

## MURPHREE AND VAPORIZATION EFFICIENCIES IN MULTICOMPONENT DISTILLATION

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**Abstract**—A quantitative comparison between Murphree and vaporization efficiencies is presented based on ternary distillation data for the systems acetone/methanol/ethanol, acetone/benzene/chlorobenzene, benzene/toluene/*m*-xylene and *n*-hexane/methylcyclopentane/benzene. The influence of experimental errors on calculated values of Murphree efficiencies is also analysed.

It is shown that the vaporization efficiency model fails to describe the behaviour of distillation plates and it is suggested that Murphree's model gives a more useful representation of the behaviour of distillation columns.

### INTRODUCTION

In the design of distillation columns the knowledge of accurate values of plate efficiencies is very important as they have a direct effect on the number of plates required and an indirect effect on the running costs of the equipment.

Murphree's model[17] was the first of several models leading to different efficiency definitions.

Vapour phase Murphree efficiency for component *i* and plate *n* can be defined as

$$E_{MVn,i} = \frac{y_{n,i} - y_{n+1,i}}{y_{n,i}^* - y_{n+1,i}} \quad (1)$$

where  $y_{n,i}$  and  $y_{n+1,i}$  are the mole fractions of component *i* in the vapour leaving and entering plate *n* respectively and  $y_{n,i}^*$  is the mole fraction of component *i* in the vapour in equilibrium with the liquid leaving plate *n* (this liquid is considered to be a saturated liquid).

The original Murphree definition was generalized by Taylor[20] allowing for unsaturated liquid and vapour streams.

Holland[11] defined the vaporization efficiency for component *i* and plate *n* as

$$E_{vn,i} = \frac{y_{n,i}}{Y_{n,i}} \quad (2)$$

where  $Y_{n,i} = K_{n,i} x_{n,i}$ ,  $x_{n,i}$  is the mole fraction of component *i* in the liquid leaving plate *n* and  $K_{n,i}$  is the vapour-liquid equilibrium ratio evaluated at the actual temperature and pressure at which liquid leaves plate *n*.

Naturally  $Y_{n,i} = y_{n,i}^*$  if the liquid leaving the plate is a saturated liquid.

Several papers were published recently discussing the relative merits of Murphree and vaporization efficiencies.

Holland and McMahon[12] attempted to show that in the distillation of multicomponent mixtures, conditions could exist in which the values of Murphree efficiencies were zero and infinity while vaporization efficiencies had finite, bounded values. Their statements were later questioned by Standart[19].

Experimental values of vaporization efficiencies were published by Gucalp[10] and Miskin *et al* [16] for the distillation of the ternary system *n*-hexane/methylcyclopentane/benzene in an Oldershaw column, it was shown that average ternary vaporization efficiencies were in close agreement with binary values obtained in the same column.

Arguments in favour of the vaporization efficiency concept were also put forward by Castells Pique *et al* [3], pointing out that its experimental determination is easier, above all for columns not operating at total reflux, and by Ellis and Boyes[6].

Advantages of the use of vaporization efficiencies in distillation calculations were referred to by Holland[11], Yamada and Holland[24] and Yamada *et al* [25].

It is the purpose of the present work to present a quantitative comparison between Murphree and vaporization efficiencies using published ternary distillation data for the systems acetone/methanol/ethanol[8], acetone/benzene/chlorobenzene[8], benzene/toluene/*m*-xylene[18] and *n*-hexane/methylcyclopentane/benzene[10, 16].

It is important to emphasize that all the experimental work was carried out in small laboratory columns in which the liquid in each plate could be considered completely mixed.

### VAPOUR-LIQUID EQUILIBRIUM DATA

The calculation of plate efficiencies requires the knowledge of accurate vapour-liquid equilibrium data. As for each ternary system limited experimental information is normally available, it is common practice to adopt correlating equations using the experimental vapour-liquid equilibrium points to determine the constants in the equations. For this purpose a computer program using the descent method of Davidson[5] for the minimization of the differences between experimental and predicted vapour mole fractions was prepared. Margules three suffix equations[13] were used to correlate liquid phase activity coefficients. The vapour phase was considered to be ideal.

Pure component vapour pressures were evaluated in

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terms of the Antoine equations written as

$$\log_{10} p_i^0 = A_i - \frac{B_i}{C_i + T} \quad (3)$$

where  $p_i^0$  is the vapour pressure of component  $i$  (mm Hg),  $A_i$ ,  $B_i$ ,  $C_i$  are the Antoine constants for component  $i$  and  $T$  is the temperature ( $^{\circ}\text{C}$ )

Values of the Antoine constants used are presented in Table 1 Sources of ternary equilibrium data for the different systems are listed in Table 2 The system benzene/toluene/*m*-xylene can be considered as an ideal one [18, 23]

A summary of the fitted Margules constants is presented

in Table 3 together with the numerical values of root mean square deviations (r m s d) for the mole fraction of each component, the boiling point temperature and the total pressure

#### PLATE EFFICIENCIES

Computer programs were developed [14] for the calculation of vapour phase plate efficiencies from experimental liquid compositions and temperatures Neither Nord [18] nor Free and Hutchison [8] measured liquid plate temperatures and so, in the treatment of their results, the liquid in each plate was assumed to be a saturated liquid

Table 1 Antoine constants

Component	A	B	C
Acetone	7 1171	1210 595	229 664
Benzene	6 90565	1211 033	220 790
Chlorobenzene	6 9781	1431 053	217 55
Ethanol	8 1122	1592 864	226 184
n-Hexane	6 8778	1171 530	224 366
M C P	6 8628	1186 059	226 042
Methanol	8 0810	1582 271	239 726
Toluene	6 9580	1346 773	219 693
m-Xylene	7 0065	1460 183	214 827

Table 2 Vapour-liquid equilibrium data

System	Author	Reference
Acetone/Methanol/Ethanol	Amer, Paxton and Van Winkle	1
Acetone/Benzene/Chlorobenzene	Free and Hutchison	7
n-Hexane/M C P /Benzene	Belknap and Weber	2 *
Benzene/Toluene/ <i>m</i> -Xylene	Gajewski and Westphely	9,23

Table 3 Correlation of vapour-liquid equilibrium

System	Acetone (1)/ Methanol (2)/ Ethanol (3)	Acetone (1)/ Benzene (2)/ Chlorobenzene (3)	n-Hexane (1)/ M C P (2)/ Benzene (3)
Margules constants			
M (1,2)	0 6334	0 4708	0 1499
M (2,1)	0 6283	0 2602	0 1695
M (1,3)	0 5600	0 2456	0 1772
M (3,1)	0 3161	0 2530	0 2084
M (2,3)	0 0794	0 0125	0 00133
M (3,2)	-0 0470	-0 1053	0 01578
R M S D			
$y_1$	0 007	0 008	0 005
$y_2$	0 007	0 005	0 005
$y_3$	0 006	0 009	0 007
temp ( $^{\circ}\text{C}$ )	0 341	0 375	0 168
press (mm Hg)	9 531	8 471	4 012

From the large number of results obtained, those presented in Tables 4-7 were selected as typical examples for the systems benzene/toluene/*m*-xylene, acetone/methanol/ethanol, acetone/benzene/chlorobenzene and *n*-hexane/methylcyclopentane/benzene respectively

Plots of experimental composition profiles and calculated values of Murphree and vaporization efficiencies for the first three systems are presented in Figs 1-3. Similar plots for the system *n*-hexane/methylcyclopentane/benzene were published elsewhere [10, 16]

#### INFLUENCE OF EXPERIMENTAL ERRORS ON CALCULATED VALUES OF MURPHREE EFFICIENCIES

In order to assess the influence of experimental errors, liquid composition errors (due to sampling and analysis) and vapour-liquid equilibrium errors, on calculated values of Murphree efficiencies, a computer program was

written [14] to allow the definition of the possible extremes of calculated values of Murphree efficiencies

The following experimental errors were assumed

Liquid composition error—0.001 (mole fraction)

Vapour-liquid equilibrium error—0.005 (mole fraction)

For any plate *n* two extreme situations were defined, as follows

#### Situation 1

$$(x_{n-1})_1 = x_{n-1} + 0.001$$

$$(x_n)_1 = x_n - 0.001$$

$$(y_n^*)_1 = (K_n)_1(x_n)_1 - 0.005$$

Table 4 Comparison between Murphree efficiencies and vaporization efficiencies—system benzene/toluene/*m*-xylene

Plate number	Component	x	y <sup>*</sup>	E <sub>MV</sub>	E <sub>V</sub>
1	Benzene	0.926			
	Toluene	0.058			
	<i>m</i> -Xylene	0.016			
2	Benzene	0.906	0.968	0.322	0.960
	Toluene	0.066	0.027	0.207	2.12
	<i>m</i> -Xylene	0.028	0.005	0.512	3.52
3	Benzene	0.888	0.963	0.239	0.941
	Toluene	0.071	0.030	0.122	2.21
	<i>m</i> -Xylene	0.041	0.007	0.380	4.12
4	Benzene	0.868	0.957	0.224	0.928
	Toluene	0.079	0.034	0.177	2.09
	<i>m</i> -Xylene	0.053	0.009	0.272	4.58
5	Benzene	0.850	0.952	0.176	0.912
	Toluene	0.083	0.036	0.086	2.18
	<i>m</i> -Xylene	0.067	0.012	0.253	4.59
6	Benzene	0.835	0.947	0.134	0.897
	Toluene	0.089	0.040	0.121	2.11
	<i>m</i> -Xylene	0.076	0.013	0.144	5.03
7	Benzene	0.814	0.940	0.166	0.888
	Toluene	0.097	0.044	0.150	2.03
	<i>m</i> -Xylene	0.089	0.016	0.178	4.76
8	Benzene	0.786	0.931	0.193	0.874
	Toluene	0.104	0.048	0.126	2.01
	<i>m</i> -Xylene	0.110	0.021	0.234	4.37
9	Benzene	0.664	0.891	0.537	0.882
	Toluene	0.113	0.061	0.171	1.72
	<i>m</i> -Xylene	0.223	0.048	0.647	2.28
10	Benzene	0.465	0.792	0.609	0.839
	Toluene	0.129	0.090	0.410	1.26
	<i>m</i> -Xylene	0.406	0.118	0.636	1.89
11	Benzene	0.252	0.596	0.619	0.780
	Toluene	0.132	0.133	2.77	0.969
	<i>m</i> -Xylene	0.616	0.271	0.608	1.50

Table 5 Comparison between Murphree efficiencies and vaporization efficiencies—system acetone/methanol/ethanol

Plate number	Component	x	y <sup>*</sup>	E <sub>MV</sub>	E <sub>V</sub>
1	Acetone	0 420			
	Methanol	0 464			
	Ethanol	0 116			
2	Acetone	0 351	0 495	0 481	0 849
	Methanol	0 495	0 435	0 517	1 07
	Ethanol	0 154	0 070	0 454	1 65
3	Acetone	0 262	0 419	0 566	0,837
	Methanol	0 519	0 473	0 522	1 05
	Ethanol	0 219	0 108	0 584	1 43
4	Acetone	0 201	0,356	0 393	0 735
	Methanol	0 526	0 500	0 268	1 04
	Ethanol	0 273	0 144	0 418	1 52
5	Acetone	0 135	0 272	0 481	0 738
	Methanol	0 519	0 528	0 829	0 997
	Ethanol	0 346	0 200	0 501	1 36
6	Acetone	0 073	0 170	0 637	0 793
	Methanol	0 484	0 541	0 618	0 960
	Ethanol	0 443	0 289	0,630	1 20
7	Acetone	0 046	0 117	0 381	0 625
	Methanol	0 414	0 499	0 821	0 969
	Ethanol	0 540	0 384	0 622	1 15

Table 6 Comparison between Murphree efficiencies and vaporization efficiencies—system acetone/benzene/chlorobenzene

Plate number	Component	x	y <sup>+</sup>	E <sub>MV</sub>	E <sub>V</sub>
1	Acetone	0 404			
	Benzene	0 574			
	Chlorobenzene	0 022			
2	Acetone	0 263	0 491	0 620	0 824
	Benzene	0 684	0 503	0 608	1 14
	Chlorobenzene	0 053	0 006	0 664	3 47
3	Acetone	0 134	0 333	0 650	0 791
	Benzene	0 750	0 650	0 660	1 05
	Chlorobenzene	0 116	0 017	0 640	3 02
4	Acetone	0 062	0 199	0 526	0 673
	Benzene	0 713	0 756	0 866	0 992
	Chlorobenzene	0 225	0 045	0 607	2 55
5	Acetone	0 020	0 084	0 655	0 737
	Benzene	0 570	0 795	0 637	0 898
	Chlorobenzene	0 410	0 121	0 641	1 85
6	Acetone	0 008	0 041	0 362	0 486
	Benzene	0 408	0 723	0 514	0 788
	Chlorobenzene	0 584	0 236	0 500	1 74
7	Acetone	0 002	0 013	0 529	0 599
	Benzene	0 212	0 520	0 636	0 785
	Chlorobenzene	0 786	0 467	0 632	1 25

Table 7 Comparison between Murphree efficiencies and vaporization efficiencies—system *n*-hexane/methylcyclopentane (M C P)/benzene

Plate number	Component	x	Y	$E_{MV}$	$E_v$
1	n-Hexane	0 476	0 505	0 577	0 977
	M C P	0 305	0 293	1 07	0 977
	Benzene	0 219	0 204	0 126	1 07
2	n-Hexane	0 449	0 480	0 905	0 994
	M C P	0 313	0 302	0 672	1 01
	Benzene	0 238	0 220	0 988	1 00
3	n-Hexane	0 431	0 464	0 570	0 971
	M C P	0 318	0 308	0 470	1 02
	Benzene	0 251	0 231	0 607	1 04
4	n-Hexane	0 396	0 431	1 02	1 00
	M C P	0 334	0 326	1 92	0 976
	Benzene	0 270	0 246	0 778	1 02
5	n-Hexane	0 382	0 416	0 417	0 953
	M C P	0 331	0 323	-0 359	1 04
	Benzene	0 287	0 258	0 580	1 05
6	n-Hexane	0 353	0 392	0 744	0 974
	M C P	0 346	0 343	5 61	0 964
	Benzene	0 301	0 272	0 487	1 05
7	n-Hexane	0 326	0 369	0 622	0 956
	M C P	0 349	0 352	-0 933	0 982
	Benzene	0 325	0 294	0 770	1 02
8	n-Hexane	0 282	0 324	1 05	1 00
	M C P	0 357	0 363	-1 31	0 961
	Benzene	0 361	0 320	0 878	1 02
9	n-Hexane	0 249	0 298	0 667	0 944
	M C P	0 332	0 350	1 36	1 02
	Benzene	0 419	0 369	1 17	0 977
10	n-Hexane	0 214	0 263	0 713	0 946
	M C P	0 308	0 331	1 04	1 00
	Benzene	0 478	0 411	0 876	1 02
11	n-Hexane	0 178	0 231	0 674	0 925
	M C P	0 279	0 315	0 807	0 978
	Benzene	0 543	0 467	0 850	1 02
12	n-Hexane	0 132	0 180	0 956	0 988
	M C P	0 238	0 279	0 994	0 999
	Benzene	0 630	0 525	0 831	1 03
13	n-Hexane	0 097	0 150	0 658	0 879
	M C P	0 183	0 242	0 939	0 985
	Benzene	0 720	0 631	1 01	0 999
14	n-Hexane	0 054	0 092	1 14	1 06
	M C P	0 138	0 198	0 752	0 925
	Benzene	0 808	0 716	0 952	1 00
15	n-Hexane	0 032	0 059	0 825	0 920
	M C P	0 093	0 143	0 898	0 964
	Benzene	0 875	0 787	0 766	1 03

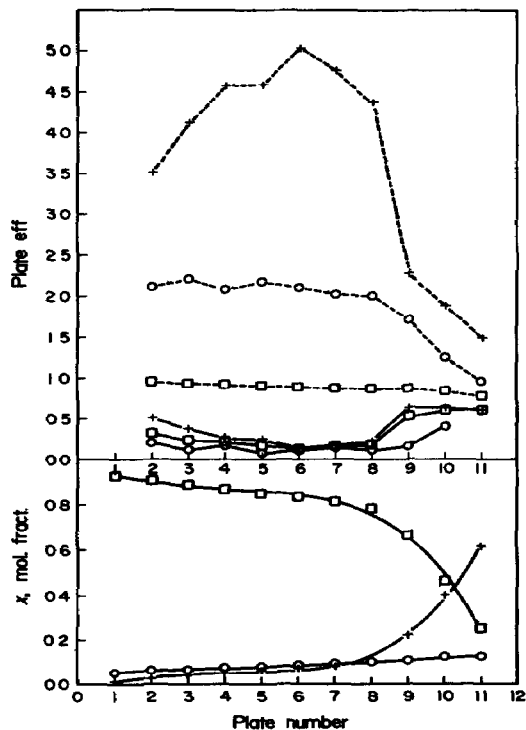


Fig 1 Variation of plate efficiency and composition with plate number—system benzene/toluene/*m*-xylene —, Murphree eff, —, vaporization eff, □, benzene, ○, toluene, +, *m*-xylene

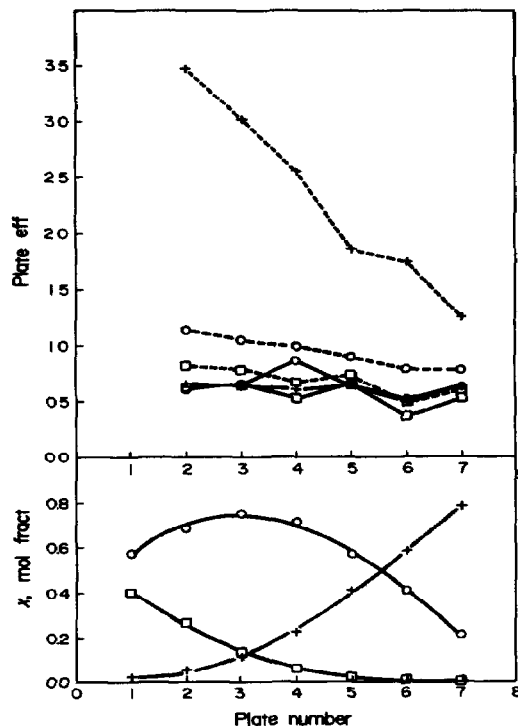


Fig 3 Variation of plate efficiency and composition with plate number—system acetone/benzene/chlorobenzene —, Murphree eff, —, vaporization eff, □, acetone, ○, benzene, +, chlorobenzene

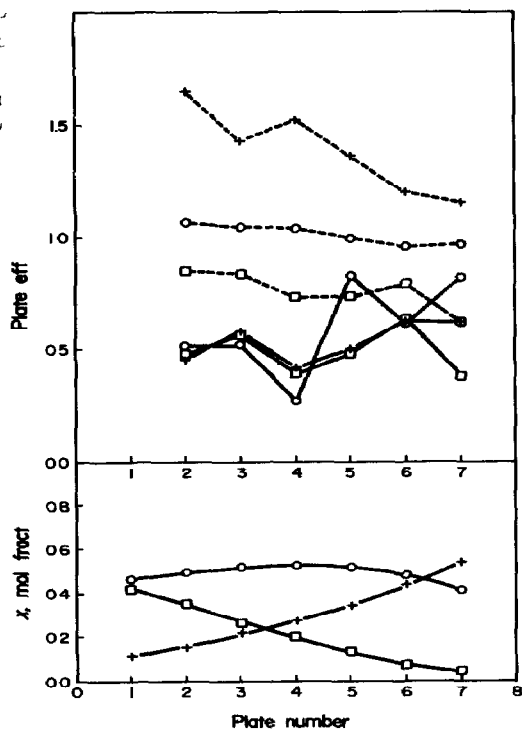


Fig 2 Variation of plate efficiency and composition with plate number—system acetone/methanol/ethanol —, Murphree eff, —, vaporization eff, □, acetone, ○, methanol, +, ethanol

#### Situation 2

$$(x_{n-1,i})_2 = x_{n-1,i} - 0.001$$

$$(x_{n,i})_2 = x_{n,i} + 0.001$$

$$(y_{n,i}^*)_2 = (K_{n,i})_2(x_{n,i})_2 + 0.005$$

where  $x_{n-1,i}$  and  $x_{n,i}$  are the mole fractions of component  $i$  in the liquid entering and leaving plate  $n$  respectively and  $(K_{n,i})_1$  and  $(K_{n,i})_2$  are the vapour liquid equilibrium ratios for situations 1 and 2

For total reflux the equations defining vapour phase Murphree efficiencies for situations 1 and 2 can be written as

$$(E_{MVn,i})_1 = \frac{x_{n-1,i} - x_{n,i} + 0.002}{(K_{n,i})_1(x_{n,i})_1 - x_{n,i} - 0.004}$$

$$(E_{MVn,i})_2 = \frac{x_{n-1,i} - x_{n,i} - 0.002}{(K_{n,i})_2(x_{n,i})_2 - x_{n,i} + 0.004}$$

The extreme values based on the assumed errors are plotted in Fig 4 for benzene (system *n*-hexane/methylcyclopentane/benzene)

#### DISCUSSION OF RESULTS

An analysis of the calculated values of plate efficiencies allows the following comments to be made

##### (a) Murphree efficiencies

(i) Most of the calculated values of Murphree efficiencies lie in the interval (0,1)

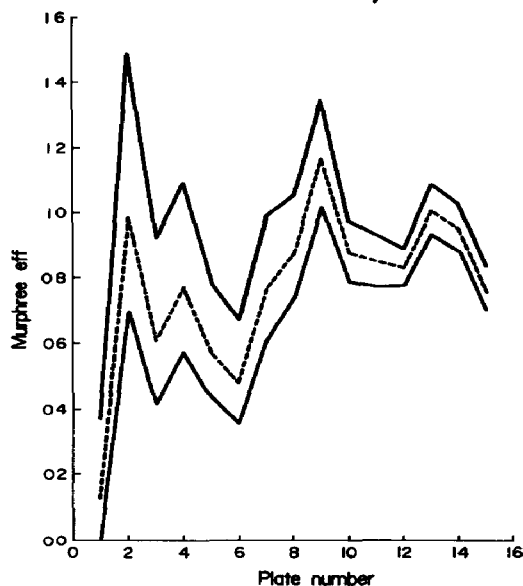


Fig 4 Influence of experimental errors on Murphree efficiencies—system *n*-hexane/methylcyclopentane/benzene—component benzene —, Extreme situations 1 and 2, ---, experimental values

(ii) The largest variations of Murphree efficiencies with composition occur for the intermediate component for which calculated values of Murphree efficiencies often fall outside this interval. This is particularly evident for methylcyclopentane as, in this case, negative values appear together with very high positive values.

(iii) The influence that experimental errors have on calculated values of Murphree efficiencies may be enormous. This is particularly important for the intermediate component in the region in which a maximum or a minimum of concentration occurs. In fact the range of possible values can be infinite when the difference appearing in the denominator of Murphree's definitions is smaller than the experimental error.

(iv) Though the consideration of the possible range of experimental errors can lead to a wide range of values of Murphree efficiencies there is often an interval of this range which lies between zero and one.

(v) Some negative values of efficiencies as well as some high positive values can be explained by previous considerations.

The above comments do not imply the non-existence of negative point efficiencies or of point efficiencies greater than unity. Such situations can occur [15, 21, 22] and will be discussed later in detail [15].

The previous evidence shows the difficulty in assigning a specific numerical value to a Murphree efficiency in some circumstances and it raises the question of whether the error on the evaluation of Murphree efficiencies affects the determination of composition profiles. Table 8 summarizes the results of the evaluation of the composition of the vapour leaving a plate (system *n*-hexane/methylcyclopentane/benzene—plate 6) using three different sets of efficiency,  $E_{MV}$ ,  $(E_{MV})_1$ ,  $(E_{MV})_2$ . It can be seen that, in spite of the large differences between the

three sets of efficiencies, calculated vapour compositions vary only slightly. This is because the wide variation in the efficiency values is due to the low dependence of vapour composition on efficiency. Conversely a well defined efficiency value results from the case where the vapour composition is heavily dependent on efficiency. The resulting error in the computed vapour composition is naturally of the same size in both cases. These results explain the observations of Cilianu *et al* [4].

#### (b) Vaporization efficiencies

(i) Vaporization efficiencies are normally smaller than unity for the more volatile component (MVC) the concentration of which is increasing upwards and

$$\lim (E_{v, MVC}) = 1 \quad (4)$$

$$x_{MVC} \rightarrow 1$$

(ii) Vaporization efficiencies of the less volatile component (LVC) are normally greater than unity and

$$\lim (E_{v, LVC}) = 1 \quad (5)$$

$$x_{LVC} \rightarrow 1$$

(iii) Vaporization efficiencies of the intermediate component are less than unity when the concentration of the component is increasing upwards and greater than unity when the concentration is decreasing. In fact the vaporization efficiency is bound to be equal to unity whenever a maximum or minimum of concentration is reached.

(iv) For the less volatile component calculated values of vaporization efficiencies spread over a wide range, typical examples occur for the systems benzene/toluene/*m*-xylene and acetone/benzene/chlorobenzene. Table 9 shows the limits of variation for these two systems and shows that the results of Miskin *et al* [16] cannot be generalized.

(v) It is interesting to note that in a hypothetical column in which no separation occurs, that is to say plate compositions are the same for plates 1 to *N*, vaporization efficiencies are different from zero. An example is presented in Table 10 for acetone/benzene/chlorobenzene.

It is clear that the range of possible values of vaporization efficiencies say for the more volatile component is smaller than the interval (0, 1) and depends on the component mole fraction. As the mole fraction of the more volatile component approaches unity the size of the interval of possible values of vaporization efficiencies tends to zero.

#### CONCLUSIONS

Experimental data obtained by Nord [18], Free and Hutchison [8] and Gucalp [10] for the ternary systems benzene/toluene/*m*-xylene, acetone/methanol/ethanol, acetone/benzene/chlorobenzene and *n*-hexane/methyl-

**Table 8** Influence of experimental errors on plate to plate calculations (system *n*-hexane methylcyclopentane/benzene-plate 6)\*

Component	Murphree efficiency	Predicted vapour composition
<i>n</i> -Hexane	0 744	0 382
M C P.	5 61	0 331
Benzene	0 487	0 287
<i>n</i> -Hexane	0 912	0 381
M C P	1 72	0 330
Benzene	0 355	0 289
<i>n</i> -Hexane	0 613	0 380
M C P	-7 712	0 336
Benzene	0 677	0 284

\* Plate composition -  $x_H = 0.353$ ,  $x_{MCP} = 0.346$ ,  $x_B = 0.301$

**Table 9** Limits of variation of vaporization efficiencies

System	Component 1		Component 2		Component 3	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Benzene (1)/ Toluene (2)/ <i>m</i> -Xylene (3)	0 780	0 960	0.969	2 21	1 50	5 03
Acetone (1)/ Benzene (2)/ Chloro- benzene (3)	0 486	0 824	0 785	1 14	1 25	3 47

**Table 10** Vaporization efficiencies for a zero separation situation (system acetone/benzene/chlorobenzene)

Plate number	Component	Plate composition	Vaporization efficiencies
1	Acetone	0 002	0 150
	Benzene	0 212	0 407
	Chlorobenzene	0 786	1 685
2	Acetone	0 002	0 150
	Benzene	0 212	0 407
	Chlorobenzene	0 786	1 685
3	Acetone	0 002	0 150
	Benzene	0 212	0 407
	Chlorobenzene	0 786	1 685



cyclopentane/benzene were used on a quantitative comparison between Murphree efficiencies and vaporization efficiencies. It was shown that

(a) The vaporization efficiency concept fails to describe the behaviour of the phases in a distillation plate due to its mathematical limitations. The pattern of calculated values of vaporization efficiencies is the same for all the systems as the vaporization efficiency of the more volatile component is normally less than unity, the vaporization efficiency of the less volatile component is normally greater than unity and the vaporization efficiency of the intermediate component takes values close to unity.

(b) A wide variation of the vaporization efficiency with composition can exist above all for the more volatile component.

(c) The range of possible values of vaporization efficiencies is limited and depends on the component mole fraction.

(d) Vaporization efficiencies differ from zero in situations in which no separation occurs.

(e) "Murphree type" efficiencies are in agreement with physical reality as their values normally belong to the interval (0, 1). Values falling outside this interval can normally be justified in terms of the influence that experimental errors have on calculated Murphree efficiencies, alternatively such values highlight interesting physical situations (reverse diffusion, diffusion barriers).

(f) The influence that experimental errors (liquid composition errors and vapour-liquid equilibrium errors) have on calculated values of Murphree efficiencies may be enormous. This effect is particularly important for the intermediate component in the region in which a maximum of concentration occurs.

(g) Although experimental errors seriously affect calculated values of Murphree efficiencies their influence on plate to plate calculations is limited. Such influence is of the order of magnitude of the experimental errors.

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#### NOTATION

$A, B, C$	Antoine constants
$E_{MV}$	Murphree vapour phase plate efficiency
$E_v$	vaporization efficiency
$K$	vapour-liquid equilibrium ratio

$p^0$	vapour pressure
$T$	temperature
$x$	liquid mole fraction
$y$	vapour mole fraction
$y^*$	equilibrium vapour composition

#### Subscripts

$n$	plate number
$i$	component

#### REFERENCES

- [1] Amer H. H., Paxton R. R. and Van Winkle M., *Ind Engng Chem* 1956 **48** 142
- [2] Belknap R. C. and Weber J. H., *J Chem Engng Data* 1961 **6** 485
- [3] Castells Pique F., Bugarel R. and Mora J. C., *Rev Inst Franc Pétrole* 1974 **29** 849
- [4] Cihanu S., Brauch V. and Schlunder E. U., *Verfahrenstechnik* 1974 **8** 84
- [5] Davidson W. C., *Report ANL 5990 (Reg)* Argonne National Laboratory 1959
- [6] Ellis S. R. M. and Boyes A. P., *Trans Instn Chem Engrs* 1974 **52** 202
- [7] Free K. W. and Hutchison H. P., *J Chem Engng Data* 1959 **4** 193
- [8] Free K. W. and Hutchison H. P., *Int Symp Distillation* Brighton, England 1960
- [9] Gajewski Z., *Koks, Smola, Gaz* 1958 **3** 106
- [10] Gucalp U., Ph.D. Thesis, Birmingham University, Birmingham, England 1966
- [11] Holland C. D., *Multicomponent Distillation* Prentice Hall, Englewood Cliffs, New Jersey 1963
- [12] Holland C. D. and McMahon K. S., *Chem Engng Sci* 1970 **25** 431
- [13] McDermott C. and Ellis S. R. M., *Chem Engng Sci* 1965 **20** 545
- [14] Medina A. G., Ph.D. Thesis, Birmingham University, Birmingham, England 1976
- [15] Medina A. G., McDermott C. and Ashton N., in preparation
- [16] Miskin L. G., Ozalp U. and Ellis S. R. M., *Br Chem Engng Proc Tech* 1972 **17** 153
- [17] Murphree E. V., *Ind Engng Chem* 1925 **17** 747
- [18] Nord M., *Trans Am Instn Chem Engrs* 1946 **42** 863
- [19] Standart G., *Chem Engng Sci* 1971 **26** 985
- [20] Taylor D. L., M.Sc. Thesis, Texas A & M University, U.S.A. 1962
- [21] Toor H. L. and Burchard J. K., *A I Ch E J* 1960 **6** 202
- [22] Vogelwohl A. and Ceretto R., *Chem Ing Tech* 1972 **44** 936
- [23] Westphely H., *Chem Ing Tech* 1970 **42** 1367
- [24] Yamada I. and Holland C. D., Preprints for PACHEC'72 of the Society of Chemical Engineers of Japan 1972
- [25] Yamada I., Matsumoto N. and Suzuki M., *J Chem Engng Japan* 1973 **6** 68