¼ to 1 9/16
Agitator speed, strokes/min.	0 to 2,800	0 to 1,250
Total throughput, gal./(hr.)(sq. ft.)	544 to 1,841	424 to 804

*Tabular material has been deposited as document 6052 with the American Documentation Institute, Photoduplication Service, Library of Congress, Washington 25, D. C., and may be obtained for $2.50 for photoprints or $1.75 for 35-m.m microfilm.

Effect of Reciprocating Speed, Strokes Per Minute (S.P.M.)

Figure 4 shows all the data for the M.I.K.–acetic acid–water system plotted as strokes per minute vs. H.E.T.S. Separate curves are shown for the different combinations of amplitude and plate spacing. Figure 5 shows similar data for the *o*-xylene–acetic acid–water system. In the figures the letter *F* designates the estimated strokes per minute at which flooding first occurs. The subscripts 1, 2, and 3 correspond to the different indicated throughputs. Generally no minima in the H.E.T.S. values were detected for the M.I.K. system. However definite minima were observed for the xylene system at the low throughput of 424 gal./(hr.)/(sq. ft.) but not at the higher throughput of 804 gal./(hr.)/(sq. ft.). As shown in Figure 4 H.E.T.S. values as low as 4.3 in. were achieved, and the minimum H.E.T.S. varies with the throughput as well as the combination of plate spacing and amplitude. This is discussed further below.

Effect of Throughput

Most of the data shown in Figures 4 and 5 indicate that up to the flood points H.E.T.S. is substantially independent of throughput and depends only on strokes per minute. Some of the data indicate that at low values of strokes per minute H.E.T.S. is not quite independent of throughput, but low values of strokes per minute are not of particular practical interest. In Figure 4 it is seen that the strokes per minute at which flooding occurs decrease with increased throughput. This is also shown for one case in Figure 6. Since H.E.T.S. decreases continuously with increased strokes per minute, it follows that the minimum H.E.T.S. attainable increases with increasing throughput. This is shown in Figure 7, where the minimum H.E.T.S. attained is plotted against throughput. Thus for the case water dispersed–water extractant shown in Figure 7 the following minimum H.E.T.S. values were attained:

Throughput, gal./(hr.)(sq. ft.)	Min. H.E.T.S., in.
547	4.3
1,172	5.0
1,707	7.75

Only a twofold range of throughput was studied for the xylene system, and no definite increase in the minimum H.E.T.S. attained is observed with increasing throughput (Figure 5). The probable reason for this is that for this system the H.E.T.S.–Strokes-per-minute curve passes through a minimum, and the minimum H.E.T.S. is the same for both throughputs.

Effect of Amplitude

In this paper the amplitude is defined as the distance between the lowest and highest position of the plates, expressed in inches. Before the data were obtained it was felt that small amplitudes would be the best for obtaining minimum H.E.T.S. values. It was expected that by reciprocating the plates at high speed and small amplitude there would be a minimum of back mixing between adjacent plates. Indeed, inspection of Figures 4 and 5 shows that at the highest amplitude of 1 9/16 in. the minimum H.E.T.S. values obtained were the highest. However for amplitudes up to 1 in. no superiority of the smaller amplitudes is apparent. From a practical point of view it appears that amplitudes of ¼ to 1 in. are optimum. At smaller amplitudes excessively high agitator speeds are required.

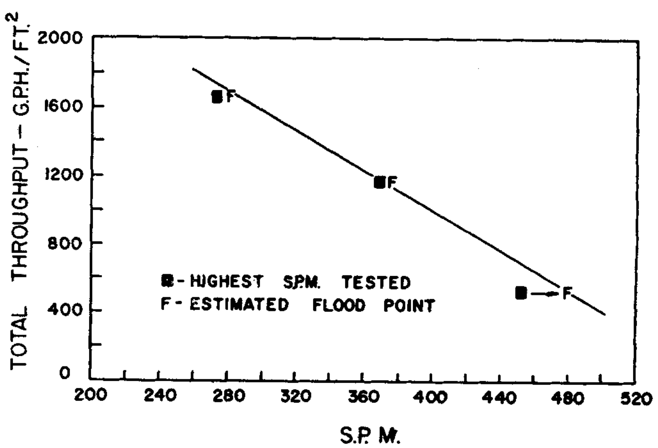

Fig. 6. Effect of strokes per minute on maximum throughput; M.I.K. system; water dispersed–water extractant; twelve plates, 2-in. plate spacing, ½-in. amplitude.

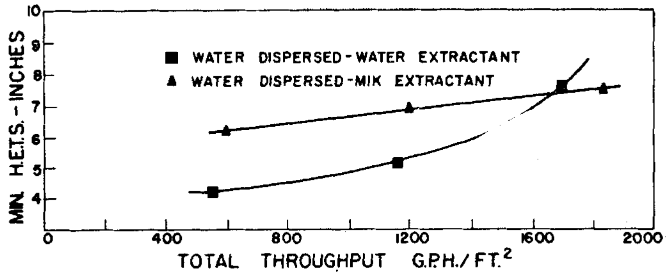

Fig. 7. Effect of throughput on minimum H.E.T.S. attained; M.I.K. system; twelve plates, 2-in. plate spacing, ½-in. amplitude.

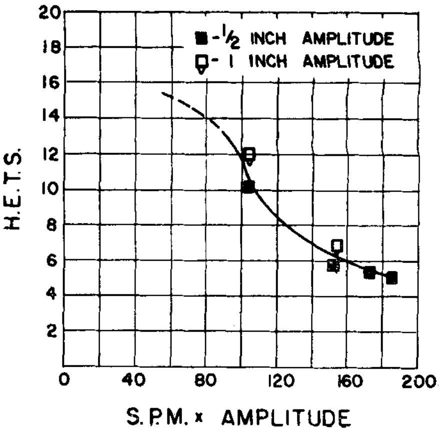

Fig. 8. Example of correlation of H.E.T.S. with product of strokes per minute × amplitude; M.I.K. system; water dispersed-water extractant; throughput 1,167–1,185 gal./(hr.) (sq. ft.), twelve plates, 2-in. plate spacing.

Effect of Plate Spacing

From Figure 4 and Tables 1*a*, *b*, and *c* no significant effect of plate spacing on the minimum H.E.T.S. attained was apparent for plate spacings of 1 and 2 in. However at a 4-in. plate spacing, although plate efficiences as high as 60% were obtained, the minimum H.E.T.S. value obtained was 6.7 in. This compares with minimum H.E.T.S. values of 4.3 in. obtained with 1- and 2-in. plate spacing on the same type of operation, namely water dispersed–water extractant. Thus it can be concluded that in order to obtain the greatest number of stages in a given height of column the plates should be spaced not more than 2 in. apart. Although this conclusion applies to the M.I.K.–acetic acid–water system, it can probably also be applied to the xylene–acetic acid–water system as inspection of Figure 5 will indicate.

Actually, for optimum performance of an extraction column the plate spacing should not be constant throughout the column. This is discussed further in a subsequent section.

Effect of Physical Properties

A comparison of Figures 4 and 5 shows that the M.I.K. system requires lower agitator speeds and gives lower H.E.T.S. values than the xylene system. This has also been observed in previous work on these systems (*3*, *7*). The ratio of density difference to interfacial tension ($\Delta\rho/\sigma$) for the M.I.K. system is about 5.5 times that for the xylene system (*3*). The author has used this function as a useful guide in selecting values of strokes per minute and in predicting minimum H.E.T.S. values for other systems. However insufficient data are available to present a quantitative correlation.

CORRELATION OF DATA

It is apparent that there is an infinite number of combinations of strokes per minute, amplitude, and plate spacing which will result in the same H.E.T.S. An attempt was made at an approximate correlation of these variables.

On the bases of the available data it was found that for a given throughput and plate spacing H.E.T.S. was a fairly consistent function of the product of strokes per minute times amplitude. Figure 8 is an example of the several plots of this type which were made. Strokes per minute times amplitude represents the average linear velocity of the plates. To introduce plate spacing, a plot was made of H.E.T.S. vs. (strokes per minute times amplitude)/plate spacing. This ratio can be considered to represent the average total linear rate of motion of the plates in a given height of column. Figure 9 shows the data for the M.I.K. system for the case water dispersed–M.I.K. extractant. The subscripts 1, 2, and 3 correspond to three different total flow rates ranging from 598 to 1,841 gal./(hr.) (sq. ft.). The different flow rates were included in the plot, since it had been previously shown that H.E.T.S. was not significantly affected by flow rate. The range of amplitudes represented in Figure 9 is ⅛ to 1 in., and the range of plate spacing is 1 to 4 in. The range of the ratio amplitude/plate spacing is $\frac{1}{16}$ to 1. It is seen that for the range of variables covered the correlation is significant. A similar plot for the case water-dispersed–water extractant was not quite so consistent as Figure 9 but was fairly good considering the 16 to 1 variation in amplitude/plate spacing. The xylene data could also be correlated satisfactorily by the method shown in Figure 9.

The correlation shown in Figure 9 should be used with caution, since it is strictly empirical and probably not valid over wider ranges than indicated. It applies to a particular system and to a particular dispersed phase–extractant combination. Furthermore it does not take into consideration the flooding data shown in Figure 4. If Figure 9 is used to select an operating amplitude, strokes per minute, and plate spacing, it is necessary first to check whether this condition is below the flood point. Flooding is a complicated function of amplitude, strokes per minute, plate spacing, and throughput, and no satisfactory correlation was found.

COMPARISON WITH OTHER COLUMNS

The data presented show that the reciprocating-plate column employed in this work has a high capacity as well as a high efficiency. Table 3 compares the present capacity and efficiency data with those of other types of extraction columns reported in the literature within the past decade. The minimum H.E.T.S. and maximum throughput for any system depends to some degree on which phase is dispersed as well as which phase is the extractant. In Table 3 most of the data are for the case water dispersed, but some data for the case M.I.K. dispersed are also included because the particular investigator did not operate with water as the dispersed phase.

The fact that the diameters of the various columns listed in Table 3 are different complicates a comparison of the relative merits of the different columns; nevertheless, if it is accepted that the present reciprocating-plate column can be scaled up with no increase in H.E.T.S., then the following statements can be made:

1. The reciprocating-plate column has a considerably higher throughput than that reported for the other columns listed in Table 3.

2. At comparable throughputs the minimum H.E.T.S. values achieved are equal to or lower than those obtained with most of the other columns. Scheibel (*18*) reported somewhat lower H.E.T.S. values than those obtained in the present work at relatively low throughputs. However as seen in Table 3 the capacity-efficiency relationship of the reciprocating-plate column is such that the lowest volume of column is required to do a given extraction job. This is shown in the last column of Table 3. The throughput per volume per stage which has the net units reciprocal hour was suggested by Treybal (*21*) as a measure of the effectiveness of a given column. The greater this number is, the smaller is the volume of column required to do a given extraction job.

TABLE 3. PERFORMANCE DATA REPORTED IN THE LITERATURE

Reference	Type of column	Diameter of column, in.	Max. total throughput reported, gal./(hr.)(sq. ft.)	Dispersed phase	Minimum corresponding H.E.T.S., in.	Throughput/volume /stage, cu. ft./(hr.) (cu. ft.)
	System: M.I.K.—acetic acid—water					
(*6*)	Rotating disk, R.D.C.	8	980	Water	4.3*	366
		8	1,030		6.3†	262
(*9*)	Pulsed—spray	1.5	920	M.I.K.	HTU_{OO} = 0.26 ft. HTU_{OA} = 1.55 ft.	
(*18*)	Turbine agitator—horizontal baffles	11.5	458	Water	3.0	245
(*7*)	Alternate agitated and packed sections	11.5	595	Water	9.2	104
(*4*)	Turbine agitators in vertically baffled compartments	6	286	M.I.K.	3.7	124
			500	M.I.K.	5.5	146
(*10*)	Pulsed—packed	1.57	149	M.I.K.	5.1	47
	Pulsed—sieve tray	1.57	267		10.1	42
Present work	Reciprocating plate	3	547	Water	4.3	204
			1,172		5.0	376
			(Water extractant) 1,707	Water	7.75	353
			(M.I.K. extractant) 1,837	Water	7.5	393
	System: O-Xylene-acetic acid—water					
(*18*)	Turbine agitator—horizontal baffles	11.5	385	Water	6.0	103
(*7*)	Alternate agitated and packed sections	11.5	330	Water	13.3	40
Present work	Reciprocating plate	3	424	Water	7.7	88
			804		9.1	142

*Rotor diameter = 3.1 in.; stator opening = 4.9 in.
†Rotor diameter = 4.7 in.; stator opening = 6.3 in.

DESIGN OF AN EXTRACTION COLUMN

As mentioned previously, the present reciprocating column was developed because it was felt that such a column has the ideal characteristic of H.E.T.S. and throughput per unit area being independent of the diameter of the column. To date no actual data are available to substantiate this, but it is hoped that such data will soon be available.

Until more basic mass transfer information is available, an extraction column must be designed from performance data obtained on a pilot-scale column. In the case of the reciprocating plate column it is only necessary to increase the column diameter. The plate spacing, strokes per minute, and amplitude will remain the same as the optimum values determined in the pilot-scale column. The plate spacing in an extraction column requiring many theoretical stages is of paramount importance. Normally the plate spacing will not be uniform throughout the column because of the differences in concentration in different parts of the column. In a simple countercurrent extraction column one end of the column is usually high and the other end low in solute concentration. Consequently if the plate spacing were uniform throughout the column, the mixing obtained would be good in the rich portion of the column but worse in the lean portion. To overcome this effect the plates are placed closer together in the lean portion of the column. This is necessary if the maximum number of stages in a given height of column is desired.

The effect of solute concentration on the intensity of agitation required for a given H.E.T.S. is related to the physical properties of the two phases in the different sections of the column. It was previously shown (*3*) that the single most important physical property is interfacial tension. Thus, as the solute concentration increases, the interfacial tension of most liquid-liquid systems decreases rapidly, and the mixing energy required to obtain a good dispersion decreases. In the case of the reciprocating plate column this would necessitate placing the plates further apart in the rich section of the column, if premature flooding of the column is to be avoided. In a fractional liquid extraction column the solute concentrations are usually greatest near the feed stage, and thus the plates would be placed further apart at the feed stage than at the ends of the column.

The above analysis is of course only qualitative. Although the writer has been able to correlate extraction efficiency with the function $(\Delta\rho/\sigma)^{1.5}$ (*3*), usually insufficient data are available to permit an accurate prediction of optimum plate spacing required in different portions of the column. Therefore it is recommended that an experimental approach be employed, tempered by the foregoing discussion. Usually only one change in plate spacing is necessary after visual observation of the first design of the pilot scale column. The reciprocating plate column is so simple in design and so easy to take apart and put together again that this procedure is very convenient.

Extraction columns with rotating agitators must also take into account the differences in agitation required in different portions of the column for optimum performance. Because of the complicated internals of such columns the above optimizing procedure is much more difficult with these columns. Furthermore, as previously discussed, the scale up of such columns must be done empirically.

Figure 10 shows a section of a 3-in.–diameter pilot plant fractional liquid extraction column 22 ft. high. For optimum performance it was necessary to vary the plate spacing from 4 in. near the center feed stage to 1 in. at one end of the column and 2 in. at the other end. The plates used in this column were made of commercially available flattened expanded stainless steel. A photograph of a single plate is shown in Figure 11. The mesh width is 0.46 in., and the mesh length is 1.26 in. The strand width is 0.085 in.

Several 1-in.–diameter laboratory colums with reciprocating plates have been built. The plates were punched out of Teflon sheet. Figure 12 is a photograph of the plate employed. A 6-in.–diameter by 20 ft. all–Teflon-and-glass reciprocating-plate column is now being employed for a pharmaceutical application

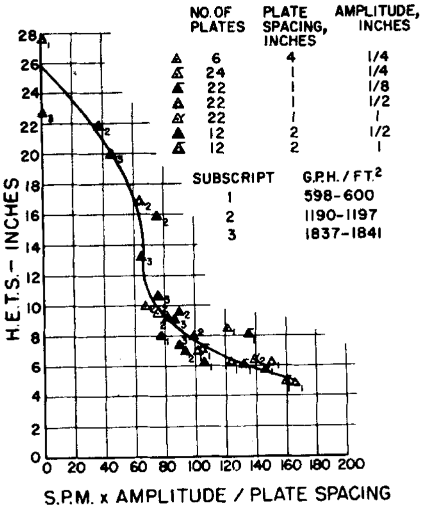

Fig. 9. Correlation of H.E.T.S. with strokes per minute × amplitude/plate spacing; M.I.K. system; water dispersed–M.I.K. extractant.

in which no metals can be tolerated. The Teflon plates are 3/16 in. thick and are drilled with 9/16-in. holes on 0.64-in. triangular centers.

SUMMARY

A reciprocating-plate extraction column was developed because it is believed that such a column can be scaled up in diameter with no increase in H.E.T.S.

For the M.I.K. system H.E.T.S. was found to decrease continuously with strokes per minute until flooding occurs. This performance is unlike that in other columns reported in the literature (*4, 6, 7, 18*), in which H.E.T.S. goes through a minimum value. The xylene system did exhibit a minimum H.E.T.S. for the lower throughput studied (424 gal./(hr.)/(sq. ft.), but at the higher throughput of 804 gal./(hr.)/(sq. ft.) no minimum was observed.

H.E.T.S. was found to be substantially independent of throughput, especially at values of strokes per minute approaching the flood point. The capacity of the reciprocating plate column was shown to be higher than other columns reported in the literature (Table 3). Furthermore, the reciprocating-plate column required the smallest volume of column to do a given extraction job.

The H.E.T.S. data were satisfactorily correlated by the function strokes per minute times amplitude/plate spacing. The limitations of the correlation were pointed out.

Extraction-column design procedures are discussed.

ACKNOWLEDGMENT

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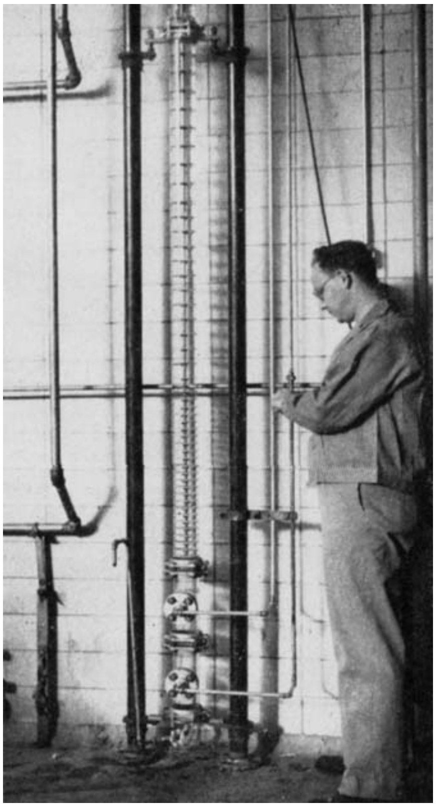

Fig. 10. Section of 3-in. pilot plant extraction column.

NOTATION

F = flooding point
H = flow rate of heavy phase, lb./(hr.) (sq. ft.)
L = flow rate of light phase, lb./(hr.)(sq. ft.)
$\Delta\rho$ = density difference, g./ml.
σ = interfacial tension, dynes/cm.
S.P.M. = strokes/min.

Subscripts

Rot. = rotameter
M.S.C. = mutual solubility curve

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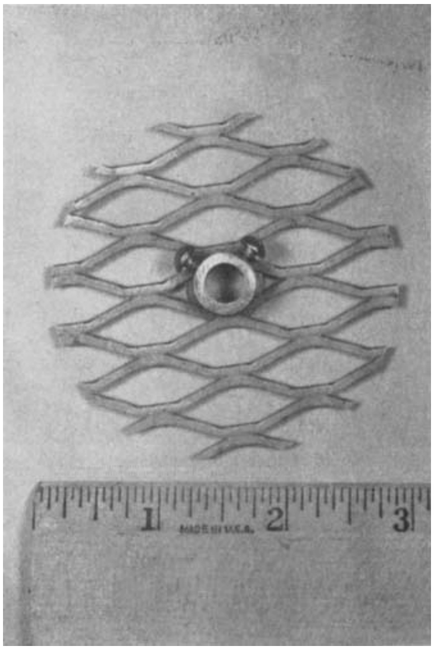

Fig. 11. Reciprocating plate made of expanded metal.

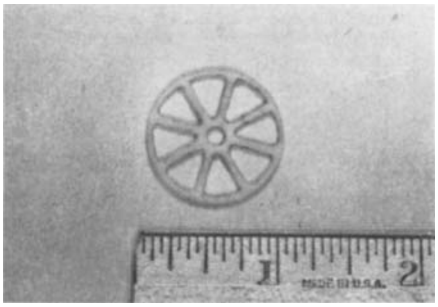

Fig. 12. One-inch reciprocating plate made of Teflon sheet.

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