Oscillating Behavior on Distillation Trays

The objective of this work was to study the undesirable oscillating behavior which can develop on distillation trays. This takes the form of violent lateral movements of the gas/liquid mixture, causing premature flooding and reduced efficiency. It has been demonstrated that entrainment is significantly increased by the presence of oscillations. A simple predictive method by which a designer may evaluate the likelihood of oscillations occurring is proposed. It is concluded that columns of greater than about 1.0 m diam. operating at atmospheric pressure or above are unlikely to oscillate. However, reduced pressure columns of greater diameter may oscillate. A very simple mesh baffle system which completely prevents oscillations developing is described.

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SCOPE

The objective of this work was to study the violent lateral oscillations of the gas/liquid mixture which can occur on distillation trays operating at high vapor loadings. A further objective was to develop a simple method which would be useful for a designer to assess the likelihood of oscillations developing in a column.

Oscillations are generally undesirable since they lead to reduced capacity and premature flooding. These symptoms have often been noticed in newly constructed columns, and while direct observation of the cause is usually impossible, it is suggested here that oscillations may have been responsible. It appears likely that columns operating at pressures below atmospheric are more susceptible to oscillations, and some conclusions on this are presented. Since previous observations of oscillation have been on fairly small columns (about 0.3 m diam.), a larger column of diam. of 0.69 m was set up and operated with the system air/water. The column was completely transparent to allow close observation of the operating behavior. All the usual parameters were noted, and in addition the backmixing due to turbulence was measured using the salt injection technique of Barker and Self (1962). Entrainment was measured with oscillations present and then with the same loadings but with oscillations prevented by baffles. Two different sieve trays were studied with a range of air and water rates. The oscillation results were compared with those previously reported.

CONCLUSIONS AND SIGNIFICANCE

It was observed that two distinct types of oscillation are possible. In the first type, Full-wave oscillation, the gas/liquid biphase moves simultaneously from the walls to meet at the center of the tray. Then the motion reverses and the biphase moves outwards across the direction of liquid flow to strike the walls at the same time. When the biphase comes to a peak in the center and when it hits the walls, spray is hurled upwards and entrainment is increased. This oscillation occurs when a fairly well defined critical vapor velocity is reached. If the vapor velocity is increased, the nature of the biphase becomes somewhat confused, with peaks moving about the tray and occasionally hitting the walls and causing spray to be hurled up towards the tray above. This was still defined as Full-wave oscillation and has not previously been reported. Full-wave oscillation can increase entrainment by about 40%.

With further increase in the vapor velocity a critical point is reached when the oscillation becomes a violent sloshing from side to side across the direction of liquid flow. This is the form of oscillation previously reported and will be called Half-wave oscillation. These two types are shown in Figures 2 and 3. Both these types of oscillation are undesirable, although the Half-wave type is more violent. It is suggested here that the Full-wave oscillation occurs when the wavelength of waves always present in the biphase becomes equal to the column diameter. It is also suggested that Half-wave oscillations occur when the wavelength becomes equal to twice the column diameter. If the vapor velocity is increased above the critical value for Half-wave oscillation, oscillations continue and become more violent with a slightly reduced frequency. Half-wave oscillations can increase entrainment by more than 70%.

Using as a basis the comprehensive theory of Hinze (1965) with some modifications, a dimensionless number has been developed which should have critical values corresponding to Full-wave oscillation and Half-wave oscillation.

The group is defined as

$$B_S = \frac{V \epsilon h_f \rho_g}{g d^3 \rho_L \bar{a}}$$

It has been found by experiment that when $B_S = 0.5 \times 10^{-5}$, Full-wave oscillation is initiated and continues until, with increasing vapor rate, $B_S = 2.5 \times 10^{-5}$. At this condition Half-wave oscillation is initiated.

Thus the value of this simple group is proposed as a test for satisfactory operation of a distillation tray. Equations are recommended for the prediction of the biphase properties to enable a designer to assess the likelihood of undesirable operating characteristics. A simple arrangement of mesh baffles has been tested and is proposed as being desirable for any column thought likely to oscillate. The indications are that reduced pressure columns are more likely to oscillate than columns operating at atmospheric pressure or above.

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There have been many occasions when the performance of a newly constructed distillation column has failed to meet the design specifications. A fairly common symptom of the inadequate performance is a reduced capacity compared with that expected. It is often difficult to identify the cause since it is usually not possible to observe directly the situation existing within the column.

One of the possible causes of reduced capacity in sieve-tray and bubble-cap-tray columns is biphase oscillation. This phenomenon can be described as follows. At certain vapor and liquid flow rates, large scale oscillations can be set up in the gas/liquid mixture (biphase) on the tray. This causes violent movements of the biphase about the tray. During this study, careful observation from below a transparent tray has shown that these movements initially take place equally in all directions. However, the observation has usually been that the biphase sets up steady movements in a direction at right angles to the direction of liquid flow. It is considered that this is because in a conventional column there are walls running more or less parallel to the direction of liquid flow, and so movements can reflect off these walls and reinforce when conditions are favorable. No reflection is possible in the direction of liquid flow over the outlet weir. The result is that biphase sloshes across the tray and back again. It will later be suggested that at least two types of oscillation can occur depending on the wavelength/column diameter ratio.

The sloshing of the biphase against the walls causes froth and spray to be hurled up to the tray above, resulting in increased entrainment. This can occur when the normal foam height is much less than the tray spacing. Increased entrainment causes reduced tray efficiency and in addition local weeping can occur.

There have recently been suggestions by Ellis (1972) and by Ravicz (1972) that columns operating at reduced pressure may be more susceptible to oscillations than columns operating at atmospheric pressure or above. There is evidence to indicate that some commercial reduced pressure columns have failed to operate satisfactorily due to oscillations. This paper describes an attempt to develop a simple criterion which will enable the likelihood of oscillations occurring in a column to be assessed quickly. All the observations so far reported have been at atmospheric pressure, but it is proposed that the criterion suggested here indicates an increased likelihood of oscillating operation at lower pressures.

OBSERVATIONS OF BIPHASE OSCILLATION

The previously reported observations of rhythmic oscillations have all been in small columns (about 0.3-m diam.) since observation is impractical in larger commercial columns.

McAllister and Plank (1958) and McAllister et al. (1958) have reported oscillations occurring in 0.4-m diam. sieve tray column and a 0.2-m diam. bubble-cap column. The columns exhibited oscillations while operating with organic and aqueous systems.

Barker and Self (1962) have reported oscillations in an open rectangular tank having a sieve plate 0.34 m wide and 1.74 m long as its base, operating with air/water.

M. W. Biddulph has previously observed oscillations occurring in the following situations:

1. A 0.4-m diam. sieve tray column distilling *n*-pentane/*iso*-pentane.
2. A 0.3-m diam. sieve tray column operating with air/water.
3. A rectangular sieve tray 0.1 m wide and 0.46 m long with air/water.

Foss and Gerster (1956) also observed oscillations occurring on various sieve trays 0.24 m wide.

The object of this study was to set up a larger column to study the oscillations.

McAllister and Plank (1958) suggested that the oscillation phenomenon is caused by a resonance which is fundamentally acoustic in nature. Their analysis is based on equations derived for pulsation frequencies in air ducts and includes consideration of the length and volume of the closed recirculation system employed. Their equations correlated the observations well, but as has been noted above, oscillations have been observed occurring in open tanks. In this situation the volume of the system is infinitely large, and the equation of McAllister and Plank predicts an oscillation frequency of zero. Therefore, the model is suspect unless the oscillations are caused by pressure fluctuations below the plate. This is also unlikely since the pressure fluctuations which have been detected below sieve trays have been of fairly high frequency.

A more likely explanation is that the oscillations are created by turbulent disturbances inducing oscillations in a biphase of suitable character.

In 1965, Hinze presented a theoretical analysis of disturbances occurring in the biphase on a sieve plate. By combining mass and momentum balances and assuming a sine form for perturbations in height and pressure, an equation was obtained for the wavelength of stable waves. It is now suggested that the observed sloshing can occur when the wavelength/diameter ratio reaches certain critical values. These values of the ratio are 1.0 and 2.0. The two different modes of operation corresponding to these critical values will be described later.

DEVELOPMENT OF A CRITERION

The theoretical approach of Hinze (1965) together with dimensional analysis has been used to develop a dimensionless group which is now proposed as a criterion for the onset of instability.

One of the simplifying assumptions made by Hinze was that the eddy kinematic viscosity ϵ was zero. This assumption has been avoided. However, when a sign error which occurred in one of the basic equations of Hinze's derivation was corrected, it was found that the absolute values of predicted wavelengths did not match well with observed values. It has been assumed here, however, that the theory of Hinze does correctly predict the directional effect of the important variables on the value of the wavelength. Thus the sign of each of the partial derivatives of wavelength with respect to each variable has been determined, and the power of each variable has been determined. For example it was found that wavelength was predicted to have a positive linear response to superficial vapor velocity raised to the power approximately 1/3. Other variables were treated similarly. On the basis of this assumption, the following dimensionless group is suggested as being a criterion for the onset of oscillations.

$$B_S = \frac{V \epsilon h_f \rho_g}{g d^3 \rho_L \bar{a}}$$

This group is very sensitive to vapor velocity since ϵ and h_f both increase with V while $\bar{a}$ decreases.

Since eddy kinematic viscosity ϵ is difficult to evaluate, we assume that the value of the turbulent Schmidt Number is constant at unity, and so $\epsilon = De$, the eddy diffusiv-

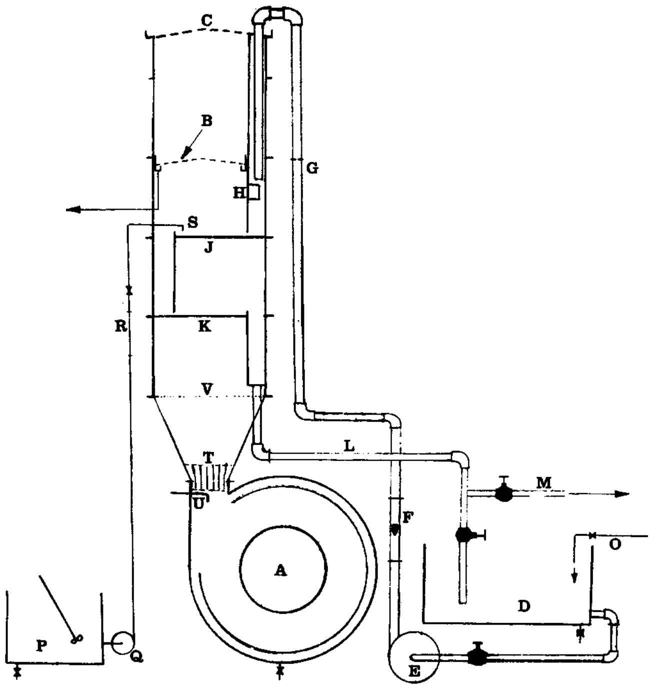

Fig. 1. Sieve tray test rig.

ity. The critical values of B_S are based on this assumed equality. De is fairly easily measured using the salt injection method described by Barker and Self (1962).

The value of B_S has been evaluated for each of the experimental observations in this study, and for some of the earlier data, where reported values permit.

EXPERIMENTAL APPARATUS

A diagram of the apparatus is shown in Figure 1.

A large centrifugal blower A driven by a 15 HP motor through a variable speed gearbox blows air through a flow director T and up through the column. This consists of a 0.69-m diam. tube constructed in lengths of 0.61 m from clear polyvinylchloride. The perspex flanges on these sections provide strength and rigidity. The air passes first through a wire mesh screen V, to even out the air flow, and then through the sieve trays K, J. Most of the tests were carried out on the upper tray. Air leaving the tray J passes up through the entrainment measuring device B. This takes the form of a narrow trough around the column wall which collects the liquid caught in a three-layer wire mesh screen in the form of a very shallow cone. The height of the trough above the test plate can be adjusted to measure entrainment at different levels. The collected liquid runs away through a drain line. The air leaves the column through a wire mesh top screen C to catch any droplets which have passed through the lower screen. This small amount of liquid is also returned to the trough.

Water is pumped from a 0.45 m^3 tank D by a small centrifugal pump E through a rotameter F and an orifice plate G to the top of the column. The rotameter is used to measure small rates of flow and the orifice plate is used for higher flow rates. Water passes into the downcomer on tray J with a liquid distributor H. Water flows over the trays in the usual way and out through line L back to the water tank D, or straight to drain M. A fresh water make-up line O is provided.

Eddy diffusivity values in the liquid/vapor biphase were measured using a steady state salt injection technique, as described by Barker and Self (1962). This involved pumping concentrated salt solution from a stainless steel tank P through a rotameter R and to an injector tube S running parallel to the outlet weir of tray J. This injection tube consisted of a 12.7-mm diam. stainless steel tube with 0.8-mm diam. holes drilled every 12.7 mm along the underside of the tube. Thus salt solution was injected in a uniform stream across the entire width of the plate. Liquid samples were obtained from tubes set into the plate between rows of holes. The sample tubes passed out through the column wall and into 250 cc sample bottles. The tubes were positioned at intervals of 50 mm starting from directly beneath the injector tube, towards the inlet weir, along the center line of the tray. Salt concentrations were determined by using conductivity measurements. Eddy diffusivity values were calculated by the method described by Barker and Self (1962).

The trays were also instrumented to measure total pressure drop and liquid head using a manometer tube set into the tray floor. The air rate into the column was measured using a pitot tube in the ducting above the blower.

The procedure for a run was as follows: The blower was started up and set to a speed to give sufficient air to prevent liquid weeping through the trays. The water was then pumped into the column at the required rate and the valves set to pass the water leaving the column straight to drain. The water make-up line O was used to maintain a constant level of fresh water in the tank D. With the air rate set to the desired value, the salt solution was pumped in through the injector. This was allowed to continue for a few minutes before commencing sampling. The screw-clips on the sample tubes were then opened, and samples were continuously taken into the 250 cc sample bottles. The sample was allowed to overflow the bottles for a period of about 30 min. to ensure a representative sample. The samples were then analyzed and the value of eddy diffusivity calculated. During each run readings of air rate, water rate, tray pressure drop, liquid head, static pressure at the base of the column and froth height were taken. Entrainment values were measured by allowing a suitable quantity of water to collect over a measured time interval.

RESULTS

Two different perspex sieve trays were studied at atmospheric pressure. These trays had 6.4 mm holes, tray I having 10% free area while Tray II had 5% free area. The biphase character was observed and the following measurements taken: total tray pressure drop, clear liquid head, eddy diffusivity, froth height, air rate, and liquid rate. It was observed that at low air rates the biphase was steady but was not the same height over the entire tray. Hills and valleys could be clearly seen moving slowly around the tray. As the air was increased, the wavelength L of the waves appeared to become equal to the column diameter d and a steady oscillation was set up as shown in Figure 2. This will be referred to as Full-wave oscillation. The biphase hitting the walls caused spray to be hurled into the air stream, and the peak in the center of the tray also caused additional entrainment. There appeared to be a definite critical air rate at which these oscillations became steady. As would be expected, the phenomenon caused maldistribution in the air stream,

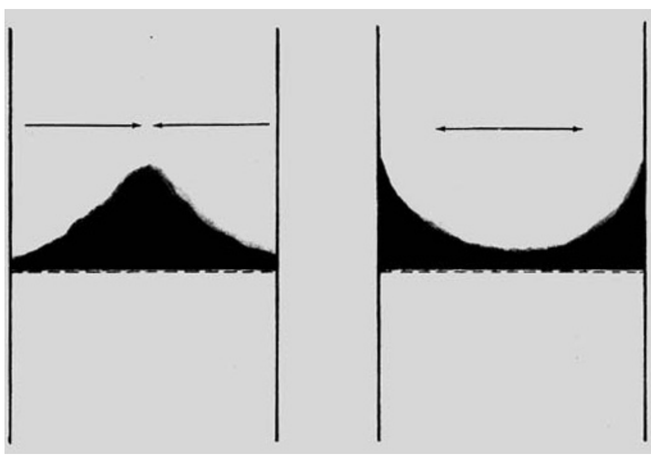

Fig. 2. Full-wave oscillation $L = d$.

a fact which could be easily observed by the movements of water droplets in the upper part of the column when the de-entraining device B was absent. The frequency of these oscillations was measured. Typically Full-wave oscillation occurred with a frequency of about 1.2 Hz.

With the air rate increased above the critical value for Full-wave oscillation, the movements on the tray became somewhat confused. Occasional peaks hit the walls and

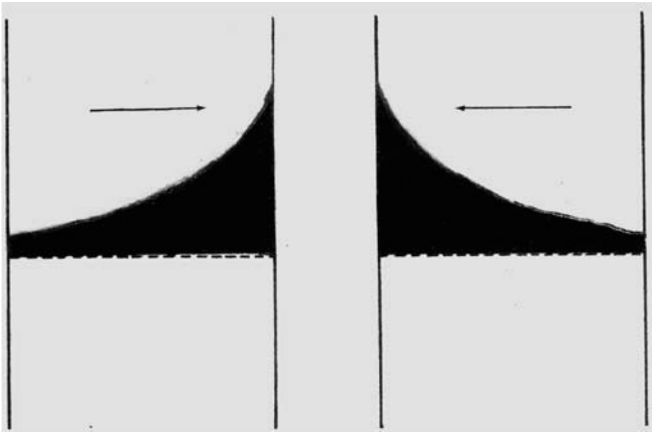

Fig. 3. Half-wave oscillation L = 2d or L > 2d.

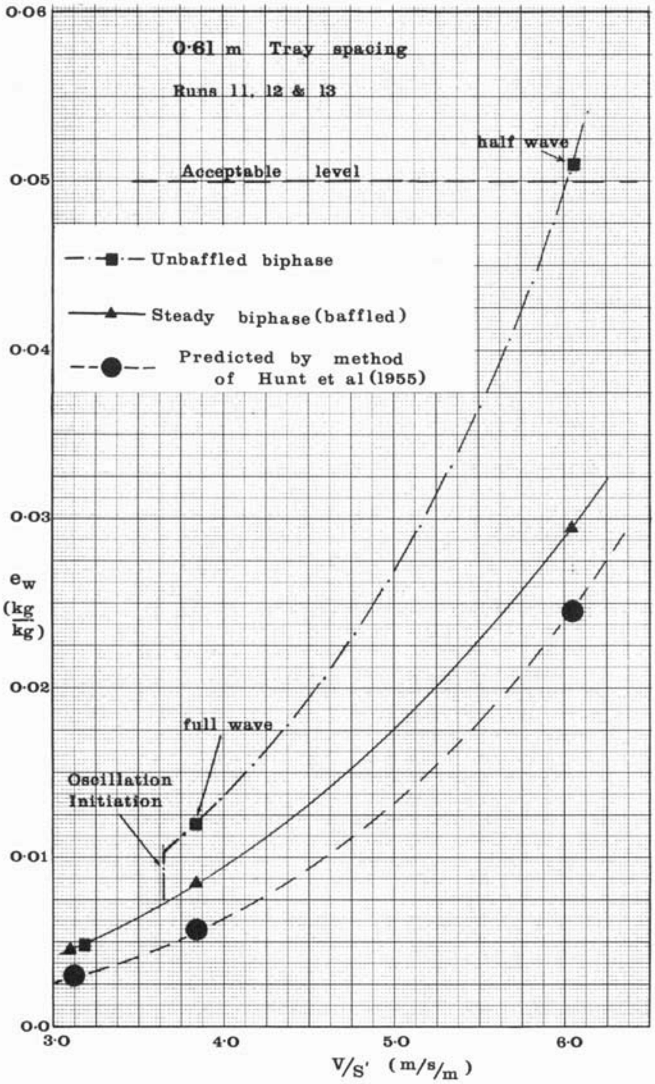

Fig. 4. Effect of oscillation on entrainment (tray spacing 0.61 m).

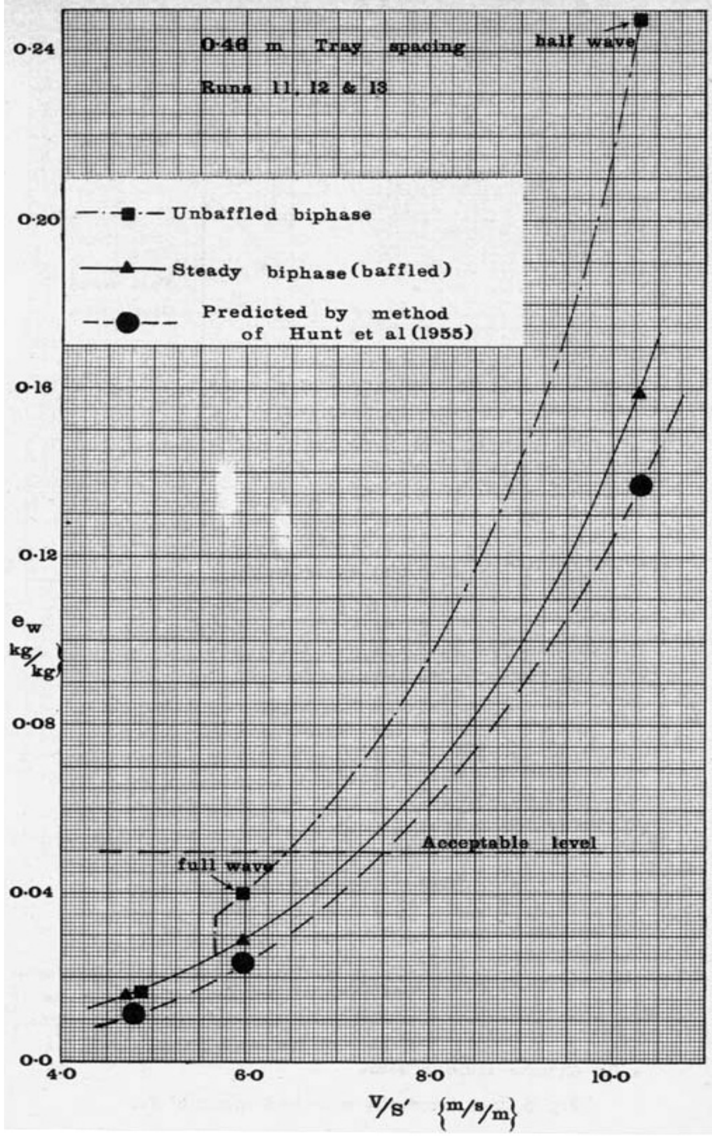

Fig. 5. Effect of oscillation on entrainment (trap spacing 0.46 m).

moved around on the tray. Entrainment was still severe. Another critical air rate was reached when the oscillations became steady and were as shown in Figure 3. This will be referred to as Half-wave oscillation since it is suggested that the wavelength has become equal to twice the column diameter. In this condition the peak can reflect off the walls and be reinforced as it moves across the plate. The frequency was observed to be of the order of 2/3 Hz. It has been previously observed by McAllister and Plank (1958) and McAllister et al. (1958) that this frequency reduces as the air rate increases beyond the critical value. At the same time the oscillations become more violent. It was observed that adjacent trays appear to oscillate out of phase with each other. Since the oscillations naturally cause maldistribution in the vapor velocity, the out-of-phase situation would tend to accentuate the effect from one tray to the next tray above.

The effect of the presence of oscillations on entrainment levels has been studied. The entrainment levels at tray spacings of 0.61 m and 0.46 m were measured during oscillating conditions for the typical series of runs, numbers 11, 12, 13. The column was subsequently operated at the same loadings but with baffles installed to prevent oscillations. The baffles are described later. The results are shown in Figures 4 and 5. The results are plotted in

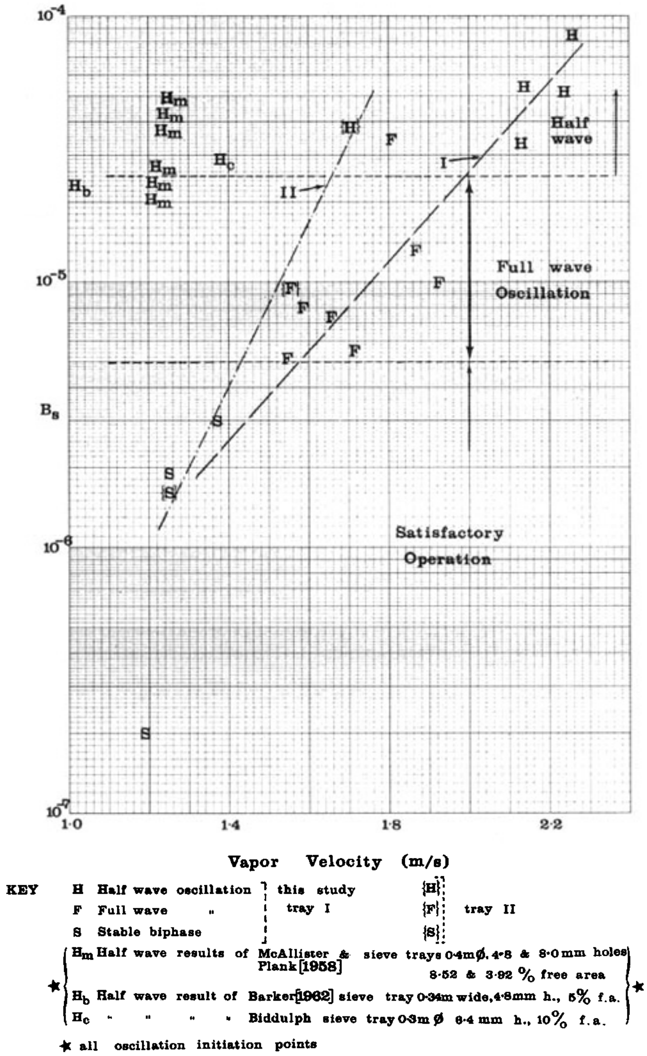

Fig. 6. Experimentally measured values of B_S.

the form of entrainment level e_w (kg liquid/kg vapor) against the ratio V/S', as used by Hunt et al. (1955).

It can be seen from Figure 4 that the measured entrainment values from a steady biphase are quite close to the values predicted using the method of Hunt et al. (1955). When the baffles are absent it can be seen that entrainment levels are increased when Full-wave oscillation is present and increased even more when the more violent Half-wave oscillation is present. The value below the oscillation initiation point indicates that the baffles had no noticeable effect on the entrainment levels from a steady biphase.

It can be seen in Figure 4 that all the runs shown would be below the normally tolerated entrainment level of $e_w = 0.05$ if the biphase were steady. However, the presence of the Half-wave oscillation has increased the entrainment to such an extent that the normal flooding limit has been exceeded. Thus a column designed using normal methods to be just below flooding may well be in the entrainment flooding region if oscillations develop.

The equivalent graph for a reduced tray spacing of 0.46 m is shown in Figure 5. The entrainment levels are much higher as would be expected. A similar trend of increases due to oscillation is shown. Thus the presence of oscillations would be undesirable since most columns would be designed to operate fairly close to the flooding limit based on a steady biphase.

The other undesirable effect of oscillation is localized weeping. In this study it was observed that localized weeping did occur to a small extent during Full-wave oscillation. The holes along the center line of the tray allowed some liquid to weep through when the wave peak occurred at the tray center. Similarly some weeping occurred near the walls when the wave peaks struck the walls.

No localized weeping was observed during Half-wave oscillation in this study. The air rates appeared to be high enough to prevent weeping.

Full-wave oscillation has not been previously reported in small columns (about 0.3 m diam.). This does not necessarily mean that it was not present for some vapor rates, but it may be that the amplitude of Full-wave oscillation in small columns is insufficient to make it very noticeable.

It has been suggested above that the group

$$B_S = \frac{V \epsilon h_f \rho_g}{g d^3 \rho_L \bar{a}}$$

may be used as a criterion for the onset of oscillations. The value of this group has been calculated for all the runs in this study and for some previous studies where sufficient data are available. The tabulated results of this study are shown in Table 1.

The values of B_S for the tabulated results are plotted in Figure 6, together with the results from earlier studies. The key to the significance of symbols is also shown. On the basis of this it is suggested that the onset of Full-wave oscillation occurs at a critical value of $B_S = 0.5 \times 10^{-5}$. Above this value unstable operation is present on the tray although this may not be so in very small columns. At a critical value of about 2.5×10^{-5}, the regime becomes rhythmic Half-wave oscillation. These are, of course, approximate values, but they should enable a designer to decide whether a column is near the danger area. Taking into account the inherent uncertainties and error possibilities in the various measurements, the consistency of B_S values in different sizes of column and different % free area trays is quite good. It is of interest to note that the cube root of the ratio of the suggested critical values of B_S is 1.71 compared with the expected value of 2.0 based on the hypothesis that Half-wave oscillations occur at double the wavelength for Full-wave oscillation.

APPLICATION TO COLUMN DESIGN

The problem facing a designer is that of how to predict the values of the variables contained in the group B_S. For a proposed design the values of V, ρ_g, ρ_L, and d should be known. As for the values of ϵ, h_f, and $\bar{a}$ the equations of Barker and Self (1962) have been used. These are given below, the constants being specific to S.I. units.

$$De = \epsilon = 0.0067V^{1.44} + 0.0922h_L - 0.0056$$

$$h_L = 0.024 + 1.74L^* + 0.372W - 0.012V$$

$$h_f = 0.0354 + 4.81L^* + 1.05W + 0.0384V$$

These equations, which were developed from measurements on the system air/water, have been used to predict the value of B_S for the series of runs carried out in this study. The results are plotted in Figure 7. It can be seen that they are close enough to those measured results for tray I in Figure 6 to allow the same criteria to be proposed. The predictions for tray II are not as satisfactory due to the equations of Barker giving low

TABLE 1. OSCILLATION RESULTS

Run no.	Liquid flow, m^3/s m of weir $\times 10^4$	Vapor velocity, m/s	Weir ht., cm	Holes size, cm	% hole area	ΔP tray total, cm H_2O	Liquid head, cm H_2O	Froth height, cm	Eddy viscosity, ϵ (m^2/s)	B_S $\times 10^5$	Remarks
1	19.8	1.8	2.54	0.635	10	8.6	0.9	18	0.0133	3.4	Pronounced full-wave oscillation
2	19.8	1.54	2.54	0.635	10	7.7	1.3	13	0.0063	0.51	Full-wave initiation
3	19.8	1.19	2.54	0.635	10	4.5	1.5	8	0.00093	0.02	Stable biphase
4	41	1.71	2.54	0.635	10	8.0	1.5	13	0.0072	0.55	Full-wave initiation
5	41	1.92	2.54	0.635	10	9.2	1.3	15	0.0075	1.0	Pronounced full-wave oscillation
6	41	2.13	2.54	0.635	10	13	1.0	21	0.013	5.4	Half-wave oscillation
7	41	1.86	7.62	0.635	10	9.4	3.0	20	0.0114	1.3	Pronounced full-wave oscillation
8	41	1.58	7.62	0.635	10	6.5	3.3	18	0.013	0.8	Full wave initiation
9	41	1.25	7.62	0.635	10	4.5	3.7	15	0.0062	0.19	Stable biphase, weeping
10	41	2.13	7.62	0.635	10	11.6	2.4	22	0.0195	3.4	Half-wave oscillation
11	55	2.23	7.62	0.635	10	14.0	1.7	24	0.0216	5.2	Half-wave oscillation
12	55	1.65	7.62	0.635	10	9.0	2.7	18	0.0093	0.74	Full-wave oscillation
13	55	1.37	7.62	0.635	10	7.3	3.4	17	0.0063	0.3	Stable biphase
14	65	2.25	7.62	0.635	10	13.0	1.3	23	0.023	8.4	Pronounced half-wave oscillation
15	65	1.71	7.62	0.635	5	34.0	3.0	30	0.0186	3.8	Pronounced half-wave oscillation
16	65	1.55	7.62	0.635	5	29	5.0	27	0.0102	0.95	Full-wave oscillation
17	65	1.25	7.62	0.635	5	18.5	4.5	20	0.0037	0.16	Stable biphase

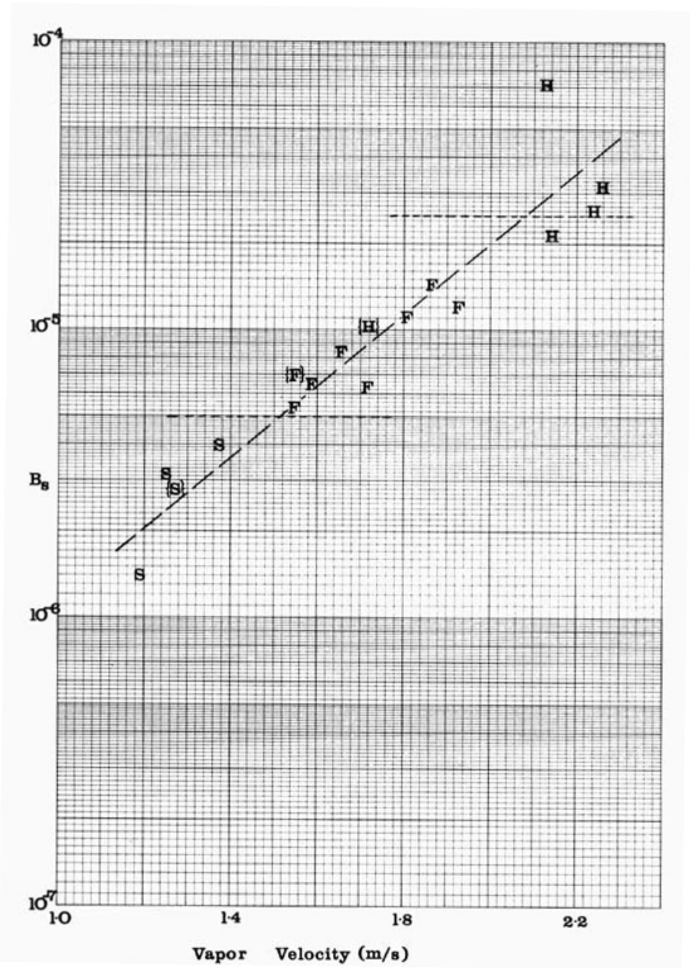

Fig. 7. Values of B_S predicted from equations of Barker and Self (1962). Key is the same as for Figure 6.

foam heights, high liquid heads, and low values of eddy diffusivity.

For systems other than air/water, the method recommended by Ludwig (1964) for liquid head (h_L) may be used. The froth height correlation of Fair (1963) and the liquid mixing correlation of the American Institute of Chemical Engineers (1958) are recommended. The suggested approach would be to calculate the vapor velocity for a given tower corresponding to the lower critical value of B_S. This will be a trial-and-error calculation. Although there is some scatter in the values of the critical group, the slope is such that it should be possible to predict the vapor rates giving rise to concern over oscillation within ± 15%.

The applicability of the suggested criterion for systems other than air/water, and for changes in other variables, is currently under investigation. It would appear that the higher vapor densities encountered in many other systems would give rise to an increased likelihood of oscillations. This would also follow due to possibly greater froth heights. The generalized predictions of De are quite close to those measured in the present study near the critical region.

Tray spacing had no noticeable effect on the onset of oscillations. A comparison of results from other studies with the present results indicate that hole size and free area variations within the range covered do not have a noticeable effect on the critical value of B_S. The present study has indicated that the same critical value of B_S should apply for variations in weir height and liquid rate within the ranges studied.

IMPLICATIONS FOR REDUCED PRESSURE COLUMNS

One of the objects of the present study was to make an assessment of the increased likelihood of oscillations occurring in columns operating at reduced pressure.

Tray columns operating under moderately reduced pressure do have higher linear vapor velocities. Take for example the proposed xylene superfractionator design by Leva (1971). This column has bubble cap trays of 1.55-m diam. with average vapor velocities in the middle trays of the column of about 3 m/s. The results of McAllister and Plank (1958) indicate that bubble cap trays show similar tendencies to oscillation as sieve trays. Taking a critical value of B_S of 0.5×10^{-5}, and if the eddy viscosity, foam height, and foam density are similar to those

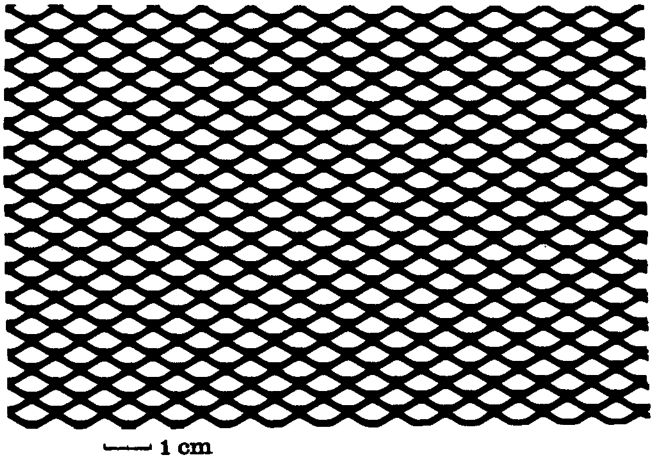

Fig. 8. Baffle material.

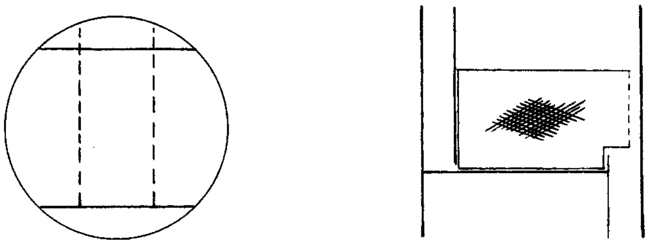

Fig. 9. Baffle system.

obtained in the present study, then a column diameter of about 0.91 m would show a tendency to oscillate. However, this would depend on the above assumptions. Thus the xylene superfractionator design of 1.55 m diameter should be stable. The upper trays in the column have an increased velocity but a correspondingly reduced vapor density. Thus their tendency to oscillate would only be increased if the values of ϵ and h_f were increased and if the value of $\bar{\alpha}$ were decreased, as is likely. Further work is in progress to determine the effect of pressure reduction on these properties. It does seem that reduced pressure columns will show a greater tendency to oscillation but that the magnitude will depend on the response of the above variables, and it is possible that commercial columns of about 1.5-m diam. operating at reduced pressures could oscillate.

REMOVAL OF INSTABILITY

It has been found that the Half-wave oscillations can be prevented by the presence of a vertical expanded metal baffle installed along the center line of the tray so that the liquid flows along both sides. The height of the baffle is approximately the foam height. Even at very high vapor rates the biphase remains stable. A solid baffle is not desirable since this merely provides another wall for reflection of waves, with the likelihood of both sides of the baffle oscillating. The high open area expanded metal shown in Figure 8 provides sufficient resistance to lateral liquid motion. While this center-line baffle removes Half-wave oscillations, as would be expected it does not remove Full-wave oscillation. In order to remove both types of oscillation, it is necessary to install two offset baffles as shown in Figure 9. With these baffles installed, the biphase remains stable up to very high vapor rates, when very violent oscillations would be present without the baffles. The baffles are similar to the center-line baffle described above, spaced at about 1/3 and 2/3 across the diameter.

Any column which seemed to be near the oscillation region should have these simple baffles installed.

CONCLUSIONS

An experimental study of oscillating operation of sieve trays has been carried out using the air/water system at atmospheric pressure, including mixing studies.

Oscillations have been observed in a larger column (0.69 m) than previously reported.

Oscillations have been shown to increase entrainment by as much as 70% compared with steady biphase at the same loadings.

A dimensionless group has been proposed which can be used as a criterion for the onset of oscillations.

The values of this group have been calculated under various conditions, and critical values of 0.5×10^{-5} and 2.5×10^{-5} are proposed. Below 0.5×10^{-5}, operation is satisfactory. Between 0.5×10^{-5} and 2.5×10^{-5}, Full-wave oscillation is present, and above this range Half-wave oscillations will occur.

It has been found that for the conditions studied, the use of the equations of Barker and Self (1962) for De, h_L, h_f is permissable and allows an estimation to be made of the likelihood of biphase oscillation occurring, within ± 15% on vapor velocity.

Work is continuing with the object of further checking the general applicability of the proposed criterion, in particular at reduced pressures.

The indications are that at atmospheric pressure and above, columns with a diameter of 1.0 m and above are unlikely to oscillate at normal vapor throughputs. However, reduced pressure columns of up to 1.5 m in diameter may develop instability.

Oscillations can be removed by the installation of simple open-mesh baffles.

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NOTATION

B_S = dimensionless group based on superficial vapor velocity, —
De = eddy diffusivity, m²/s
d = column diameter, m
e_w = entrainment (kg LIQUID/kg VAPOR), kg/kg
h_f = froth height, m
h_L = clear liquid head, m
L^* = liquid rate, (m³/s(m of weir))
L = wavelength, m
S' = distance from top of froth to tray above, m
V = superficial vapor velocity, m/s
$\bar{\alpha}$ = (h_L/h_f) = froth density, —
ϵ = eddy kinematic viscosity, m²/s
ρ_g = gas density, kg/m³
ρ_L = liquid density, kg/m³

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Analysis of the Normal Stress Extruder

A theoretical and experimental investigation of the pumping characteristics of the normal stress extruder was made. The theoretical model requires only material property data and extruder dimensions and rotation speed to evaluate the main velocity field, flow rate, and pressure. The flow from the extruder was measured for two viscoelastic polymer solutions and a polymer melt as a function of gap setting and angular velocity. These measurements were in reasonable agreement with the proposed model.

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SCOPE

Two important operations in the polymer processing industry are the melting of polymer feed stocks and the mixing of additives, such as plasticizers or coloring agents, with the polymer to give desired properties to the finished products. These operations are usually performed in a screw extruder, which can simultaneously develop the large pressures necessary for later processing steps.

An alternate process to perform these operations is the elastic or normal stress extruder. This device utilizes the normal stresses developed between a rotating and stationary disk to pump polymer melts out the center of one disk. Desirable mixing characteristics of the normal stress extruder have generally been neglected because it does not develop large operating pressures. Blends of incompatible polymers from the normal stress extruder are characterized by a filament structure (Starita, 1972) which contrasts sharply with the granular structure resulting with some other types of mixers (Paul, 1972). This highly oriented mixing enhances the mechanical properties of the product and could possibly help stabilize such drawing operations as filament formation.

Development of the normal stress extruder may have been hampered by lack of an adequate model of its operation. This paper is concerned with obtaining an explicit model for the operation of the normal stress extruder. Experimental measurements of the flow rate from the normal stress extruder are made for several viscoelastic materials to verify the proposed model.

CONCLUSIONS AND SIGNIFICANCE

A model of the normal stress extruder which allows the flow rate and pressure generated in isothermal operation of the extruder to be calculated is developed here. The model is largely analytical with some numerical iteration required to evaluate several integrals. The only inputs required for the model are basic rheological data, shear and normal stresses, and extruder dimensions and rotation speed.

Experiments were performed to measure the extrusion rate of a polyisobutylene solution and a polyacrylamide solution. These are viscoelastic fluids which can be pumped isothermally from the normal stress extruder used in the experiments. Comparison of the experimental extrusion rates and the predicted rates indicate the proposed model is adequate for engineering purposes. The model was also used to analyze the polyethylene melt data of Fritz (1971). Comparison of the experimental and predicted flow rates was not as good as the solution data. Due to shear heating the melt was not extruded isothermally. Work is in progress to extend the proposed

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