Determination of gas hold-up of Pasig River using dynamic gassing out method in a bubble column reactor

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Abstract. This study determines the gas hold-up of Pasig River in a bubble column reactor using dynamic gassing out method by sparging air at different initial liquid height (13 and 25 inches) and superficial gas velocity (0.15, 0.20 and 0.24 cm/s) under atmospheric condition. Discrete grab water sampling was used for water sample collection. Experimental findings showed that the gas hold-up profiles were linear with respect to superficial gas velocity with R² of 0.997 and 0.999 for 13 inches and 25 inches of liquid height, respectively. The values of gas hold-up decreased with increased liquid height to compensate for the increased in liquid hold-up in the column. Experimental results showed that the desired sparging conditions was at high superficial gas velocity and at low initial liquid height in the reactor. The highest dissolved oxygen concentration resulted to the highest gas hold-up in the bubble column reactor. With the results of the study, the data of gas hold-up can be used for future studies to better understand the mass transfer mechanism of the aerated water sample in Pasig River, which eventually leads to the design and scale up of bubble column reactors and aerators for future rehabilitation projects of Pasig River to increase dissolved oxygen content.

1. Introduction
Philippines has many rivers and one of the main is the Pasig River and it was praised for its beauty before. In the Philippines, river’s ecosystems damage is continuously occurring because of the development of economy and the urbanization is accelerating. Severe pollution of water system is due to the massive quantities of household and manufacturing wastewater which flows into the river. The water environment is extremely deteriorating, and the river has lost its purpose as a natural source of water. The difficulties of metropolitan river pollution and biological harm are becoming more and more serious. Aeration can refurbish and augment the growth and the strength of micro-organisms to improve the water characteristics. The aeration technology is a simple and applicable process which began to be applied since the early river restoration [1]. Experimentation for this can be done in a bubble column reactor to assess different properties and water parameters.

A bubble column reactor is a cylinder-shaped container used to flush fluid in either liquid or solid-liquid phase. The reactor comprises of sparger/s usually positioned at the bottom of the vessel to flush gas or liquid to the system. Bubble columns are used predominantly in chemical practices involving reactions such as oxidation, chlorination, alkylation and hydrogenation, in the manufacture of synthetic fuels by gas conversion processes and in biochemical processes such as fermentation and
wastewater treatment [2]. Several gases can be used as flushing agent for gas hold-up to remove dissolved gases and volatile organic compounds such as oil contaminants in water. This gas hold-up is essentially described as the volume fraction of gas phase occupied by the gas bubbles. Fundamental aspects affecting gas hold-up includes superficial gas velocity, liquid properties, column dimensions, operating temperature and pressure, gas distributor design and solid phase properties [3]. Multiple studies using bubble column reactor presented that the volumetric mass transfer coefficient depends mainly on the gas hold-up [4].

Recent studies show that air can be used as flushing agent for water remediation to remove volatilized contaminants and enhanced biodegradation and sparging can be applied to situations in which dewatering is not feasible [5]. Different results of gas hold-up measurement may vary due to specific operating conditions and specifications of the reactor to be used. In general, air sparging is applicable at sites where water is contaminated with volatile, semi volatile, and/or non-volatile aerobically biodegradable organic contaminants. Due to severe water pollution in Pasig River, data for gas hold-up is necessary to assess increase in dissolved oxygen content, self-purification capacity of the river during aeration. Gas hold-up data is needed to establish the volumetric mass transfer coefficient and develop mathematical relations to better understand the mass transfer mechanism of the aerated water sample of Pasig River.

The main objective of the study is to determine the gas hold-up using dynamic gassing out method. At different superficial gas velocity and height of the reactor, the desired sparging conditions based on experimental data of gas hold-up will be determined to increase dissolved oxygen concentration.

The mass transfer coefficient of aerated liquid depends mainly on gas hold-up [6]. Measurement of gas hold-up aims to provide information on the determination of volumetric mass transfer coefficient of aerated Pasig River water sample which is very important to the design and scale up of bubble column reactors and aerators that can be used for future rehabilitation projects of Pasig River. Transformation of Pasig River into sewage is the result of the presence of pollutants which reduced the water quality of Pasig River consequently disturbing its ecological balance. Understanding the effects of gas hold-up will help for the future study and remediation of Pasig River to improve self-purification capacity of water body and to balance the ecological system.

In this study, together with these concepts, characteristic parameters specifically gas hold-up using only air as flushing agent will be used. Specific method to be used is the extended dynamic gassing out method and a discrete grab sampling will be used during the first two weeks of June, 2014. The range of the study is bounded only for Pasig River water and not for other river remediation. And that the study is limited only to sparging/aerating and not for other types of physical, chemical and biological remediation.

2. Methodology
The experiment was divided into four major parts; (1) selection of sampling station; (2) gathering and preparation of materials and equipment; (3) water sampling; and lastly, (4) laboratory experiment for the study of gas hold-up of Pasig River water sample in a bubble column reactor.

After checking DO concentration sample, the water was transferred immediately to the column using a funnel with hose to avoid formation of bubbles during the transfer. The column was filled up to the desired height of the reactor. In the presence of respiring organisms, the system was brought to a steady state operating condition where air was used as the sparging gas species at varying flow rates and height and was maintained until the DO concentration stabilized for two minutes. The air supply was shut off until the DO concentration fell to its lowest point. The air supply was turned back on again until the DO concentration stabilized for two minutes to reach its saturation point. The dissolved oxygen content was monitored and recorded at an interval of 10 seconds using the dissolved oxygen probe connected in the LabQuest2.

The gas hold-up was computed using the equation developed by Al-Saraj et.al [7] as shown in the equation,
\[ \varepsilon = 1 - \frac{h_1}{h_D} \]

where \( h_1 \) is the corresponding static height (mm) when no gas flows in the column and \( h_D \) is the aerated liquid height (mm), keeping all other conditions the same. Both parameters will be determined at different superficial gas velocity and different heights of the reactor.

The determination of gas hold-up was based on gas-liquid mass transfer studied by Son et al. [8]. The succeeding theories were considered to simplify the determination of gas hold-up [9]: a) ideal gas behavior in the system, b) isothermal conditions, c) the system comprises only of liquid and gas phase, d) the gas hold-up is uniform within each individual region.

3. Results and discussion

3.1. Effect of increasing superficial gas velocity on gas hold-up

Equation used to determine the total gas hold-up,

\[ \varepsilon = 1 - \frac{h_1}{h_D} \]

where \( h_1 \) is the corresponding static height (mm) when no gas flows in the column and \( h_D \) is the aerated liquid height (mm).

The gas hold-up was assessed as the percentage increase in volume of the gassed liquid compared to the ungassed liquid volume. Bubble column reactor, changes in the height of the liquid was determined by monitoring the height of the ungassed liquid and aerated liquid sample of Pasig River. The liquid height was estimated by observing the position of the liquid level on a measuring tape on the side of the column. During aeration, the liquid surface became very turbulent due to gas flow rates, with the level changing unsteadily, the mean height was estimated by Christi M Y [10].

| Table 1. Gas hold-up data at liquid height of 13 inches. |
|-----------------|-----------------|-----------------|
| Superficial Gas Velocity, cm/s | Gas Hold-up | Standard Deviation |
| 0.15 | 0.012762615 | 0.001677078 |
| 0.20 | 0.032548344 | 0.001658100 |
| 0.24 | 0.051107325 | 0.000000000 |

| Table 2. Gas hold-up data at liquid height of 25 inches |
|-----------------|-----------------|-----------------|
| Superficial Gas Velocity, cm/s | Gas Hold-up | Standard Deviation |
| 0.15 | 0.004651163 | 0.000000000 |
| 0.20 | 0.009015971 | 0.000892350 |
| 0.24 | 0.012933264 | 0.000883997 |

| Table 3. Parameters generated for equation \( y = Ax + B \). |
|-----------------|-----------------|-----------------|
| Liquid Height | A | B | R² |
| 13 inches | 0.0192 | -0.0445 | 0.9997 |
| 25 inches | 0.0041 | -0.0077 | 0.9999 |

The collected data of gas hold-up were summarized on tables 1 and 2. Every experimental point shown was the average of 3 runs of experiments. Gas hold-up measurements were done at varying superficial gas velocities and at two different initial liquid height in the reactor. The resulting equation from the determination of gas hold-up was summarized on table 3.
Based on the results of measuring the gas hold-up using differential height method, showed in figure 1 that gas hold-up increases linearly with increasing superficial gas velocity. Also, in the study of Moshtari et.al [11], the gas hold-up has been measured at different superficial gas velocity and results presented that with increasing superficial gas velocity, the total gas hold-up increased.

Mostly, experimental gas hold-up summaries obtained were linear with reference to superficial gas velocity. The overall gas hold-up is higher when the gas is produced in spite of the fact that the average gas velocity in the whole bed is lower. According to Buffière P et.al [12], this can be described by the occurrence of entrapped bubbles without velocity all along the column height. The increase in gas hold-up can increase liquid circulation and decrease bubble size as the gas velocity increases. This can be attributed to the bubble size which strongly depends on the sparger used. The smaller the bubbles, the greater the gas hold-up values [13].

3.2. Effect of varying liquid height on gas hold-up
Value of gas hold-up decreases slightly with increasing initial liquid height on the reactor as depicted at figure 1. The same principle was also observed in other studies, that the gas hold-up increases with the decrease in bottom clearance, therefore decrease in liquid volume [14]. This fact was also observed by Gavrilescu and Tudose [15] while working with large concentric-tube airlift reactors of 2,500 and 5,200 liters.

3.3. Effect of operating condition on gas hold-up
Effect of operating condition such as superficial gas velocity and initial liquid height on the bubble column reactor was observed to determine the best condition to obtain high gas hold-up. The superficial gas velocity was measured using an Omega Air-flow meter while the mean height measurement was estimated using a tape measure attached to the bubble column reactor. The experimental data indicated that the minimum quantity of air means the lowest aerated liquid height, the low aerated liquid height meant that there was a rather low level of gas bubbles in the reactor which reduced the gas hold-up. At high superficial gas velocity, the aerated liquid height increased which generated more bubbles, thus increased gas hold-up [6]. On the other hand, the effect of increase of initial liquid height leads to the decrease of the gas hold-up to compensate for the increased in liquid hold-up in the column. To obtain a high value of gas hold-up, the conditions should be at high superficial velocity and at low initial liquid height in the bubble column reactor.

3.4. Effect of dissolved oxygen concentration on gas hold-up
Oxygen transfer occurs when there is concentration gradient. The DO concentration is high at the oxygen bubble compared to the rest of the fluid. This results in oxygen transfer from the gas bubble to the fluid resulting in an increase of dissolved oxygen concentration in the column. Transfer of oxygen
Dispersion of oxygen from gas phase to liquid phase was achieved by bubbling the gas through the liquid by using sparger at the bottom of the bubble column reactor. Contact was produced between gas phase and liquid phase by using three different superficial gas velocity to introduce oxygen in the liquid phase. Tables 4 and 5 show the data of gas hold-up and dissolved oxygen concentration at different superficial gas velocity and height of the reactor.

**Table 4.** Gas hold-up and dissolved oxygen data at liquid height of 13 inches.

| Superficial gas velocity, cm/s | Gas hold-up | Final dissolved oxygen concentration, mg/L | Standard deviation, dissolved oxygen concentration |
|-------------------------------|-------------|-------------------------------------------|-----------------------------------------------|
| 0.15  | 0.012762615 | 6.80                                      | 0.039404398                                  |
| 0.20  | 0.032548344 | 7.17                                      | 0.022957908                                  |
| 0.24  | 0.051107325 | 7.27                                      | 0.009245003                                  |

**Table 5.** Gas hold-up and dissolved oxygen data at liquid height of 25 inches.

| Superficial gas velocity, cm/s | Gas hold-up | Final dissolved oxygen concentration, mg/L | Standard deviation, dissolved oxygen concentration |
|-------------------------------|-------------|-------------------------------------------|-----------------------------------------------|
| 0.15  | 0.004651163 | 6.50                                      | 0.025035587                                  |
| 0.20  | 0.009015971 | 7.10                                      | 0.031210160                                  |
| 0.24  | 0.012933264 | 7.47                                      | 0.021014172                                  |

Every data points shown in figure 2 was the output signal of the dissolved oxygen probe with operating conditions of 0.15, 0.20, 0.24 cm/s; and liquid height of 13 and 25 inches. The profile depicted in figure 2 described the superficial gas velocity and liquid height affects dissolved oxygen concentration in the column, and therefore affected the gas hold-up. The dissolved oxygen concentration increased with increasing superficial gas velocity in all of the cases studied. Results were due mainly to the increased in contacting area between the gas and liquid phases which increased the gas hold-up [7]. From the experiment result for liquid height of 13 inches, the gas hold-up are 0.01276, 0.03255 and 0.05111 with final dissolved oxygen concentration of 6.80, 7.17 and 7.27 mg/L, respectively. For liquid height of 25 inches, the gas hold-up were 0.00465, 0.00902 and 0.01293 with final dissolved oxygen concentration of 6.50, 7.10 and 7.47 mg/L, respectively. The highest dissolved oxygen concentration resulted the highest gas hold-up in the bubble column reactor. Moreover, in 0.24 cm/s superficial gas velocity, the increase in dissolved oxygen concentration and gas hold-up was much lower compared to 0.15 and 0.20 cm/s superficial gas velocity. According to Molina *et al.* [16], when the coalescence of the bubble was well established, the hold-up again increased relatively strong with increasing gas velocity because of the formation of large spherical cap bubbles.

**Figure 2.** Gas hold-up and final dissolved oxygen concentration profile.
4. Conclusion
Gas hold-up of Pasig River was determined experimentally in a bubble column reactor using dynamic gassing out method by sparging air at different liquid height and superficial gas velocity under atmospheric condition. Discrete grab water samples are taken upstream at Jones Bridge, Escolta ferry station. The gas hold-up was obtained using variance height process, experimental findings showed the gas hold-up in bubble columns is extremely affected by superficial gas velocity, liquid height and dissolved oxygen concentration. The experimental gas hold-up profiles are linear with respect to superficial gas velocity which decreases with increasing liquid height to compensate for the increased in liquid hold-up in the column. Increase in gas hold-up is affected by circulation of the liquid and the bubble size due to different gas velocity. The bubble size attributes strongly depend on the use of the sparger. At high superficial gas velocity, liquid height increases which generate more bubbles and increases gas hold-up. Assumed that the increase of the liquid height indicates compensation of the liquid hold-up. Highest dissolved oxygen concentration resulted to the highest gas hold-up in the bubble column reactor since coalescence of the bubble is due to high gas velocity. Desired sparging conditions based on experimental data of gas hold-up will be at high superficial velocity and at low liquid height. With the results of the study, data for gas hold-up can be used in future studies to better understand the mass transfer mechanism of the aerated water sample in Pasig River, which is very important to the design and scale up of bubble column reactors and aerators that can be used for future rehabilitation projects of Pasig River to increase dissolved oxygen content.

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