x = axial variable, m
u = gas velocity, $M\sqrt{\gamma RT}$
$\hat{v}$ = volume of a vapor molecule, m^3
v = average molecular velocity, m/s
Z = Zeldovich factor

Greek Letters

β = $P_v\ 4\pi(r^*)^2/\sqrt{2\pi R_v T}$
$\delta(r - r^*)$ = Dirac delta function
γ = ratio of specific heats, 1.16
σ = surface tension of liquid slag, 0.32 N/m
λ = mean free path for vapor in stream, m
ξ = radial distance from the center of a droplet, m.
ρ = mass density, kg/m^3
ϕ = energy function = $2\alpha m_c/\rho_l r$
ζ = transformed nondimensional variable for r coordinate defined by Equation (28).

Subscripts

b = evaluated at nonphysical boundary b in Figure 1
c = condensable species (= vapor)
g = noncondensable gas in stream
l = liquid slag
s = evaluated at the droplet surface
sat = evaluated at saturation
v = vapor in stream
$+$ = toward drop surface from boundary b
$-$ = toward the surface b from s in Figure 1

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Mass Transfer in Periodically Cycled Plate Columns Containing Multiple Sieve Plates

A five plate distillation column, 100 mm in diameter, has been used to study both fluid mixing and the mass transfer separations of mixtures of methylcyclohexane and *n*-heptane under periodically cycled conditions. Both the fluid mixing and mass transfer could be successfully analyzed using the (2S) model to describe the liquid movement in the column. Previously reported results by McWhirter and Lloyd could not be reproduced. Only moderate improvements in separating ability can be obtained with sieve plates and packed sieve plate columns operated in the cycled mode.

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SCOPE

Periodic cycling is a method of improving the performance of plate columns by operating with an on-off control of the vapor and liquid flow rates. During the vapor on period, liquid is retained on the plate as downcomerless sieve plates are used in the column. During the vapor off period, liquid drains from a plate to the plates below. The mass transfer theory covering these two periods indicates that the cycled column should operate with separations equivalent to a conventional column containing twice the number of plates. Some experimental results in the early 1960's showed these high levels of performance in multiple sieve plate columns. Other results failed to meet the theoretical improvements in performance. Recently, a good agreement between theory and experiment was obtained on a single sieve plate column. The reason for the mixed literature results is due to a simplistic modeling of the liquid movement down the column during the vapor off period. More elaborate models based on liquid bypassing a plate have been experimentally measured on a number of cycled columns. With multiple sieve plate columns, the fluid mixing during the liquid drain period dominates the mass transfer separation. The following experiments are an attempt to bring together the experimental measurements on fluid mixing and mass transfer separations obtained in a multiple sieve plate column. The method should unify the numerous experimental results reported in the literature on periodic cycling of plate columns.

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CONCLUSIONS AND SIGNIFICANCE

A five plate column, 100 mm in diameter, has been operated in a periodically cycled mode from a program residing in a JOLT microprocessor system. The two parameters in the (2S) model to describe the fluid mixing have been measured over a wide range of liquid drain times. The experimental method involved the injection of potassium ions into the column and an analysis of the plate potassium compositions by atomic absorption spectroscopy. The theoretical improvements in performance given by the ratio N_{SS}/N_{PC} are in the range 1.01 to 1.22 using these two parameters in the (2S) model.

The mass transfer experiments were based on calculating the number of ideal plates in the column for the separation of mixtures of methylcyclohexane and *n*-heptane at atmospheric pressure. The column was operated with sieve plates and packed sieve plates. The packed sieve plates showed a marginal improvement in performance over sieve plates. The ratio N_{SS}/N_{PC} for the experimental results was in the range 1.07 to 1.26, which provided a satisfactory agreement with the theory. An important result of these mass transfer experiments is that the reported results of McWhirter and Lloyd of $N_{SS}/N_{PC} = 2.0$ could not be reproduced. The mechanism causing the reduction in the ratio N_{SS}/N_{PC} to be in the range 1.07 to 1.26 is due to liquid bypassing the plates during the liquid drain period. The (2S) model was successful in modeling both the fluid mixing and the mass transfer separations in this periodically cycled column.

The on-off control of plate distillation and absorption columns leads to a cycle which can be subdivided into a vapor flow period (VFP) followed by a liquid drain period (LDP). Several experiments have been reported in the literature investigating the advantages that result in this periodic cycling. Gaska and Cannon (1961) first reported these results by operating a 51 mm (2 in.) glass column in a periodically cycled manner. They used a benzene-toluene mixture at atmospheric pressure. They used three types of plates: a sieve tray made of 3 mm (⅛ in.) thick brass with nineteen holes 3 mm in diameter, giving a free area of 7.4%; a plate similar to the first type, but with sixty-one holes, giving a free area of 23.8%; and a 10-mesh screen with a free area of 56%.

The column was run both as a dual flow column and a periodically cycled column, so that the performance of the latter mode of operation could be compared with a steady state mode under the same operating conditions

Gaska & Cannon (1961) found that the first plate type flooded at such a low boil up rate, when operated under dual flow, that it could not be accurately measured. However, when the column was switched to periodic cycling, the throughput was increased to an F number of 1.71 $\text{kg}^{0.5}/\text{m}^{0.5}$ s with an overall plate efficiency of 60%. When the second plate types were used in dual flow, the operating range of F number was from 1.83 to 2.81, with a maximum overall efficiency of 90%. By changing to the cycling mode, the range of vapor velocities was doubled so that the F numbers ranged from 2.0 to 4.29, but the maximum overall efficiency was only 70%. A similar characteristic was noted for the third plate types in dual flow, when the operating range of F numbers was from 4.27 to 4.76. This range was expanded to F numbers between 4.88 and greater than 6.7 in the cycling mode; however, the overall efficiency was low at approximately 45%.

It should be noted, however, that in all the cycling runs the VFP was kept fixed at 5.4 s, the LDP ranged from 0.4 to 2.0 s, and no attempt was made to try to maximize the column performance.

McWhirter and Cannon (1961) studied a 51 mm (2 in.) column with an *n*-heptane/methylcyclohexane mixture. Instead of using sieve trays, they used packed plates. The packing was made of 6 mm protruded packing, and depths of 25, 51 and 76 mm were used. No attempt was made at comparing the cyclic performance with dual flow. As in Gaska and Cannon's work (1961), the VFP was fixed, at a value of 3.3 s. The LDP was varied between 1.1 and 4.4 s. At the shorter drain times, high efficiencies were obtained with a narrow operating range, while at the longer drain times, efficiencies were low but the operating range was broad with F numbers ranging from 0.98 to 2.26. Overall efficiencies of 140 and 160% were obtained for the 51 and 76 mm depths of packing, respectively. This is the first report of periodic cycling producing efficiencies of over 100% in a distillation column.

A comparison between Raschig rings and protruded packing was also made. They found that the protruded packing gave a higher efficiency owing to the fact that it has 60% more surface area per unit volume than the Raschig rings.

McWhirter and Lloyd (1963) also studied a 150 mm (6 in.) column with five plates packed with 76 mm (3 in.) of protruded packing. Efficiencies of over 220% were obtained with cycling, this, compared with a maximum of 90% when the column was operated in dual flow. They noted that this did not necessarily represent the maximum plate performance of the column, since the ability to manipulate the length of the VFP and LDP allows one a great degree of flexibility.

Schrodt et al. (1967) designed a 300 mm (12 in.) column with fifteen stages on conventional dual flow lines. An average plate efficiency of 50% was assumed, and the plates were designed with a free area of 20% based on laboratory work carried out on a 38 mm (1½ in.) column. The system used was acetone/water. Reflux was added to the top plate with a distributor to provide a uniform flow of liquid over the column cross section. Feed was added to the fifth plate from the bottom, without any distributor.

When operated conventionally, the column performed as expected with a maximum overall efficiency of 50% and a narrow operating range. When operated in a cycling mode, the operating range became broader, allowing a throughput of about twice that of the conventional operation, but the overall efficiency did not match that of the dual flow operation. This was attributed to the fact that the trays were designed for conventional operation, which is not necessarily the best design for periodic cycling, and that the two bottom plates drained dry before any liquid left the top plate, in spite of these two plates having half the free area of the rest. Simple modeling of the hydrodynamic behavior of the column showed that there was a lag in the pressure transient up the column. They suggested it was this lag which caused the bottom plates to drain dry. The model also showed that this effect only became significant in columns with more than ten or twelve plates. To overcome this problem, it was recommended that a pressure equalizing manifold be added to the column.

Gerster and Scull (1970) used a 150 mm (6 in.) gas stripping column with four sieve trays having a free area of 13.9%. The system used was air-water-ammonia. The fraction of the liquid holdup (η) was calculated by dividing the amount of liquid pumped onto the top plate each cycle by the mean holdup in the column. Equal holdups on all plates was assumed. The plate efficiency was determined from a series of experimental results in which liquid of a known composition was stripped for a predetermined time. The composition at the end of this period was again measured. The plate efficiency can then be calculated from

$$\epsilon = \frac{h}{mVt} \ln \frac{x(0)}{x(t)} \tag{1}$$

A mixing parameter (γ) was also included in their analysis which represented the liquid fraction on each plate which was assumed to be perfectly mixed. Their experimental results showed that the column operated with a (γ) value in the range of 0.3 to 0.5, giving a maximum overall column efficiency of 90% for a plate efficiency of ϵ=52%. The results were obtained at high values of (η), since at low values the top plate would flood and the bottom plate would drain dry. It was also noted that unless the bottom of the column was vented, the level on the bottom two plates would be much higher than the top two. This was attributed to a pressure buildup in the bottom section of the column as liquid drained into it during the LDP.

While this paper reported the first case of trying to match the theory with experiment by measuring relevant parameters independently and then predicting the performance of the column, it made no attempt at giving a definite reason for not achieving the expected overall column efficiencies. Mixing during the LDP is suggested for the decrease in performance, but this was not verified experimentally.

It still remained to be proven that the improved performance of periodic cycling over steady state operation could be predicted from theoretical considerations. Duffy and Furzer (1978) worked with a single plate. By using only one plate, the effects of mixing during the LDP are avoided, provided that the plate is refilled at the commencement of the VFP. They showed that for a single plate (N_{PC}=1)

$$\frac{N_{SS}}{N_{PC}} = \frac{\ln\left\{\frac{\lambda - X_{PC}}{1 - X_{PC}}\right\} - \ln\lambda}{\ln\left[1 + \epsilon(\lambda - 1)\right]} \qquad (2)$$

where X_{PC} is the separation factor for the periodically cycled column and for a specified λ, ϵ and η is given by

$$X_{PC} = \frac{1 - e^{-\lambda\epsilon\eta}}{1-(1-\eta)e^{-\lambda\epsilon\eta}} \qquad (3)$$

For the special case when λ = 1, Equation (2) reduces to

$$N_{SS} = \frac{1 - e^{-\epsilon\eta}}{\epsilon\eta e^{\epsilon\eta}} \qquad (4)$$

The experimental results were obtained on a 610 mm (24 in.) stripping column using an ammonia-air-water system. The liquid level was kept constant to ensure a fixed value of the plate efficiency of 74%. The value of λ was kept as close to 1 as possible. The fraction dropped was varied by changing the length of the LDP. The separation factor for each run was measured, and experimental values of N_{SS} were calculated. These values were corrected to λ=1 and compared with the theoretically derived values of N_{SS} obtained using Equation (4). The agreement was excellent. The work done by Duffy and Furzer (1978) shows conclusively that when there is no bypassing during the LDP, periodic cycling gives an improved performance over steady state operation and that this performance can be predicted theoretically.

For multiplate columns, high efficiencies can be obtained, but never as high as would be expected theoretically. This has always been attributed to liquid mixing during the LDP. This departure has been modeled by a series of stirred tanks by Horn and May (1968) or by assuming that part of the plate behaves as a well-stirred tank by Gerster and Scull (1970). However, any model that assumes stirred tanks introduces another set of differential equations into the theory, thus complicating the solution. Furzer and Duffy (1976) have proposed an algebraic model, thus avoiding the complexity of solving differential equations. They assumed that a fraction (a) of the plate holdup was transferred in a plug flow manner to the plate below, a fraction (b) dropped two plates, etc. In view of the fact that some of the liquid is assumed to be transferred two stages, the model has been called the (2S) model. An expression for the response of a column to a unit impulse and a unit step of tracer was calculated. Since the tracer remains unaffected during the VFP, the output concentration of tracer given by the concentration leaving the bottom plate is only a function of the mixing parameters (a) and (b) and the number of plates. This response is called the discrete residence time distribution (DRTD). It is called discrete as the output of this system is similar in appearance to that obtained by discrete sampling of a system with a continuous output. Periodic cycling only gives liquid output during the LDP, and the concentration during any given drain period is essentially constant. Values of (a) and (b) were obtained from the response of a five plate column. The value of η calculated from the (a) and (b) values obtained compared favorably with the experimentally determined value of (η). The model can also take into account weeping and entrainment during the VFP.

THEORY

The theory of periodic cycling of plate columns using the (2S) model is based on unsteady state mass balances during the VFP and mass balances during the LDP.

During the VFP

$$h_n\frac{dx_n}{dt} = V\,(y_{n+1} - y_n) \quad n=1,2...N \qquad (5)$$

$$\epsilon = \frac{y_n - y_{n+1}}{y^*_n - y_{n+1}} \quad n=1,2...N \qquad (6)$$

$$y^*_n = mx_n \quad n=1,2...N \qquad (7)$$

During the LDP, the (2S) model with the two parameters (a) and (b) provides

$$h_1\,x_1(0) = h_1[1-(a+b)]\,x_1\,(t_r) + M\,x_0 \qquad (8)$$

$$h_2\,x_2(0) = h_2[1-(a+b)]\,x_2(t_r) + h_1 a\,x_1\,(t_r) \qquad (9)$$

$$h_n\,x_n(0) = h_n[1-(a+b)]\,x_n(t_r) + h_{n-1}a\,x_{n-1}(t_r) + h_{n-2}b\,x_{n-2}(t_r) \qquad (10)$$

These equations can be written in dimensionless terms using a dimensionless parameter λ, where

$$\lambda = \frac{mV}{L} \qquad (11)$$

The solution of this set of differential and algebraic equations has been given by Furzer (1979) in both tabulated and graphical form. The solution can be expressed as

$$\frac{N_{SS}}{N_{PC}} = f(N_{PC},\lambda,\epsilon,a,b) \qquad (12)$$

EXPERIMENTAL

A 100 mm (4 in.) glass column was used for the discrete residence time distribution (DRTD) and mass transfer runs. The plates were made of 0.8 mm (1/32 in.) thick brass, with thirty-eight holes 6.32 mm (1/4 in.) in diameter giving a free area of 14.8%. The column had five plates with a 635 mm (25 in.) spacing. Overhead vapors were condensed in a stainless steel condenser which was open to the atmosphere. When the liquid reflux was being pumped onto the column, a level control on the accumulator was used to determine when enough liquid had been pumped on. Liquid was only added to the column at the end of the LDP, thus minimizing mixing effects during the LDP. When liquid was not being pumped onto the column, it was recycled from the pump back to the condensate accumulator, ensuring good mixing of the liquid in the accumulator. The direction of liquid flow, that is, either to the column or back to the accumulator, was controlled by two pneumatic valves operated by a three-way pneumatic solenoid valve. This solenoid valve in turn was controlled by the level controller. Steam flow to the column was supplied by means of a thermosyphon reboiler. During the LDP, the vapor was diverted from the column to a bank of condensors which were open to the atmosphere, thus avoiding any pressure buildup in the reboiler. This was done using two 51 mm (2 in.) butterfly valves, mechanically actuated by an electric solenoid.

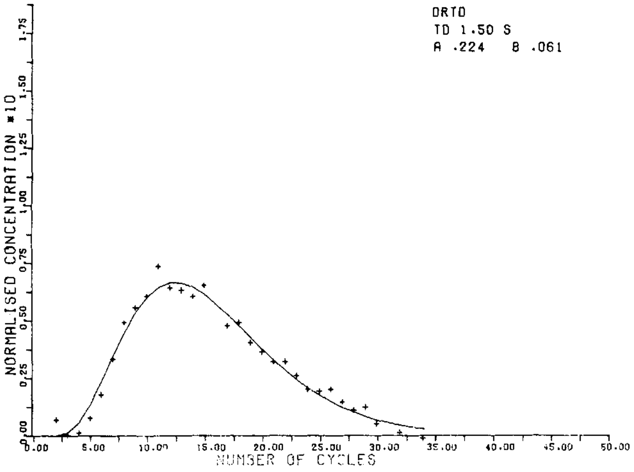

Figure 1. DRTD in a packed sieve plate column.

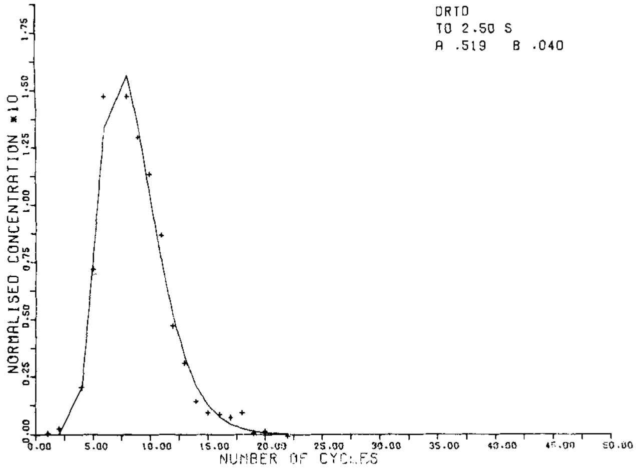

Figure 3. DRTD in a packed sieve plate column.

Table 1. Parameters in the (2S) Model

Packed sieve plates, vapor flow time 20 s			
$t_D(s)$	a	b	$\bar{\eta}$
1.50	0.224	0.061	0.334
1.75	0.263	0.079	0.407
2.00	0.374	0.057	0.481
2.25	0.332	0.108	0.529
2.50	0.519	0.040	0.594
2.75	0.496	0.068	0.623

The column itself was made of 305 mm (12 in.) sections of 100 mm (4 in.) flanged QVF glass pipe. Above and below each plate there were 10 mm thick stainless steel rings with an inside diameter of 100 mm. Each ring had three threaded holes 6.32 mm (¹/₄ in.) in diameter. These rings were used to allow samples to be taken from each plate, tracer to be added to a plate and to allow pressure tappings to be made.

The plates used in packed sieve plate experiments were the same as the ones already mentioned but with 90 mm (3½ in.) of 13 mm (½ in.) Raschig rings dumped on them. To prevent heat loss from the column, it was lagged using clear Perspex covers. This allowed one to observe the behavior of the column and still effectively reduce the heat loss.

Three column parameters were monitored: static head below the bottom plate, liquid level in the accumulator and reflux temperature. The static head and the liquid level were measured using a Foxboro differential pressure transmitter cells type 614DM and E13D2, respectively. A thermistor type F2311./300 was used to measure reflux temperature. The timing and level control for the column were performed by a JOLT microprocessor.

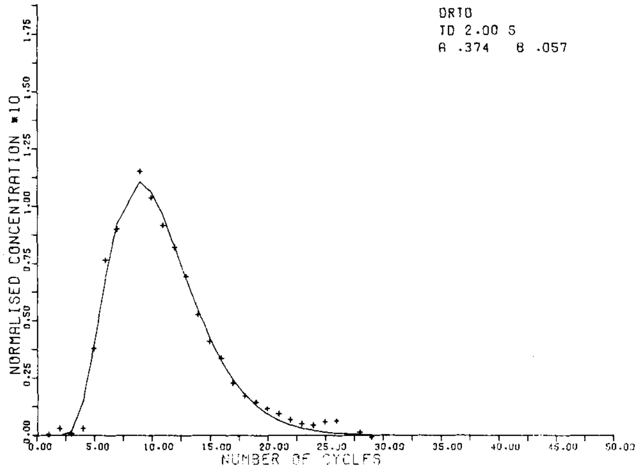

Figure 2. DRTD in a packed sieve plate column.

The microprocessor was programmed by feeding a paper tape through the teletype. This program allows the user to specify the length of the VFP and LDP and the number of cycles of column operation. The level control on the condensate collector was also performed by the microprocessor. The control used was a simple on/off type. A comparator compared the voltage from the pressure transducer monitoring the level in the accumulator with a reference voltage. This reference voltage was set by the user using a slide potentiometer. If the measured voltage was greater than the reference one, an interrupt was set in the processor; if it was less, then the interrupt was closed. At the end of the LDP, the processor checked the state of the interrupt. If it was set, a signal was sent to the air solenoid controlling the pneumatic valves, and liquid would then be pumped onto the top plate. Once the liquid reached the reference level such that the measured voltage was less than or equal to the reference one, the interrupt would be cleared. The signal to the air solenoid would be reversed, so that liquid would now be recirculated to the accumulator.

Full details of the apparatus, microprocessor and program details are given by Goss (1979).

DISCRETE RESIDENCE TIME DISTRIBUTION

The column was operated with distilled water at its boiling point for the measurement of the DRTD's. A sample of K^+ was injected onto the top plate and 2 ml samples withdrawn from the bottom plate at the end of the VFP. Analysis for K^+ was by a calibrated atomic absorption spectroscope with detection limits to 0.1 ppm K^+. The column was operated for at least 100 cycles before starting a DRTD run. Measurements of the DRTD's for sieve plates in the column have been reported by Furzer (1978).

Measurements of the DRTD's for packed sieve plates with a VFP of 20 s are shown in Figures 1, 2 and 3 for drain times of 1.50, 2.00 and 2.50 s. The parameters in the (2S) model were obtained by a Simplex optimization routine that minimized a least-square objective function based on the differences between the experimental and modeled DRTD's. Values of (a) and (b) in the model are given in Table 1. Values of the mean liquid

Table 2. Comparison Between Experimental $\bar{\eta}_{2S}$ and $\bar{\eta}_{exp}$

Sieve plates					
t_r = 20 s			t_r = 25 s		
$t_D(s)$	$\bar{\eta}_{2S}$	$\bar{\eta}_{exp}$	$t_D(s)$	$\bar{\eta}_{2S}$	$\bar{\eta}_{exp}$
0.50	0.257	0.262	0.50	0.338	0.322
0.75	0.354	0.324	0.75	0.360	0.407
0.88	0.355	0.347	1.00	0.452	0.446
1.00	0.395	0.462	1.25	0.515	0.452
1.25	0.460	0.397	1.50	0.549	0.518
1.50	0.575	0.465			
2.00	0.969	0.849			

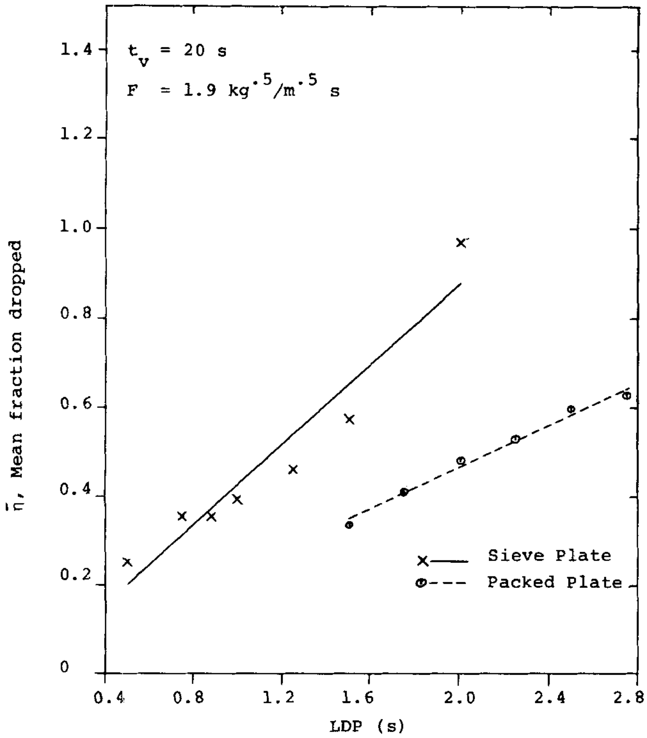

Figure 4. Mean liquid holdup fraction drained per cycle.

plate holdup $\bar{\eta}$ dropped per cycle calculated from the (2S) model are also given in Table 1. Experimental values of $\bar{\eta}$ were estimated from the total static head under the plate, the vapor velocity and the pressure drop characteristics of sieve plates given by McAllister et al. (1958). There was a good agreement between the experimental η_{EXP} and modeled values of $\bar{\eta}_{2S}$ as shown in Table 2 and Figure 4. Values of the (a) and (b) parameters in the (2S) model are shown on Figures 5 and 6 for sieve plates and packed sieve plates for various liquid drain times.

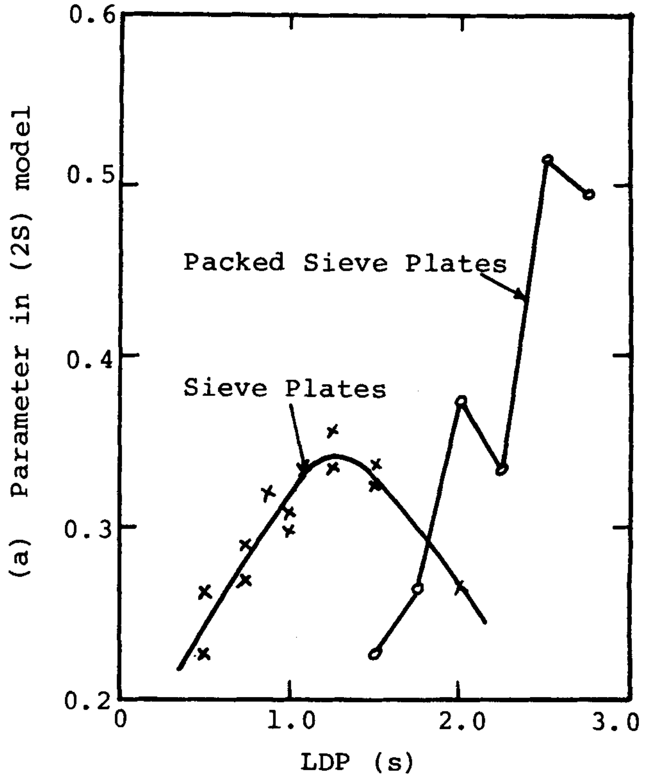

Figure 5. Parameter (a) in the (2S) model.

MASS TRANSFER RESULTS: DUAL FLOW

All mass transfer experiments were performed with the methylcyclohexane—n-heptane system at atmospheric pressure. The methylcyclohexane was purified by contacting with sulfuric acid and rinsing in sodium carbonate and distilled water until its refractive index reached $n_D^{20} = 1.4231$. Liquid analysis was by refractive index to an accuracy of ±0.0001. The equilibrium data for the system are given by Bromiley and Quiggle (1933). The equilibrium curve approaches a straight line with a slope of 1 when the liquid composition is between 30 and 70 mole% n-heptane, as given by

$$y = x + 0.019 \tag{13}$$

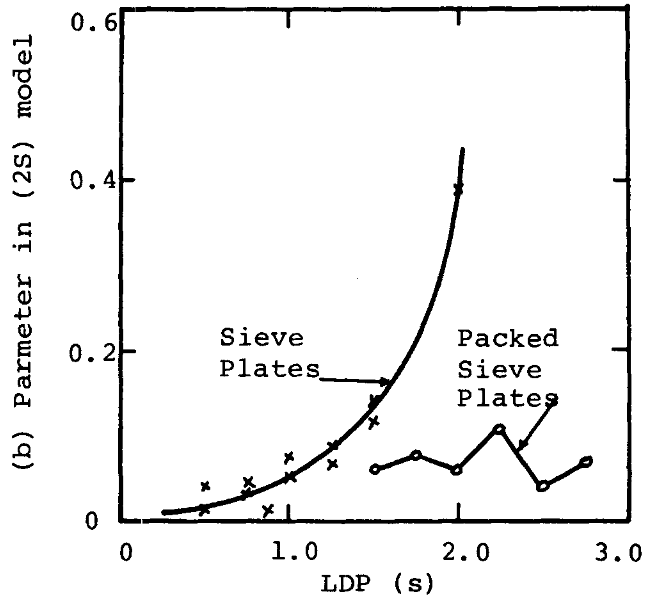

Figure 6. Parameter (b) in the (2S) model.

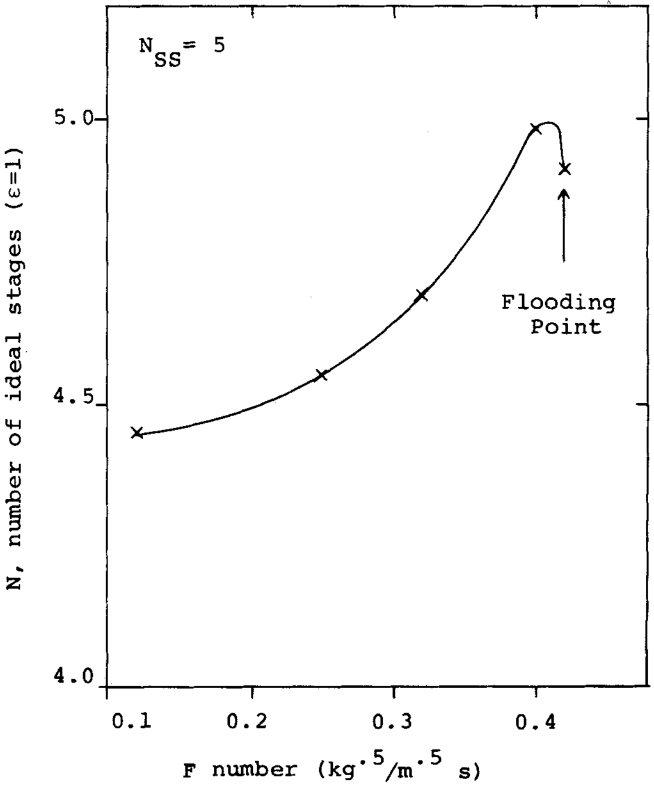

Figure 7. Mass transfer in a dual flow column.

TABLE 3. MASS TRANSFER IN A PERIODICALLY CYCLED COLUMN

$F = 0.52$ kg$^{0.5}$/m$^{0.5}$ s
Sieve plates

$t_D(s)$	$N(\epsilon = 1)$	$\frac{N_{SS}}{N_{PC}}$ ($\epsilon = 0.75$)
0.10	4.02	1.07
0.20	4.34	1.16
0.40	4.75	1.26
0.80	4.49	1.20
1.20	4.31	1.15

$t_v = 5.5$ s
Packed sieve plates

$t_D(s)$	$N(\epsilon = 1)$	$\frac{N_{SS}}{N_{PC}}$ ($\epsilon = 0.85$)
0.60	4.53	1.07
0.80	5.01	1.18
0.90	4.95	1.16
1.00	4.95	1.16
1.20	5.14	1.20
1.50	4.68	1.10

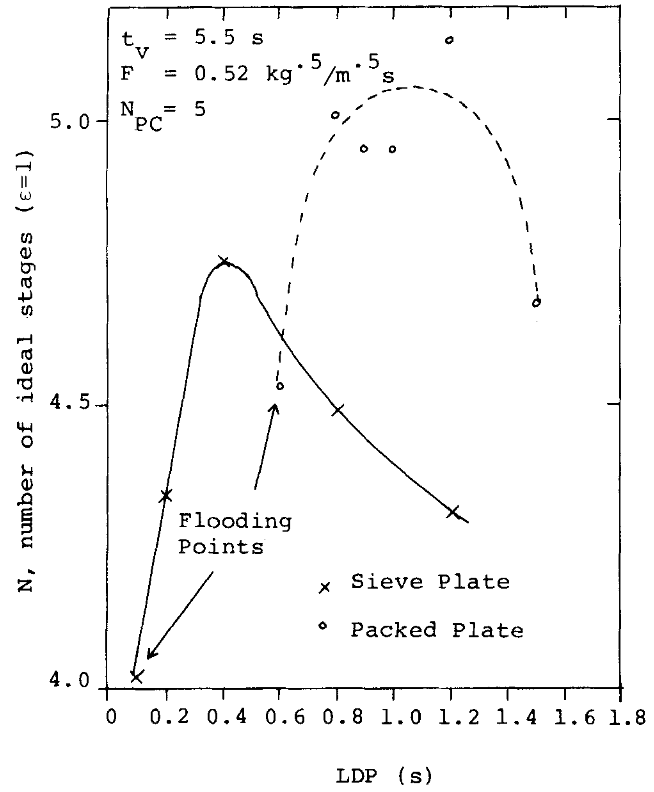

Figure 8. Mass transfer in a periodically cycled column.

If the column is operated at total reflux and liquid samples obtained from the entry line to the top plate and from the reboiler, then the number of ideal plates in the column is given by

$$N = \frac{x_0 - x_R}{0.019} - 1.000 \tag{14}$$

The column was operated in dual flow with liquid and vapor competing for orifice flow over a range of F numbers from 0.12 to 0.42 kg$^{0.5}$/m$^{0.5}$ s. The number of ideal plates in the column is shown in Figure 7, reaching 4.98 stages prior to flooding at F=0.42.

MASS TRANSFER RESULTS: PERIODIC CYCLING

During the mass transfer runs with periodic cycling, the F number and the VFP were kept constant at 0.52 kg$^{0.5}$ s and 5.5 s, respectively. The drain times varied from 0.10 to 1.20 s for sieve plates and from 0.60 to 1.50 s for packed sieve plates. The results are shown in Table 3 and Figure 8. The maximum number of ideal plates in the sieve plate column was 4.75 when the drain time was 0.40 s. With packed sieve plates, the maximum increased to 5.14 ideal plates at a drain time of 1.20 s.

The theory of periodic cycling of plate columns results in

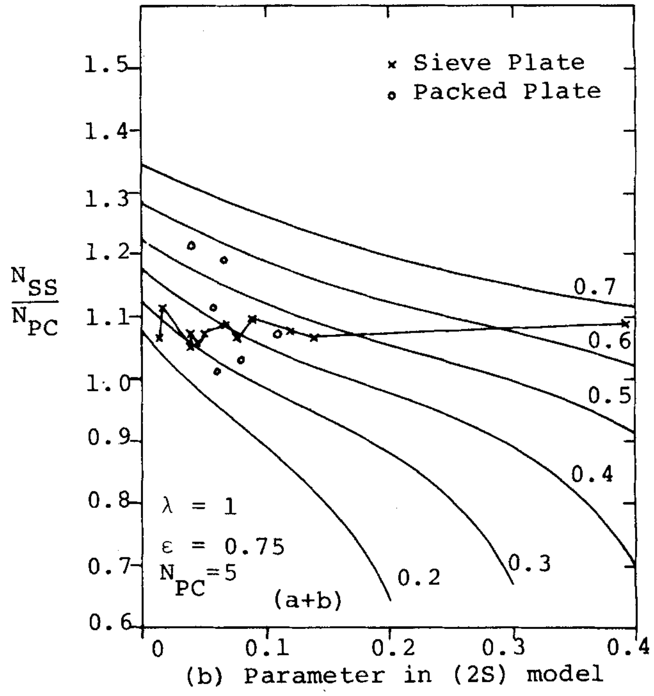

Figure 9. Ratio N_{SS}/N_{PC} for a cycled five plate column, ϵ=1.00.

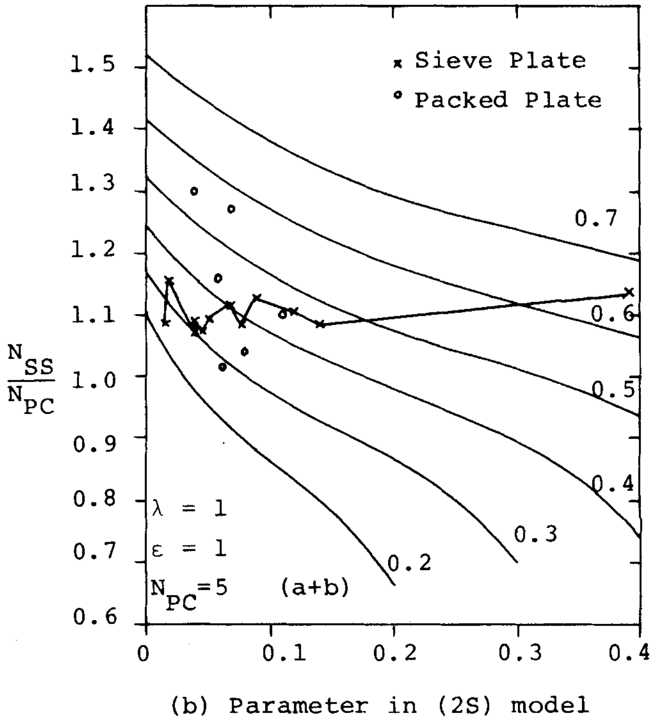

Figure 10. Ratio N_{SS}/N_{PC} for a cycled five plate column, ϵ=0.75.

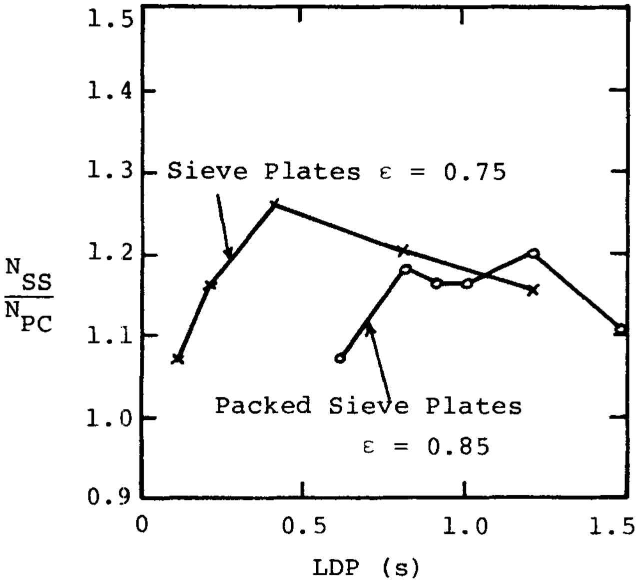

Figure 11. Ratio N_{SS}/N_{PC} for a cycled five plate column. Sieve plates and packed sieve plates.

$$\frac{N_{SS}}{N_{PC}} = f(N_{PC},\lambda,\epsilon,a,b) \qquad (15)$$

This ratio can be estimated from the DRTD runs which have provided values of (a) and (b) under similar hydrodynamic conditions, since N_{PC} and λ are accurately known and ϵ is estimated to lie in the range 0.75 to 1.00. Computer runs to solve for the function (f) have been completed over wide ranges of the parameters (a) and (b) and are shown on Figures 9 and 10 for $\epsilon=0.75$ and $\epsilon=1.00$, respectively. Also shown on these figures are the estimated ratios of N_{SS}/N_{PC} from the DRTD runs. If the (2S) model was satisfactory, then the ratio N_{SS}/N_{PC} should lie in the range 1.01 to 1.22.

The experimental results can be expressed as the ratio N_{SS}/N_{PC} by assuming $\epsilon=0.75$ for sieve plates and $\epsilon=0.85$ for packed sieve plates. For sieve plates, $N_{SS}=0.75\times5$, and for packed sieve plates, $N_{SS}=0.85\times5$. The ratio N_{SS}/N_{PC} is shown in Figure 11 for both types of plates for drain times from 0.10 to 1.50 s. All the experimental results lie in the range 1.07 to 1.26. There is a reasonable agreement between the theoretical values of N_{SS}/N_{PC} obtained with the (2S) model and the experimental values on the five plate cycled column.

DISCUSSION

McWhirter and Lloyd (1963) have reported mass transfer results on a 150 mm (6 in.) diameter column containing five plates packed with 76 mm (3 in.) of protruded packing. When this column was periodically cycled, measurement of the overall column efficiency gave results over 220%.

The mass transfer results reported in this paper lead to considerably lower overall column efficiencies than those reported by McWhirter and Lloyd (1963). The maximum improvement in separation performance occurred when N_{SS}/N_{PC} was 1.26 for sieve plates with a drain time of 0.40 s. The results for packed sieve plates had a maximum of 1.20 for a drain time of 1.20 s. The increases in separation performance are small and are similar to the expected values provided by the (2S) modelling technique. To achieve values of $N_{SS}/N_{PC} = 2.0$ which are possible by periodic cycling of plate columns, the theory requires (a)→ 1 and (b)→ 0.

In order that the results of McWhirter and Lloyd (1963) could reach values of $N_{SS}/N_{PC}>2.20$, the theory would require (a)→1 and (b)→0. The extensive DRTD measurements on the column reported in this paper indicate that the maximum (a) value for sieve plates was 0.334 and for packed sieve plates 0.519.

We may conclude that the mass transfer results for multiple plate columns are in line with the (2S), theory and the previous reported results of McWhirter and Lloyd (1963) could not be reproduced. To achieve high ratios of N_{SS}/N_{PC}, it is necessary to modify the internals of the column to achieve control over the (a) and (b) parameters in the (2S) model. Such control is not available with sieve plates or packed sieve plates.

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NOTATION

a = parameter in the (2S) model
b = parameter in the (2S) model
F = F number = $v\sqrt{\rho}$
h = liquid holdup on a plate
m = slope of the equilibrium line
M = mass of the liquid admitted per cycle
N = number of theoretical plates in the column
N_{PC} = number of plates in a periodically cycled column
N_{SS} = number of equivalent plates with an efficiency ϵ in a steady state column
t = time
v = vapor velocity
V = vapor flow rate
x = liquid composition
X_{PC} = dimensionless liquid composition in a cycled column
y = vapor composition

Greek Letters

γ = parameter in Gerster and Scull's model
ϵ = plate efficiency
$\bar{\eta}_{exp}$ = mean liquid holdup drained, experimental
$\bar{\eta}_{2S}$ = mean liquid holdup drained, modeled
λ = ratio of slopes of equilibrium and operating line
ρ = density

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