

STUDY OF THE EFFECT OF SURFACE TENSION AND ITS INFLUENCE ON SPECIFIC INTERFACIAL AREA IN DISTILLATION LABORATORY COLUMN

Zhivko Ivanov, Mariana Karaivanova, Dobrin Georgiev, Adriana Georgieva

Faculty of Technical Sciences, "Prof. D-r. Asen Zlatarov", Prof. Yakimov Blvd, 8010 Bourgas, Bulgaria

ABSTRACT

The sieve tray columns refer to the bubbler apparatus. Mass transfer between the two phases carry out on one above other contacting devices or trays. Their role is to ensure the formation of the developed interfacial area between the vapor and liquid phases. The influence of these surface tension changes has been studied by Zuiderweg and Harmens who defined systems as positive when the less volatile component of a binary mixture had the higher surface tension, and negative when this component had the lower surface tension. Surface tension and its gradient are known to influence the efficiency of distillation trays by affecting the froth structure of gas-liquid mixtures. Since surface tension of liquids affects the size and stability of bubbles in froth.

The aim of this work was to studies how to amend the specific interfacial area as a result of the change in the value of the gradient of the surface tension. For realization of this work were used mixtures with different values of surface tension of the individual components and the results were summarized as a dimensionless equation.

Key words: *specific interfacial area, distillation, surface tension*

INTRODUCTION

The sieve tray columns refer to the bubbler apparatus. Mass transfer between the two phases carry out on one above other contacting devices or trays. Their role is to ensure the formation of the developed interfacial area between the vapor and liquid phases. Usually, the two-phases dispersion in the contacting area of a tray is either in the spray regime, which is also known as the churn turbulent regime or (mixed) froth regime. Operation in the spray regime is associated with low liquid rates, low liquid heights and low gas rates [1]. In the column the two-phases move countercurrent. One of the main problem of the sieve tray distillation columns are kinetic studies on mass transfer which are complicated by the difficulties in determining the interfacial area, which is formed by dispersing the vapor phase in the liquid phase on the tray. The amendment in the value of the surface tension influence the foam structure in the vapor-liquid mixture, which is formed immediately above the tray and thus directly influences the efficiency of the separation process. The influence of these surface tension changes has been studied by Zuiderweg and Harmens who defined systems as positive when the less volatile component of a binary mixture had the higher surface tension, and negative when this component had the lower surface tension [2].

The aim of this work was to studies how to amend the specific interfacial area as a result of the change in the value of the gradient of the surface tension. For realization of this work were used mixtures with different values of surface tension of the individual components and the results were summarized as a dimensionless equation.

MATERIALS AND METHODS

Surface tension and its gradient are known to influence the efficiency of distillation trays by affecting the froth structure of gas-liquid mixtures. Since surface tension of liquids affects the size and stability of bubbles in froth [3], as the most appropriate methodology was selected that associated with physical and chemical properties of the mixtures. According to the proposed method the specific interfacial area are depends on the cross section of column A , bubble rise velocity u_b , bubble formation frequency f_b and the bubble surface S_b [4,5]:

$$a_{pred.} = \frac{f_b S_b}{A u_b} \cdot h_L \quad (1)$$

The liquid holdup is traditionally described as the sum of two terms, i.e. the hold up bellows the weir and the hold up over the weir. Hofhuis however showed that his data and other literature data could as well be represented by one single equation [6]:

$$h_L = 0.6H_w^{0.5} P^{0.25} \left[\left(\frac{\rho_G}{\rho_L} \right)^{0.5} / b \right]^{0.25}$$

(2)

The surface of an ellipsoidal bubble can be calculated as follows:

$$S_b = \pi \frac{l^2}{2} \left[1 + \left(\frac{h}{l} \right)^2 \frac{1}{2e} \ln \frac{(1+e)}{(1-e)} \right]$$

(3)

To determine the bubble rise velocity u_b is necessary to know the value of the surface tension σ and the diameter of the bubble d_b :

$$u_b = \sqrt{\frac{2\sigma}{\rho_L d_b} + \frac{g d_b}{2}}$$

(4)

The bubble formation frequency f_b (i.e., the number of bubbles formed at the orifice per unit time) is determined as [7]:

$$f_b = \frac{Q_v}{V_b}$$

(5)

Due to small liquid hold-up and low gas loading in the Oldershaw column, the bubbles departed from the orifice coalesce before forming secondary bubbles. Therefore, the bubbles in the froth are essentially the primary bubbles detached from the holes of the sieve tray. Wilkinson proposed the following correlation for the bubble diameter [8]:

$$\left(\frac{g \rho_L d_b^2}{\sigma} \right) = 8.8 \left(\frac{u_G \mu_L}{\sigma} \right)^{-0.04} \left(\frac{\sigma^3 \rho_L}{g \mu_L^4} \right)^{-0.12} \left(\frac{\rho_L}{\rho_G} \right)^{0.22}$$

(6)

The bubble length l and height h can be estimated by the formulas derived by Terasaka *et al* [9]:

$$l = \frac{d_b}{1.14 Ta^{-0.176}}$$

(7)

$$h = 1.3d_b Ta^{-0.352} \quad (8)$$

The physical and chemical properties (viscosity, density, surface tension) of the individual components also and vapor velocity which are necessary for calculating are done for the sieve tray laboratory column equipped with one sieve tray.

EXPERIMENTAL RESULTS

Under the proposed method have been calculated the specific interfacial area a , bubble rise velocity u_b , bubble diameter d_b , bubble length l , bubble height h , bubble volume V_b and the liquid hold-up h_L . Experimentally determined the volumetric vapor flow rate Q_v and vapor velocity u_G . Used experimental data on the influence of surface tension on the effectiveness of binary mixtures Propan-1-ol – Water (positive system), Methanol – Propan-1-ol (neutral system) and 1,2-Dichloroethane – Propan-1-ol (negative system).

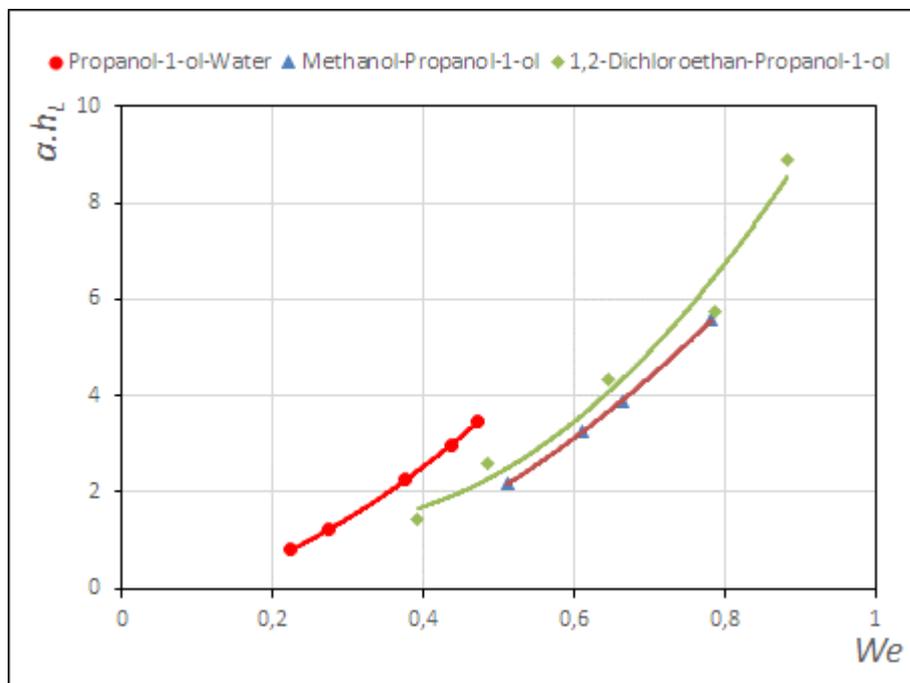


Fig.1. Interfacial area as a function of the We number

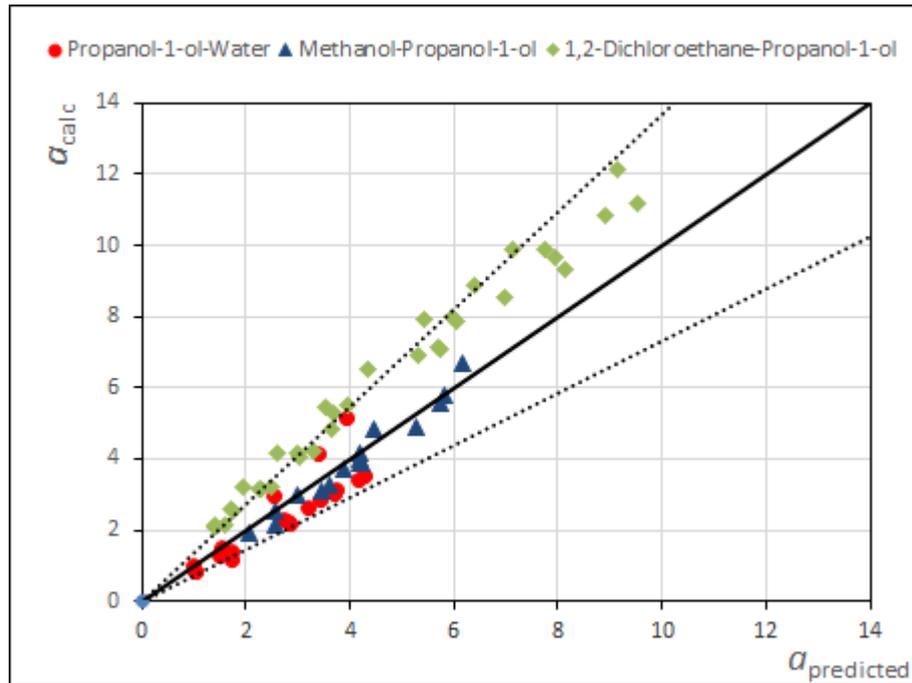


Fig.2. Interfacial area calculated with proposed physical method a_{pred} . against interfacial area calculated from dimensionless equation.

The influence of the surface tension on the interfacial area is shown in figure 1. For all three investigated mixtures the value of the interfacial area increases with the value of the criterion of Weber, respectively decreasing the value of the surface tension. As can be seen the value of the interfacial area of the negative mixture 1,2-Dichloroethane - Propan-1-ol is twice larger than the positive mixture Propan-1-ol – Water.

Mass transfer in sieve tray column is carried out under intensive regime, wherein determining the influence of the ratio between the inertial forces and the friction forces which is characterized by the Reynolds number. For reporting the influence of surface tension and diffusion processes it is necessary to calculate the Weber number and Schmidt number. To complement this analysis, we have undergone a fit for specific interfacial area as a function of dimensionless numbers (fig. 2). The equation obtained is the following:

$$a = 0.85 Re^{0.63} We^{0.9} Sc^{1.1} \quad (9)$$

Predicted values agree well with observed ones. The correlation indicates a good fit of the data within $\pm 25\%$.

CONCLUSIONS

The physical model is applicable for predicting specific interfacial area measured in three different binary mixtures, in a laboratory column with one sieve trays under atmospheric pressure. The specific interfacial area between vapor and liquid phases in a distillation column is a very important feature, which has been researched theoretically in this paper.

NOMENCLATURE

A	cross section of a column [m ²]
a	specific interfacial area [m ⁻¹]
d_b	bubble diameter [m]
e	bubble eccentricity
f_b	bubble formation frequency [s ⁻¹]
g	gravitational acceleration [m.s ⁻¹]
h_L	liquid hold-up [m]
h	height of a bubble [m]
l	length of a bubble [m]
S_b	bubble surface [m ²]
u_b	bubble rise velocity [m.s ⁻¹]
μ_L	liquid viscosity [Pa.s]
ρ_G	gas density [kg.m ⁻³]
ρ_L	liquid density [kg.m ⁻³]
σ	surface tension [N.m ⁻¹]

Morton number $Mo = \frac{g \cdot \mu_l^4}{\rho_l \cdot \sigma^3}$

Bubble Reynolds number $Re = \frac{d_s \cdot u_b \cdot \rho_l}{\mu_l}$

Tadaki number $Ta = Re \cdot Mo^{0.23}$

Weber number $We = \frac{\rho_L 2d_s (u_s g d_s)^{2/3}}{\sigma} \left(\frac{\rho_G}{\rho_L} \right)^{1/3}$

Schmidt number $Sc = \frac{\mu_G}{\rho_G \cdot D_G}$

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