HYDRODYNAMICS OF TWO-PHASE FLOW IN A DEEP AIR-LIFT REACTOR

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There are several reasons why adding oxygen to a water body is beneficial, and it has many direct applications in civil engineering. The two most common types of devices used to aerate a deep water body are bubble plumes and hypolimnetic aerators. Bubble plumes will replenish the depleted oxygen levels and tend to destratify the water body to help prevent anoxic conditions and algal blooms, while hypolimnetic aerators only mix the layer below the thermocline while maintaining straitification.

One common type of hypolimnetic aerator consists of a central column that extends below the thermocline of the water body. Air is injected into the central column causing the water to rise. An outer shell exists around the central column where the aerated water is directed back to the bottom of the water body. Burris and Little[1] and Bernhardt[2] have used such columns in drinking water reservoirs for Norfolk, Virginia, and Bonn, Germany, respectively

Due to the applicability of reoxygenation, the studies above and others have been performed to determine the most efficient method of oxygenation at the lowest cost. The main parameters that need to be quantified are gas void ratio, average bubble diameter, and the rate at which gas is transferred from the bubbles into the water. Many aspects of a bubble plume are simulated with a bubble column (BC), which consists of one column with upward flow in the middle of the column and downward flow near the walls. This type of reactor allows for horizontal entrainment from the adjacent downward flowing water, but the dilution of the plume is not simulated. The aeration portion of a hypolimnetic aerator is accurately simulated using an air-lift reactor (ALR).

The main disadvantage of the results found from previous studies performed in the laboratory is that they were determined using columns and reactors that are significantly shallower than the typical depth of a lake or reservoir, which may cause inaccuracies when attempting to scale the results to greater depths. For example, certain assumptions are made when using a shallow column that cannot be made in a deeper column, such as assuming a constant void ratio or gas transfer coefficient with column height.

The current study uses a 26.0 m ALR, which can be converted to a BC, to test the assumptions and results from other studies that have used significantly smaller columns. Three different spargers were used for comparison: perforated plate, soaker hose, and coarse-bubble diffuser. Comparisons are made with the other studies concerning the void ratio and bubble diameter, while experiments to determine the gas transfer rates under various operating conditions in the present setup are currently underway. Void ratio is measured using a series of six pressure taps located along the length of the column. Bubble diameter is measured photographically from inside the column, and a Sauter mean bubble diameter is calculated using these measurements.

It was found that the void ratio does vary with column height and superficial gas velocity, while bubble diameter does not. It was also found that void ratio behaves similarly for all sparger types when using an ALR, but the results from the BC showed that void ratio increased faster with height in the BC than in the ALR. The Sauter mean bubble diameter was largest for the coarse-bubble diffuser (Table 1), but when the few largest bubbles were removed there was almost no different between the spargers. In addition, the Sauter mean bubble diameter was significantly greater in the BC than in the ALR, which is in contrast to the findings of Colella et al.[3] who concluded that both types of columns exhibit similar behaviors when using columns that are smaller than 5 m tall. Again, when the few outlying larger bubbles were removed, this difference was reduced. These results show that any differences between the calculated mean diameters for each sparger and column type is the result of a few large bubbles.

Overall, the results show that the type of sparger used does not significantly affect the effectiveness of a hypolimnetic aerator in terms of void ratio and bubble diameter, but that the type of column used does have an effect. All of the information found in the present study can and will be used to develop design characterizations that can be applied to almost any lake or reservoir so that an aeration system, whether it be a bubble plume or a hypolimnetic reactor, can be installed and be highly efficient at a low cost.

Table 1. Sauter mean bubble diameters and standard deviations calculated from the standard deviations of the log-normal distributions for all sets of operating conditions.

Operating Conditions	# Bubbles (Outliers)	$d_b \times 10^3$ (m) Outliers retained	$d_b \times 10^3$ (m): Outliers removed
Sparger Type			
Perforated Plate	1812 (9)	2.44	2.30
Soaker Hose	1823 (0)	2.28	2.28
Coarse-Bubble Diffuser	1822 (9)	2.76	2.37
Column Type			
EALR	1387 (7)	2.50	2.36
BC	1392 (6)	3.84	2.79

Keywords: Two-phase flow, Hypolimnetic aerator, Bubble plume, Bubble column, Air-lift reactor, Oxygenation, Destratification, Void ratio, Sauter mean bubble diameter

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