COMPARISON OF MASS TRANSFER COEFFICIENTS DETERMINED BY DIFFERENT METHODS IN DISTILLATION COLUMN WITH THREE TRAYS

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ABSTRACT

The process of mass transfer systems gas (vapor)-liquid is a complex field in chemical engineering, industrial and laboratory level. In the first case, the process is carried out by a special apparatus in which it is very difficult to predict the behavior only of theoretical models. Therefore, it is necessary to evaluate the mass transfer coefficients and interfacial laboratory level. Crucial for mass transfer is the diameter of the bubbles. It is one of the most important parameters that help in finding the greater part of the parameters necessary for the design of the column. Classical gas is released in the form of small bubbles to give the effective mass transfer between the gas and liquid phases. To improve the efficiency of mass transfer is necessary interfacial mass transfer area and mass transfer coefficient can be controlled.

The aim of this work is to compare of the mass transfer coefficients in rectification obtained by two completely different methods. The experiment was carrying out in laboratory column at conditions near to model of ideal mixture for liquid phase and ideal displacement for vapor phase.

Key words: *rectification, mass transfer coefficient, tray column*

INTRODUCTION

Prediction of mass transfer coefficient is an important part of gas–liquid contactor design. The individual terms in volumetric mass transfer coefficients are difficult to measure directly. The volumetric gas-liquid mass transfer coefficient depends on the properties of the fluid, the hydrodynamic regime, and the configuration of the gas–liquid contacting device. The intensity of interfacial mass transfer is characterized by the volumetric mass transfer coefficient ($K_{OG}a$) and determines the amount of gas transferred from bubbles into the liquid phase. Bubble size is an important design parameter which has a strong influence on the hydrodynamic behaviour and on the volumetric mass transfer coefficients [1].

MATERIALS AND METHODS

Mass transfer effectiveness in gas–liquid contactors is most often expressed by means of the volumetric mass transfer coefficient ($K_{OG}.a$). This may be correlated, for example, with power input per unit volume and gas superficial velocity, but the resulting correlations do not achieve any degree of generality. Too many phenomena contribute to the values of the film coefficient, K_{OG} and of the specific area a and their combined effect cannot easily be predicted. Separation of K_{OG} and a in the volumetric mass transfer coefficient is thus first step for a better understanding of the underlying phenomena [2].

In the first model the pure mass transfer coefficient is found through following depends:

$$(K_{OG})^{Exp} = \frac{K_{OG} \cdot a}{a} \tag{1}$$

The volumetric gas-phase mass transfer coefficient $K_{OG}.a$, is calculated from the following equation:

$$K_G a = \frac{u_G \rho_G (-\ln(1 - E_{OG}))}{h_f M} \tag{2}$$

Where overall point efficiency, which takes into account effects of mass transfer on tray and in the settling zone, is defined as

$$E_{OG} = \frac{(y_n - y_{n-1})}{(y^* - y_{n-1})} \tag{3}$$

In order to calculate the gas-side mass transfer coefficient K_{OG}, one also needs to know how to calculate the specific interfacial area, a. The specific interfacial area a is a function of the gas and liquid density ρ_L, ρ_G, vapour velocity u_G, free area of the tray φ, liquid surface tension σ, and liquid viscosity [2]:

$$a = \frac{\rho_L^{0.33} \rho_G^{0.34} u_G^{0.68}}{\varphi^{0.14} \sigma^{0.67} \mu_L^{0.1}} \tag{4}$$

In the second one mass transfer coefficient is obtained by theoretical model, based on the geometric characteristics of the bubbles like sauter mean diameter, bubble formation frequency, number of bubbles in the dispersion, bubble surface, height and length of a bubble.

Under the examined operating conditions the theoretical model cannot be applied successfully for the sake of mass transfer coefficient (K_{OG}) prediction since this model is explicitly valid only for rigid spherical bubbles. For all other bubble shapes (ellipsoidal in our case) some correction term is needed since the theoretically calculated (K_{OG}) values are somewhat inflated and that is why some mitigation will reflect to a greater extent the reality. In the case of stripping of carbon dioxide from the aqueous solution with air, Miller has introduced the correction factor for the ellipsoidal shape of bubbles. [3]:

$$f_C = 683 d_S^{1.376} \tag{5}$$

According to the above logic the mass transfer coefficient is depending on the bubble shape [4]:

$$(K_{OG})^{Cal} = f_C \sqrt{\frac{4 D_L R_{sf}}{\pi S_b}} \tag{6}$$

Where f_C is a correction factor.

The surface area S_b of an ellipsoidal bubble can be calculated as follows [1]:

$$S_b = \pi \frac{l^2}{2} \left[1 + \left(\frac{h}{l} \right)^2 \frac{1}{2e} \ln \frac{(1+e)}{(1-e)} \right] \tag{7}$$

The bubble rise velocity u_b and both the bubble length l and height h of an ellipsoidal bubble take part in the calculation of the rate of surface formation R_{sf}:

$$R_{sf} = \pi \sqrt{\frac{l^2 + h^2}{2} + \frac{(l-h)^2}{8}} u_b \tag{8}$$

Terasaka derived the following equations for calculating the ellipsoidal bubble length l and height h [5]:

$$l = \frac{d_S}{1.14.Ta^{-0.176}} \tag{9}$$

$$h = 1.3.d_S.Ta^{-0.352} \tag{10}$$

The bubble diameter is needed also for the calculation of the bubble rise velocity [4]:

$$u_b = \sqrt{\frac{2\sigma}{\rho_L.d_S} + \frac{gd_S}{2}} \tag{11}$$

The Sauter mean bubble diameter is estimated by means of Wilkinson correlation which is one of the most recommended in literature [9]:

$$\left(\frac{g\rho_L d_S^2}{\sigma}\right) = 8.8\left(\frac{u_G\mu_L}{\sigma}\right)^{-0.04}\left(\frac{\sigma^3\rho_L}{g\mu_L^4}\right)^{-0.12}\left(\frac{\rho_L}{\rho_G}\right)^{0.22} \tag{12}$$

Bubble shape, motion and any tendency for the interface to ripple, fluctuate or otherwise deform are all related to the bubble size. In turn, bubble size is determined by the physical characteristics of the system and operating conditions. Equation (12) implies that the bubble size decreases with the increase of both superficial gas velocity and gas density [6].

EXPERIMENTAL RESULTS

Figure 1 shows the profile of the gas-side mass transfer coefficient $K_{OG,}$ obtained by experimental and theoretical methods, as a function of the superficial gas velocity. It is to be noted that the maximum difference between calculated and experimentally obtained values of the coefficients is no more than 20% for the mixture Methanol-Water. This can be seen even better in Figure 2, where this comparison is shown.

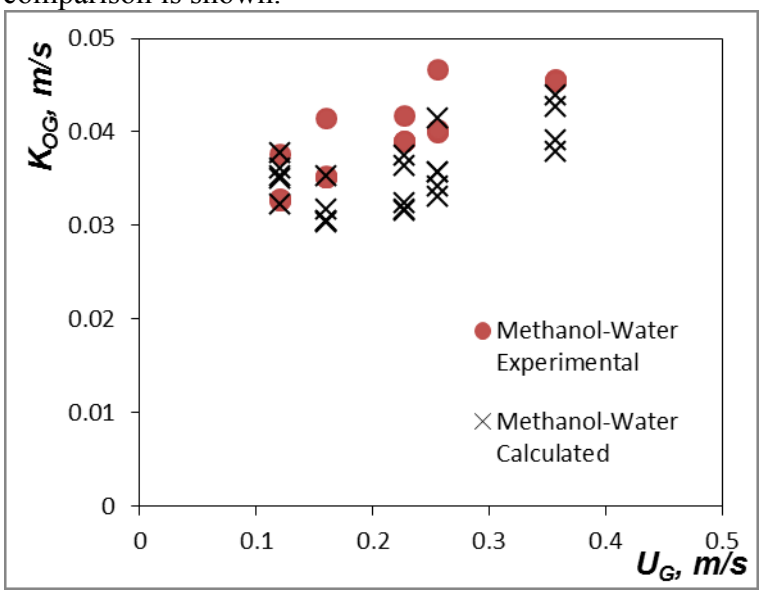

Fig.1. Effect of gas velocity and gas-side mass transfer coefficient

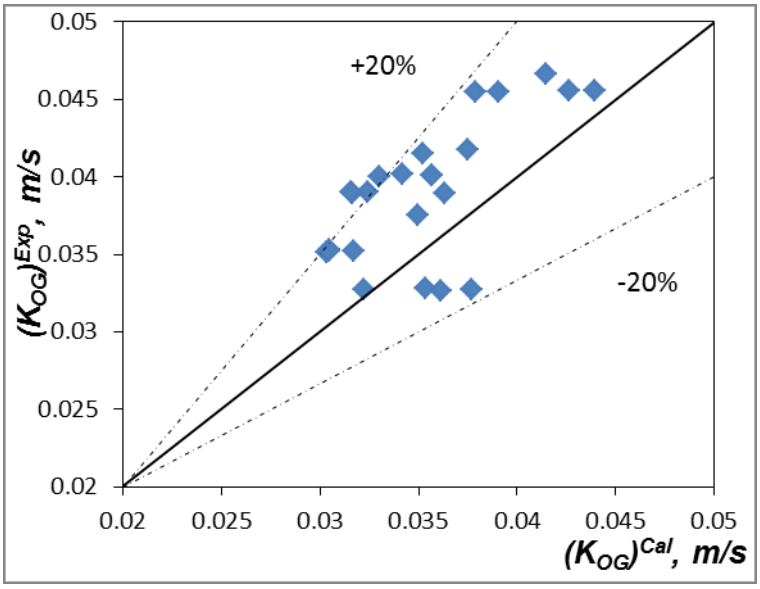

Fig.2. Comparison between experimental $(K_{OG})^{Exp}$ values and calculated $(K_{OG})^{calc}$ values

Figure 2 shows that the experimental values of $(K_{OG})^{Exp}$, calculated by equation (1), are in reasonable agreement with the theoretical results obtained by equation (6).

CONCLUSIONS

The classical penetration theory is applicable for predicting gas-side mass transfer coefficient measured in methanol-water, in a laboratory column with sieve trays under atmospheric pressure.

NOMENCLATURE

a	specific interfacial area [m^{-1}]
d_s	sauter mean bubble diameter [m]
e	bubble eccentricity
E_{OG}	Overall point efficiencies [%]
f_c	correction factor
g	gravitational acceleration [$m.s^{-1}$]
h_f	aerated liquid height [m]
h	height of an ellipsoidal bubble [m]
K_{OG}	gas-side mass transfer coefficient [$m.s^{-1}$]
$K_{OG}.a$	volumetric gas-side mass transfer coefficient [kmol/m3.s]
l	length of an ellipsoidal bubble [m]
M	molecular weight [kg/kmol]
R_{sf}	surface formation [$m^2.s^{-1}$]
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 $$Mo = \frac{g.\mu_l^4}{\rho_l.\sigma^3}$$

Bubble Reynolds number $$\mathrm{Re}_b = \frac{d_S.u_b.\rho_l}{\mu_l}$$

Tadaki number $$Ta = \mathrm{Re}_b.Mo^{0.23}$$

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