Bubble Size Distribution: Comparison between Six-bladed Curve Blade Impeller and Rushton Turbine

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ABSTRACT

In this work, bubble size distribution generated by six-bladed curve blade impeller (6CB) was compared with Rushton Turbine (6RT) in a 40 cm diameter cylindrical tank for gas-liquid and gas-liquid-solid systems. Bubbles were drawn out from the tank using a suction pump and captured by digital camera when the bubbles passed through a specially built cylindrical perspex tube. The Sauter mean diameter, d_{32} and distribution curves were compared at 5 L/min aeration rate and 60, 80 and 100 rpm for two (0% inert solid) and three phase systems (addition of 2% wt inert solid). The investigation showed that at 60 rpm, d_{32} for 6CB was lower than 6RT by about 10% at locations very close to the impeller region. However, at higher agitation speed (80 and 100 rpm), 6RT recorded lower d_{32} values than 6CB. Addition of solid 2% wt inert solid was found to decrease the d_{32} values (compared to gas-liquid system) but became almost similar and a bi-modal distribution was also observed for both the impellers.

Keywords: *Bubble size distribution, Sauter mean diameter, Rushton Turbine, Curve blade impeller*

Introduction

In chemical engineering operations and practices, gas-liquid contactors are widely used for carrying out reactions and mass transfer operations. The presence of a gas phase dispersed in a continuous liquid is the reason why such kind of reactors can provide high interfacial area for mass and heat exchange, good mixing and high thermal stability. To develop sufficient understanding of the basic mechanisms of gas-liquid mixing in these systems, one requires more detailed knowledge of the gas-liquid flow and the structure of gas dispersion. This information is of great importance for determining the true mass transfer conditions.

The dispersion of gas in liquid systems can be studied by determining gas bubble sizes and their surface areas, in order to determine mass transfer efficiencies. Smaller bubbles are more desirable in mass transfer operations as they provide larger mass transfer surface areas. Bubbles are produced from trailing vortices behind impeller blades, and the size and shape of the trailing vortices determine the number of bubbles produced and their size distribution. In some early studies, a sophisticated capillary probe technique was used for measuring the local bubble size distribution at 22 locations in a 1.0 m stirred vessel [1], [2]. The fully submersible probe developed was interfaced to a microcomputer for high-speed data acquisition and data processing. A detailed quasi-point investigation was carried out of the structure of bubble size distribution in coalescing and non-coalescing gas liquid dispersions the stirred vessel. With a Rushton Turbine, they found that bubble size distribution depends on the position in the tank and the agitation intensity of the impeller. This automated bubble size measurement technique achieved very high rates of sampling from bubble sizes down to 0.3 mm.

Then, a study was made on the effect of agitation and impeller speed due to a Rushton Turbine, on the bubble size and bubble size distribution in an aerated vessel [3]. A non-coalescing system was used, which made it possible to study the bubble breakup process in isolation. With no agitation, the bubble populations were found to exhibit a log-normal distribution. A year later, a researcher gave a comprehensive review on gas dispersion in agitated vessels [4]. He classified the three areas of interest in gas dispersion in agitated tanks as (i) the hydrodynamic flow regimes occurring around the impeller and in the tank (ii) the bubble size and holdup, and (iii) the mass transfer coefficient. He found that a number of the processes are area controlled and depend on transport across the gas-liquid interface. Insufficient transfer may cause failure of the process, reduction in yield or production of undesired by-products. The main performance criterion is the maximum mass transfer in such vessels, which is determined by gas holdup and the size distribution of bubbles in dispersion. One of his main findings is that the ability to predict bubble size and bubble size distribution as a function of the operating parameters such as power input and so on.

From literature studies made, it was found that more information on bubble size distribution is available for the Rushton Turbine compared to the Curve blade impeller, because most researchers carried out experiments using the flat bladed Rushton Turbine. Less information on bubble size distribution is available for the Curve blade impeller, which is the modification of the Rushton Turbine, where the impeller blades are curved to a certain degree. From some studies conducted, the Rushton Turbine was found to have lesser gas handling capacities when compared to the Curve blade impellers [5]. Therefore, the aim of the present study is to compare the gas handling capacities and efficiencies of a Rushton Turbine and Curve blade impeller and to obtain some information on the bubble breakup characteristics of the Curve blade impeller when compared to the Rushton Turbine.

6RT and 6CB are increasingly becoming popular for gas-liquid-solid system. Therefore the effect of solid on bubble size distribution will be useful in understanding mass transfer and gas hold-up characteristics of these impellers. However, from the authors' search, no such information is available in the literature.

Materials and Methods

A fully baffled Perspex stirred vessel with an inner diameter of 0.4 m and an air-tap water system was used in the study. The experimental rig is shown in Figure 1. Liquid height used was approximately equal to the tank inner diameter. Sodium chloride (NaCl) was added as non-coalescing media. Six-bladed Rushton Turbine (6RT) and the six-bladed Curve blade impeller (6CB) were used in the study. The schematic of the impellers are shown in Figure 2. For aeration, a perforated ring sparger with holes of 2 mm in diameter was used. All experiments were conducted at room temperature and pressure. Aeration rate of 5 L/min and impeller rotational speeds of 60, 80 and 100 rpm were used. Spherical glass particles with an average diameter of 300 μm were used as the inert solid particles.

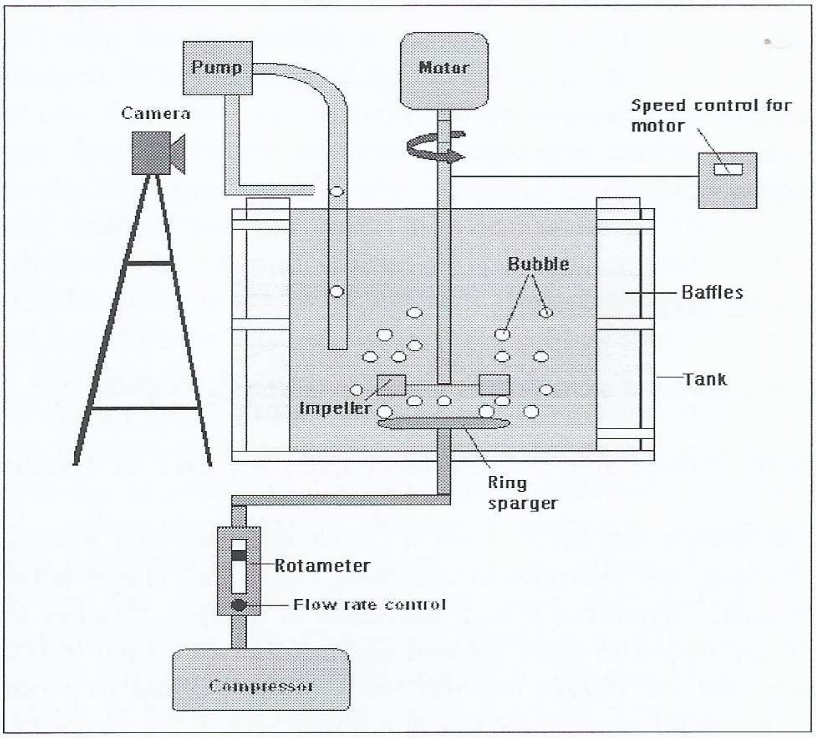

Figure 1: Experimental Rig


(a) (b)

Figure 2: Six-bladed (a) Curve Blade Impeller (6CB) and (b) Rushton Turbine (6RT)

In this work, the main task was to draw out bubbles from the mixing tank using system shown in Figure 1 above. The system proved to be efficient and produced sufficiently reliable results. A sample of 100 bubbles was drawn out from the impeller region for each experimental run. Bubbles captured in the device were cylindrical in shape, and their equivalent spherical diameter, d_b was determined. Then the bubble Sauter mean diameter was calculated using equation (1):

$$d_{32} = \sum n d_{bi}^3 / \sum n d_{bi}^2 \qquad (1)$$

Where,

d_{32} – Sauter mean diameter (mm)
n – number of bubbles in group i
d_{bi} – average bubble size in group i

Results and Discussion

Effect of Impeller Type for a Gas-Liquid System

Figure 3 shows bubble size distribution (BSD) for 6RT at aeration rate of 5 L/min.

At all the speeds the BSD shows a Gaussian behaviour with difference in spread. At 60 rpm, the distribution is almost like a bell shape where d_{32} of 4.1 mm was obtained. When the speed increased to 80 rpm, smaller bubbles with less than 3.0 mm diameter were formed and number of bigger bubbles reduced. This indicates that the bigger bubbles were broken down to produce smaller bubbles. The d_{32} at 80 rpm for 6RT was 4.0 mm where the range of bubble size was not very wide. When the speed was increased to 100 rpm, very small bubbles with less than 2.0 mm diameter were formed and on the other hand very big bubbles with more than 7.0 mm diameter were formed too. This

indicates that both bubble breakup and bubble coalescence may be occurring at 100 rpm for 6RT and the d_{32} was found to be 3.9 mm.

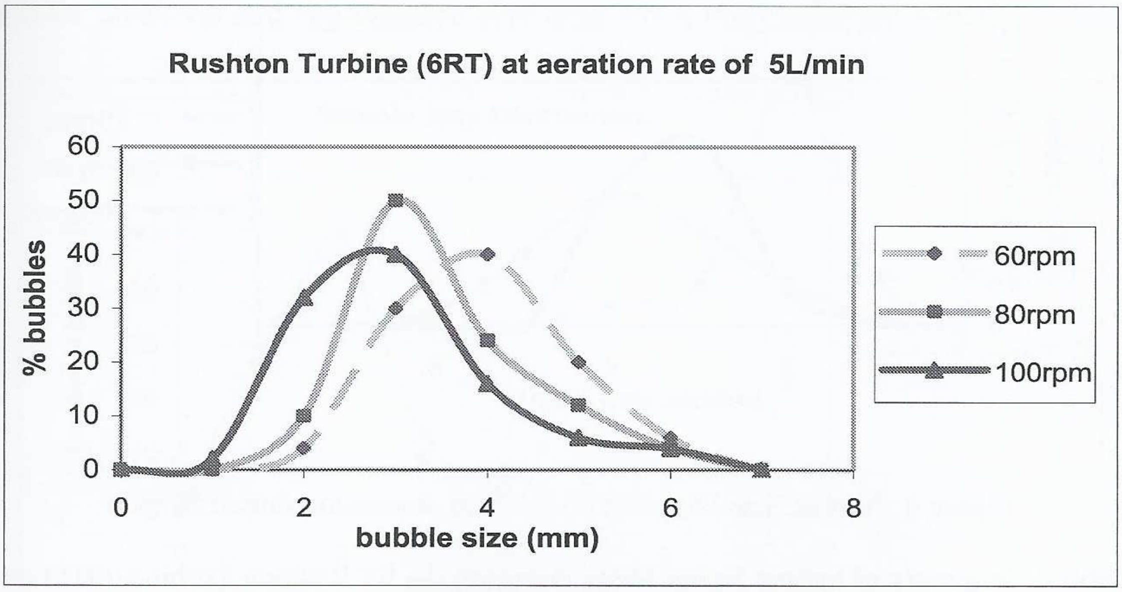

Figure 3: Bubble Size Distribution for 6RT at aeration rate of 5L/min

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Figure 4 shows the BSD for 6CB at 5 L/min aeration rate. At 60 rpm, 6CB was found to produce smaller bubbles with a d_{32} of 3.7 mm compared to 80 rpm where the d_{32} increased to 4.7 mm. The occurrence is reversed from 6RT where the d_{32} values decreased as the speed increased. However at 100 rpm middle range bubbles (4 – 5mm) were formed where d_{32} of 4.3 mm was obtained. From the analysis, it can be seen that bubble breakup and coalescence are occurring simultaneously resulting in difference in spread and shift of the BSD curves for both 6CB and 6RT. The resulting d_{32} is dependent on the net result in between bubble breakup which produces smaller bubbles and bubble coalescence which produces bigger bubbles. The d_{32} values for all the cases studied are shown in Table 1.

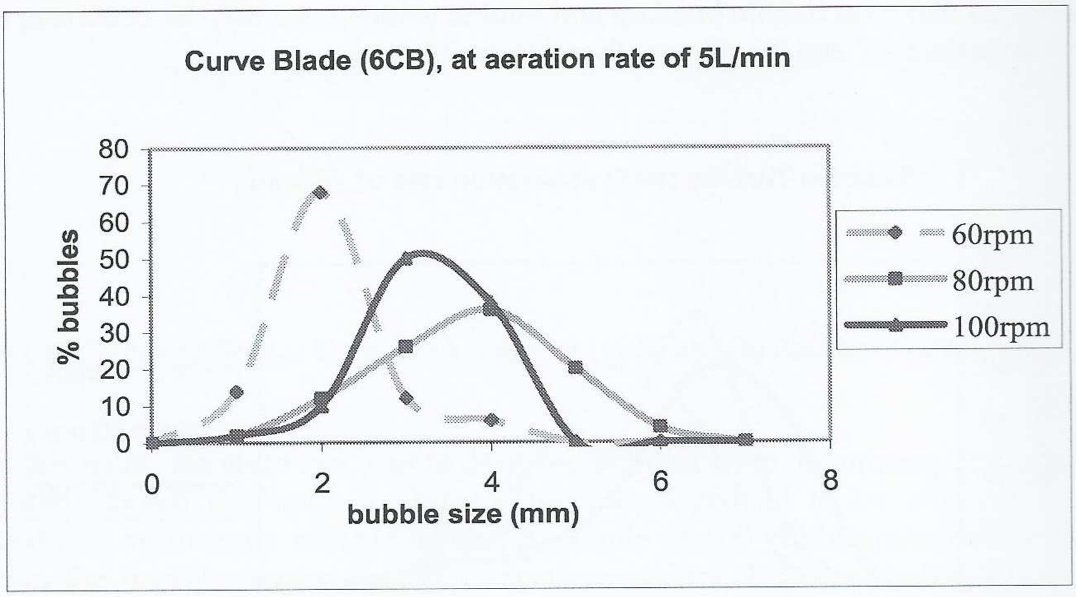

Figure 4: Bubble Size Distribution for 6CB at aeration rate of 5L/min

Table 1: Summary of bubble Sauter Mean diameter, d_{32} for Rushton Turbine (6RT) and Curve Blade impeller (6CB)

Blades	Gas flow rate (L/min)	Rotational speed (rpm)	d_{32} (mm)
6 (6RT)	5	60	4.1
		80	4.0
		100	3.9
6 (6CB)	5	60	3.7
		80	4.7
		100	4.3

The variation in BSD of 6CB on the opposite manner compared to 6RT and difference in d_{32} values are due to variation in bubble creation mechanism (changes in the type of cavities from clinging to large cavities and also cavity growth), gas handling capacity of both impellers and amount of energy imparted by the impeller to the air slugs. Further in depth studies may be required before generalized conclusions can be made on these observations. Smaller bubbles are desirable for higher mass transfer efficiencies.

Effect of Inert Solid Addition for a Gas-Liquid System

Figure 5 shows the bubble size distribution for 6RT and 6CB at aeration rate of 5 L/min, 60 rpm and added with 2% wt glass particles. The d_{32} values for 6RT and 6CB were 3.6 and 3.5 mm respectively. Addition of solid particles resulted in decrease in d_{32} values for both the impellers. The distribution for both the impellers became almost similar and Figure 5 also shows the emergence of bi-modal distribution where the number of smaller bubbles and bigger bubbles increased compared to gas-liquid system. This indicates that there are active bubble break-up and coalescence activities when inert solid are added.

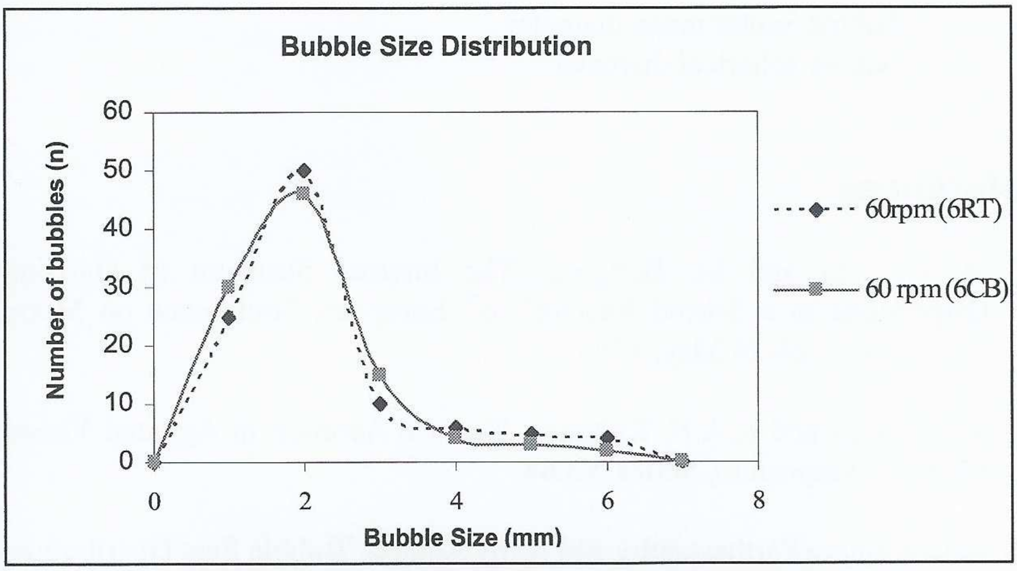

Figure 5: Bubble Size Distribution at aeration rate of 5L/min, 60 rpm and 2% inert solid

Conclusion

From the investigation conducted, the following conclusion can be made:

i) Bubble size distributions of Gaussian function were obtained for both the Rushton Turbine (6RT) and Curve blade impeller (6CB) for gas-liquid system.
ii) The d_{32} value for 6CB was about 10% smaller than that of 6RT for the gas-liquid system at 60 rpm and 5 L/min. However at 80 and 100 rpm (at constant aeration rate of 5 L/min) the d_{32} values for 6RT was lower than 6CB by about 10 – 15%.
iii) Addition of 2% wt inert solid into gas-liquid system at 5 L/min aeration rate and 60 rpm reduced the d_{32} values for both the impellers and the value and distribution became almost identical. A bi-modal distribution also emerged for both the impellers.

Nomenclature

BSD – bubble size distribution
6RT – 6 bladed Rushton Turbine impeller
6CB – 6 bladed Curve Blade impeller
d_{32} – bubble Sauter mean diameter
d_b – bubble spherical diameter

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