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EFFECT OF THE COEFFICIENT OF MASS TRANSFER BY RECTIFICATION OF TETRACHLOROMETHANE-TOLUENE MIXTURE

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Abstract: The mass transfer occurring during the rectification in plate columns is not fully studied and has not been described theoretically so far because it takes place under hydrodynamic conditions. To avoid hydrodynamic effects, the experimental studies on the efficiency of the rectification process were carried out with a small diameter laboratory column. The aim of the study was to obtain experimental data on the local efficiency and, respectively, the number of transferred units by the rectification of the model mixture methanol-toluene using a laboratory column with one sieve tray under atmospheric pressure and full reflux.

Key words: coefficient of mass transfer, rectification ...

INTRODUCTION

Mass transfer is a process of movement of mass which is directly related to the movement of gas or liquid. It comprises a number of phenomena the final result from which is the transportation of active component of a fluid flow to a interphase boundary and vice versa. A prerequisite is the existence of difference of the concentrations of the active component at the core of the flow and at the interphase boundary. To avoid the influence of hydrodynamics, the experimental studies on the efficiency of the rectification process were carried out on laboratory columns with small diameter. It was assumed, however, that both phases are under ideal hydrodynamic conditions – the vapor phase ascends through the vapor-liquid layer under regime of ideal displacement while the liquid phase moves under regime of ideal mixing (Biddulph & Kalbassi, 1990). Under these conditions, experimental data on the local efficiency were obtained and their processing provides information about various kinetic relationships of the mass transfer process occurring by the rectification.

According to the thin film theory (Lewis & Davidson, 1982 and Whitman, 1923), thin films (layers) are formed on both sides of the interphase boundary and they exert substantial resistance to the process since the mass transfer through them occurs by molecular diffusion.

The aim of the present paper is to obtain data on the local efficiency and, respectively, the number of transferred units by rectification of the model mixture tetrachloromethane-toluene using a laboratory column with one sieve tray at atmospheric pressure and full reflux. The results obtained were processed further to determine the volume coefficient of mass transfer by the rectification of the mixture mentioned above.

EXPERIMENTAL

Laboratory glass installation was used to carry out the experimental work (Radev & Stefanov, 2013). It is used for measurements of the efficiency by rectification of binary mixtures. The column is equipped with external weirs for elimination of the wall effect on the vapor-liquid two-phase layer formed on the tray. The small diameter of the tray makes it possible to assume full mixing of the liquid and allows direct experimental determination of the local coefficient of efficiency.

To determine the compositions of the incoming and outgoing flows, the method of refractometric determination was used. Due to the lack of literary data on the dependence of the coefficient of refraction at 20°C on mixture composition, the concentrations were determined by precision of 4 digits. Analytic scales KERN model ABS 220-4 equipped with a thermostat was employed for the measurements. With the experimental data obtained, the dependence of the coefficient of refraction at 20°C was plotted as function of the composition of the mixture tetrachloromethane-toluene and presented in Fig.1.



Fig 1. Dependence of the refraction coefficient on the composition of the model mixture tetrachloromethane-toluene.

The mixture of tetrachloromethane-toluene studied was placed in a 1 l flask with a funnel and its initial composition was determined. The flask was equipped with internal heater with power of 0,5 kW connected to the power grid by a regulating transformer. The latter was used to vary the voltage from 160 to 210 V which results in changes of the vapor load in the column and, respectively, the vapor velocity in the column. Samples for analysis were taken from the incoming and outgoing flows from the tray at each of the preliminarily set voltages. This was done by specially mounted taps, as well as by a syringe. The readings of the four thermometers were recorded and of special significance were considered these from the temperatures of the vapors above and below the tray. The samples taken from the vapor flows were cooled to condense the vapor. A water glass condenser was mounted at the top of the column (reflux condenser). Thus, the experiments were carried out under atmospheric pressure and full reflux.

The analysis of the compositions of the binary mixtures was performed using Abbe refractometer – AR4D equipped with additional thermostat. The coefficient of refraction at 20°C was measured with accuracy of \pm 0,0001 which corresponds to an error by determination using standard curves of about \pm 0,25 mol %. The temperature was measured by local mercury thermometers in the cube and at the top of the column. The visual observations of the two-phase layer showed formation of hydrodynamically stable layer. Foam height was measured visually.

For each experiment, the composition of the initial mixture and, when the column entered working regime, samples were taken for analysis to measure the average compositions of the vapor flows incoming and outgoing the tray, as well as the liquid going out of the tray. The temperature

and debit of the reflux were also measured. Among the samples taken, only these were processed for which the error of the material balance was less than 10 %.

RESULTS AND DISCUSSION

The coefficients of mass transfer are kinetic characteristics of the overall process of transfer. They reflect the amount of substance transferred from one phase to another per unit time normally through unit interphase surface per unit driving force. Since the interphase boundary of tray columns, which actually is the real geometric surface of the vapor-liquid layer, is created by bubbling of the vapor phase through the liquid phase as a dynamic system, it is a value hard to determine. Thus, tit is often done using the interphase boundary. Then, the basic equation is:

$$M = K_{OG} \cdot aV \cdot \Delta Y = K_{OL} \cdot a. \tag{1}$$

In the basic equation, $K_{OG.a}$, $(K_{OL.a})$ are the volume coefficients of mass transfer which indicate the amount of substance transferred between the two phases in unit volume per unit driving force. To determine the volume coefficient, it is necessary to find the following parameters of the process (Stefanov & Ivanov, 2010):

• Vapor velocity in the column is calculated from the ratio between the volume debit of the vapor and the column area using the following equation:

$$W_{\rm p} = \frac{\sigma_{\rm p}}{F} = \frac{1}{15} \tag{2}$$

• The volume debit of the vapor is calculated from the relationship:

$$G_v =$$
 (3)

where L_F is the volume debit of the reflux.

• reflux density in eq.(3) is calculated by the following equation:

$$\rho_F - X_{F^*} \rho_A + (1 - 1) \tag{4}$$

• From the equation of Mendeleev-Clapeyron, the average density of the vapor in the column is determined:

$$\rho_{\psi} =$$
 (5)

where M_v is the molecular weight of the vapor phase calculated by the expression:

$$M_{\rm w} = y_{\rm over} M_A + (1 - y_{\rm over}$$
 (6)

• The number of transferred units is calculated using the following relationship:

$$N_{OG} = -\ln\left(1 - \right) \tag{7}$$

• The local efficiency (E_{OG}) is calculated from the experimental data and the expression:

$$E_{OG} =$$
(8)

where:

 y_1 – concentration of the readily volatile component in the vapor phase beneath the tray, mol/mol;

 y_2 - concentration of the readily volatile component in the vapor phase above the tray, mol/mol;

 y^* - the equilibrium concentration of the readily volatile component in the vapor phase calculated by the y-x diagram vs the concentration of the liquid phase flowing out of the tray.

• The volume coefficient of mass transfer in a vapor phase is determined by the following equation:

$$K_{\rho\sigma}a = W_{\nu}\rho \tag{9}$$

where h_v is the height of the foam formed by the dispersion of the vapor phase in the liquid one.

The dependence of the total volume coefficient of mass transfer on the vapor velocity in the column for certain composition of the model mixture is presented in Fig.2. At concentrations of the readily volatile component in the initial mixture 9,4; 18,4; 22,9; 27,9 and 38,6 %, the increase of vapor velocity results in a decrease of the total volume coefficient of mass transfer.



Fig.2. Dependence of the total volume coefficient of mass transfer on vapor velocity in the column.

Fig.3 shows the dependence of the total volume coefficient of mass transfer on the composition of the binary mixture at certain velocities. At velocities of 0,03-0,04 m/s and 0,07 m/s, slight increase of the total volume coefficient of mass transfer was observed with the increase of concentration of the readily volatile components in the initial mixture from 9.4 to 38.6% while the change of vapor velocity in the column from 0,04 to 0,06 m/s resulted in a sharp increase of the volume coefficient of mass transfer.



Fig. 3. Dependence of the total volume coefficient of mass transfer on the composition of the binary mixture in the column

CONCLUSIONS

1. Using laboratory rectification column with one sieve tray with diameter of 32 mm, the local efficiency, number of transferred units, the total volume coefficient of mass transfer and the resistance on the two phases were determined under conditions of full reflux for the model mixture tetrachloromethane-toluene.

2. With the increase of the load and, respectively, the velocity of the vapor in the column, the total volume coefficient of mass transfer decreased within the whole interval of concentrations studied.

3. For the whole concentration interval studied, the volume coefficient of mass transfer had the highest values at vapor velocity in the column between 0,04 and 0,06 m/s.

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