

EFFECT OF SOLIDS ON GAS-LIQUID MASS TRANSFER

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Abstract: The effect of the solids on the mass transfer characteristics in a bubble column was studied experimentally for the systems air/water/Polyvinyl chloride (PVC) and air/water/glass beads. Volumetric liquid side mass transfer coefficient, $k_L a$, was determined under different solid concentrations, gas flow rates and solid sizes.

The presence of solids affects negatively $k_L a$ being this effect more pronounced for the largest particles. For smaller size particles, surface properties play an important role in mass transfer as opposite effects in $k_L a$ are observed for the hydrophobic and hydrophilic particles.

Keywords: Bubble column; mass transfer; multiphase reactors; hydrophobic particle; hydrophilic particle.

1. INTRODUCTION

Bubble columns are frequently used in industry as gas-liquid and gas-liquid-solid contactors. Chemical or biochemical reaction operations, separation of mixtures by rectification, absorption and waste-water treatment are examples of their application (Hong and Brauer, 1989). Recently, bubble columns have also gained importance in the field of biotechnology (Álvarez, 2000). Frequently, in multiphase systems, gas-liquid mass transfer is the rate determining step for the overall process. Therefore, the knowledge of gas-liquid mass transfer rates characterized by volumetric gas liquid mass transfer coefficients ($k_L a$) is required for reliable design and operation of such reactors (Ozkan, 2000). A full understand of the influence of the operating parameters on each component of $k_L a$, - the liquid side mass transfer coefficient (k_L) and the interfacial area (a) - is required. In three phase systems, the presence of a solid phase is an important parameter that may have a positive or negative effect on the mass transfer process. Thus, the effect of solid characteristics such as loading, size, density, shape and surface properties (hydrophobic vs hydrophilic) on gas-liquid mass transfer has been a challenging task for researchers. Yagi and Yoshida (1974) verified that the effect of dead microorganisms on k_L was negligible. However, the presence of such substances caused a remarkable change in the bubble size distribution, and consequently decreased the gas holdup, the interfacial area a , and the $k_L a$. To study the effect of solids concentration on $k_L a$, Albal et al. (1983) added glass beads and oil shale particles to water. For low values (2-5 % v/v) of the solids concentration, $k_L a$ increased about 10%-30% and then decreased with further increases in the solids concentration. Sada et al. (1986) observed that the influence of fine suspended particles on bubble column performance depends upon the particle size. More recently, Freitas and Teixeira (2001) showed that $k_L a$ diminishes with the increase in solids loading, especially for high airflow rates, due to an increase in bubble coalescence. Solid density also affects $k_L a$.

2. EXPERIMENTAL

2.1 Experimental Set-Up

Mass transfer experiments were performed at 25°C in a perspex cylindrical bubble column of 84 mm internal diameter and 600 mm high. A perspex rectangular box covers the column and was used for temperature control. The gas enters in a gas chamber and then passes through a sparger where the bubbles are formed. The sparger consists of 13 uniformly spaced needles with an inner diameter of 0.3 mm. The shape and size of the needles ensures the formation of small and well-defined bubbles.

2.2 Mass transfer experiments

Oxygen mass transfer experiments were performed in two and three-phase systems. Air and water were the gas and liquid phases, respectively, and PVC beads (with a mean diameter – d_p - of 12, 163 and 549 μm) and glass beads (d_p of 11 μm) were the solid phase. The experiments were done for several gas flow rates (up to 30 cm^3/s), and solid concentrations (0, 1, 3, 5, 10 % v/v).

The experimental procedure is initiated by bubbling nitrogen to deoxygenate the liquid phase. When the dissolved oxygen concentration is zero, humidified air is fed into the column. At this moment, the oxygen transfer process from bubbles to the liquid begins and continues until oxygen concentration in the liquid reaches saturation. Dissolved oxygen concentration values are measured using an O_2 electrode (CellOx 325, WTW) and recorded directly on a PC, through a data acquisition board, and the dissolved oxygen concentration variation with time, t , is obtained. The mass balance for oxygen in the liquid is written as:

$$\frac{dC}{dt} = k_L a. C^* - C \quad (1.1)$$

where $k_L a$ is the volumetric mass transfer coefficient, and C^* and C , respectively, the oxygen solubility and the oxygen concentration in the liquid. Assuming the liquid phase homogeneous and the oxygen concentration C_0 at $t=0$, the integration of the previous equation leads to:

$$\ln C^* - C = \ln C^* - C_0 - k_L a t \quad (1.2)$$

The volumetric mass transfer coefficient ($k_L a$) can now be determined by plotting $\ln(C^*-C)$ against time (t).

3. RESULTS AND DISCUSSION

3.1 Size and loading effects

Fig. 1 shows how volumetric mass transfer coefficient, $k_L a$, varies with superficial gas velocity, solid loading and solid size, for polyvinyl chloride beads.

It can be seen that $k_L a$ increases with superficial gas velocity. The effect of the solids on mass transfer increases with superficial gas velocity, solids concentration and size. According to Fig. 2, size is a very important parameter in mass transfer experiments as mass transfer coefficient clearly decreases with solid size. In what concerns the effect of solids concentration, an exception occurs for the smaller particles at 1% v/v as, for this particular case, the presence of solids has a positive effect on $k_L a$. These results are reproducible with an average relative error of 5%. Zahradnik et al. (1992) studied the effect of some operating parameters on hydrodynamics and mass transfer characteristics of multi-stage three-phase slurry reactors and found that increasing concentration of solid particles (in

the range 0-5 wt%) reduced the $k_L a$ values. Freitas and Teixeira (2001) working with a three-phase internal loop airlift reactor noticed a similar behaviour for the effect of solids.

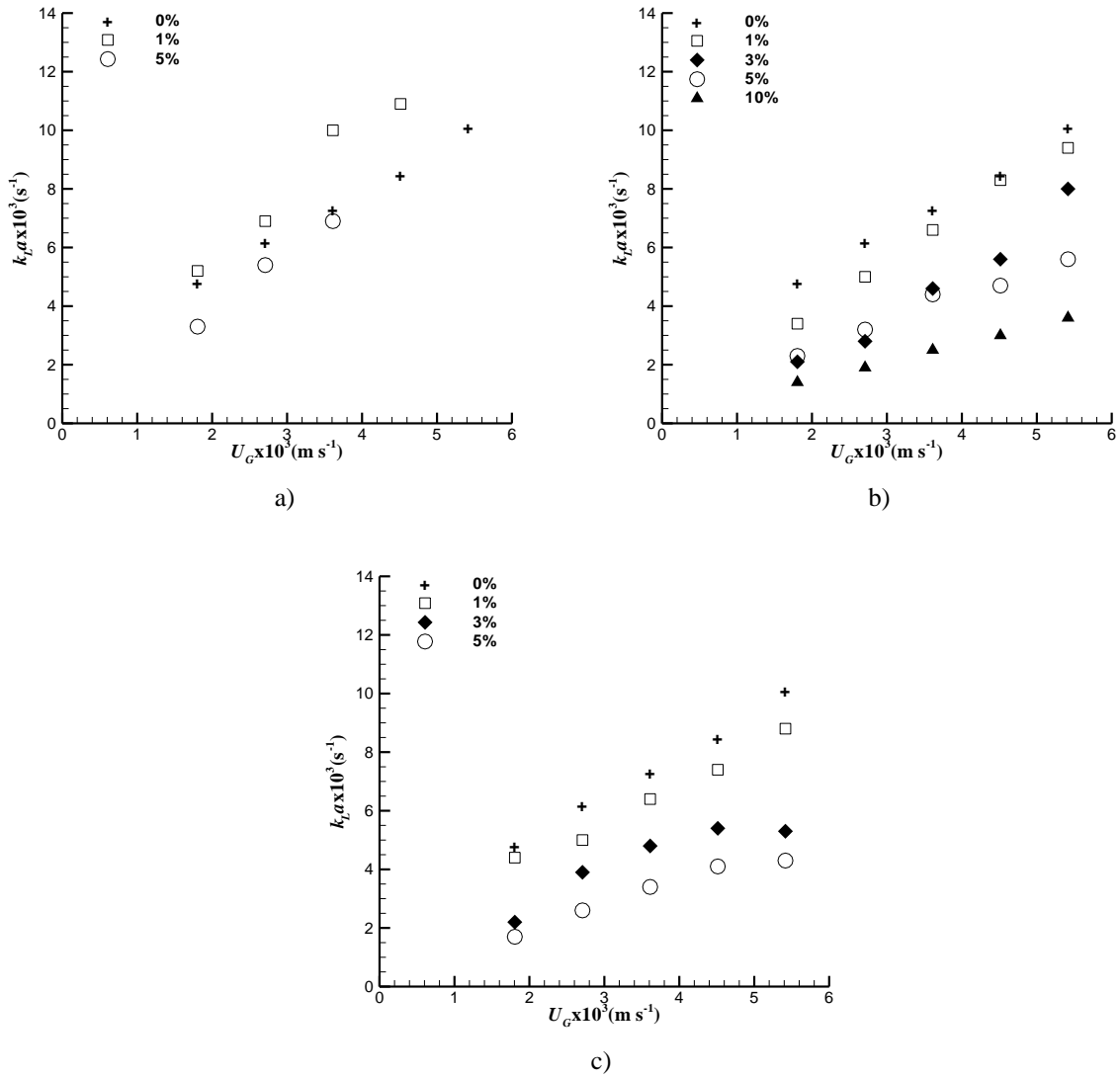


Fig. 1. Dependence of $k_L a$ on superficial gas velocity U_G , for different polyvinyl chloride concentrations (0, 1, 3, 5 % v/v) and three different diameter particles: a) $d_p = 12 \mu\text{m}$; b) $d_p = 163 \mu\text{m}$; c) $d_p = 549 \mu\text{m}$.

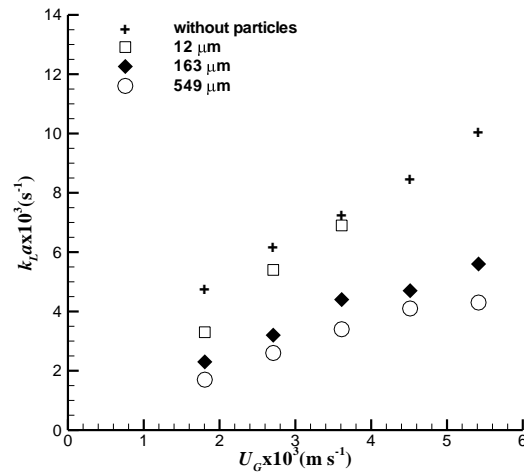


Fig. 2. Dependence of $k_L a$ on superficial gas velocity U_G , for polyvinyl chloride beads with different diameters (12, 163 and 549 μm) at a 5% v/v concentration

3.2 Particle properties effects

According to the literature (Tsutsumi et al., 1991), hydrophilic particles have a good dispersion in solution, contrarily to hydrophobic particles that normally are aggregated on the gas-liquid bubble interface. Fig. 3 shows the influence of particles surface properties into the mass transfer coefficient, indicating that, for the smallest particles at very small solid concentrations, hydrophobic particles increase $k_L a$ and the opposite effect is observed in the presence of hydrophilic particles.

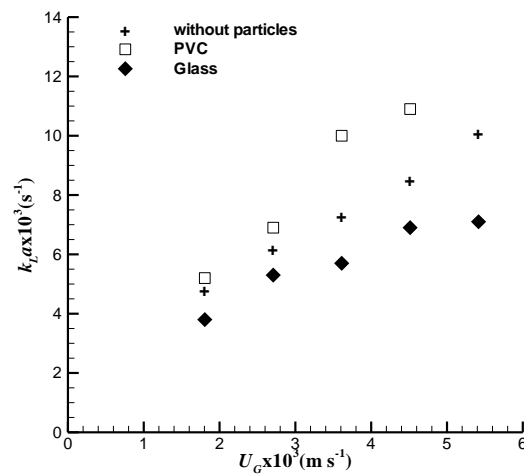


Fig. 3. Dependence of $k_L a$ on superficial gas velocity U_G , for hydrophobic (PVC) and hydrophilic (glass beads) particles ($d_p=12 \mu\text{m}$) at a 1% v/v concentration

4. CONCLUSIONS

Solids have a negative effect on the volumetric liquid side mass transfer coefficient, k_{La} . This effect increases with the solid concentration and is more pronounced for the larger particles used.

The surface properties of particles play an important role in mass transfer on three phase systems as hydrophobic and hydrophilic particles have opposite effects on k_{La} when small concentrations of small particles are used.

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