

EFFECT OF PHYSICOCHEMICAL PROPERTIES OF THE SEPARATED MIXTURE ON THE LOCAL EFFICIENCY BY RECTIFICATION

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ABSTRACT

Rectification is widely used in chemical industry as basic method for separation of liquid homogeneous mixtures. The process is carried out in column apparatuses with plates and filler. The main parameter by which rectification installations are distinguished is their separation efficiency. Together with the multitude of constructive and technological parameters, the nature of the mixture to be separated is also important. The effects of some physicochemical properties like dynamic viscosity, density, diffusion of vapor and liquid phases, etc. on the local efficiency by rectification was studied with the mixtures benzene-heptane, heptanes-toluene, methanol-toluene and dichloroethane-propanol. The local efficiency was found to increase with viscosity, vapor phase density and the coefficients of diffusion in liquid and vapor phases.

Key words: distillation, local efficiency, viscosity, density, coefficient of diffusion

INTRODUCTION

Rectification is widely used industrial method for separation of liquid homogeneous mixtures into fractions or individual components of certain concentration. The facilities; rectification columns, heat-exchangers, measuring and control gauges are complex and expensive and their performance usually limits the technical and economical parameters of the whole installation, especially in large scale production units. The practical importance of rectification explains the long and incessant interest demonstrated by the researchers towards the problems it poses. The results of the numerous studies are summarized in a number of monographies [1-9]. Nevertheless, a lot of problems related to process kinetics and its dependence on the hydrodynamics, construction and the contact elements used in rectification columns, the nature of the separated mixtures, etc. remain not fully clarified.

A basic characteristic of the process of rectification is its efficiency. The efficiency is estimated by various methods. Practically mostly plate columns are used. Plate efficiency shows the real separation ability of particular plate depending on the working conditions and the nature of the separated mixture. This is a kinetic characteristic allowing direct determination of the number of actual plates necessary to separate certain mixture by a set of plates. Several definitions have been suggested for the determination of the efficiency of contact facilities. Lewis [3] defined the total (average) efficiency coefficient of rectification column (E_0) as the ratio between the theoretical number of plates N_t and that of the actual number of plates N_r necessary to carry out certain separation:

$$E_0 = N_t / N_r \quad (1)$$

The effectiveness of the mass-transfer process on the plate is characterized by differential and integral characteristics [2]. The differential characteristic (local) determines the mass-transfer in a unit (local) volume of the system vapor-liquid while the integral one – over the whole plate. Among the many methods suggested for quantitative estimation of the efficiency, the most general and convenient with respect to the model of "theoretical plate" is the definition of the coefficient of efficiency suggested by Murphree back in 1925 [10]. The local efficiency coefficient (local efficiency) is used as the differential characteristic and as integral characteristic of the mass-transfer efficiency – the efficiency coefficient of the plate (coefficient of efficiency of Murphree). Assuming constant flow rates (vapor and liquid) throughout a counter-flow column, for the n^{th} plate we have:

- Coefficient of efficiency of the plate for the vapor phase E_{MV} :

$$E_{MV} = \frac{(y_n - y_{n-1})}{(y^* - y_{n-1})} \quad (2)$$

-Coefficient of efficiency of the plate for the liquid phase E_{ML} :

$$E_{ML} = \frac{(x_{n+1} - x_n)}{(x_{n+1} - x^*)} \quad (3)$$

In equations (2) and (3), the average concentrations of the incoming and outgoing flows are as follows:

y_n, y_{n-1} – average composition of the vapor flowing out and in (respectively) the n^{th} plate, mol/mol;

x_n, x_{n+1} – average composition of the liquid flowing out and in (respectively) the n^{th} plate, mol/mol;

y^* - composition of the vapor in equilibrium with the outgoing liquid with composition x_n , mol/mol;

x^* - composition of the liquid in equilibrium with the outgoing vapor with composition y_n , mol/mol.

The physical meaning of the coefficient of efficiency of Murphree is, taking for example the vapor phase eq.(2), the ratio between the real change of the average concentration of the vapor passing through the n^{th} plate ($y_n - y_{n-1}$) to the theoretically possible change ($y^* - y_{n-1}$) which would have taken place if the outgoing vapor reached equilibrium composition y^* corresponding to the composition of the outgoing liquid x_n .

For the definition of the local efficiency coefficient, analytical expression similar to that in eq.(2) is used but all the concentrations refer to flows coming to and leaving random elementary volume of the vapor-liquid layer. Thus, the local efficiency coefficient is defined by the expressions:

$$E_{OG} = \frac{(y_p - y_{p-1})}{(y^* - y_{p-1})} \quad (4)$$

$$E_{OL} = \frac{(x_{p+1} - x_p)}{(x_{p+1} - x^*)} \quad (5)$$

Where the indices $p, p+1, p-1$ refer to the flows coming to and leaving an elementary volume of the layer.

The local characteristics of the mass-transfer efficiency depend on the kinetic parameters of the process and include mainly the diffusion resistances of the two contacting phases. The local efficiency coefficient of the plate has precise physical meaning and it can vary from 0 to 1.

The separation efficiency depends on three groups of factors: design and size of the apparatus, hydrodynamic conditions and the physicochemical properties of the separated mixture.

The aim of the present work is to study the influence of some physicochemical properties – viscosity, density and coefficient of molar diffusion in both phases, on the local efficiency of rectification of four model mixtures: benzene-heptane, heptanes-toluene, methanol-toluene and dichloroethane-propanol.

MATERIALS AND METHODS

A laboratory glass column with 1 sieve plate was used [11]. The column is equipped with external weirs to eliminate the wall effect on the vapor-liquid two-phase layer forming on the plate. The equilibrium graphical dependencies $y^* = f(x)$ were plotted on the basis of equilibrium data [12]. Based on the experimental data obtained in this work for benzene-heptane model mixture, the local efficiency was calculated. All the analyses of the binary mixtures were performed refractometrically with refractometer ABBE – AR4D equipped with thermostat. The precision at

which the coefficient of refraction was measured was $\Delta n_d^{25} = \pm 0.0001$ which corresponds to error when the concentrations are determined by standard curve $n_d^{25} = f(x)$ about ± 0.25 mol %. Experimental data are used for local effectiveness and by other authors [13-15].

RESULTS AND DISCUSSION

The influence of some basic physicochemical properties on the local efficiency by rectification of 4 hydrocarbon mixtures was studied. The effect of liquid phase density ρ_L on the local efficiency E_{OG} is presented in Fig.1. It can be seen from the figure that the local efficiency increased with the increase of the density of the separated mixture liquid phase.

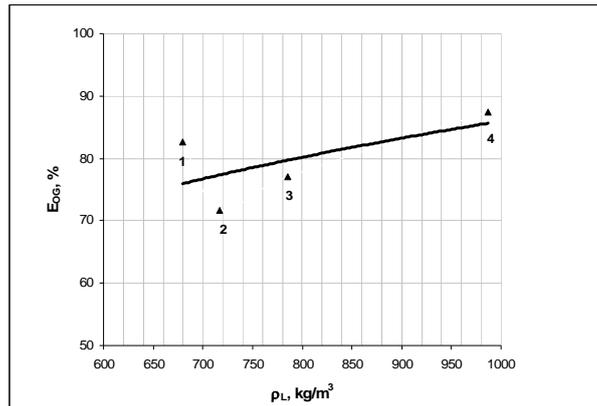


Fig. 1. Effect of liquid phase density ρ_L on the local efficiency E_{OG} :
*p.1 – Benzene-heptane, p.2 – heptane-toluene, p.3 – methanol-toluene,
 p.4 – Dichloroethane-propanol*

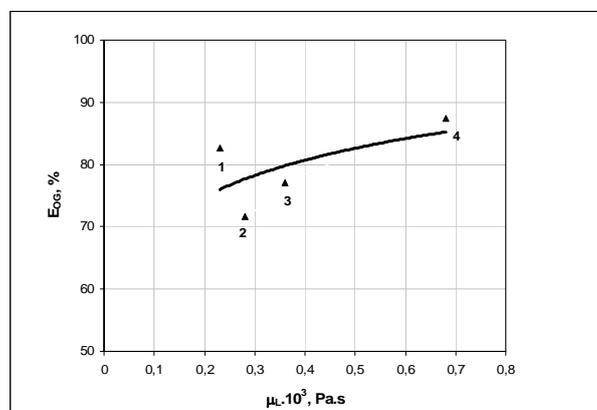


Fig. 2. Effect of liquid phase viscosity μ_L on the local efficiency E_{OG} :
*p.1 – Benzene-heptane, p.2 – heptane-toluene, p.3 – methanol-toluene,
 p.4 – Dichloroethane-propanol*

Similar effects were observed for the other physicochemical properties studied – liquid phase viscosity μ_L (Fig. 2), as well as the coefficients of molar diffusion in the liquid phase D_L (Fig.3) and in the vapor phase D_G (Fig. 4).

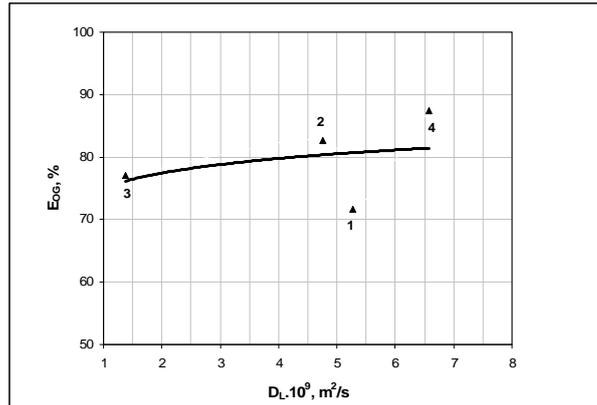


Fig. 3. Effect of the coefficient of molar diffusion in the liquid phase D_L on the local efficiency E_{OG} :
*p.1 – Benzene-heptane, p.2 – heptane-toluene, p.3 – methanol-toluene,
 p.4 – Dichloroethane-propanol*

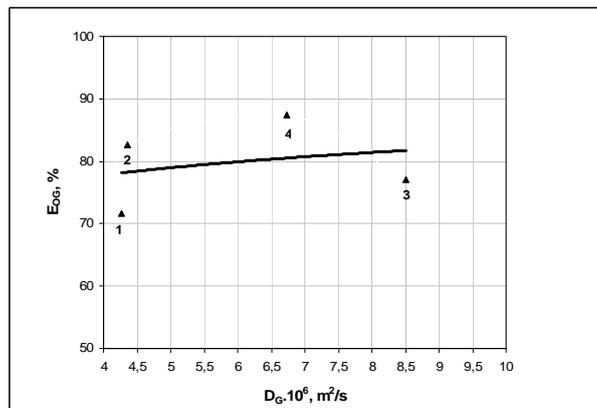


Fig. 4. Effect of the coefficient of molar diffusion in the vapor phase D_L on the local efficiency E_{OG} :
*p.1 – Benzene-heptane, p.2 – heptane-toluene, p.3 – methanol-toluene,
 p.4 – Dichloroethane-propanol*

The experimental studies were carried out in wide concentration interval with respect to the content of the high-boiling component (LBC) in the initial two-component mixture. Considering the effect of the concentration on the physicochemical properties of the two-component mixtures separated, the graphical dependencies presented above were taken at initial LBC concentration in the liquid phase on the plate 0,55 – 0,6 mol/mol for all the mixtures studied.

CONCLUSIONS

1. Experimental studies were carried out on the effect of the separated mixtures physicochemical properties on the local efficiency of separation by rectification in a plate column with one sieve plate.
2. The increase of the density, viscosity and coefficient of molar diffusion in the vapor phase resulted in an increase of the local efficiency. The strongest influence on the local efficiency was observed for the change of the density of the separated mixture liquid phase while the weakest – the coefficient of molar diffusion in the vapor phase.

ACKNOWLEDGEMENT

The present study was carried out owing to the financial support of the National Science Fund of Bulgaria at the Ministry of Education, Youth and Science.

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