

A NEW METHOD TO PREDICT SPECIFIC INTERFACIAL MASS TRANSFER AREA IN DISTILLATION COLUMN WITH SIEVE TRAY

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ABSTRACT

One of the main problems in the tray tower distillation columns are the mass transfer kinetic studies, which are complicated by the difficulties in determination the specific interfacial area. The specific interfacial area is an important characteristic of the gas-liquid layer on the trays, directly influencing the process mass transfer. The last is formed by the vapour dispersion in the liquid phase on the tray, as well as and the mixing of the liquid which is moving on the trays. It has been studied the specific interfacial area in distillation of various binary mixtures under the conditions of completely mixed liquid phase and the alternate plug flow model for the vapor phase. To approach these ideal models of motion of the two phases the experiments were conducted in small scale laboratory glass column with one sieve tray.

The present work is a contribution in this field, which is quite actual in the last years. This method has an experimental and computational nature, since the definition of interfacial mass transfer area "a" goes through processing of experimental data and theoretical calculations.

Key words: interfacial area, mass transfer coefficient, tray column

INTRODUCTION

One of the main problems in the tray tower distillation columns are the mass transfer kinetic studies, which are complicated by the difficulties in determination the specific interfacial area. The last is formed by the vapour dispersion in the liquid phase on the tray, as well as and the mixing of the liquid which is moving on the trays [1]. The interfacial surface is an important characteristic of the gas-liquid layer on the trays, directly influencing the process mass transfer. The present work is a contribution in this field, which is quite actual in the last years. This method has an experimental and computational nature, since the definition of "a" goes through processing of experimental data and theoretical calculations. The method is only applicable to the laboratory model column with glass sieve tray if the following conditions:

- the liquid entering the tray is assumed to be perfectly mixed;
- for the vapor is provided the alternate plug flow model;
- the trayed column works in total reflux mode at atmospheric pressure;
- the column is equipped with sieve tray with outlet weir.

It has been studied the specific interfacial area in distillation of various binary mixtures under the conditions of completely mixed liquid phase and the alternate plug flow model for the vapor phase. To approach these ideal models of motion of the two phases the experiments were conducted in small scale laboratory glass column.

MATERIALS AND METHODS

In the mass transfer processes, the liquid and the vapor phases come in direct contact with one another. As a result, during the process between them is formed the so-called interfacial surface. The interfacial surface is an important characteristic of the gas-liquid layer on the tray, affecting directly the mass transfer processes. The interfacial surface in bubbling apparatus depends on hydrodynamic regimes, which in turn depend on both fluid flows and the structure of the contact devices [2].

It is developed a method for calculating the specific interfacial mass transfer area in distillation of binary mixtures. The method is based on the comparison between the volumetric gas-phase mass transfer coefficient $K_{OG} \cdot a$ obtained experimentally and the one given by the Higbie's

penetration theory overall mass-transfer coefficient based on vapor K_{OG} for same mixture and conditions [3]:

$$a = \frac{(K_{OG}a)^{exp}}{(K_{OG})^{cal}} \quad (1)$$

The calculating of overall gas-phased mass transfer coefficient K_{OG} is based on two-resistance theory and penetration model [4]:

$$\frac{1}{K_{OG}} = \frac{1}{\beta_G} + \frac{m}{\beta_L} \quad (2)$$

According to Higbie's penetration model, for explaining the mass transfer through the free surface, it is assumed that the turbulence brings elements of bulk liquid to the free surface. In the short time of contact, the molecules of the bulk liquid are transferred to another phase by unsteady mass transfer, also called penetration. After the time of contact the element is returned to the bulk liquid and is replaced by another one [8].

The liquid and vapor mass transfer coefficients are obtained by the following equations, for same time of contact [5]:

$$\beta_G = \sqrt{\frac{4D_G}{\pi\theta_G}} \quad (3)$$

$$\beta_L = \sqrt{\frac{4D_L}{\pi\theta_L}} \quad (4)$$

For the calculation of molecular diffusion coefficients for vapor phase D_G and liquid phase D_L , are used the formulas:

$$D_G = \frac{4,3 \cdot 10^{-7} T^{3/2}}{p(v_A^{0,333} + v_B^{0,333})^2} \sqrt{\frac{1}{M_A} + \frac{1}{M_B}} \quad (5)$$

$$D_L = \frac{KM_B^{0,5} T}{\mu_B (V_A V_B)^{1/3}} \quad (6)$$

It is impossible to measure the time of contact for vapor phase, θ_G , that's why it is estimated by assuming that the time of contact of the vapor is the time taken by the vapor phase to pass through the gas-liquid layer and it can be expressed as follows:

$$\theta_G = \frac{h_L}{u_G} \quad (7)$$

The contact time for the liquid phase is:

$$\theta_L = \theta_G \frac{\rho_G}{\rho_L} \quad (8)$$

where h_L is clear liquid height. The clear liquid height on a sieve tray plays an important role in the mass transfer because of its influence on θ_G and θ_L . Nearly all tray performance correlation includes clear liquid height as a variable. Under total reflux conditions the correlation is given by [6];

$$h_L = 0.6 h_w^{0.5} p^{0.25} \left[\left(\frac{\rho_G}{\rho_L} \right)^{0.5} / b \right]^{0.25} \quad (9)$$

The overall vapor mass transfer coefficient $K_{OG} \cdot a$ is given as [7]:

$$K_{OG} a = \frac{u_G \rho_G [-\ln(1 - E_{OG})]}{h_f M} \quad (10)$$

Then for the specific interfacial mass transfer area from eq. (1) we can finally obtain:

$$a = \frac{u_G [-\ln(1 - E_{OG})]}{h_f K_{OG}} \quad (11)$$

In eq. (11) the parameters u_G , E_{OG} and h_f , are experimentally determined, and K_{OG} is calculated. That's what gives the experimentally-calculated character of the method for predicting the specific interfacial mass transfer area.

EXPERIMENTAL RESULTS

Figure 1 shows that the calculated value of the specific interfacial mass transfer area varies as a function of vapor velocity in the column for four binary systems propanol – water, methanol – propanol, dichlorethan – propanol and water acetic acid at atmospheric pressure. As the height of the gas-liquid layer varies for the four systems, this means the variation of the specific interfacial area as a function of the vapor velocity will be different.

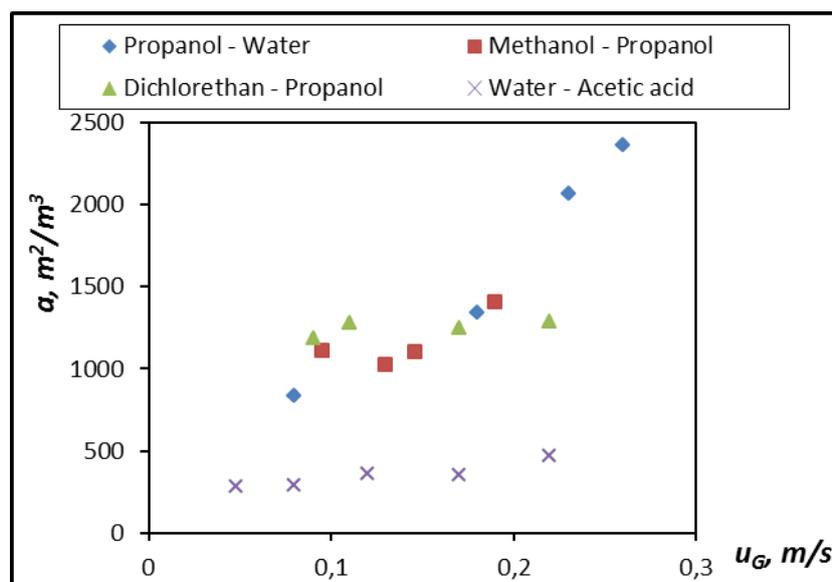


Fig. 1. Specific interfacial mass transfer area (a) as a function of the vapour phase velocity (u_G).

The specific interfacial mass transfer area increases with increasing the vapor phase velocity within the range of investigation for the four binary mixtures. Biggest value has the mixture propanol - water, and lowest value has the mixture water – acetic acid varying in the range of 284 to 2358 m^2/m^3 .

For a certain type of tray and all other same conditions the specific interfacial area depends only on the physical properties of the separated mixture – density, viscosity and surface tension.

According to Kolmogoroff's theory for the local isotropic turbulence we can consider that the viscosity does not affect the specific interfacial area [5]. After statistical processing of literature Gistrich and Kraus offer correlation. According to these properties of the liquid phase essentially influencing specific interfacial mass transfer area as exponent takes into account the properties of the equation is 0.003 [9].

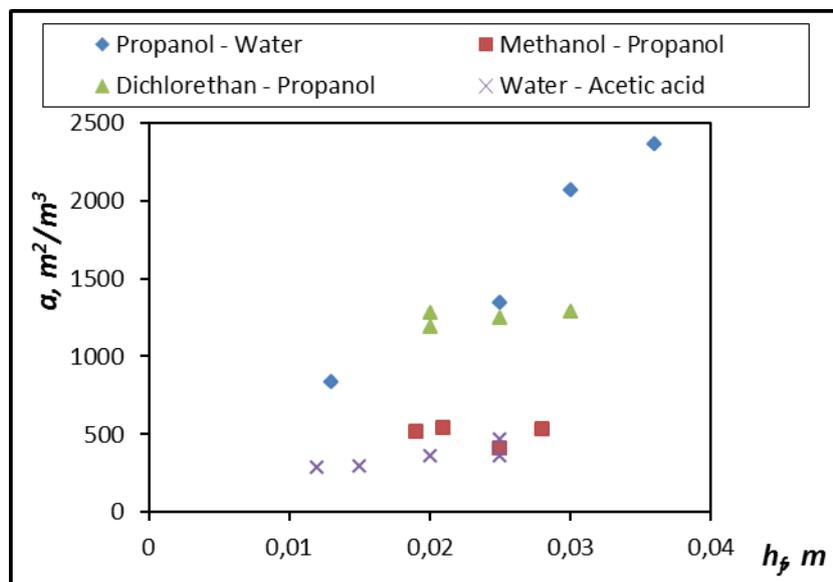


Fig. 2. Specific interfacial mass transfer area (a) as a function of aerated liquid height h_f .

Figure 2 shows that the specific interfacial mass transfer area obtained by the experimental model as a function of the aerated liquid height. As it can be seen in Figure 2, for the binary mixture propanol – water the specific interfacial mass transfer area increasing with increment the aerated liquid height and amended in the range 834 to 2358 m^2/m^3 . For all three binary mixtures increasing the aerated liquid height does not significantly affect over specific interfacial mass transfer area and amended in a very narrow range.

CONCLUSIONS

New models to predict the specific interfacial mass transfer area developed in this study. The classical penetration theory is applicable to predict specific interfacial mass transfer area for binary systems propanol – water, methanol – propanol, dichlorethan – propanol and water-acetic acid in a laboratory column with one sieve tray under atmospheric pressure.

NOMENCLATURE

a	Specific interfacial mass transfer area [m^2/m^3]
D_G	Molecular diffusion coefficients for vapor phase [m^2/s]
D_L	Molecular diffusion coefficients for liquid phase [m^2/s]
h_f	Aerated liquid height [m]
h_L	Clear liquid height [m]
h_w	Outlet weir height [m]
K_{OG}	Gas-side mass transfer coefficient [$\text{m}\cdot\text{s}^{-1}$]
$K_{OG}a$	Overall mass transfer coefficient [$\text{kmol}/\text{m}^3\cdot\text{s}$]
M	Molecular weight [kg/kmol]
m	slope of vapor-liquid equilibrium line
N_{OG}	Number of overall vapour phase transfer units
u_G	Vapour phase velocity [m/s]
β_G	Vapour-phase mass transfer unit
β_L	Liquid-phase mass transfer unit
θ_G	Contact time in vapour phase [s]
θ_L	Contact time in liquid phase [s]
ρ_G	gas density [$\text{kg}\cdot\text{m}^{-3}$]
ρ_L	liquid density [$\text{kg}\cdot\text{m}^{-3}$]

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