SURFACE TENSION EFFECTS IN SIEVE PLATE DISTILLATION COLUMN

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ABSTRACT

Rectification is one of the methods for separating liquid mixtures based on different distribution between the liquid and vapour phases of the components in the mixture. Vapor and liquid flow are passed countercurrent, repeatedly interacting with one another through special apparatuses (rectification columns), in which part of the vapor (or liquid) leaving the column is recovered after condensation (in the case of the vapour) or evaporation (in the case of the liquid). Contact between the two phases takes place on the contact devices (trays) horizontally located along the height of the column.

The purpose of this work was to study the effect of surface tension on the rectification efficiency of the methanol-water mixture in the conditions of complete mixing of the liquid phase and the ideal displacement regime in vapour phase, as well as to compare the results with those for chloroform-benzene mixture according to experimental data.

Key words: distillation, surface tension, local efficiency, efficiency by Murphree

INTRODUCTION

Rectification is one of the well known methods for separation of liquid mixtures based on the different distribution between liquid and gaseous phases of the components in the mixture. By continuous rectification, the gaseous and liquid streams flow in opposite directions while interacting with each other in special installations (rectifying column or rectifier), where part of the gas (or liquid) flowing out of the column is refluxed after condensation (for vapors) or evaporation (for liquids). The contact between phases takes place on horizontal plates or trays mounted at different heights. The main characteristic of the process is its efficiency. It is well known that the vapor-liquid layer formed on the plates, as well as the process of mass-exchange taking place within it, are affected by the gradient of the surface tension during the mass-exchange. [1]. According to their surface tension, the binary mixtures are classified into positive ($d\sigma/dx \prec 0$), negative ($d\sigma/dx \succ 0$) and neutral ($d\sigma/dx = 0$) [1]. To estimate the effect of the surface tension on the mass-exchange, the values stabilization index (M-index) and Marangoni-number criterion. M-index is the product of the driving force of the process in the liquid phase and the surface tension gradient of the liquid phase composition. [2-4]:

$$M_{index} = \left(x - x^*\right)\frac{d\sigma}{dx}$$

The Marangoni-number criterion can be expressed by several formulae:

$$M_a = \frac{\left(-\frac{\partial \sigma}{\partial c}\right).c_o.H}{\mu.D} \quad ; \quad M_a = \frac{\Delta\sigma}{k_L^*.\mu}$$

where: x – mole part of low-boiling component in the liquid phase, mol/mol; x*- mole part of low-boiling component мin the liquid phase which is in equilibrium with the low-boiling component in the gaseous phase, mol/mol; $d\sigma/dc$ - change of the surface tension depending on low-boiling component concentration in the liquid phase, H- characteristic geometric size, m; D – coefficient of diffusion, m^2/s; k_L^*- local coefficient of mass-exchange, kmol/m^3.s; μ - viscosity, Pa.s; $\Delta\sigma$ - difference between the values of the surface tensions, mN/m.

The aim of the present work is to study the effect of the surface tension on the efficiency by the rectification of a mixture of methanol and water under conditions of full mixing of the liquid phase and regime of ideal shift by gaseous phase, as well as compare the results obtained with these for mixtures of chloroform-benzene according to experimental data.

MATERIALS AND METHODS

Laboratory glass installation was used for experimental measuring the efficiency by rectification of binary and multi-component mixtures **[5]**. The column is equipped with external overflow drains to eliminate the wall effect on the two-phase gaseous-liquid layer forming on the plate. A glass column with one reticulated plate was used **[6].** Binary mixture of methanol and water was used as model mixture. For the experiments, equilibrium data on the model mixture methanol – water were used **[7].** With these data, the equilibrium dependence $y^* = f(x)$ was plotted. The method of refractometry was used to determine the compositions since it is simple and provides enough precision. Due to the lack of literary data, the values of the refraction coefficients for the different binary mixtures were determined experimentally (Table 1). From these data, the dependence $n_d^{20} = f(x)$ was plotted.

Table 1. Coefficients of refraction n_d^{20}

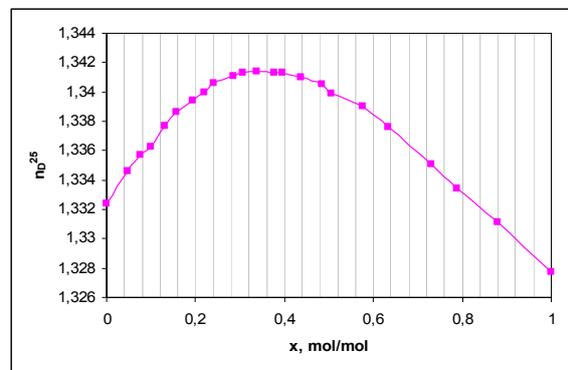| n_d^{20}	x, mol %	n_d^{20}	x, mol %
1,3324	0	1.3413	37.60
1,3346	4.71	1.3413	39.52
1,3357	7.49	1.3410	43.72
1,3363	9.96	1.3405	48,31
1,3377	12.98	1.3399	50,63
1,3386	15.69	1.3390	57,62
1,3394	19.34	1.3376	63,45
1,3400	22.04	1.3351	72,99
1,3406	24.12	1.3334	78,89
1,3411	28.48	1.3311	87,83
1,3413	30.66	1.3277	100
1.3414	33.68		

Fig.1. *Dependence* $n_d^{20} = f(x)$

The experiments were carried out by a well-known technique **[8]**.

All the analyses of the binary mixtures were carried out on a Refractometer of ABBE -AR4D requipped with thermostat. The refraction coefficients were measured with precision of $\Delta n_d^{25} = 0.0001$, which corresponds to the error in the determination of a concentration by standard curve $n_d^{25} = f(x)$ of about $\pm 0,20 \, mol\%$.

The column performed under the following load by vapor phase: vapor velocity vs the total cross-section of column $w_v = 0,07 \div 0,23$ m/s; vapor velocity vs the free cross-section (openings) $w_o = 2,66 \div 8,75$ m/s. From the more than 100 samples measured, only these were used for which the error in the materials balance for the two phases was less than 10%. Based on the experimental data obtained, the local efficiency was calculated by the formula **[9]**:

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

where y_n, y_{n-1} is the average composition of the outflowing and inflowing vapor flows on the nth plate, mol/mol; y^* - composition of the vapor in equilibrium with the liquid flowing out of the plate with composition x_n, mol/mol.

RESULTS AND DISCUSSION

The experimental data on the effect of vapor velocity (w_v) and low-boiling component concentration in column cube (x_w) on the local efficiency coefficient (E_{OG}) are presented in Figs.2 and 3. As can be seen from Fig.2, at low-boiling component concentrations in the initial mixture

1.5 mol% and 2.1 mol%, the local efficiency coefficient had maximum at vapor velocities in the interval 0.13 – 0.15 m/s. At low-boiling component concentrations in the initial mixture 41.5mol% and 47.6 mol%, the local efficiency coefficient gradually decreased from 98.88 to 94.60% throughout the interval of velocities employed.
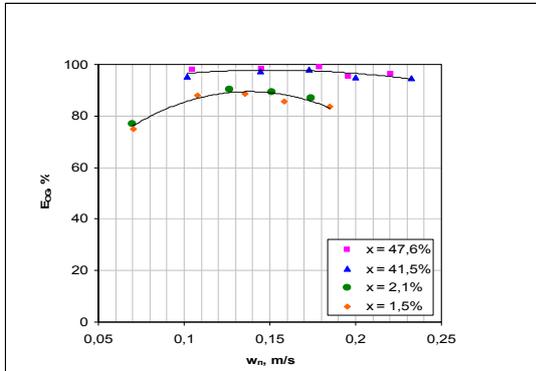

Fig.2. Dependence of the local efficiency coefficient on the vapor velocity in the column w_v at mixture composition in column cube x_W =1,5 mol/%, x_W =2,1 mol/%, x_W = 41,5 mol/% and x_W = 47,6 mol/%
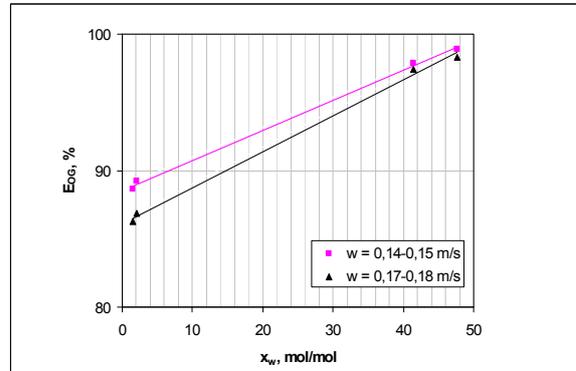
Fig.3. Dependence of the local efficiency coefficient on the composition of the binary mixture methanol – water in column cube x_w

Fig.3 shows the dependence of the local efficiency coefficient on the composition of the mixture methanol – water in column cube x_w. It can be seen from the plot that in the interval of velocities from 0.14 to 0.18 m/s, the change of low-boiling component concentration affects the separation efficiency. In the interval of concentrations from 1,5 % to 47,6%, the local efficiency coefficient increased with the low-boiling component concentration in the initial mixture. For the model mixture studied, the change of the methyl alcohol content in the initial mixture from 1,5 to 47,6% gave change in the local efficiency coefficient from 86,3% to 98,9%.

Without impurities in the model mixture, it was assumed that the local efficiency depends on the surface behavior of the model mixture. For the mixture of methanol – water, the surface tensions of the pure components at boiling temperature are σ_{CH_3OH} = 18,90 mN/m, σ_{H_2O} =58,9 mN/m, i.e.

$\Delta\sigma$ = -39,99 mN/m. The mixture methanol – water is positive since $d\sigma/dx < 0$.

A comparison between the experimental data obtained on the local efficiency for the positive mixture methanol-water and the neutral mixture chloroform-benzene **[10]** is presented in Fig.4. It can be seen that the local efficiency for the neutral mixture did not change with the increase of low-boiling component concentration in the initial mixture and remained about 86-87% while the values of the local efficiency coefficient for the positive mixture methanol-water were about 10-12% higher than these for the neutral mixture chloroform-benzene and slightly increased within the interval of concentrations studied.
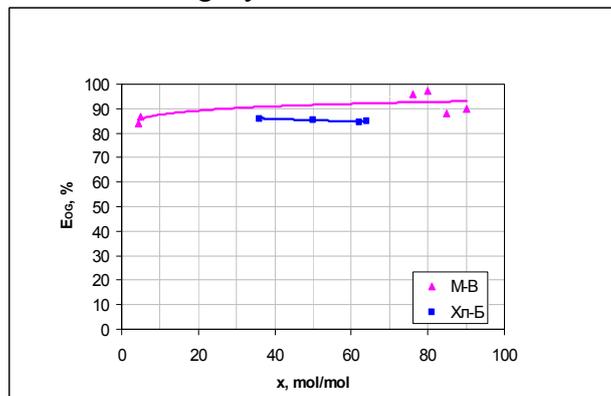

Fig.4. Change of the local efficiency coefficient on the composition of the mixtures methanol-water and chloroform-benzene under rectification

The change of the M-index of the mixtures chloroform-benzene is illustrated in Figs.5 and 6. The values of M-inex for the mixture chloroform-benzene changed in the interval from 0,007 to 0,25 and the change of the index increase exponentially depending on the mixture composition. For the mixture methanol-water, the values of the M-index changed in the interval 3,5 до 16,5 with a maximum of the curve M=f(x) in the concentration interval x = 0,6 – 0,7 mol/mol. The values of the M-index for the mixture methanol-water were 70 to 500 times higher than these for the mixture chloroform-benzene.
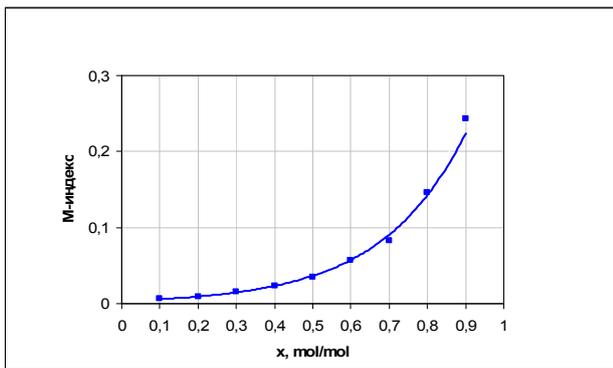

Fig.5. Dependence of the M-index on the composition of the mixture chloroform-benzene
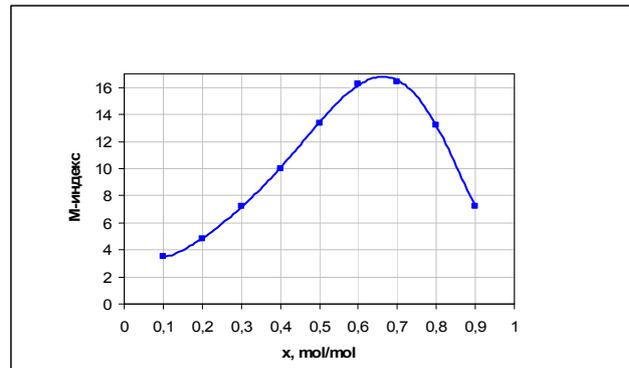

Fig.6. Dependence of the M-index on the composition of the mixture methanol-water

An attempt was made to estimate quantitatively the effect of the surface tension on the local efficiency coefficient (E_{OG}). For this purpose, the dependence of E_{OG} on the M-index at certain concentration was plotted using the diagrams in Figs.4, 5 and 6. The results obtained are presented in Fig.7 for the mixture chloroform-benzene and Fig.8 for methanol-water.

For the positive mixture methanol-water, the values of the local efficiency coefficient (E_{OG}) increased linearly with the increase of M-index. For the neutral mixture chloroform-benzene, the change of the M-index did not affect the E_{OG}, i.e. the surface tension had no influence on the degree of separation during rectification of the mixture chloroform-benzene.
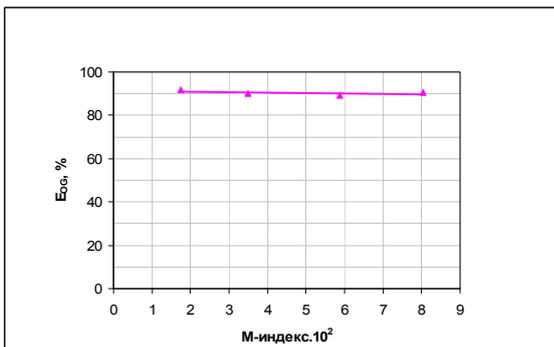

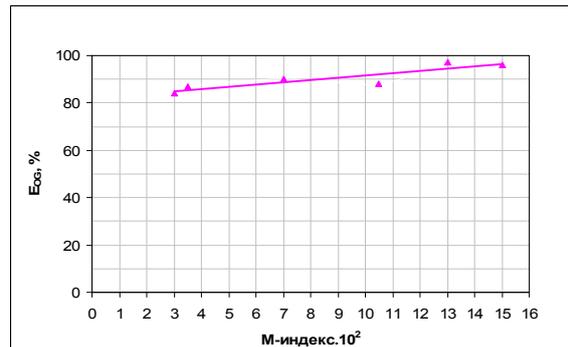**Fig.7.** Dependence of the local efficiency coefficient on the M-index for the mixture chloroform-benzene.

Fig.8. Dependence of the local efficiency coefficient on the M-index for the mixture methanol-water

CONCLUSIONS
1. Experiments on rectification at full phlegm of model system methanol-Water with different initial compositions and velocities of the vapor phase were carried out on a laboratory rectifier with one reticulated plate, diameter of 32 mm. The compositions of the inflowing and outflowing flows were measured, the temperature profile of the column and the height of the gas-liquid layer.

2. The effect of surface tension on the efficiency of separation by rectification (E_{OG}) of the mixtures Methanol-Water and Chloroform-Benzene was analyzed.
3. Linear dependence was found between E_{OG} and the stabilization M-index for the positive mixture methanol-Water. For the neutral mixture Chloroform-Benzene, the local efficiency coefficient (E_{OG}) did not depend on the M-index.

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