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An Experimental Study on a Bubble Column Reactor

Kamal Kishor Yadav
Department of Chemical Engineering, Dr. K. N. Modi University Newai, Rajasthan, INDIA

ABSTRACT

Bubble column reactors have many important role in chemical, petrochemical and biochemical industries due to their relatively simple construction, favorable heat and mass transfer properties and low operating cost. In this study, bubble column reactor used as a photobioreactor. Efficiency of a bubble column depends on various design parameters and column geometry (configuration). In this study, an experimental investigation of the bubble column configuration on its hydrodynamics has been conducted with different superficial gas velocities. Hydrodynamics (gas holdup, bubble diameter and superficial velocity) of a bubble column system were studied at laboratory conditions.

Keywords: Bubble column, gas hold up, flow regime, superficial velocity.

I. INTRODUCTION

Bubble column reactors owe their wide application area to a number of advantages they provide both in design and operation as compared to other reactors. First of all, bubble column have good heat and mass transfer characteristics, means it gives high heat and mass transfer rates. Bubble column requires little maintenance and low operating costs because of lack of moving parts and compactness.

Bubble column reactor is one of multiphase reactors which are divided into three main categories namely, the trickle bed reactor or packed bed reactor, fluidized bed reactor, and the bubble column reactor [1]. A bubble column reactor is basically a cylindrical column with a gas sparger at the bottom. The gas is sparged through the gas sparger in the form of bubbles in a liquid phase or in a liquid-solid mixture. When a solid phase exists in a bubble column, the reactor generally termed as slurry bubble column reactors. Bubble column are generally used as a contractor of two phases, sometimes more than two phases and used in chemical, petrochemical, biochemical and metallurgical industries [2]. They are used mostly in chemical operations and processes, sometimes involving reactions such as oxidation, chlorination, alkylation, polymerization and hydrogenation. For example bubble columns are used for the manufacture of synthetic fuels by conversion of gas and in biochemical industries they are used for fermentation and biological wastewater treatment [3, 4].

II. LITERATURE REVIEW

Superficial gas velocity:

Superficial gas velocity is the average velocity of gas that is sparged into the column using a sparger which is simply expressed as the volumetric flow rate divided by the cross-sectional area of column. Superficial gas velocity directly effect on gas hold up means with increasing gas velocity gas hold up also increases [1].

Gas hold up:

Gas hold up is one of the most important parameter for design and scale up of bubble column. It has been known that gas hold up depends mainly on the superficial gas velocity and often is very sensitive to the physical properties of liquid [6]. Gas holdup is a dimensionless key parameter for design purposes that characterizes transport phenomena of bubble column. Basically gas hold up defined as volume fraction of gas phase occupied by the gas bubbles. Thus the gas hold up was calculated:

$$\varepsilon_g = \frac{H_f - H_i}{H_i}$$

In literature, there are many correlations to obtain gas hold up some of are shown in table.

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Research Group	Correlation
Joshi and Sharma[8]	$\varepsilon_g = \dfrac{V_g}{0.3 + 2V_g}$
J.C. Kuo[9]	$\varepsilon_g = 6.5V_g^{1.1}$
Godbole et al.[10]	$\varepsilon_g = 0.239V_g^{0.634}D_t^{-0.5}$

Flow regime:

The fluid dynamic characterization of bubble column reactors has a significant effect on the operation and performance of bubble column [1]. In the bubble column flow pattern depend upon the superficial gas velocity, low velocity (less than 2 cm/s) gives homogenous regime or bubbly flow [7]. This flow regime is characterized by bubbles of relatively uniform small sizes and rise velocities. A uniform bubble distribution can be observed over the entire cross sectional area of the bubble column and there is practically no bubble coalescence or break-up. This uniform bubble size and distribution depend on the sparger design and system properties [1]. At higher gas velocity large bubbles are formed by coalescence, this type of flow pattern is referred to as heterogeneous regime and it is characterized by wide bubble size distribution.

III. EXPERIMENTAL SET-UP

A glass cylinder of 97cm length 8.2cm inner diameter and 9.9cm outer diameter with one inlet in the bottom and one outlet at the top as an exhaust was used. One rotameter was connected with the bubble column for air in-flow. The experiment was performed in three conditions, initially the bubble column was operated with a porous gas distributer (sparger -1) which have 1mm pore diameter. In the other condition a ceramic gas distributer (saprger-2) was used which have approx. 0.01mm average diameter. In the final operating condition the ceramic gas sparger was used with three mesh plates are used in the bubble column.

Fig. 1: Bubble size distribution with different spargers.

The bubble size distribution depends on the superficial gas velocity and gas distributer, in this study two spargers was used which were having different pore size. Sparger-1 gives bigger bubbles than that of sparger-2 as shown in fig. 1. Bubble size effect the gas hold up because large bubbles have less surface contact area so smaller bubbles more gas hold up.

IV. RESULT AND DISCUSSION

Gas hold up was checked at all the three operating conditions and the study shows that the gas hold up was increased with superficial gas velocity as shown in fig. 2.

In the experiment it was found that increase in gas hold is directly proportional to gas velocity in the bubble column reactor. In this experiment it was also found that the flow regime totally depends on the superficial gas velocity. Lower gas velocity (less than 3 cm/sec) gives bubbly flow regime, medium gas velocity (between 3 to 5 cm/sec) the flow goes on changing from homogenous to heterogeneous regime (transition phase). At higher gas velocity more than 5 cm/sec the flow pattern was heterogeneous type.

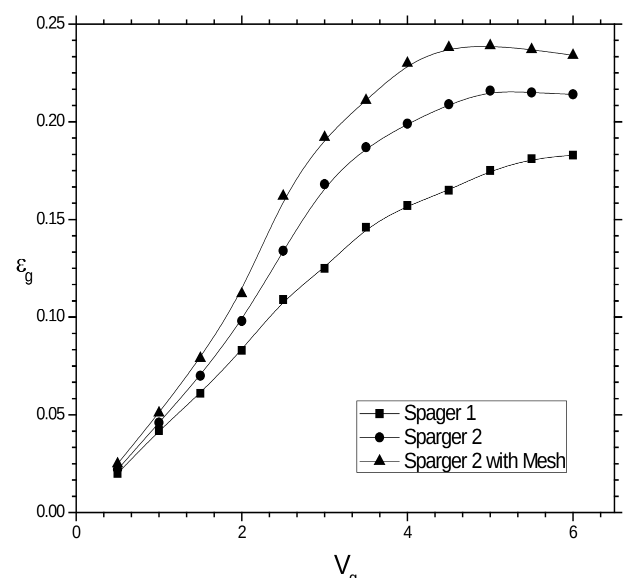

Fig. 2: Gas hold up in bubble column.

In fig. 3 experimental data of gas hold up for different gas distributers, are compared with empirical values of gas hold up. The experiment shows that the correlations are fit for the bubble column at lower superficial gas velocity (less than 2 cm/s). At this velocity the flow regime was homogeneous for all the gas distributers. But all the correlations were not show the significant results at $V_g = 3$ cm/s. At higher superficial gas velocity (more than 3 cm/s), heterogeneous regime was occurred for all the gas distributers [11].

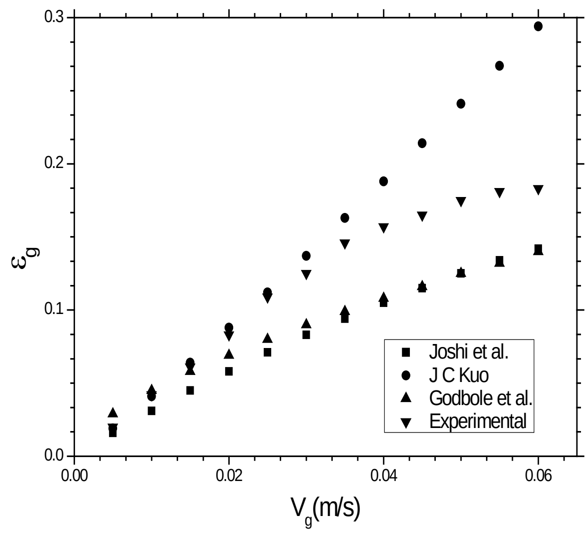

Fig. 3(a): Comparison of experimental and empirical gas hold up with Sparger-1

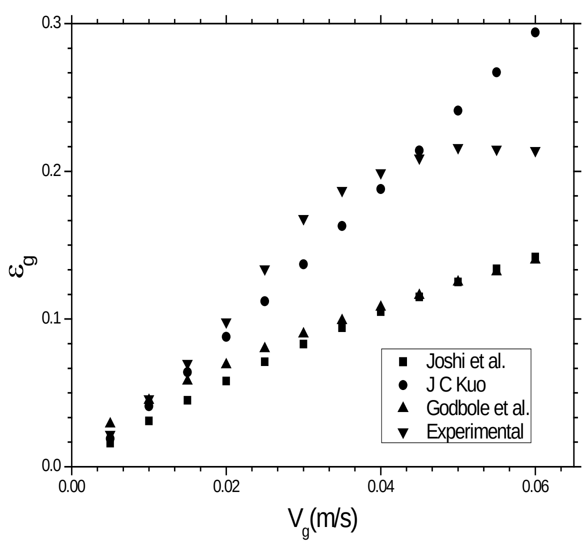

Fig. 3(b): Comparison of experimental and empirical gas hold up with Sparger-2

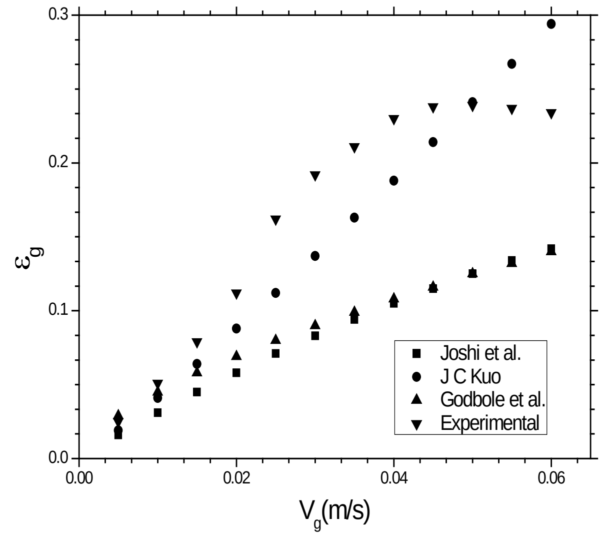

Fig. 3(c): Comparison of experimental and empirical gas hold up with Sparger-2 and mesh plates.

Since it is often desirable to operate under homogenous condition, it is of utmost importance to accurately determine limits between regimes. The first experimental way to identify the flow pattern consists in measuring the evolution with superficial gas velocity of the mean value of a parameter closely related to the flow structure. The chosen parameter must exhibit an extremum or a significant break-up when transition occurs. Fig. 2 illustrates ε_g vs V_g data obtained with the different gas distributors for the bubble column. In the batch bubble column equipped with a distributor (sparger-2) which produces a uniform gas distribution the curves exhibit a pronounced maximum reflecting the transition between the homogeneous and heterogeneous regime. The regime is homogeneous at superficial gas velocities lower than 2 cm/s and is characterized by the linearity of ε_g vs V_g. On the contrary, with sparger-1 that yields a non-uniform gas distribution (fig. 1), the ε_g vs V_g curve never rises linearly and does not exhibit a maximum. This means that heterogeneous conditions prevail even with the lowest gas flow rate used in this work. With the sparger-2, the fully developed heterogeneous regime is observed at $V_g > 4.5$ cm/s starting from the point when ε_g exhibits a minimum. In all cases, transition to churn-turbulent flow cannot be delayed by the distributor design beyond a certain value of superficial gas velocity above which bubble-bed behavior is governed by the macro scale circulation patterns.

Another way to describe regime limits with ε_g measurements is provided by the classical drift-flux analysis [12, 13] reported in Fig. 4. In batch operation for the liquid, the drift-flux is defined as:

$$U_{df} = (1- \varepsilon_g)\, Vg$$

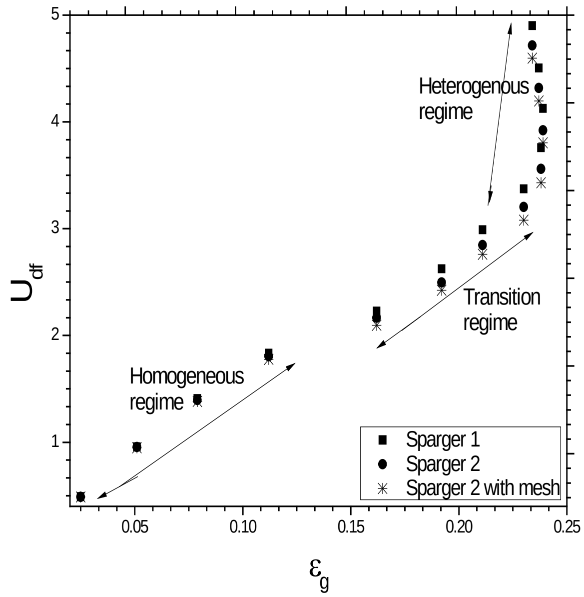

Fig. 4: Characterization of regime transitions with the drift-flux model.

The plot of U_{df} vs ε_g reveals immediately which regime prevails in the bubble column. A change in flow pattern is indicated by an increase in the slope of the U_{df} vs ε_g curve. One can see in Fig. 4 that homogeneous regime ends at approximately V_g = 0.025 m/s and heterogeneous regime prevails at V_g > 0.045 m/s. The transition regime exists between the 0.025 m/s to 0.045 m/s gas velocity.

NOMENCLATURE

H_f	Final height of liquid
H_i	Initial Height of liquid
V_g	Superficial gas velocity
D_t	Column diameter
U_{df}	Drift flux
ε_g	Gas hold up

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