Experimental and Theoretical Model of Gas-Liquid Interaction in A Closed System

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Abstract - Bubble columns are widespread and important for various absorption processes, with/without chemical reaction and various bioreactions, etc. Simplicity in operation, low labor cost and their flexibility in using the liquid phase make these equipments preferred in the field of chemical engineering research. The importance of this paper is based on achieving the application of a system that implements the way our body system processes ethanol. In the experimental study we focused on measuring the key parameters that determine the efficiency of three bubble column (air jet) set systems in measuring the ethanol concentration. The basic system parameters were determined and modeled in order to evaluate the system performance which are the superficial gas velocity ($U_G$), gas hold up ($\varepsilon_G$).

Keywords - Bubble columns, superficial gas velocity, gas hold up

I. INTRODUCTION

A change in gas properties can cause changes in bubble size distributions and bubble growth rates. In general, the gas phase impact on $\varepsilon_G$ is discussed in terms of gas density ($\rho_G$). A change in gas density can result from high pressure work, use of different gases or a combination of both. In columns with $d_c$ varying from 0.12 m to 0.17 m, higher values of $\rho_G$ results in higher $\varepsilon_G$ values, also a change in $\rho_G$ means a change in time period of dispersed phase inside the vessel. We can link the influence of $\rho_G$ on $\varepsilon_G$ often attributed to differences of the bubble size distributed from the sparger. High density gases have higher $\varepsilon_G$.

Akita and Yoshida (column, 0.15 × 0.15 m) tested four gases (air, He, O₂, CO₂) with water and showed that the effect of $\rho_G$ on $\varepsilon_G$ values can be neglected, although $\varepsilon_G$ in helium’s case is slightly lower for high velocities of gas [1, 2]. Through this process it is possible to evaluate equilibrium concentration of alcohol in the solution and in the air. [3]. Also, we studied influence of different factors such as temperature, pressure and flow when this balance is established. In order to adapt the system to be similar as the human lung system and to achieve high efficiency, the system was built to function in the same way as instead with our lungs.

II. EXPERIMENTAL DESCRIPTION

The experimental set up and its application is described below (fig.1). Columns were placed in a water bath where we periodically measured main parameters as temperature, pressure and concentration of alcohol and dissolved oxygen. The glass columns were filled to the desired level with equal amounts of water-ethanol solution that had known concentrations, which can change depending on the experiment. The system can be placed with three or four vessels in series and is a closed system. The continuous flow is specific each time, depending on the diameter tube that was used to connect vessels. The tube diameter is important in order to calculate the pressure drop during the process. The air enters in the upper part of the first vessel by means of a tube which is in the end composed of porous material which is used in order to uniformly spread bubbles throughout the column space. The sparged air in the first column carries with it a certain amount of ethanol vapor, which being volatile evaporates in the upper part of the solution. This process is repeated in the second column where the air from the first column passes to the second column and again absorbs a quantity of ethanol vapor and is passed to the third column where, unlike the first two, this column achieves the equilibrium between the concentration alcohol in the water and alcohol concentration in air. The air stream after leaving the third column is passed to the analyzer of alcohol concentration. So the closed system simulates (alveole) in the lungs where the exchange of the mass of ethanol from the blood into the air occurs. Based on the assumptions that the lungs behave as a closed system, the instead temperature and pressure remain constant during breathing, and we can build a lung simulation process. By this process it is possible to observe the degree of equilibrium between alcohol concentration in the solution and the concentration of alcohol in air, and evaluate different factors that influence our experiment.
III. RESULTS AND DISCUSSIONS

Fine spargers (air distributors) have higher \( \varepsilon_G \) compared to coarse spargers and for the same sparger (smaller diameter of spargers holes, \( d_0 \)) leads to an increase in \( \varepsilon_G \). Depending on the size of the spargers holes, the prevailing flow regime varies. The most common method for measuring \( \varepsilon_G \) is through different diameters. This method is based on the measurement of free surface level of the fluid before and after airing. Another known method is based on differential pressure measurement between two or more points in the column under the hypothesis of negligible acceleration and friction pressure losses. For example, Hikita determined \( \varepsilon_G \) by measuring the static pressure in three columns at 0.25 m intervals, the lowest being 0.15 m above the sparger [4-6].

Experimental values of superficial velocities \( U_G \), were compared to different theoretical values evaluated from models as eq. 1 from Hikita 1970. We also used other models that performed in similar way.

\[
\frac{(k_a) U_G}{g} = 14.9 \left( \frac{U_G \mu_L}{\sigma} \right)^{0.76} \left( \frac{\rho_G}{\rho_L} \right)^{0.243} \left( \frac{\rho_L}{\rho_L D_{GL}} \right)^{-0.604}
\]

(1)

Where:
- \( D_{GL} \) Diffusion coefficient of gas/liquid phases [-]
- \( k_{la} \) Mass transfer coefficient \( [s^{-1}] \)
- \( \varepsilon_G \) Gas hold up [-]
- \( U_G \) Superficial gas velocity \( [m/s] \)
- \( \mu_L \) Dynamic liquid viscosity \( [kg*m/s^2] \)
- \( \rho_L \) Liquid density \( [kg/m^3] \)
- \( \rho_G \) Gas density \( [kg/m^3] \)
- \( \sigma \) Superficial tension \( [N/m] \)
- \( g \) Acceleration constant \( [m/s^2] \)

It is known that the capture efficiency (the relation between \( \varepsilon_G \) and \( U_G \)) summarizes the complexity of the liquid phase dynamics in the column by the "bubble scale" development in the "vessels scale".

Through different studies the bubble scales were varied from the finest to coarse when gas distribution velocities were increased. As it can observed in fig. 2, we achieved a monotone curve from our experimental data while theoretical models were less monotone [7-9]. This is explained with the different bubble formed when fine spargers are taken into account in the modeled values. In our set up, the spargers used were coarse and produced air bubbles that dispersed fast in the solution. Coarse gas distributors (spargers) lead to monotone gas retention curves contrary to the case of fine gas distributors, a curve appears in the theoretical lines due to the size of dispersed bubbles [5,10].
We observe that theoretical and experimental values have smaller variation during the initial steps but further deviate towards higher theoretical values, though they don’t pass the 50% accuracy (fig. 3).

IV. CONCLUSION

The design of gas distribution affects not only the flow regime but also the value of gas hold-up and in particular, the dependency of superficial gas velocity on gas hold-up. It is difficult to provide a general model because of the many parameters influencing the stability of this process. Different behaviors are due to the dynamics of the bubble (i.e.), the formation of bubbles in the gas sparger and the phenomena of bubble collision); in coarse air spargers, there is a persistent display of large bubbles, while in fine distributors large bubbles begin to appear at larger gas flow rates. This study compared experimental and theoretical models, in ethanol-water solution, based on superficial gas velocity and gas hold up. The evaluated results were similar but varied depending on specific set up parts, like tube diameters or number of vessels used.

REFERENCES


