

HYDRODYNAMIC STUDIES IN STIRRED BUBBLE COLUMN

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ABSTRACT

One of the major and modern equipments that play a vital role in Chemical Engineering is stirred bubble column reactor for promoting gas-liquid contact. It is particularly suitable where higher interfacial areas between phases are desirable and also where precise temperature control is required. These are gaining more importance recently because of higher residence time, higher transfer rate per unit volume, minimum space requirement and less investment cost. A systematic work was undertaken to focus the effect of various parameters like superficial gas velocity (V_G), height to diameter (H/D) ratio and speed of the stirrer (N) on fractional gas holdup in a bubble column. For this purpose, experiments were conducted in 0.14 m ID column having 2 m height. Water and air were used as liquid and gas phase, respectively. The column with ring sparger having 67 % active area is used as sparger for dispersing the dispersed phase into the continuous phase. For the optimized sparger plate, the effect of various parameters on fractional gas holdup for air-water system was studied. Also the effect of various parameters on fractional gas holdup for air-water with electrolytes like NaOH, BaCl₂, MgCl₂ and NaCl of various concentrations were studied and reported.

Keywords: fractional gas holdup, electrolyte, bubble coalescence, interfacial area.

INTRODUCTION

One of the major and modern equipments that play a vital role in chemical industries for production is bubble column reactor. Bubble column reactors are mostly used in practice of gas-liquid contactor and liquid aeration. Vertical sparged reactors are frequently used in various chemical processes including coal-liquefaction, Fischer Tropsch synthesis and production of liquid fuels from biological materials. Stirred bubble

columns are the bubble columns fitted with internal stirrer in order to increase the dispersed phase hold up. These reactors have gained importance due to their ease of operation. These are simple in construction and offer favourable operating costs. Major advantages are the absence of moving parts, the ability to handle solid particles without erosion or plugging of parts, good heat transfer at the wall, high interfacial area and high mass transfer coefficients. The choice of bubble column reactor has been motivated to decrease the sticky by-products that

accumulate on the side walls. In bubble column reactors, gas bubbles flow upward through a slower moving or stagnant liquid. The bubbles, which rise in essentially plug flow, draw liquid in their wakes and thereby induce back mixing in the liquid with which they have come in contact. Bubble column reactors are used where higher interfacial areas between phases are desirable. Bubble column reactors are used for reactions where the rate-limiting step is the liquid phase or for slow reactions where contacting is not critical. These seem to be exclusive choices wherever precise temperature control is required. Bubble column reactors find applications in ethylene dimerisation and other polymer reactions.

Works are being carried out in hydrodynamic, heat and mass transfer in bubble column for the past two decades [1-5]. Fractional gas hold up is a key parameter in bubble column reactors. Superficial gas velocity, height to diameter ratio (H/D ratio) and power also play an indispensable role in determining dispersed phase hold up. The advantages of stirred bubble column reactors are: it promotes axial and radial flow which reduces formation of dead zones in the reactors, gas conversion per loop is increased by external stirring and uniform mixing is possible; fractional gas hold up is high as the coalescence of large bubbles into small bubbles is more with the increase in fractional gas holdup; mass transfer coefficient will also be high. Time required for homogenization will be less in extremely stirred bubble column when compared with conventional bubble column [6, 8-12].

The present work enlightens the effect of H/D ratio, superficial gas velocity, concentration of electrolyte and speed of the stirrer on dispersed gas hold up. For this purpose, the experiments were carried out in 0.14 m I.D., 2 m column equipped with the sparger and stirrer for developing correlation to predict gas hold up for electrolytes (NaCl, BaCl₂, NaOH, MgCl₂) at different H/D ratio, stirrer speeds, superficial gas velocity and various concentrations of electrolyte.

Our main mode of this work is to increase the gas hold up. The rise in gas hold up will increase the interfacial area of contact between gas-liquid phases and also it will lead to higher residence time of gas bubbles in the continuous phase.

EXPERIMENTAL

Experimental set up

The experimental set up is shown in Fig. 1. The bubble column is of 2 m height, 5 mm thickness and 0.14 m ID made of acrylic material. The bottom of the column is fitted with a sparger vessel. The sparger is very vital as it is responsible to sparge the column. It is placed in between the bottom end of the column and the sparger vessel. The sparger vessel is of 3 mm thickness and made up of mild steel. The vessel has provision for manometer tapings, air inlet and drainage. A compressor supplies the air needed for sparging the column. A rotameter of 50-500 lpm range is used to measure flow rate of air. Manometer is used to measure the pressure drop and agitator with Rushton type impellers is used. The compressed air from the compressor is passed to sparger through rotameter wherein gas flow rate is measured. The pressure drop across the column is measured using U-tube manometer. In order to achieve effective mixing in the conventional bubble column the external stirrer is coupled. The rotational speed of the impeller is controlled by an autotransformer connected to a D.C. motor. The fractional gas hold up is measured by visual observation. The reproducibility of

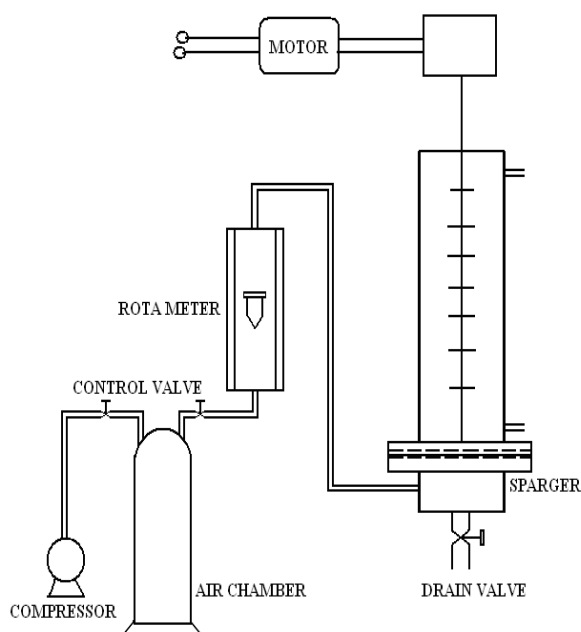


Fig. 1. Stirred Bubble Column Set up.

the results was ensured by repeating the experiments 3 to 4 times. The error was found to be less than 15 %.

Table 1. Experimental conditions of the investigations.

Column diameter	0.14 m
Column length	2 m
Number of holes in distributor	45
Total area of sparger	0.0154 m ²
Effective area of sparger	67 %
Diameter of hole for square and triangular pitch	6.7 x 10 ⁻³ m
Diameter of hole for single orifice	4.5 x 10 ⁻³ m
Number of impellers	3
Type of impeller	Rushton
Speed of rotation, rpm	50,100,150,200,250
Gas flow rate, lpm	50,100,150,200,250

The design details of the experimental set up is shown in the Table 1.

EXPERIMENTAL PROCEDURE

The initial height of water, which is retained inside the column stagnantly, is measured. Air is bubbled from the bottom of the column. The final height is noted down. The change in height divided by the initial height gives the fractional gas holdup.

The ϵ_G is measured for different H/D ratio of the bubble column. The effect of the electrolyte addition on ϵ_G is also studied.

• Measurement of parameters

Many parameters are taken for the effective scale-up and design of bubble column reactor. But in this experimental work, limited number of parameters is taken into account depending on the experimental conditions: fractional gas hold up (ϵ_G); superficial gas velocity (V_G); speed of the stirrer (N).

• Fractional gas holdup (ϵ_G)

It is the amount of gas held by the liquid in reactor column, during sparging of gas through liquid. The initial height of water in the column was set with re-

spect to the H/D ratio. This height of water remains stagnant, till air is bubbled from bottom of the column for a specified flow rate. When the air is bubbled, the rise in height was taken on all sides of the column and an average yielded the correct final height. For the next set of readings, the flow rate of air or the speed of the stirrer is varied and the same procedure was repeated to find hold up.

The effect of various salts was also studied in the similar fashion, but varying the mass of the salt added corresponding to 1 %, 1.5 %, 2 %. Thus the fractional gas hold up was calculated:

$$\epsilon_G = (H_F - H_S) / H_S$$

where: ϵ_G - fractional gas hold up;

H_F - final height of liquid, cm;

H_S - initial height of liquid, cm.

• Superficial gas velocity (V_G)

It is the speed at which the gas passes through the column without any packing. It is also called as empty tower velocity, which is calculated by measuring the volumetric gas flow rate.

$$\text{Superficial gas velocity} = \frac{\text{Vol. flow rate of gas (m}^3/\text{s)}}{\text{Cross Sec. area of column (m}^2\text{)}}$$

• Speed of the stirrer (N)

It is the speed at which the impeller rotates inside the column. Its value is noted down from the optical tachometer. The rotational speed can be varied by an auto transformer connected to a D.C. motor.

RESULTS AND DISCUSSION

Effect of V_G on fractional gas holdup ϵ_G

Superficial gas velocity is found to be a vital parameter which affects the gas holdup considerably. For this purpose the superficial gas velocity was varied in the range of 0.0541 m s⁻¹ to 0.2706 m s⁻¹. The effect of V_G on ϵ_G is shown in the Figs. 2 and 3.

From the graphs it could be seen that for an increase in superficial gas velocity ϵ_G increases vigorously initially (V_G up to 0.1624 m s⁻¹). This is because of the accumulation of less number of gas bubbles which in turn causes the flow to be laminar in the continuous phase. Moreover, the frequency of coalescence (CF) which is the function of collision frequency and efficiency per collision is the most influencing parameter

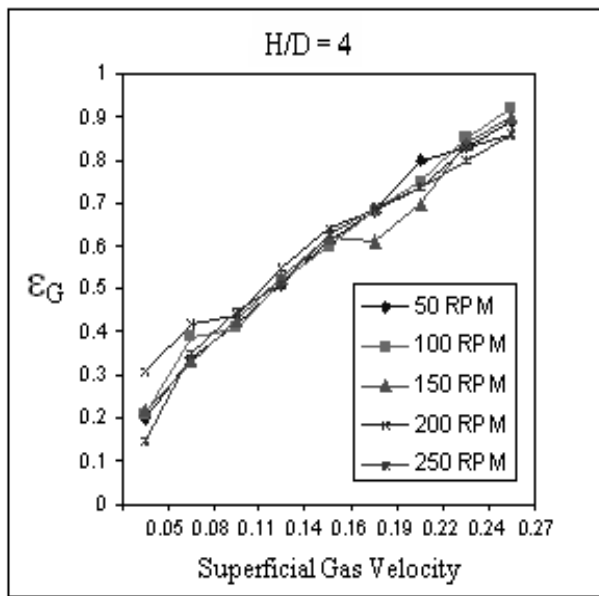


Fig. 2. Effect of superficial gas velocity on fractional gas hold up for H/D ratio of 4.

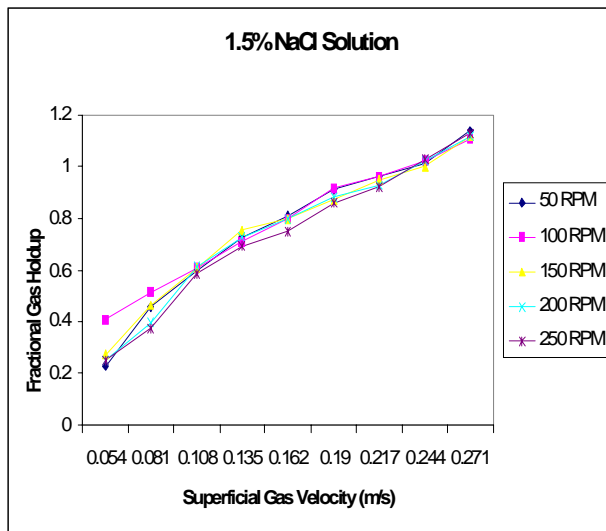


Fig. 3. Effect of superficial gas velocity on fractional gas hold up for 1.5 % NaCl solution.

for analyzing ϵ_G . This coalescence frequency (CF) between the gas bubbles would be less at lower V_G than CF at higher V_G . And also the formation of protective film around the gas bubbles prevents the coalescence at lower V_G . This protective film depends on the solution in which they are dispersed. But at higher gas velocities as mentioned above, gas hold up either increases slowly or does not show major deviation among

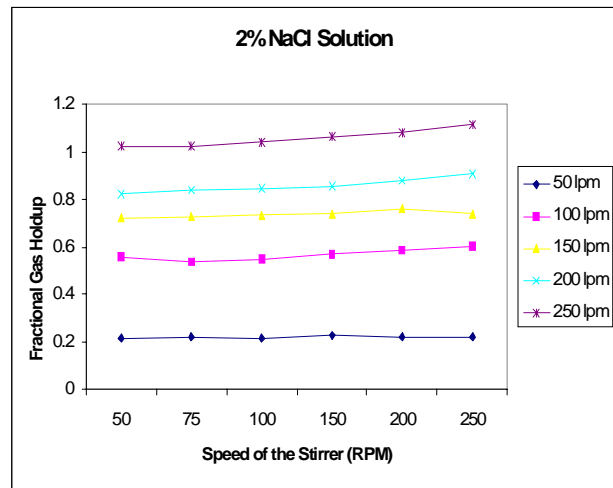


Fig. 4. Effect of stirrer speed on fractional gas hold up.

them. This is due to the turbulence created by the higher flow rate of gas bubbles.

Effect of speed of the stirrer on ϵ_G

Speed of the stirrer was varied in the range of 50 rpm to 250 rpm. The speed of the stirrer was found to affect the gas hold up marginally. The effect of N on ϵ_G is shown in Fig. 4.

From the graphs it could be seen that with the increase in the speed of the stirrer, the gas holdup remains constant at lower GFR (50 lpm). But at higher gas flow rates (> 100 lpm) the gas holdup increases marginally. This may be due to the formation of larger gas bubbles at higher GFR and the stirrer plays a vital role in breaking of large bubbles, thereby increasing the gas hold up.

Effect of electrolytes on ϵ_G

The bubble coalescence results in the formation of more bubbles which causes more dispersed phase of bubbles. This is due to the addition of electrolytes [7]. This statement was verified by conducting experiments using electrolytes such as NaCl, BaCl₂, NaOH and MgCl₂ of various concentrations. The effect of electrolyte concentration on fractional gas holdup is shown in the Fig. 5.

The addition of electrolyte increases gas hold up initially, but further electrolyte addition in excess concentration doesn't affect the gas hold up consider-

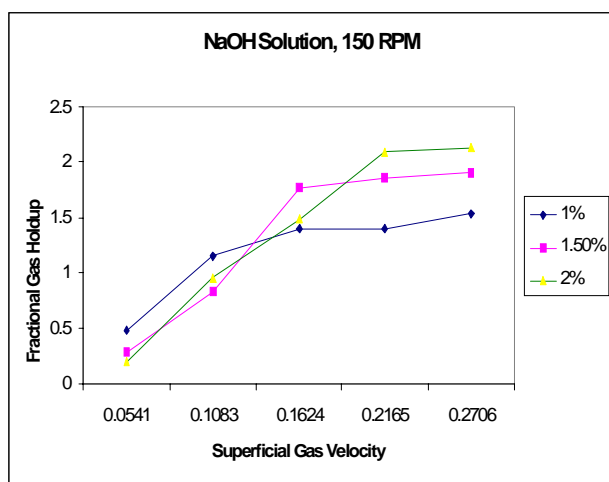


Fig. 5. Effect of concentration of NaOH solution on fractional gas hold up.

ably because of decrease in drag forces exerted over the bubbles by the incremental amount of ionic component in the solution. This causes the bubbles to coalesce very slowly. Hence, the gas hold up does not vary after the addition of electrolyte of higher concentration. In the case of NaOH solution, the easy electrolysis of it contributes more free ions which are responsible for more bubble formation.

Comparison of the effect of electrolytes and water on fractional gas hold up

The effect of electrolytes was studied in stirred bubble column reactor and the results are shown in Fig.6. The gas hold up increases with the addition of electrolytes in the following trend:

$$\text{MgCl}_2 < \text{NaCl} < \text{BaCl}_2 < \text{NaOH}$$

The coalescence of bubbles generally occurs in two consecutive steps. First, the liquid drains from the space between the surfaces of two approaching bubbles until a certain minimum film thickness is reached in the following step. The film ruptures and bubble coalesces. The rate of coalescence of two approaching bubbles will therefore depend on the rate of drainage of the liquid phase between the bubbles which thereby depends on the thickness and strength of the remaining film. In a pure liquid the interface of the approaching bubbles are free to move along with the liquid in the film and the rate of thinning is therefore controlled only by the inertia of the liquid pushed away by the film while ionic forces between the ionic species of a film

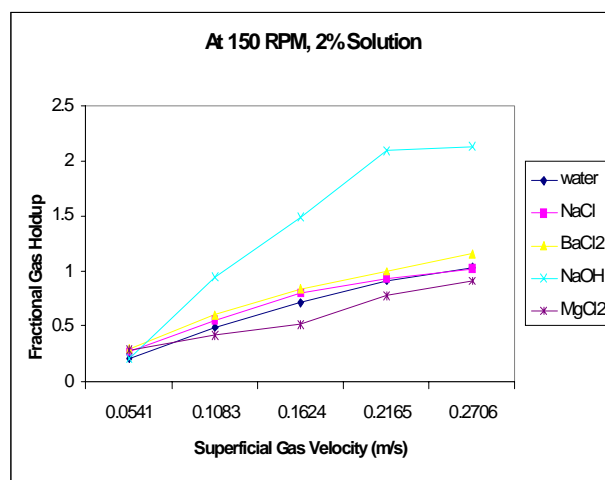


Fig. 6. Effect of electrolytic solutions on fractional gas hold up compared with water.

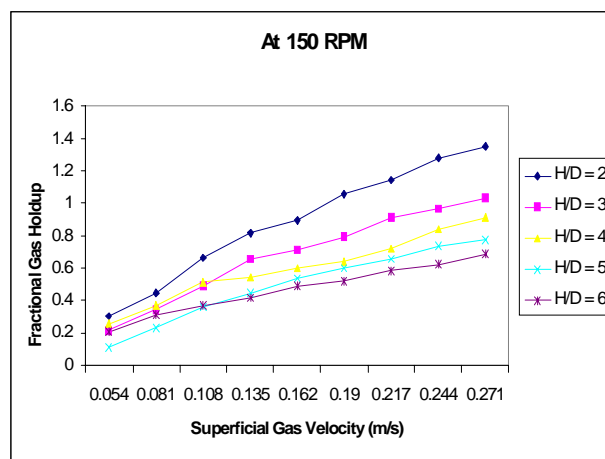


Fig.7. Effect of H/D ratio on fractional gas hold up.

and water molecule makes them more cohesive. This increases the strength of the film against the bubble coalescence and decreases the bubble size. The overall results of the two effects are a higher gas holdup as compared to that of other systems.

Effect of H/D ratio on ϵ_G

The H/D ratio is also one of the important parameters for the design of bubble column. The effect of H/D ratio on ϵ_G is shown in Fig.7. The graph implies that the increase in H/D ratio decreases the gas hold up gradually, but at the range of H/D ratio ($H/D > 4$), the deviation between the gas hold up would be low (ϵ_G) (i.e. ϵ_G may remain the same value with further increase in H/D ratio). At higher H/D ratio, the gravitational

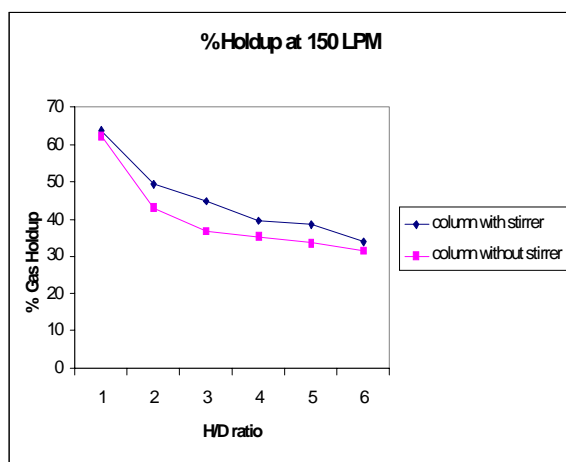


Fig. 8. Effect of stirrer on % gas hold up for tap water/air system.

force exerted by continuous phase on bubbles would be dominant over the buoyancy force exerted by the bubbles. This condition decreases the frequency of coalescence which in turn makes ϵ_G to be less at higher H/D ratio.

Comparison of hold up with stirrer and without stirrer

Comparison of fractional gas hold up with stirrer is done for air-water system and also for air-electrolyte solution and viscous solutions (Fig. 8). As discussed already, because of the breaking of large bubbles by the stirrer, the gas hold up increases well in all the cases with the help of stirrer.

Correlation

A correlation has been developed for fractional gas hold up for stirred bubble column based on the statistical method.

$$\epsilon_G = 0.23(V_G)^{0.28} (H/D)^{0.2} (N/\rho)^{0.36}$$

where, ρ is density of the liquid.

The above correlation is valid in the following ranges, $V_G = 0.05$ to 0.5 m s^{-1} ; $N = 50$ to 300 rpm .

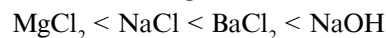
Error = $\pm 12 \%$.

CONCLUSIONS

- The fractional gas hold up is found to increase with the increase in superficial gas velocity.
- The speed of the stirrer increases the fractional gas hold up marginally.
- The fractional gas holdup increases for electrolytic solution when compared with pure water.

- The addition of electrolyte increases gas hold up initially, but further addition of electrolyte of excess concentration doesn't affect the gas holdup considerably.

- The gas holdup increases with the addition of electrolyte in the following trend



- The increase in H/D ratio decreases the gas hold up gradually.

- The use of stirrer increases the fractional gas holdup.

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