



Gas Hold up in Multiple Impeller Agitated Vessels

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Abstract

Gas hold up was measured in mechanically agitated vessels fitted with dual impellers. Different impellers like Pitched blade turbine and Disc turbine were used. 5 different combinations of dual impellers were used. A tank of 0.45 m internal diameter with an impeller diameter of 0.15m was used. Superficial gas velocity was varied from 0.005m/sec to 0.01 m/ sec. Correlations are proposed for gas hold ups for different combinations of impellers. Optimum combination of dual impellers for maximum gas hold up has been identified. The effect of bottom clearance, inter impeller clearance and physical properties like surface tension on gas hold up were also studied for the optimum combination of impellers

Keywords: Multiple impeller vessels, Gas hold up, Power per unit volume

1. Introduction

Mixing is an important unit operation and has extensive applications in chemical, bio chemical and pharmaceutical industries. Mixing means taking two or more phases such as two fluids or a fluid and solid and randomly distributing one in another.

1.1 Equipment

Mixing can be accomplished in a wide variety of equipment. Mechanically agitated vessels or stirred tank reactors are popularly used for gas liquid contacting including gas dispersion, solid suspension, crystallization, polymerization, fermentation, waste treatment etc.

1.2 Multiple Impellers

Vessels with single impeller are used when height to diameter ratio is low. Multiple impellers are used in vessels having a large height to diameter ratio. Multiple impellers are preferred over single impellers to provide better gas utilization, narrow spread in the residence time distribution in the flow systems and higher surface area per unit volume for heat transfer. They also provide low shear compared to single impellers due to overall lower speed of operation at equal power levels. They can also control the dispersed phase hold up and residence time. They have plug flow characteristics and consume lower power per impeller compared to single impeller. High gas hold up and good gas distribution are the

major benefits. Multiple impellers are thus preferred in shear – sensitive micro organism- enriched fermentation reactors.

2. Definitions and Objective of the Study

2.1 Superficial gas velocity (V_G):

It is a velocity at which gas passes upwards through (liquid filled) stirred tank. It is calculated as follows.

$$\text{Superficial gas velocity (m / sec)} = \frac{\text{Volumetric flow rate of gas (m}^3\text{/sec)}}{\text{Cross sectional area of the stirred tank (m}^2\text{)}}$$

2.2 Gas hold up (ϵ_G):

It is the ratio of gas phase volume to total volume. Gas holdup is an important hydrodynamic parameter and is a basic measure of gas-liquid contacting in mechanically agitated tanks. Gas hold up is governed by average bubble size, population of bubbles and bubble velocity. The interfacial area and mass transfer rate are dependent on holdup. Holdup also indicates the volume fraction of gas phase and mean residence time of the gas phase in the vessel. It also governs the velocity or flow field in the vessel, turbulence characteristics in the individual phases and the energy dissipation rates. Thus a study of gas holdup is important for scaling up and design of stirred tank reactors.

2.3. Measurement

Gas hold up was measured by visual method. A graduated graph paper was pasted on the outside of the vessel in between two baffles. By noting the difference between level with and without aeration the hold up was found out. The following equation was used.

$$\epsilon_G = (H_G - H) / H_G$$

Where H_G = Height of liquid after aeration (m), H = Height of clear liquid without aeration (m) and ϵ_G = (fractional) gas hold up. It is a dimensionless quantity. Its value generally ranges from 0 to 0.20.

2.4 Objective

The objective of this study is to identify the optimum combination of dual impellers that will give the maximum gas hold up for a given specific power input – power / unit volume. (Watt / m³)

3. Experimental Set-up

3.1 Details of Agitated Vessel

Experiments were conducted in a vertical cylindrical acrylic vessel having a flat bottom. The diameter (T) of the vessel was 0.45 m and the height of the vessel 1.2 m. The tank is provided with four equally- spaced vertical baffles of width $T / 10$, fixed along the wall of the vessel. A vertical shaft (stirrer) attached to a variable speed DC motor helps to mix the contents of the vessel. Two impellers were mounted on the shaft. The diameter of each of the impeller D was equal to $T/3$. The distance between the lower impeller and the bottom of the vessel – bottom clearance C_1 was equal to $T / 3$. The distance between the lower and upper impeller – inter - impeller clearance was equal to D (diameter of the impeller). The speed of revolution of the stirrer was varied by means of a speed controller. The vessel was filled with tap water up to a height equal to two times the diameter of the vessel. Air was admitted to the bottom of the vessel using a ring sparger having a diameter equal to that of the impeller. The diameter of the sparger was 6.0 mm and there were eight holes through which air was admitted to the vessel.

Three different types of impellers were used. PTD– Pitched Blade Down pumping, PTU – Pitched Blade Up pumping and DT- Disc Turbine. At any point of time two (dual impellers) were used. In all five combinations of impellers were employed.

PTD – PTU means Pitched Blade Turbine Down pumping at the bottom, Pitched Blade Turbine Up pumping at the top. Similarly DT – PTD means Disc turbine at the bottom and Pitched Blade Turbine Down pumping at the top. PTD – PTD, PTD – DT and DT – DT are other combinations.

Superficial gas velocities used were 0.005 m / sec, 0.008 m / sec and 0.01 m/ sec Stirrer speed was varied from 150 to 1200 rpm. The experiments were conducted at room temperature at about 30 to 31 °C.

The details of experimental set up are given in Table 1. Table 2 and 3 give the details of impellers

4. Results and Discussions

4.1 Optimum Combination of impellers

The experimental data were plotted in the form of graphs. In Figure.2 the gas holdup was plotted against power per unit volume for different combinations of dual impellers. As the gas holdup increases, the power per unit volume also increases. Thus there is proportionality between holdup and power per unit volume. It is also noted that of all the

combinations DT-PTD combination gives the highest gas holdup. PTD-PTD gives the second highest holdup followed by DT –DT, PTD –DT and PTD-PTU combinations. Thus DT-PTD combination was found to be optimum for getting maximum gas holdup for a given power per unit volume.

4.2 Behaviour of DT –PTD combination

In the case of DT-PTD combination the upper impeller-pitched blade down pumping turbine -produces a downward flow. This together with the radial stream produced by the lower disc turbine increases the axial velocity in downward direction. This acts against the movement of raising air bubbles and thus helps in the recirculation of air in the upper regions of the vessel. The upper impeller is responsible for gas dispersion and recirculation. In this case, the upper impeller is PTD. Mishra *et al* (1994) have reported that PTD has a higher pumping effectiveness compared to other impellers like DT. Hence the gas holdup increases significantly. The DT-PTD combination thus gives highest gas holdup

Figure 3 and 4 exhibit the same trend at higher superficial gas velocities of 0.008m/s and 0.01m/s.

4.3 Effect of superficial gas velocity

Figure.5 represents the effect of superficial gas velocity on the gas holdup. The gas holdup increases as the superficial gas velocity increases. This is understandable, as the volume of air increases a large population of raising bubbles tends to increase the hold up.

4.4 Effect of bottom clearance

The distance from the bottom of the impeller to the bottom of the tank is called the bottom clearance. Normally the value of this bottom clearance equals 1/3 (T) where T is the tank diameter. In this study the bottom clearance was varied and the effect of this variation on gas holdup was studied. Figure.6 shows the effect of bottom clearance on gas hold up. The holdup was significantly lower when bottom clearance was T/2 compared to the holdup when the clearance was T/3. The holdup was lowest when the clearance was T/6.

This is because the pumping effectiveness of the lower impeller decreases with an increase in the bottom clearance. Also if the clearance is decreased to a low value of T/6 the gas holdup falls significantly. A low clearance leads to changed flow pattern with high resistance to flow .The holdup thus decreases. This is in line with the observations reported by Saravanan *et al* (1994).

4.5 Effect of Inter- Impeller Clearance

The inter impeller clearance is defined as the distance between the centre line of the two impellers. Normally, this distance is kept equal to the diameter of the impeller. Above this value each impeller sets up its own liquid circulation loops which do not mix with that produced by other impeller. In this study the effect of inter impeller clearance on gas holdup was studied. The distance between the impeller was kept at 1.5 D, and 2.0 D and gas hold up was measured. It was observed that the gas hold up decreases with an increase in the impeller clearance. The gas holdup values for 1.5 D were significantly lower than that for 1.0 D. Gas hold up values for 2.0 D were lowest. See Figure 7. This is also in line with the findings reported by Mishra and Joshi (1994) using LDA (Laser Doppler Anemometry) method.

4.6 Effect of Physical properties on gas hold up

The physical properties of the liquid in the vessel, like density, viscosity and surface tension affect the gas hold up. As a bubble raises up its size and velocity are affected by the physical properties of the liquid through which it raises. Surface tension does play a part and its effect on gas holds was studied. Figure .8 indicates the effect of surface tension on gas hold up for a system with air – ethanol and T equal to 0.45m, D equal to 0.15m. Impeller speed was 1200rpm and superficial gas velocity 0.01m/sec. As the surface tension increases the gas holdup falls, because the size of the bubble and its upward velocity increase. If the surface tension is lower the bubble size and its upward velocity decrease leading to higher gas holdup. This is in conformity with the findings reported by Loisseau *et al* (1977).

4.7 Correlation

Based on the data obtained from experiments the following type of empirical correlation is proposed.

$$\epsilon_G = a (P / V)^b (V_G)^c \text{-----(1)}$$

- ϵ_G = Gas hold up –Dimensionless quantity
- P = Power consumed by impeller in aerated condition (w)
- V = Volume of liquid in the vessel (m³)
- V_G = Superficial gas velocity (m/sec)
- a, b, c = Constants

The values of all constants a , b and c obtained by regression of experimental data are presented in Table 4. The values of constants obtained in this work are much lower than that reported by Moucha *et al* (2003). This is due to the fact that the latter measured hold up in electrolytic solutions whereas the present work was conducted with air – water systems. The effect of electrolytic solutes on the gas hold up is due to the property of coalescence. The solutes inhibit coalescence and thus the hold up increases in the presence of electrolytic solutes.

4.8 Comparison of Correlations

The present work is also compared with that of Vasconceles *et al* (2000). See Figure 9. The gas holdup values reported by the latter are higher than that reported in the present work. The latter conducted the experiments in a tank of diameter of 0.39 m whereas a tank of 0.45 m diameter was used in the present work. The gas hold up is dependent on the tank diameter. As the tank diameter increases the hold up decreases significantly.

4.9 Parity Plots

Figures 10 and 11 compare the experimental values with that of theoretical values of gas hold up obtained using the correlation proposed in this work. Such plots are called Parity Plots. It is noted that the difference between the two values is less than 15%

5. Conclusions

The gas holdup of dual impeller combination in agitated vessel was studied in detail. Five different dual impeller combinations - PTD/PTU, PTD/PTD, PTD/DT, DT/PTD, and DT/DT were studied. It was found that DT/PTD combination gave maximum gas holdup compared to other combinations. The effects of bottom clearance, inter-impeller clearance and surface tension on gas hold up for the optimum impeller combination were studied. It was found that a bottom clearance of $T/3$ gave the maximum holdup followed by $T/2$, and $T/6$. It was also found that the gas hold up was maximum when inter-impeller clearance was D . At values of clearance $1.5D$ and $2.0D$ the gas hold up was much lower. It was found that gas hold up falls as the surface tension increases.

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Table 1. Details of experimental set up

Diameter of the vessel	0.45 m
Height of the vessel	1.2 m
Diameter of the Impeller	0.15 m
Bottom Clearance	0.15 m
Inter impeller clearance	0.15 m
No. of Baffles	4
Height of water in the vessel	0.9 m
Width of Baffles	0.045 m
Type of sparger	Ring Sparger
Diameter of the sparger	0.006 m
No. of holes	8
Drive used	2 H.P DC motor with variable speed controller
Type of impellers used	PTD Pitched Blade Turbine Down pumping PTU. Pitched Blade Turbine Up pumping DT – Disc turbine

Table 2. Combinations of dual impellers

Sl.No.	Nomenclature	Bottom	Top
1	PTD – PTD	Pitched Blade Turbine Down pumping	Pitched Blade Turbine Down pumping
2	PTD- PTU	Pitched Blade Turbine Down pumping	Pitched Blade Turbine Up pumping
3	PTD – DT	Pitched Blade Turbine Down pumping	Disc Turbine
4	DT – PTD	Disc Turbine	Pitched Blade Turbine Down pumping
5	DT – DT	Disc Turbine	Disc Turbine

Table 3. Details of Impellers

Sl.No.	Type	No. of Blades	Blade angle	Imp. Diameter	Blade width
1	PTD	6	45 °	0.15 m	0.0375 m
2	PTU	6	45 °	0.15 m	0.0375 m
3	DT	6	-	0.15 m	0.0375 m

Table 4. Values of Constants a, b and c in equation 1

Sl.No.	Type	a	b	C	Square of correlation coefficient
1	DT-PTD	0.02	0.478	0.4910	0.980
2	PTD-PTD	0.047	0.433	0.6097	0.990
3	DT-DT	0.07135	0.4244	0.6904	0.981
4	PTD-DT	0.0596	0.4459	0.6971	0.974
5	PTD-PTU	0.0768	0.4235	0.7116	0.965











