ORIGINAL ARTICLE

Investigation of Gas Hold up and Power Consumption in a Stirred Tank Bioreactor Using Single and Dual Impeller Configurations

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Received January 27, 2013; Revised April 19, 2013; Accepted May 12, 2013

ABSTRACT

A laboratory stirred tank bioreactor with six single and dual-impeller configurations was tested to obtain the optimum operating conditions for future biological processes. Six impeller combinations consisting of three basic impeller types, namely Rushton turbine (RT), pitched 4blade (P4B) and pitched 2blade (P2B) downward flow were investigated in 1.77 L bioreactor working volume. Power consumption and gas holdup measurements were taken over a range of 100-1000 rpm of stirring speed and 1-5 Lmin⁻¹ of airflowrates, for all the six combinations consisting of any single and dual impellers. Using predicted data some empirical correlations were derived which present relations in estimation of power consumption in stirred tanks with various impeller configurations. Electrical measurement method was use to determine the power drown in the stirred bioreactor. Gas hold-up increased with an increase in stirring speed and superficial gas velocity for all the impellers employed. The number and type of impellers in stirred bioreactor had considerable influence on gas hold-up behavior of the stirred bioreactor. Besides, Rushton turbine-dual Impeller gave comparably maximum gas hold-up, but at significantly higher power consumption levels. The proposed correlations offered good agreement with the experimental data.

Keywords: Gas hold-up, Stirred bioreactor, Power consumption, Dual-impeller

INTRODUCTION

Stirred tanks as a means of mechanical agitation for mixing of bioreactor media are one of the most commonly used equipment in biotechnology [1]. The most common equipment used for effective contact between gas and liquid phases in chemical and biochemical processes is Rushton turbine agitated vessel [2, 3]. Although the Rushton turbine has been used for decades as reactor agitation tool, several designs have been developed to enhance and optimize gas–liquid contact in recent years. In full-scale reactors, multiple impellers are often used with either impellers of the same type or a combination of novel and traditional blades [4]. Several researches declared that “multi-
impeller gas–liquid reactors have been found ensuring compare with the radial ones are more efficient from higher efficiency of gas utilization and longer retention view point of mixing performances [8].
time of gas than single impeller systems” [5]. Power consumption in stirred tank bioreactors is
Breaking up of bubbles is mainly caused by stirrer known as one of the most important design parameters speed and the mixing intensity in bioreactor vessels [6]. which is influence by several factors such as: the
Gas hold-up and mass transfer between several phases physical properties, operating and geometrical
of reactor media very closely linked to each other. Gas parameters of the of equipments. Most of the studies
hold-up is defined as a measure of the efficiency of gas–announced that being aware of power consumption of
liquid contacting. Several variables such as: vessel and the stirring equipments may lead to better decision
impeller design, impeller speed (power input), gas making on operating conditions so, achieving the
velocity and liquid physical properties may influence needed mixing process with a minimum expenditure of
the rate of gas hold up in an impeller agitated reactor energy and cost is of great concern [12, 13]. It was said
[7].

The effect of impeller design on gas hold-up in manufacturing cost of a bio-filtration process. Also
water and viscous liquids have been investigated in other parts of equipments air such as compressors and
several studies. Khare et al. showed that impeller circulation pumps need electrical energy; but the major
selection remains critical from the point of view of consumer is the agitator agent.

Generating gas hold-up, even in the coalescence. Given this background, it is evident that study on the
inhibited high viscosity, especially at the lower gas effect of impeller design on gas hold-up and power
velocity. They also found that total gas hold-up in consumption in bioreactors is advantageous. This study
Carboxyl Methyl Cellulose solution increases with is devoted to optimization of agitation and aeration
impeller speed at different gas velocities [7]. Gas hold conditions in a system with geometrical configuration
up, mixing intensity of dispersion and gas–liquid commonly used in laboratory scale stirred tank
volumetric mass transfer coefficient for 18 impeller bioreactors with mixing equipment consisting of single
configurations in triple-impeller have been studied by and dual impellers on a single shaft. The performance
Tomoa et al. They found that the impeller was assessed on the basis of gas hold-up, which is a
configurations with low power number provide higher basic measure of the efficiency of gas-liquid contacting
dispersion mixing intensities, while the impeller and, at the same time, very closely linked with mass
configurations with high power number provide better transfer.

mass transfer performance [8]. Dohi et al. used Rushton. The aim of this work is to compare the power
turbines and pitched blade impellers (four impellers on a dissipation and its effect on gas hold-up, which in turn
common shaft)[9]. Several Pitched blade impellers on a decides the gas-liquid interfacial area for various
common shaft have also been used by Saravanan et al. combinations of impellers. The optimum combination
who selected them as the most effective ones from can then be selected for industrial bioprocesses with
several tests [10, 11]. The axial impellers to total confidence.
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Fig 2. Schemes and details of the impellers: a. Standard Rushton turbine with vertical Blades (RT), b: Pitched 4blade (P4B), c: Pitched 2blade (P2B)

**Material and Methods**

The Stirred Bioreactor in detail

The experimental conditions have been selected between the volume of un-aerated and aerated liquid in order to generate efficient mixing condition inside the bioreactor. The gas hold-up was computed from the following equation [18]:

\[ \varepsilon = \frac{H - H_0}{H_0} \]  

Where, \( \varepsilon \) is the gas hold-up, \( H_0 \) is the un-gassed distance between impellers is chosen equal to the tank's column height (m) and \( H \) is the column dispersion diameter in order to avoid interaction between them. The height due to the presence of gas bubbles (m).

The experiments were performed at room temperature and atmospheric pressure. De-ionized water (28± 0.5 °C) was used as the liquid phase and filtered air was supplied to the system through an orifice sparger (28± 0.5 °C) was used as the liquid phase and filtered air was supplied to the system through an orifice sparger located 5 cm below the lower impeller. In order to avoid interaction between them, the impeller must be located neither close to the dispersion nor close to the free surface.” [13].

Looking at the literature, it was found that the most used systems has its own advantages and disadvantages, and is chosen based on some factors such as investment, scale, precision, and range of measurement. The first technique is electrical device nor close to the free surface” [13]. Three types of measurement that used for power draw quantifications, namely, Rushton turbine (RT), Pitched 4blade (P4B) and Pitched 2blade (P2B) impellers (blade of stirred vessels. For the case of direct current motors with 45°) with downward pumping (Fig 2) were tested. The power draw by an electrical device is simply calculated by the supplied voltage (V) and the current (I) in order to evaluate their effect on the gas hold-up and power consumption (and). Power consumption in these networks could be calculated by an ammeter, as well as directly ranging from 1 to 5 L min⁻¹ were tested in ten agitation by means of a wattmeter [12].

**Gas Hold up**

Gas hold-up (\( \varepsilon \)) as an important design parameter of bioreactor that is presented in Fig 1.

**Results**

The effect of impeller combination and power on the noticeable effect on the mass transfer coefficient (\( K_{La} \)) gas hold-up was studied for several impeller configurations. The results are represented in Fig 3. As
seen from this figure, the gas hold-up increases with increase in flowrate, although the trend is the same for all flowrates (1 to 5 L/min). Also the extent of the increase is much higher at higher flowrates. A reduction of power consumption is notable with increase of gas flowrate in each impeller configuration. This reduction for RT 2 impeller composition is about 30% in flowrate of 5 L/min to compare with 1 L/min.

In addition, Fig 3 shows gas hold-up increment of 40 to 120% in lower and higher gas flowrates respectively all flowrates (1 to 5 L/min). Also the extent of the increase is much higher at higher flowrates. A reduction in RT 2 impeller to compare with RT 1 impeller configuration. The RT 2 impeller vs. P4B and P2B in power consumption is notable with increase of gas Fig. 3 appears an increase of 90 and 100% of gas hold-
flowrate in each impeller configuration. This reduction in RT 2 impeller to compare with P4B and P2B for RT 2 impeller composition is about 30% in flowrate respectively. Comparison of single and dual impeller of 5 L/min to compare with 1 L/min.

Published online: July 11, 2013
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increase of 20 to 30% in dual configurations. Also Fig. approves the difference of gas hold-up rates in difference impeller configurations. Predictions of the absorption rate of a gaseous sparging rate that expressed as the superficial velocity species in a stirred tank are usually based on [6]. The power input per unit volume (P /V) and,
There are a lot of proposed equations for the fractional gas hold-up as a function of different variables in previous studies [8, 19, 20]. Also frequent disagreements between experimental data and those estimated from these equations are found. This can be attributed to the results of strong impact of the style and size of impellers, the different range of operational conditions, the system considered solutions or real broths, the influence of physicochemical specifications and hydrodynamics due to high viscosity of the liquid, its rheological behavior or even the measuring technique used [6]. The following equations are frequently found in the literature [8, 19, 20]:

\[ \varepsilon_g = \alpha \left( \frac{P_e}{V_L} \right)^\beta \left( V_p \right)^c \quad (2) \]

Where, \( P_e \) is the mechanical agitation power in gas liquid dispersion (W); \( V_L \) represents liquid volume (m\(^3\)); \( V_p \), gas superficial velocity (m s\(^{-1}\)); \( \alpha \), constant; \( \beta \) and \( c \) are exponents.

In this present work on the base of these concepts, some empirical correlations for the gas hold-up rate in the bioreactor with three type of single and dual-impellers are developed and gas hold-up values obtained from the experimental data were plotted against the operating variables and mathematical correlations which describe the influence of the studied parameters on the gas hold-up have been established in order to predict biodegradation performances. These correlations were developed using Datafit 9 software.

Fig 5 plots the experimental gas hold-up for three types of impellers, the RT, P4B and P2B with single and dual impeller configurations, versus calculated gas hold-up using Eq. (2) for different gas flow rates (1 to 5 Lmin\(^{-1}\)) and agitation speeds (100 to 1000 rpm). In this figure the proposed correlation offers a good agreement with the experimental data with an average deviation of ±8\%.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Gas hold-up Exponents of Eq. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \alpha )</td>
</tr>
<tr>
<td>RT, single impeller</td>
<td>21.6</td>
</tr>
<tr>
<td>RT, dual impeller</td>
<td>2.11</td>
</tr>
<tr>
<td>P4B, single impeller</td>
<td>2.73</td>
</tr>
<tr>
<td>P4B, dual impeller</td>
<td>2.64</td>
</tr>
<tr>
<td>P2B, single impeller</td>
<td>7.74</td>
</tr>
<tr>
<td>P2B, dual impeller</td>
<td>4.25</td>
</tr>
</tbody>
</table>

The gas hold-up gives the volume fraction of gas phase in the reactor and thus gives the mean value of residence time for the gas phase. The effect of impeller combination and power on gas hold-up was studied for several impeller configurations. In Fig. 3 it was found that the number of impeller in stirred bioreactor has considerable influence in gas hold-up specifications. Also it revealed that type of impeller has the most efficient impact on gas hold-up behavior of stirred bioreactor.

It is clear from Fig. 4 that even though the maximum values of gas hold-up vary markedly between the impellers tested, the power for gas dispersion is also significantly different. Based on the power consumption value, it is evident that RT dual impeller gives...
comparably maximum hold-up, but at significantly higher power dissipation levels. Also the result illustrated that the turbine impellers appear to be superior to pitched blade from the above discussion it is clear that Rushton turbine under these conditions. At the higher gas turbine-type impellers running in non-Newtonian liquid, velocity, the picture is somewhat similar to Fig. 4, gives the highest gas hold-up. It is therefore desirable to however the holdup values is also correspondingly operate this impeller, preferably in order to ensure that higher (Figures not shown). the gas bubbles are fully dispersed throughout the liquid. As the results have shown, dual Rushton turbine

In this study, it was considered the case where represents an average enhancement on the gas hold-up objective was to choose an impeller which gave the hold-up and hence the gas-liquid interfacial area. It was observed that with an increase in the gas flow rates, the gas hold-up values increased (Fig. 3). Similar results were obtained with single and dual impeller systems. Also the results presented in Fig. 3 illustrate that for different aeration rates(1-5 L/min), begins from a highly skewed curve in lower agitation rates( lower power consumption) and continue to increase, then this trend approaches to a plateau at 900 and 1000 rpm (higher power consumption). On the other hands in pitched blade impellers the gas hold-up increment in trends in different aeration rates (1-5 L/min), begin with a sloped line and this slop is maintained to all agitation speeds.

The constants obtained from the correlations of the table 1. The exponent over (P^/V_L) increased with single impellers, indicating more effective utilization of the power with multiple impeller systems. No significant effect was observed on the exponent over V_L for single and dual impeller systems especially in pitched blade impellers. In the gas hold-up data we can find many trends with number and type of impellers so it is not easy to make general conclusions about multi-impeller vessels design from the gas hold-up data. Empirical correlations for gas hold-up depend on several geometrical parameters, although there is no conformity in the literature about how to take into accounts this influence [8].

**CONCLUSION**

The objectives of this work were to study the behavior and the performances of several impeller configurations. It was found that the number of impeller in stirred bioreactor has considerable influence in gas

**ACKNOWLEDGMENT**

The support of Tehran University of Medical Sciences for supplying funds of this project is appreciated. The authors declare that there is no conflict of interest.

**Nomenclature**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha, \beta, \gamma )</td>
<td>Exponents in Eq. (2)</td>
</tr>
<tr>
<td>( \varepsilon )</td>
<td>Gas hold-up</td>
</tr>
<tr>
<td>( P_0 )</td>
<td>ungaessed column height (m)</td>
</tr>
<tr>
<td>( H )</td>
<td>Column dispersion height due to the presence of gas bubbles (m)</td>
</tr>
<tr>
<td>( T_b )</td>
<td>Bioreactor internal diameter (cm)</td>
</tr>
<tr>
<td>( H_b )</td>
<td>Bioreactor height (cm)</td>
</tr>
<tr>
<td>( N )</td>
<td>Impeller rotation speed (rpm)</td>
</tr>
<tr>
<td>( P )</td>
<td>Power consumption for mixing of non-aerated (W)</td>
</tr>
<tr>
<td>( Q )</td>
<td>Volumetric air flow rate (L/min)</td>
</tr>
<tr>
<td>( P_0/V_L )</td>
<td>Specific power input (W/L)</td>
</tr>
<tr>
<td>( V_f )</td>
<td>Superficial air velocity (m s^{-1})</td>
</tr>
<tr>
<td>( V_L )</td>
<td>Volume of the liquid in the vessel (L)</td>
</tr>
</tbody>
</table>

**REFERENCES**


