

HYDRODYNAMIC AND TRAY EFFICIENCY BEHAVIOR IN PARASTILLATION COLUMN

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Abstract - This work presents aspects of the parastillation process, which employs a unique distillation column where the vapor stream is divided into two equal parts and the falling liquid is alternately in contact with both vapor parts on a stage-by-stage basis. A laboratory-scale apparatus was used to study the parastillation column. Experiments were carried out under total and partial reflux conditions using an ethanol-water system. Experiments were conducted to analyze the effects of vapor flow rate and initial ethanol concentration in the reboiler on the hydrodynamic conditions. Limiting operating conditions were defined. Murphree separation efficiencies were calculated and discussed.

Keywords: Parastillation; Hydrodynamics; Murphree efficiency.

INTRODUCTION

Distillation is a most common separation technique and consumes enormous amounts of energy, contributing to more than 50% of plant operating costs. The best way to reduce operating costs is to improve efficiency. To achieve this, a thorough understanding of distillation principles is essential. The improvement of tower internal pieces greatly enhanced tower capacity and efficiency.

Several techniques to decrease the consumption of distillation energy have been proposed in the literature. One of these methods, referred to as parastillation, is based on the division of the vapor phase into two equal parts at the bottom of the column by an axial partition running the full height of the column. The whole stream of falling liquid is in contact alternately with both parts of the vapor on a stage-by-stage basis. Under these conditions, the

liquid always flows on the same direction in each vapor side of the column. This description of liquid-vapor flow occurring in the parastillation column perfectly fits Lewis's Case 2 flow configuration (Lewis, 1936), which is alleged to provide better separation than the conventional one.

Canfield (1984) analyzed the parastillation process under total reflux conditions, using nonrigorous computational simulation, and his results were supported by experimental tests conducted in a six-tray distillation column. Under these conditions, Canfield concluded that the parastillation process is more advantageous than conventional distillation due to the higher Murphree efficiencies. Mészáros and Fonyó (1990) developed a computational program based on the Wang-Henke method to simulate parastillation columns and analyzed the behavior of some ideal systems operating under partial reflux conditions. They verified that under partial reflux conditions higher

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Murphree efficiency values for the parastillation process were not always observed. According to them, to obtain the same separation, the number of stages in a parastillation column should be 40% larger than that in a conventional column. Despite this larger number of trays, a shorter column is obtained due to the arrangement of the trays in the parastillation column (Figure 1). They concluded that the parastillation process saves a considerable amount of energy. Gouvêa (1999) developed a computer program to simulate column operation. This simulation used the rigorous MESH equations applied to a multicomponent parastillation column. The nonlinear algebraic equations system was solved using the Nalptali-Sadholm method. He analyzed the behavior of ideal and nonideal distilling systems. According to him, although the number of stages in a parastillation column could be 55 % larger than in a conventional column, the results showed that due to its shape, for the same spacing between the trays, the parastillation column was 20 to 30 % shorter. Consequently, lower pressure drops are expected in this column. Another important observation was the decrease in column diameter in a parastillation process. The tray area obtained was about 33 to 44 % smaller. For the parastillation column, Gouvêa

(1999) noted a cost reduction of between 7 and 12 %. Finally, Murphree tray efficiencies for distillation and the parastillation process were calculated and discussed. Average values were either higher than or equal to the ones obtained for the conventional process.

Another aspect that should be pointed out here is the fact that trays in distillation columns only work well over a limited range of vapor and liquid loadings. Both the design engineer and the column operator need to know the upper (flooding) and lower (weeping) limits. According to Kister (2003) all the case studies listed involve premature floods resulting from liquid levels rising above the reboiler return inlet due to a faulty indication of level. The lower limit has been studied by several researchers (Billingham et al., 1995; Wijn, 1998).

In the present work, a laboratory-scale apparatus was used to study parastillation column hydrodynamics. Depending on the tray ethanol concentration, different regimes occurred on the tray once the liquid and vapor flow rates were established. Murphree efficiency values, considering the flooding and weeping effects, were calculated and discussed for a wide range of operating conditions.

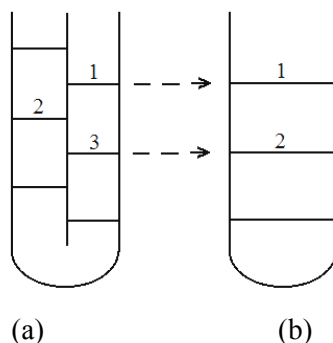


Figure 1: Comparative design of tray spacing in the column
(a) Parastillation (b) Conventional.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

A laboratory-scale parastillation column with perforated trays and circular downcomers was constructed to collect experimental data. The unit comprised the column with twelve sieve trays, a condenser, a reboiler with electric heating and a control panel (Figure 2).

The trays were made of 0.21 cm brass sheets. The cylindrical sections between trays were made of

Pyrex glass tubes, measuring 10.0 cm i.d. and 15.0 cm high, secured by support beams fastened between consecutive trays to provide a tray spacing of 30 cm. The upper section, to which a lateral pipe was welded to allow the return of the corresponding condensed liquid to the column, was made of brass.

Twenty-two circular holes with sharp edges were drilled on each semicircular tray in a triangular arrangement. The holes were 2.0 mm in diameter on all trays. Thus, 1.90 % of each tray was a free draining area. The circular downcomers, which

allowed the passage of liquid from one side to the other side of the column, had an inner diameter of 0.96 cm. The column was insulated. The liquid mixture used in the process was fed into the reboiler. Water, the cooling fluid, condensed all vapor leaving the column.

A typical stage layout is illustrated in Figure (3), which shows how the liquid flows helicoidally from one side of the column to the other side.

The experiments were carried out under total and partial reflux conditions. Column pressure was the local atmospheric pressure of 94.23 kPa. The experiments were carried out using an ethanol-water system.

Several visual observations and measurements were made under steady-state conditions: dispersion type, dispersion height, condensed vapor flow and composition. Liquid samples were collected at the downcomer exit in all of the trays.

Experiments were conducted to study the effect

of vapor velocity, ethanol composition and reflux ratio on the hydrodynamic conditions. The initial ethanol concentration in the reboiler was varied (2, 3 and 4 ethanol mol%). The limits of the operating conditions were determined for each case. The upper and lower limits corresponded respectively to the conditions when dispersion height reached 15 cm and when weeping was observed (Belincanta, 2004).

A computer program in Fortran language was developed to solve the mass and energy balance equations. Calculation provided the vapor and liquid flow rates, the vapor composition of each tray and the Murphree efficiency. The physical properties of the pure components were obtained based on experimental data presented by Vargaftik (1975). The data of vapor-liquid equilibrium at local atmospheric pressure, were predicted using the Wilson method, whose binary parameters were obtained from Gmehling et al. (1982).

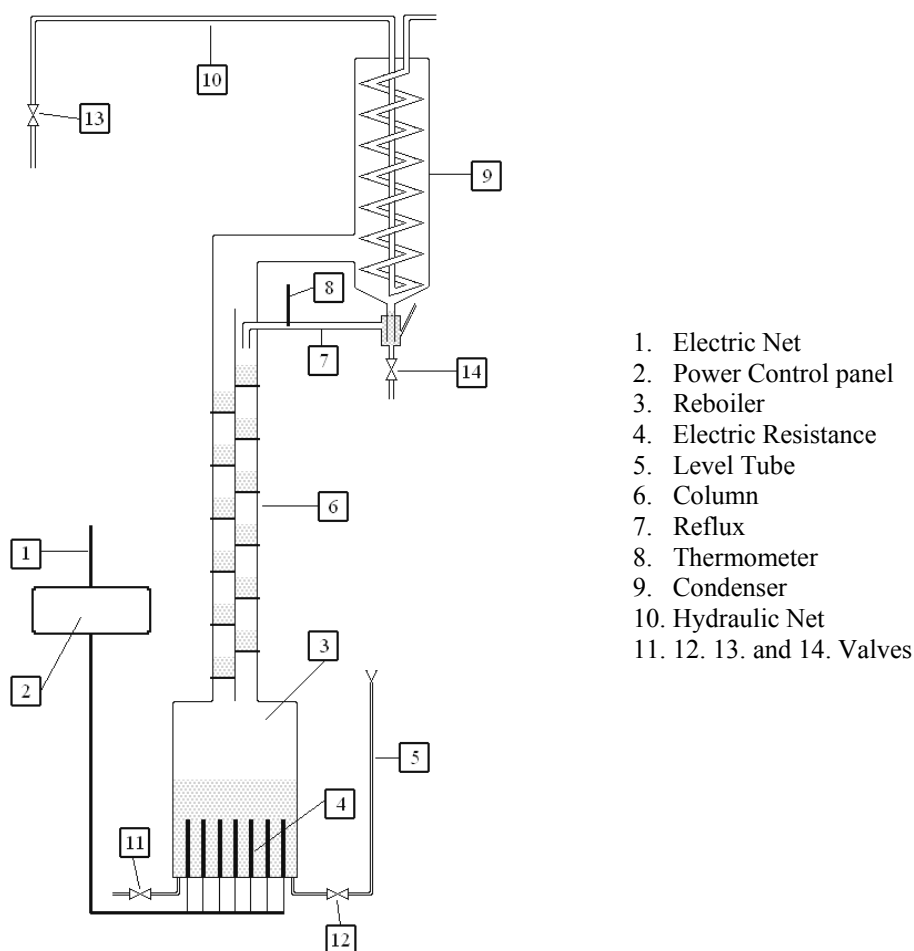


Figure 2: Schematic diagram of the experimental equipment.

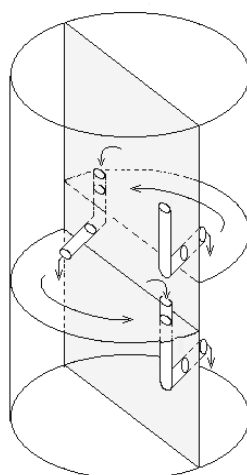


Figure 3: Parastillation column with a circular downcomer

RESULTS AND DISCUSSION

Hydrodynamics

Understanding the hydrodynamics controlling the clear liquid height on trays is central to the design and operation of distillation columns. It has an effect on pressure drop, tray efficiency, upper and lower operating limits and flow regimes on the trays.

The flow regime is defined according to the vapor-liquid dispersion on each tray. Dispersion height depends on the vapor and the liquid flow rates, the tray shape and the chemical and physical properties of the phases. The form in which the dispersion arises affects the mass transfer. Therefore, an analysis of flow regimes is important. According to Lockett (1986), different correlations are required in each regime for such things as dispersion density and entrainment predictions.

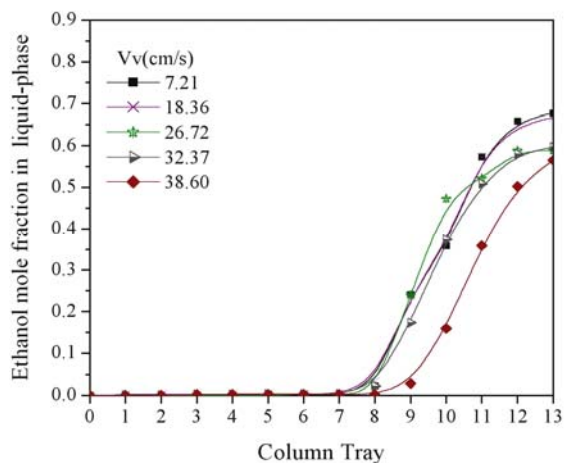
Trays in distillation columns only work well over a limited range of vapor and liquid loadings; outside of these limits, efficiency is reduced to unacceptable values. Both the design engineer and the column operator need to know the lower and upper operating limits.

The lower operating limit, referred to as the weeping point, is defined as the vapor flow rate when liquid descending through the tray perforations becomes noticeable. Under weeping conditions, one part of the liquid passes through the holes, short-circuiting the main contact zone and causing a

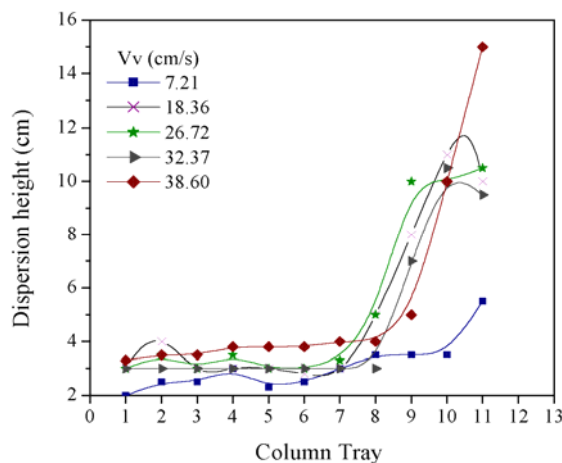
reduction in tray efficiency. Above the upper limit, flooding occurs. Flooding is the accumulation of liquid inside the column. This accumulation is generally caused by high vapor flow rates. A loss of separation is then inevitable.

In this context, under total reflux conditions, for each initial ethanol concentration in the reboiler, the effect of vapor velocity was analyzed for a wide range of values, from the minimum limit of operation (weeping) to the maximum limit of operation (flooding). Typical experimental results obtained for the parastillation column are shown in Figures (4) to (6). In these figures, stage 0 corresponds to the reboiler and stage 13 to the condenser.

The results in Figures (4), (5) and (6) indicate that increases in vapor velocity increased the dispersion heights on the upper trays, causing higher ethanol concentrations on these trays. Consequently, the bottom trays had low ethanol concentrations, as shown in Figure (6a). In this figure, the high vapor flow of 37.32 cm/s resulted in a high ethanol mole fraction for trays up to 10th tray, while for a lower vapor flow of 6.64 cm/s, a significant ethanol mole fraction was seen for trays up to third tray. Therefore, a decrease in vapor flow allowed a wider distribution of ethanol in the column. As a result, a higher ethanol concentration in the condenser was observed with a lower vapor flow. Dispersion height also increased with vapor flow, as shown in Figures (4b) to (6b).

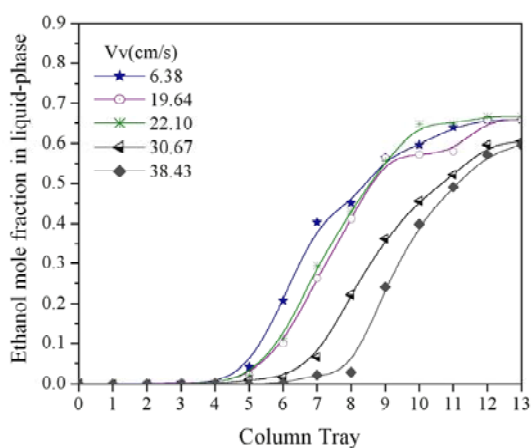


(a) Profile for liquid-phase ethanol mole fraction

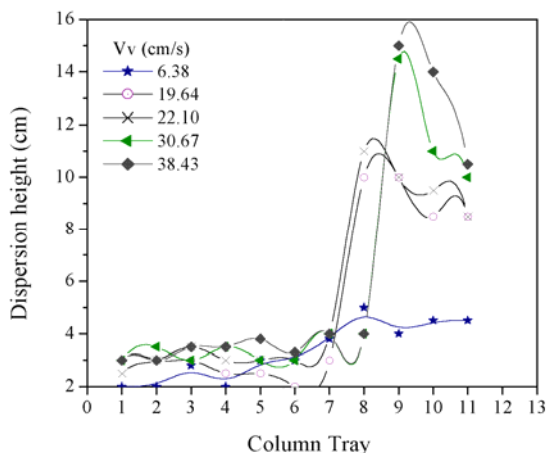


(b) Profile for dispersion height

Figure 4: Profiles for concentration and dispersion height - Xref = 2 %.

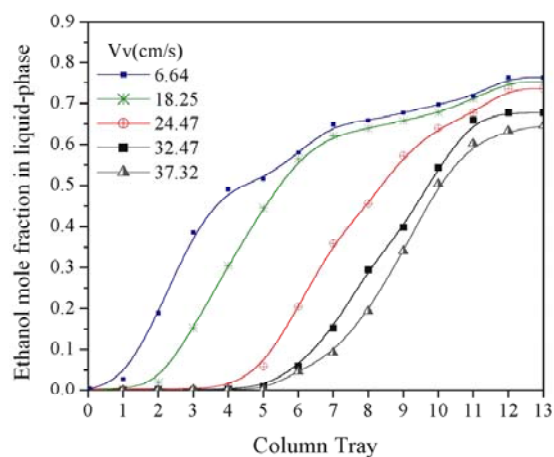


(a) Profile for liquid-phase ethanol mole fraction

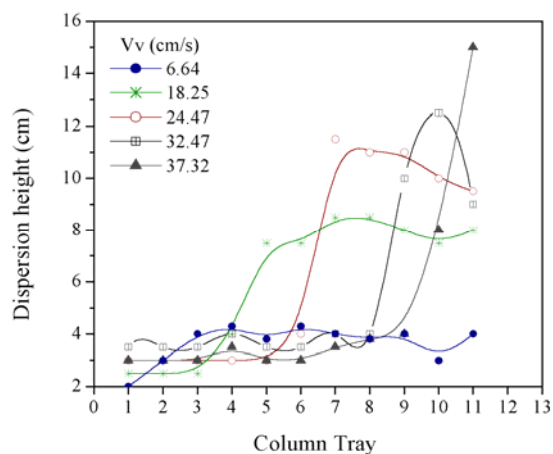


(b) Profile for dispersion height

Figure 5: Profiles for concentration and dispersion height – Xref = 3 %.



(a) Profile for liquid-phase ethanol mole fraction



(b) Profile for dispersion height

Figure 6: Profiles for concentration and dispersion height – Xref = 4 %.

The initial ethanol concentration in the reboiler was changed to analyze the effect of tray concentration on column behavior. It was observed that the increase in this initial concentration allowed a wider ethanol distribution in the column as a function of vapor velocity. Comparing Figure (4) to Figure (6), no significant changes in ethanol distribution were observed for the initial concentration of 2 %, while for the initial concentration of 4 % the ethanol distribution was quite clear.

The results in Figures (4a) to (6a) clearly show that the ethanol concentration in the condenser was higher for lower vapor velocities. This behavior is not usual. In the conventional distillation column, the composition of the liquid in the condenser increases as vapor flow increases, attaining its maximum concentration. After reaching this maximum point, the concentration decreases as vapor flow increases. The reason for this decrease in concentration with the increase in vapor flow is the large entrainment that occurs under this condition. The lower concentration at low vapor velocities is explained by the occurrence of weeping. In this work, weeping was avoided.

Analyzing Figures (4b) to (6b) for dispersion height, we can observe that height did not increase with vapor flow as in a conventional distillation. This also depends on tray concentration.

On the whole, dispersion height is affected by flow regime and ethanol concentration. Figure (7a) shows that the dispersion height reached a maximum at an ethanol mole fraction of 0.4 to 0.6, where the stabilization index reached a maximum (Lockett, 1986).

The classic hydraulic model oversimplifies tray action. There are five main flow regimes on distillation trays. These regimes may all occur on the same tray at different liquid and vapor flow rates. Lockett (1986) classified five design types: bubble, foam, froth, spray and emulsion regimes. Depending on the tray ethanol concentration and the liquid and vapor flow rates, different regime types may occur on the tray. In this study, two different types of foam (metastable cellular foam and unstable homogeneous foam) and froth regimes were observed.

Figure (7b) shows the regimes types for different liquid and vapor velocities observed in the parastillation column studied. The cellular foam

regime was observed for trays with an ethanol mole fraction in the liquid phase higher than 0.3. At low flow rates, the cellular foam regime was well established on trays operating under this regime. For higher vapor velocities, the cellular foam regime was rarely observed; in this case, homogeneous foam regime was predominant. The division of the vapor stream resulted from the occurrence of the cellular foam regime and the homogeneous regime in contrast with conventional columns.

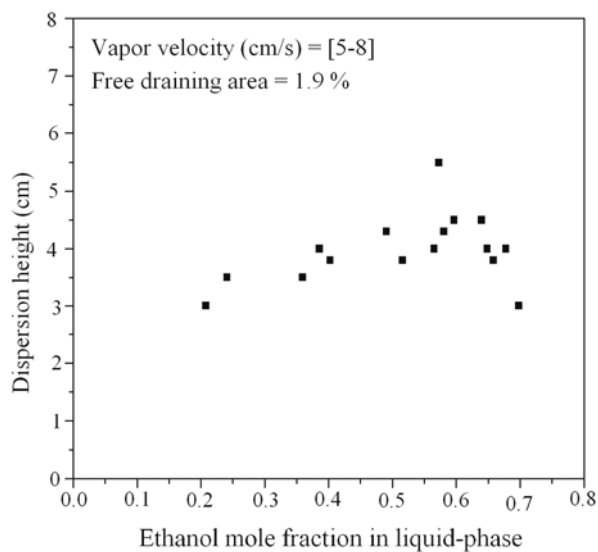
On trays with an ethanol mole fraction lower than 0.3, most of the dispersion formed was the froth regime. The percentage of each dispersion type found in the parastillation column was: 43 % froth, 21 % homogeneous and 36 % cellular foam, as shown in Figure (7b).

In a conventional distillation column operating at atmospheric pressure, the most common dispersion type is froth. As a consequence, all dispersion data (height, holdup, pressure drop and mass transfer properties) available in the literature refer to the froth-type dispersion. In the parastillation column, it was verified that only half of the data were the froth type. This can be explained by the vapor division at the base that resulted in a lower turbulence, favoring foam formation. This is the main oversimplification of the computer simulation studies. Cellular foam does not provide the same separation as froth. The increase in hole diameter probably resulted in the increase in froth formation.

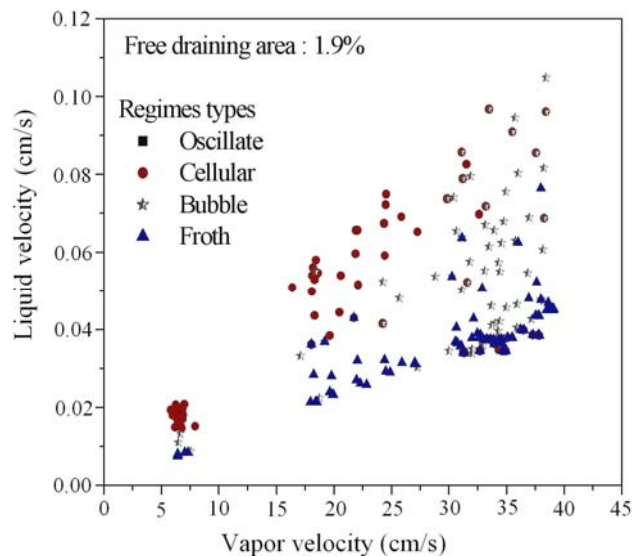
Figure (7) also shows the stable limit of the operations. The range of vapor velocity is 5 to 38 cm/s.

To analyze the partial reflux conditions, the effect of partial reflux on the hydrodynamic conditions was studied. Considering that the vapor stream is divided into two equal parts in the parastillation column and that all of falling liquid is in contact with both parts of the vapor, the ratio of liquid to vapor molar flux is approximately equal to 2 ($L/V \approx 2$).

In this context, for each initial ethanol concentration in the reboiler, the effect of the reflux ratio was analyzed for some values. Due to the low sensitivity of the value that controls distillate flow, it is not very simple to obtain the exact reflux ratio value. The results are divided into on three ranges: 5 to 7, 10 to 12 and 15 to 17. All the tests were performed within the maximum limit of operation obtained under total reflux, i.e., approximately 38 cm/s.



(a) Effect of composition on dispersion height



(b) Limiting stable operating conditions

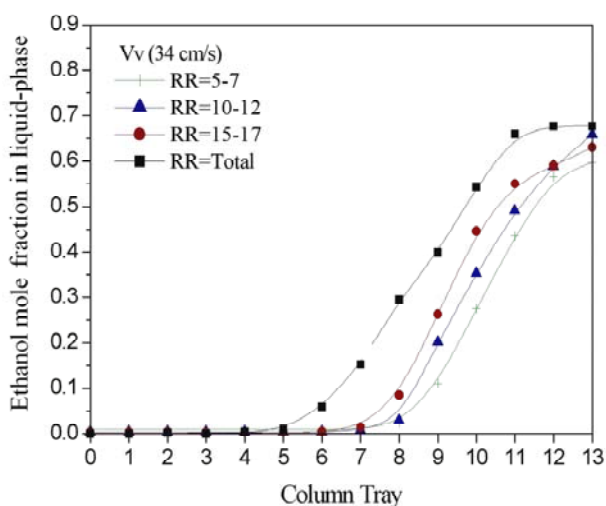
Figure 7: Hydrodynamic behavior of parastillation tray.

Typical experimental results for the parastillation column are shown in Figures (8) and (9). The results show the three ranges of reflux rate mentioned in the previous paragraph and the total reflux conditions for three different initial ethanol concentrations in the reboiler (2%, 3% and 4%).

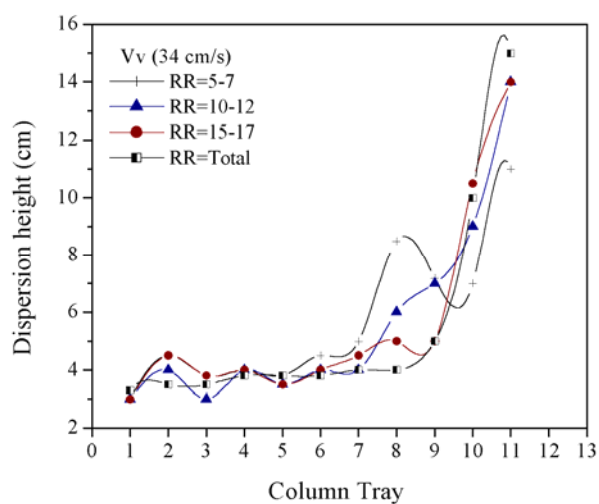
All the things shown previously for the total reflux conditions (about the dispersion height and initial ethanol concentration in the reboiler) were also verified for the partial reflux conditions. In all cases studied, it was observed that an increase in reflux rate produced results that were more similar to

the results obtained under total reflux. This was expected because an increase in the reflux ratio produces the reduction in number of trays necessary to provide a specified separation. Thus, a reduction in the reflux ratio produced a reduction in product ethanol concentration.

As the reflux flow rates adopted were relatively high, only the homogeneous foam regime was observed for trays with an ethanol mole fraction in the liquid phase higher than 0.10. For a lower ethanol mole fraction in the liquid phase, the froth regime was verified.

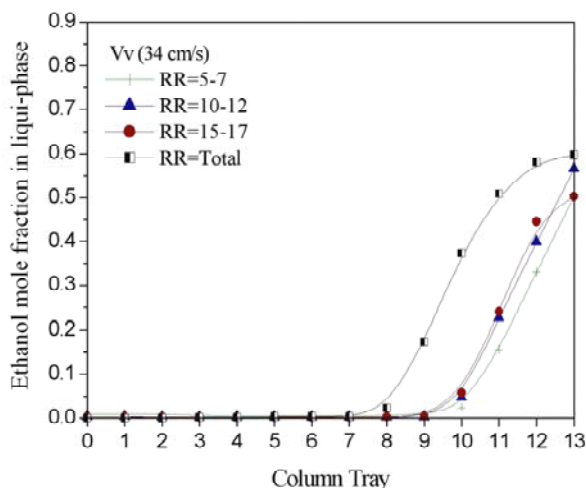


(a) Profile for liquid-phase ethanol mole fraction

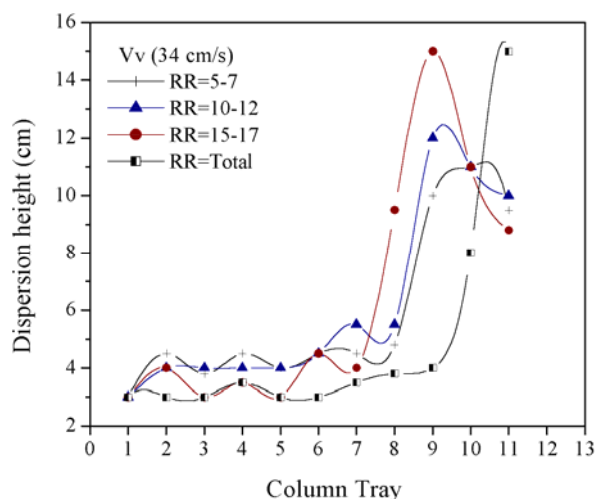


(b) Profile for dispersion height

Figure 8: Profiles for operations under total and partial reflux conditions - $X_{ref} = 2\%$.



(a) Profile for liquid-phase ethanol mole fraction



(b) Profile for dispersion height

Figure 9: Profiles for operations under total and partial reflux conditions - $X_{ref} = 4\%$.

Murphree Tray Efficiency

Capacity and efficiency are the most relevant column performance parameters. The most important condition for satisfactory tray performance is obtaining close contact between the liquid and the vapor phases. Tray design requires a combination of theory and experience. Any defective column operation will cause a reduction in tray efficiency.

Tray efficiency depends on the mass transfer between the liquid and the vapor; increases in efficiency are obtained, in general, for long contact times. Thus, the higher the dispersion height formed on the tray, the longer the contact time.

The definition of plate efficiency given by Murphree is widely used in practice. Murphree tray efficiency (E_{MV}) is defined by comparing a real tray with an ideal tray approaching equilibrium. In this case, for each component:

$$E_{MV(i)} = \frac{y_{o(i)} - y_{o(i-2)}}{y_{eq(i)} - y_{o(i-2)}} \quad (1)$$

As the liquid is never perfectly mixed in the horizontal direction on the tray (with a downcomer), a concentration gradient is established in the liquid as it moves across the tray. This, in turn, causes a concentration gradient in the vapor leaving the tray. However, Eq. (1) assumes that the output and input vapor streams are perfectly mixed. Under favorable circumstances, E_{MV} can exceed 100 %.

Lewis (1936) was the first to determine quantitative values for E_{MV} . He defined and analyzed three instances where liquid is assumed to be in plug flow across the tray. In Case 1, vapor is assumed to be completely mixed from one tray to the next; in Case 2, which represents the parastillation column, no vapor mixing occurs and liquid flows in the same direction on successive trays (parallel flow); Case 3 corresponds to the most widely applicable case where the vapor is unmixed from one tray to the next and the liquid flows in opposite directions on successive trays.

Some authors studied Lewis's Case 2: Smith and Delnicki (1975), Canfield (1984), Lockett et al. (1984), Heucke (1987), Mészáros and Fonyó (1990), Billingham et al. (1995), Gouvêa (1999). On the whole, they concluded that Lewis's Case 2 results in an enhancement of maximum efficiency. However none of them present experimental results that can be applied to the design of this tray type.

Thus, in the present work, Murphree tray efficiency for the parastillation process was calculated and discussed for a wide range of operating conditions. Therefore, a program based on Fortran language was developed for the simultaneous resolution of the mass and energy balance equations, allowing prediction of Murphree tray efficiency.

It should be observed that efficiency depends on many factors, such as vapor velocity, liquid concentration and tray shape. The effect of mixture composition on Murphree plate efficiency has been the subject of many studies. Experimental results

show that efficiency changes with liquid concentration, especially for highly nonideal systems. The variation in plate efficiency with composition is small in the middle of the concentration range and is considerable at the ends (Mostafa, 1979).

Many reasons have been suggested for the variation in distillation plate efficiency with composition. Explanations have been offered in terms of variation with composition of the sign and magnitude of the surface gradient, of the interfacial area, of the mass transfer coefficient, of the physical properties, of the slope of the equilibrium curve and of the thermal effects, but none of them alone is sufficient to explain the effect of concentration on efficiency.

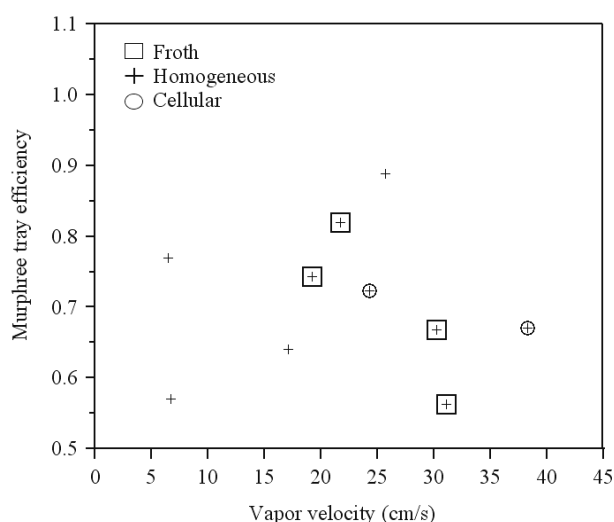
In the case of the ethanol-water system, due to the large variation in relative volatility (very high at diluted and very low at concentrated concentrations) efficiency was determined in the range of 20-40 ethanol mol%. Above and below this range, a minimal variation in composition significantly affected the efficiency value. Therefore, efficiency was analyzed on trays where the ethanol mole fraction was in either the 0.20-0.30 or the 0.30-0.40 range. Typical experimental results on efficiency and corresponding dispersion height obtained for the parastillation column under total reflux conditions

are shown in Figures (10) and (11) respectively for 0.20-0.30 and 0.30-0.40 ethanol liquid concentrations. In the figures, many dispersions occurring in the transition region had characteristics of two dispersion types. These dispersions are shown in the figures by the two overlapping symbols that represent them.

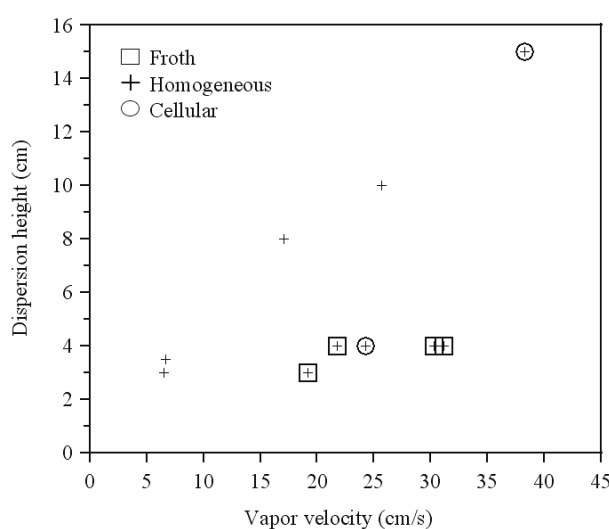
Usually, the efficiency data lie in a cloud of points when plotted. This is caused mainly by the great difficulty in obtaining experimental efficiency data. Figures (10a) and (11a) also show this cloud. It is important to observe that in our experimental set, a mistake in determination of concentration for a given tray, also affected the efficiency value for the adjacent trays. The concentration range restriction was especially chosen to minimize this problem.

Many studies in the literature indicate that for a given concentration, efficiency increases with vapor velocity until it reaches a maximum value (due to the increase in dispersion height), and then begins to decrease (due to the excessive entrainment or low contact time), i.e., like a parabolic curve. In this work, the criteria applied to define the maximum limit (maximum dispersion height), the cause of excessive entrainment, can be excluded.

The described behavior can not be clearly verified in Figures (10a) and mainly (11a). It was caused by the changes in dispersion type, as shown in these figures.



(a) Efficiency



(b) Dispersion height

Figure 10: Effect of vapor velocity on dispersion height and tray efficiency - $X = 0.20-0.30$.

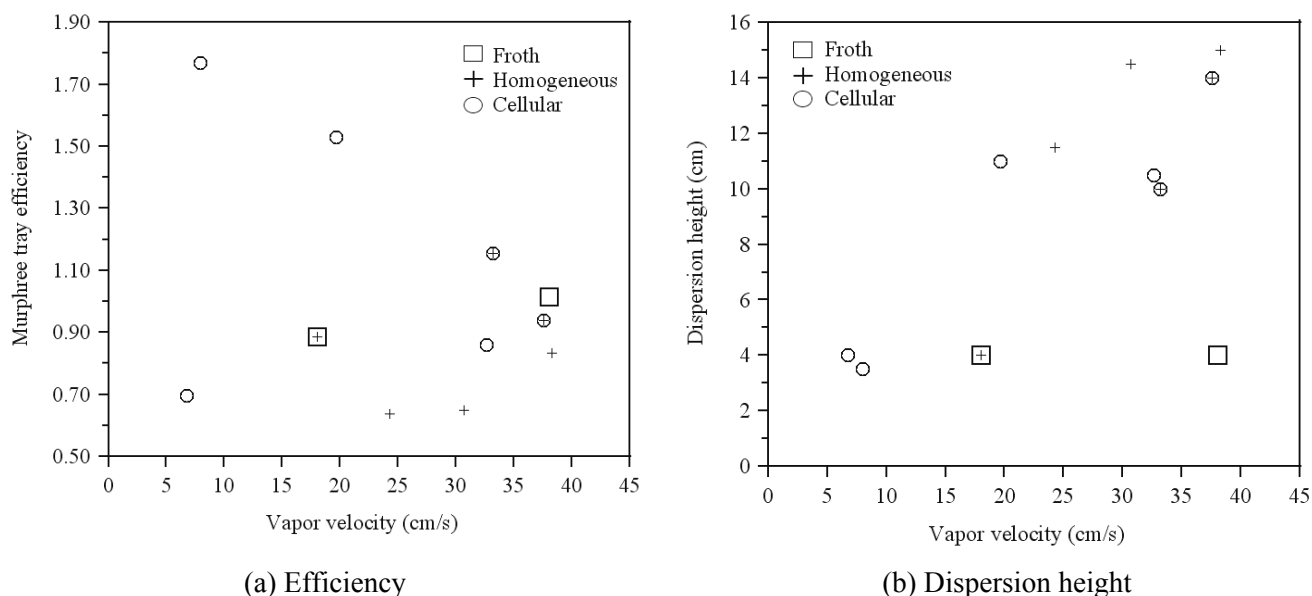


Figure 11: Effect of vapor velocity on dispersion height and tray efficiency – $X = 0.30-0.40$.

In both figures, at a lower velocity of nearly 6 cm/s, efficiency data for homogeneous or cellular foam are presented. Even the similar hydrodynamic characteristics (concentration and liquid and vapor velocities) resulted in a large difference in efficiency (0.55 to 0.75 in Figure (10a) and 0.70 to 1.8 in Figure (11a)). These results were obtained because they correspond to the weeping point operating condition. A small change in vapor velocity sometimes resulted in tray weeping and other times did not, and even under steady-state conditions, weeping was intermittent and the location where it occurred was not the same. In addition, the high gas holdup of the foam caused some difficulties for sampling only the liquid phase, mainly for the cellular foam.

At higher velocities, these differences also occurred, but they resulted from the changes in dispersion type and height. The lower dispersion heights were froth (or in a mixture with foam) and higher heights are always of the foam type, but increases in dispersion height did not mean higher efficiency, as shown in the figures.

In Figures (10a) and (10b), all dispersions occurred in the transition region of the homogeneous foam. For froth-homogeneous foam transition dispersions, increases in vapor velocity did not result in an increase in dispersion height. As a result, efficiency decreases due to a reduction in residence time. For homogeneous and cellular dispersions, it is clear that dispersion height increased with vapor velocity. However, due to the lack of efficiency data

for this dispersion type, the same behavior for efficiency cannot be taken for granted.

As shown in Figure (11a), the efficiency data obtained for the 0.30-0.40 ethanol concentration are more scattered than those shown in Figure (10a). This increased scattering may have been caused by the emergence of cellular dispersion resulting from the increase in the ethanol concentration, as previously discussed.

Comparing Figures (10b) and (11b), it can be observed that the effect of vapor velocity on dispersion height occurred in a similar form, i.e., foams were greatly affected by vapor velocity but froth was not. However, in Figure (11b), cellular foam is for lower velocities and homogeneous-foam and froth-type dispersions are observed for higher velocities, so most of them are cellular and the number of froth dispersions was reduced.

As for the mass transfer results, the efficiency values shown in Figure (11a) are higher than those illustrated in Figure (10a), especially those values resulting from the cellular foam, but the efficiency obtained for this foam strongly decreased with vapor velocity, while the efficiency for homogeneous foam and for froth dispersions shows an upward trend. These results may be explained by the changes in residence time and contact area.

In the cellular foam case, not even the increase in dispersion height associated with the increase in vapor velocity was enough to increase efficiency: residence time decreased as vapor velocity increased. In addition, the interfacial area also exerted an effect.

As vapor velocity increased, the cellular foam approached the region of homogeneous foam formation, producing changes in the contact area. Therefore, in spite of the high residence time of homogeneous foam, the efficiencies were the lowest ones. The pure froth, with a lower residence time, had a slightly higher efficiency than the froth-homogeneous foam dispersion.

For partial reflux conditions, the efficiency results are shown in terms of average values due to the small amount of experimental data. All the results for partial reflux conditions were obtained at the same superficial vapor velocity for about of 34 cm/s. Under this condition, there are only two or three efficiency values for each condition. Thus, the

arithmetic mean of these data is presented in Table (1), which shows the average Murphree tray efficiency for different ranges of the liquid-phase ethanol mole fraction under various partial and total reflux conditions. It must be observed that the absolute difference between these efficiency data did not exceed 0.1, supporting relative confidence in the results displayed in this table.

On the whole, the results presented in Table (1) show that a higher efficiency was observed for a higher reflux flow.

It was also observed that the dispersion height did not change significantly with the reflux ratio, resulting in a small decrease in the reflux ratio of around 5-7.

Table 1: Average Murphree tray efficiency under partial and total reflux conditions.

Reflux ratio	Average Murphree tray efficiency	
	Range of the liquid-phase ethanol mole fraction	
	0.20 - 0.30	0.30 - 0.40
5 - 7	0.64	0.68
10 - 12	0.65	0.93
15 - 17	0.78	---
Total	0.63	0.95

CONCLUSIONS

The hydrodynamic and mass transfer behavior of parastillation column with perforated trays and circular downcomers was determined experimentally using an ethanol-water system. The stable region of operation and dispersion regime under total reflux conditions was determined. The results show that, in the parastillation column, the foam (cellular and homogeneous) regime occurred more often than would be expected for a conventional column. It was possible to note that an increase in vapor velocity resulted in higher dispersion heights on the upper trays, causing higher ethanol concentrations on these trays. Moreover, the dispersion height reached a maximum at an ethanol mole fraction of 0.4 to 0.6. The effects of vapor velocity and ethanol concentration on Murphree efficiency were also analyzed. It was verified that the Murphree tray efficiency appears to be strongly dependent on system properties as well as on composition of the liquid on the tray. Under partial reflux conditions, it was observed that the efficiency values for the parastillation column tended to be higher for higher reflux flows.

ACKNOWLEDGEMENTS

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NOMENCLATURE

$E_{MV(i)}$	Murphree tray efficiency on tray (i)
L	Liquid molar flow
RR	Reflux ratio
V_V	Vapor velocity, cm s^{-1}
V	Vapor molar flow
X	Ethanol mole fraction for the tray
X_{ref}	Ethanol mole fraction for the reboiler
$y_{o(i)}$	Vapor-phase ethanol mole fraction leaving tray (i)
$y_{o(i-2)}$	Vapor-phase ethanol mole fraction entering tray (i) [or leaving tray (i-2)]
$y_{eq(i)}$	Vapor-phase ethanol mole fraction in equilibrium with liquid phase leaving tray (i)

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