Separation Science and Technology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713708471

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To cite this Article Fasesan, S. O. , Sanni, S. A. and Taiwo, E. A.(1998) 'Effects of System Densities on Distillation Column Performance', Separation Science and Technology, 33: 9, 1345 — 1357
To link to this Article: DOI: 10.1080/01496399808544987
URL: http://dx.doi.org/10.1080/01496399808544987

SEPARATION SCIENCE AND TECHNOLOGY, 33(9), pp. 1345–1357, 1998

Effects of System Densities on Distillation Column Performance

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ABSTRACT

Distillation experiments were carried out on three binary systems (ethanol–butanol, ethanol–propan-2-ol, and propan-2-ol–butanol) in a 0.1-m internal diameter glass column packed with 8 mm diameter Raschig rings. The experiments were performed under total reflux conditions and at atmospheric pressure. The data collected on column performance showed that performance declined with increasing average bulk liquid density. The results also lend credence to earlier reports on the behavior of column performance with respect to component concentration in the feed mixtures. The system densities of the three binary systems were measured at four different temperatures, 30, 40, 50, and 60°C. The data were compared with the predicted data of Yen–Woods and Multifluid models. The accuracy of the predictions of the Yen–Woods model was rather poor while that of the Multifluid model was very encouraging.

INTRODUCTION

The influence of liquid density on distillation column performance has been the subject of investigation in some recent research work (1). In the earlier work of Fasesan et al. (1) two aqueous systems of ethanol–water, *tert*-butanol–water, and one alcohol–alcohol system of ethanol–*tert*-butanol were studied to examine the effect of their densities on column performance variation. That investigation reported a marked deviation in the data obtained for

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aqueous systems from what was obtained for an alcohol–alcohol system with respect to column efficiency. Because the distillation operating conditions of these binary systems are above the experimental density measurement temperature of 60°C, two of the density correlation models reported in the literature were tested with the experimental data. This was done to establish the degree of confidence of these correlations, with a view to adopting the correlation model with the higher degree of confidence for the prediction of density data which lie beyond the temperature limit of the density measurements.

Reid et al. (2) defined density as a dynamic nonequilibrium property that reflects the effect of molecular motions and interactions. A number of liquid density correlations have appeared in the literature. Lee et al. (3) developed a modified equation of state to predict thermodynamic properties including the density of both binary and multicomponent mixtures of light hydrocarbons.

However, Yen and Wood (4) put forward a generalized equation which explicitly relates the reduced density to reduced temperature and pressure. This model was reported to predict literature data of 62 saturated liquids and 19 compressed pure liquids to within 2% accuracy while the predictions for other liquid mixtures was reported to be within 3% accuracy. The general equation is

$$\rho_{RS} = 1 + A(1 - T_R)^{1/3} + B(1 - T_R)^{2/3} + D(1 - T_R)^{4/3}$$

where ρ_{RS} = reduced saturated density. The parameters have their usual meanings. The generalized equation can be used to calculate the liquid density of mixtures based on a pseudocritical method between the pseudoreduced temperature of 0.3 to 1.0.

The Multifluid model constitutes a series of two-reference-fluid interpolations. It employs the acentric factor of the fluid of interest for linear interpolation and extrapolation of the reference-fluid properties. According to Teja and Rice (5), this approach is exact for the reduced vapor pressure at T_R = 0.7. These workers also suggested that at other conditions of interest, the acentric factors can be adjusted to minimize deviations between experimental and calculated values of a property for the pure fluid of interest. However, by using the multifluid model, Teja (6) represented the saturated liquid densities of the components as a function of the reduced temperature through the equation:

$$\rho_R = 1 + b(1 - T_R)^{0.35} + \sum_2^4 b_i(1 - T_R)^{(i+1)/3}$$

where ρ_R = reduced density
T_R = reduced temperature = T/T_C
T_C = critical temperature
b = constant

The critical constants of pure solvents and the acentric factors required in solving the Multifluid model equations are available in the literature (2, 7). Nevertheless, the least-squares constant b_i were obtained from experimental data.

The present investigation, however, examined further the contribution of system density of an alcohol–alcohol system to the variation of column efficiency.

EXPERIMENTAL

A quickfit visible flow packed distillation column supplied by Corning Process Plant Engineering, Staffordshire, England, was employed for experiments on the variation of column efficiency with system density. The column has an internal diameter of 0.1 m and was packed with borosilicate Raschig rings of 8 mm nominal diameter to a height of 1.7 m. The reboiler system consisted of a boiler-type heat exchanger, fitted externally to a spherical vessel of nominal capacity of about 20 L in a thermo-siphon loop. The region above the packed height but below the reflux divider and the region below the packed height but above the reboiler were chosen for accurate temperature measurement and sample collection. Temperature accuracy is of the order of $\pm$ 0.025°C. Vapor and liquid samples were collected at the top and the bottom ends of the packed bed. Figure 1 is a diagrammatic representation of the experimental setup. Analysis of the samples for their composition was performed by density and refractive index measurements. The instruments used are reported elsewhere (8). All the data were collected under the total reflux condition of the distillation column.

The method employed for density measurement of liquid samples was according to the standard of the Institute of Petroleum IP 59/57. Bicapillary Lipkin pycnometers with a nominal volume of 5.0 cm^3 were employed. The measurements were done in a constant temperature room with a constant temperature water bath. The pycnometers were calibrated at each temperature of interest. The calibration data at each temperature were fitted to a straight line by linear regression, and the coefficient of linear regression for each line was calculated and recorded. The detailed procedure is given elsewhere (8).

RESULT AND DISCUSSION

In order to eliminate errors inherent in the density data present in the literature, density measurements of the three binary systems under investigation were made in the laboratory under constant temperature conditions and within the temperature and concentration ranges of interest. These measurements could not exceed a temperature limit of 60°C without a significant loss

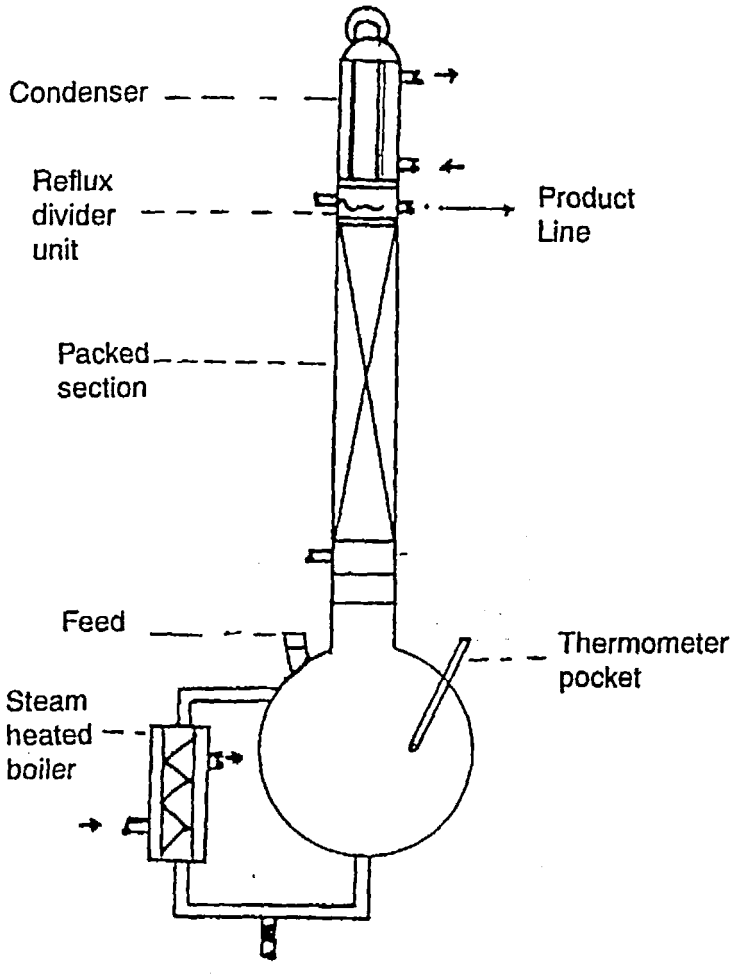

FIG. 1 Packed distillation column.

of solute by vaporization into the surrounding atmosphere. However, because the distillation operating conditions of these binary systems are above the experimental density measurement temperature of 60°C, two of the density correlation models reported in the literature were tested with the experimental data in order to establish the degree of confidence of these correlations with a view to adopting the correlation model with the higher degree of confidence for the prediction of density data which lie beyond the temperature limit of the density measurements.

TABLE 1
Constants (b_i) for Pure Solvents (Multifluid equation)

Constant	b_1	b_2	b_3	b_4
Butanol	−2.9009	9.5954	−0.1095	−4.1879
Ethanol	1.0313	2.4145	−0.0030	−0.8318
Propan-2-ol	3.2225	−2.6363	3.0000	0.6667

For this purpose, the Yen–Woods model and the Multifluid model according to Teja and Rice were tested with the experimental data of system densities. The choice of these models was based on a review of Spencer and Danner (9). These workers suggested that the Yen–Woods (4) correlation, among others, was reliable based on the available parameters. Similarly, the choice of the Multifluid model (5) was due to the report that it is a more accurate model for predicting the saturated liquid density. It is also an improvement of the two-fluid model of Teja and Rice (5). Furthermore, this model has also been tested on liquefied natural gas and its mixtures (6). Tables 1–3 show the constants employed in the two models for the predictions of the densities.

Figures 2 and 3 are plots of the measured density of the ethanol–butanol binary system against the mole fraction of ethanol for the system temperature from 30 to 60°C. Also shown in each plot are the predicted density data at each system temperature according to the two models of interest. The predictions according to the Yen–Woods model are at variance with the experimental data but the Multifluid model predicts the experimental data fairly well.

Density data for the ethanol–propan-2-ol system are presented in Figs. 4 and 5. The pattern of results obtained for this system is not significantly different from that recorded for the last system, except that the prediction of the Multifluid model is better, especially at 30 and 60°C.

The propan-2-ol–butanol binary system density data are shown in Figs. 6 and 7. The predicted data of the Multifluid model for the density of this system

TABLE 2
Constants A, B, and D in Yen–Woods Equation for Ethanol–Isopropanol Binary System[a]

Constant	A	B	D
Ethanol–isopropanol	1.8771	0.8499	0.0801

[a] Ethanol and isopropanol have the same critical compressibility factor z_c.

TABLE 3
Constants A, B, and D for Ethanol–Butanol and Isopropanol–Butanol

Composition X_{Et}/X_{IPA}	Constants		
	A	B	D
0.00	1.8076	0.7845	0.1455
0.10	1.8157	0.7923	0.1377
0.20	1.8248	0.8012	0.1288
0.30	1.8328	0.8088	0.1212
0.40	1.8390	0.8148	0.1152
0.50	1.8474	0.8228	0.1072
0.60	1.8541	0.8291	0.1009
0.70	1.8604	0.8350	0.0950
0.80	1.8663	0.8404	0.0896
0.90	1.8719	0.8454	0.0846
1.00	1.8771	0.8499	0.0801

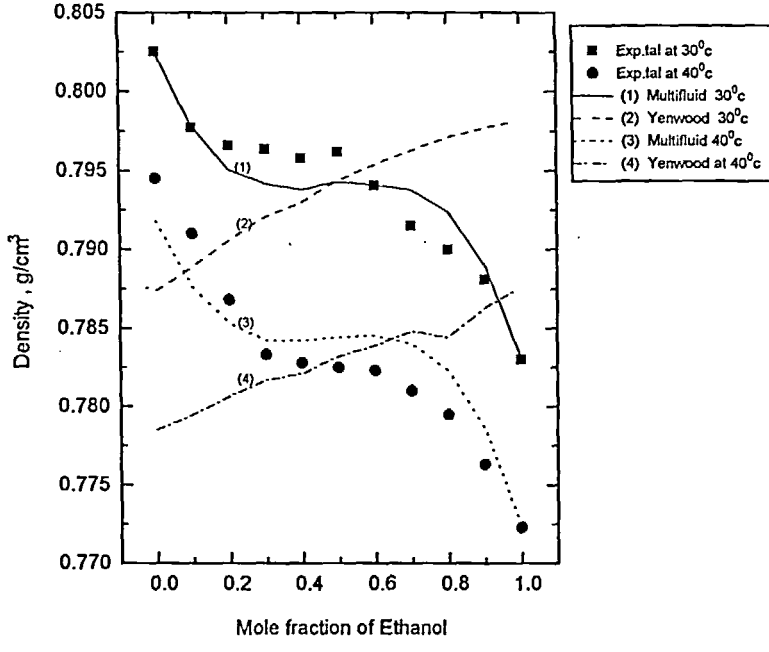

FIG. 2 Density–composition variation for ethanol–butanol system at 30 and 40°C.

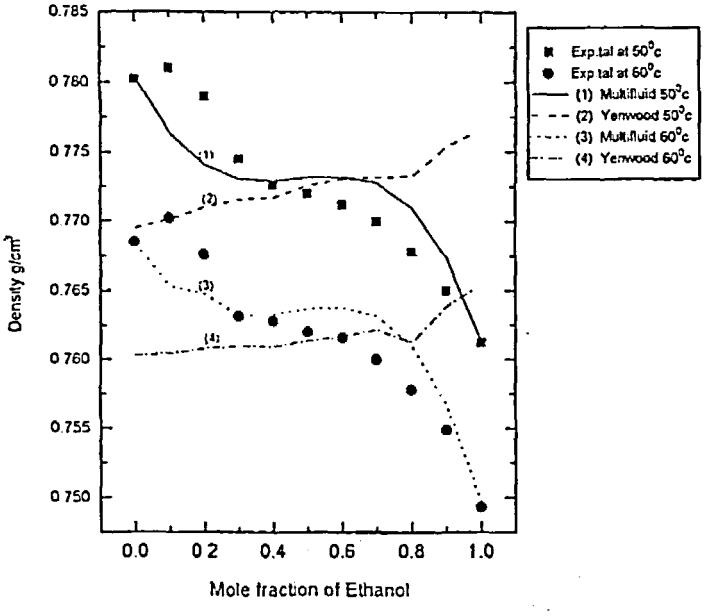

FIG. 3 Density–composition variation for ethanol–butanol system at 50 and 60°C.

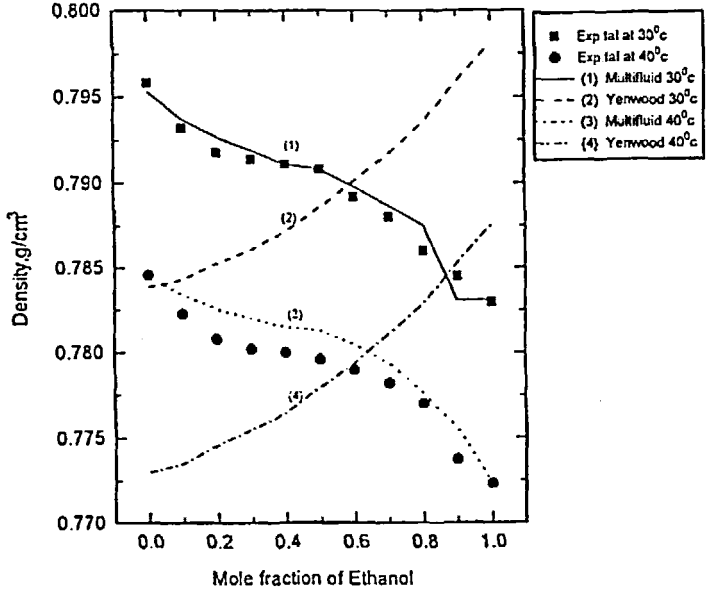

FIG. 4 Density–composition variation for ethanol–propan-2-ol system at 30 and 40°C.

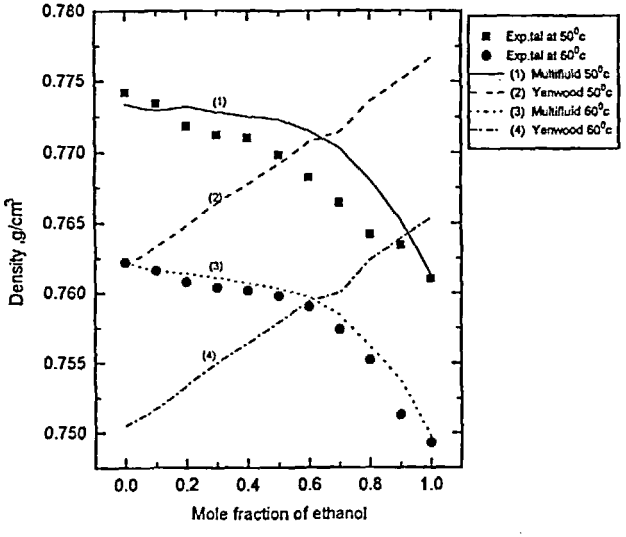

FIG. 5 Density–composition variation for ethanol–propan-2-ol system at 50 and 60°C.

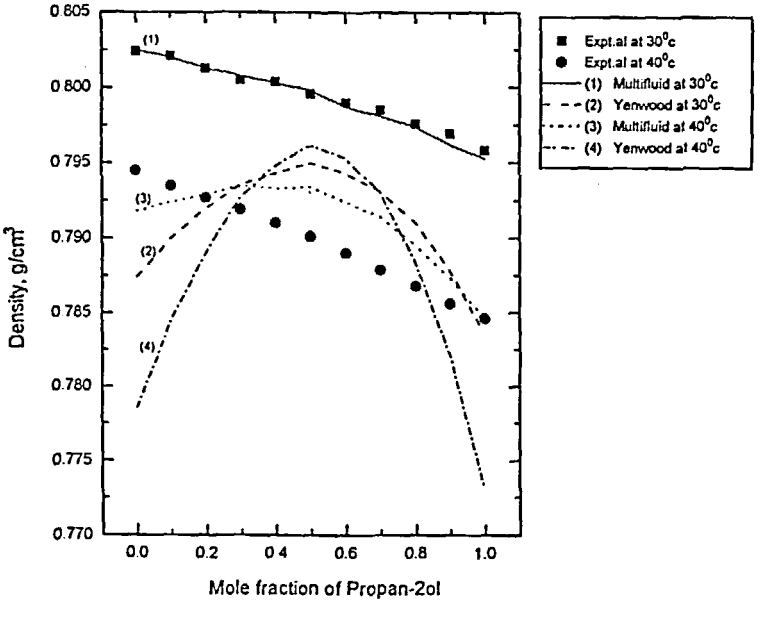

FIG. 6 Density–composition variation for propan-2-ol–butanol system at 30 and 40°C.

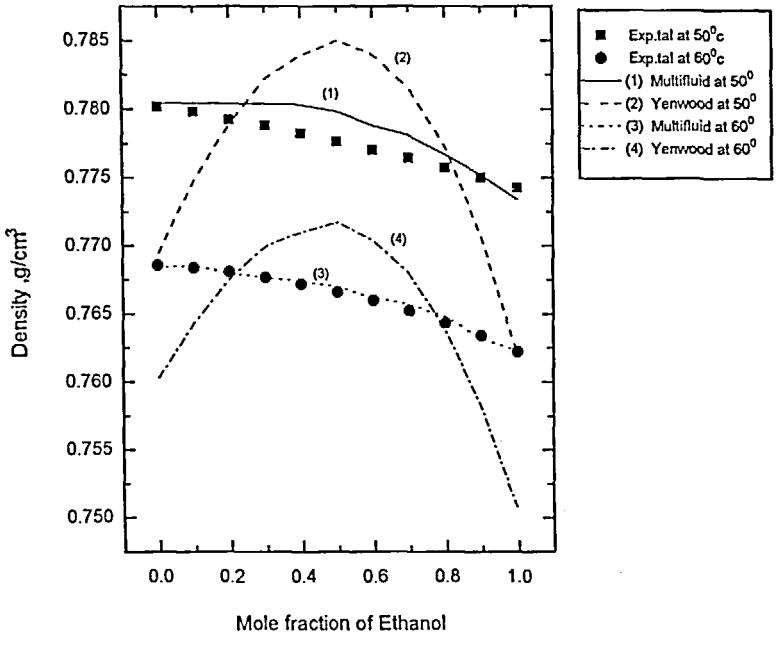

FIG. 7 Density–composition variation for propan-2-ol–butanol system at 50 and 60°C.

exhibit a higher confidence limit at 30 and 60°C with the corresponding experimental data.

The poor performance of the Yen–Woods model in this investigation is not unexpected considering the limitations reported in the literature. Some shortcomings of the earlier models were noted in the literature during the development of the Multifluid model. Expectedly, the Yen–Woods model, which has been reported to be fairly accurate for pure liquids, was found to be unsuitable for alcohol–alcohol systems. The Multifluid model, developed to accommodate multicomponent mixtures at various operating conditions, was found to be better in predicting system density for alcohol–alcohol mixtures. This is clearly visible in Fig. 8, an error plot of E versus T°C for the two models.

The variations of column performance with more volatile component (MVC) concentration in feed mixtures for the three alcohol–alcohol binary systems are presented in Fig. 9. Performance–composition plots showed that the highest performance response to MVC variation in feed is for the ethanol–propan-2-ol system. However, the results indicated that the perfor-

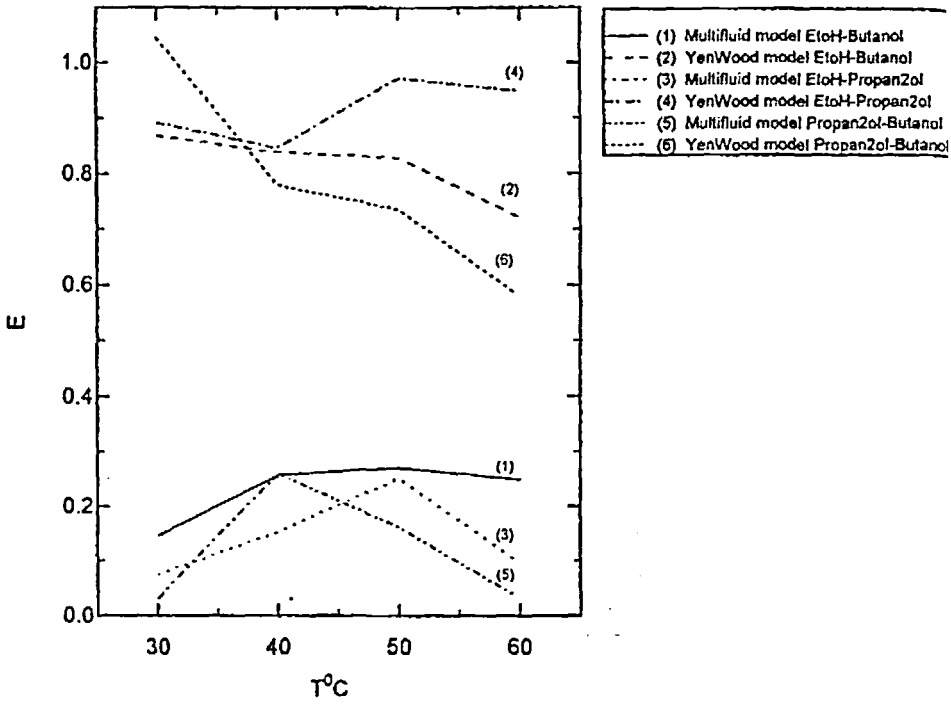

FIG. 8 Error plot of E vs T°C.

mance of the three systems examined declined with an increase in the amount of the more volatile component in the mixtures. This phenomenon was the response in column performance to a decrease in surface tension with increasing concentration of the MVC in the mixture. The reduction in surface tension of the binary occasioned reduction in liquid spread over the packing surface, which consequently led to a drop in mass transfer rates. These results compliment the earlier reports of Fasesan et al. (10) and Patberg et al. (11).

Figure 10 presents data on the response of column performance to the variation in system density for the three alcohol–alcohol systems as plots of overall number of transfer units against average bulk liquid density. The initial feed compositions of the three binary systems were made to be as close as possible at the commencement of each distillation run. These results indicated a sharp drop in column performance for a small increase in density of the ethanol–propan-2-ol system. However, the performance drop with a density increase was gradual for the ethanol–butanol system. Since ethanol was com-

mon to both these binary systems, it is implied that the variation in the density of the composite co-component in each binary system was responsible for the drastic change in column performance.

The results also showed that the level of column performance recorded for the ethanol–butanol system was comparatively lower than that recorded for the ethanol–propan-2-ol system. This situation was first noticed in Fig. 9.

Close examinations of Figs. 2 and 4 for the three binary system at 30°C indicated a gradual decrease in density with an increase in concentration of the more volatile component up to the point where both components in the system are of equal concentration (0.5 mole fraction). Beyond this point, the decrease in density becomes larger and more pronounced with any further increase in concentration. However, the third system, propan-2-ol–butanol, exhibited a gradual and almost consistent decrease in density with concentration across the entire concentration range. From these results it can be deduced that the molecules of butanol in each binary system exhibit separation retard-

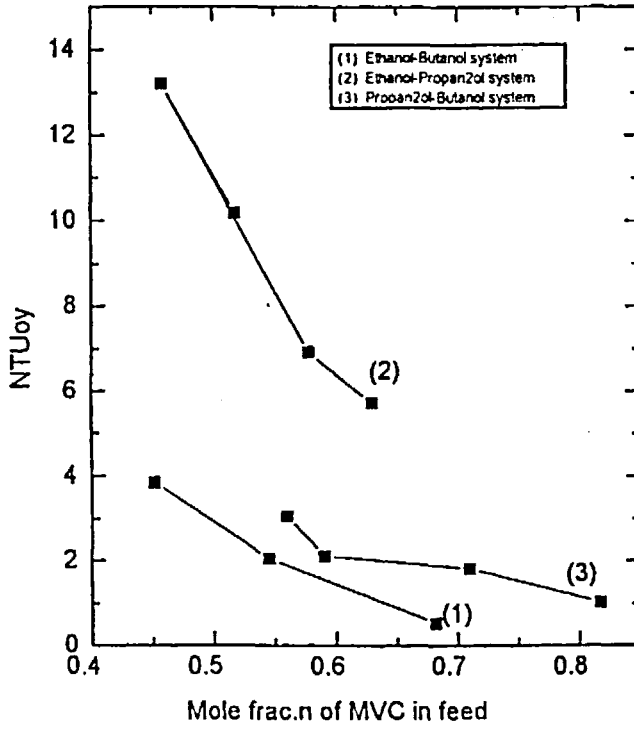

FIG. 9 Variation of binary efficiency with MVC in feed for the three binary systems.

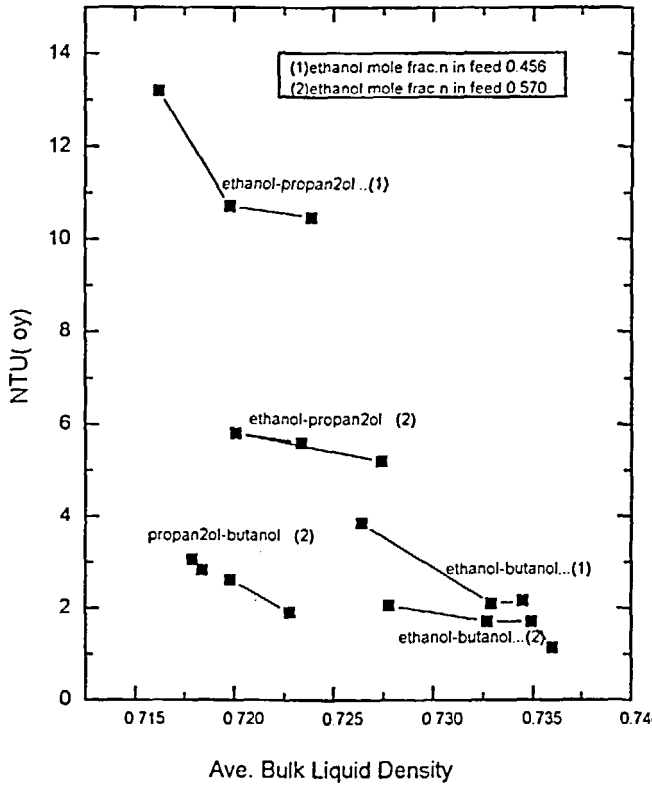

FIG. 10 Variation of binary efficiency with system liquid density for the three alcohol–alcohol systems.

ing effects on the molecules of the composite component, which is in line with the physical properties of the pure components constituting the systems.

CONCLUSION

The results obtained in this investigation demonstrated that column performance responded negatively to an increase in system density for the three binary systems investigated. It has also been shown that the molecules of butanol in the binary systems studied in the present work cause separation retarding effects on the composite binary molecule.

The results have also shown that the Multifluid model predicts experimental density data for the binary systems investigated in this study more accurately than does the Yen–Woods model.

NOMENCLATURE

A	constant
b	constant
B	constant
D	constant
E	$(\rho_{measured} - \rho_{calculated})/\rho_{measured}$
T_R	reduced temperature
ρ_R	reduced density

ACKNOWLEDGMENT

This experimental study was supported by funds from the University Research Committee of the Obafemi Awolowo University, Ile-Ife, Nigeria, for which the authors are grateful.

REFERENCES

1. S. O. Fasesan, S. A. Sanni, and H. M. Kahema, *J. Nig. Soc. Chem. Eng. Lagos*, In Press.
2. R. C. Reid, J. M. Prausnitz, and T. K. Sherwood, *Properties of Gases and Liquids*, McGraw-Hill, New York, NY, 1977.
3. L. L. Lee, K. E. Startling, and K. C. Mo, *Proc. Symp. Thermophys. Prop.*, *7*, 451–455 (1977).
4. L. C. Yen and S. S. Woods, *AIChE J.*, *12*(11), 95–99 (1966).
5. A. S. Teja and P. Rice, *Chem. Eng. Sci.*, *36*, 1–6 (1981).
6. A. S. Teja, *Ibid.*, *35*, 2349–2351 (1980).
7. M. W. Haynes and M. J. Hiza, *J. Chem. Thermodyn. 9*, 179–187 (1977).
8. E. A. Taiwo, M.Sc. Thesis, Obafemi Awolowo University, Ile-Ife, Nigeria, 1992.
9. L. F. Spencer and R. P. Danner, *J. Chem. Eng. Data Ser.*, *17*, 236 (1972).
10. S. O. Fasesan, S. A. Sanni, and R. O. Idem, *J. Sep. Process Technol.*, *9*, 21–33 (1988).
11. W. B. Patberg, A. Koers, W. D. Steenge, and A. H. Drikeburgh, *Chem. Eng. Sci.*, *38*(6), 917–922 (1983).

Received by editor December 10, 1996
Revision received September 1997