Enhanced bioremediation using ultrafine bubble suspensions: Development of an experimental method to determine the bubble diameter and oxygen content in the suspension

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Ultrafine bubbles are potentially applicable as an effective oxygen carrier for enhanced bioremediation of the subsurface impacted by organic contaminants. In our previous study, we demonstrated that a ultrafine bubble suspension generated using pure oxygen was highly supersaturated with dissolved oxygen, carrying approximately 110.78 mg/L of oxygen in either gas or dissolved phase, and the volume of water was reduced by 60 μL/L when the ultrafine bubbles were removed by sonication. In this study, we developed an experimental method to determine the bubble diameter and to estimate the oxygen partitioning in gas and dissolved forms in an ultrafine bubble suspension. Stable ultrafine bubbles in water should follow Henry's law, which establishes equilibrium between the surrounding water and the bubbles, and Young-Laplace equation that relates the bubble diameter with the internal pressure of the bubble. Using the two theoretical relationships, and the experimental data for the total amount of oxygen in a suspension and the volume reduction after removing the bubbles from the suspension, the bubble diameter and the partitioning of oxygen in dissolved and gas forms can be calculated. It was found that the total oxygen amount of 110.78 mg/L in the suspension was partitioned into 0.21 mg/L in the gas phase and 110.57 mg/L in the dissolved phase. The internal pressure of the bubble was calculated to be 2.86 atm, giving the bubble diameter of 1540 nm. The major challenge of the developed method was the determination of volume reduction by bubble removal because of a very small change in the suspension volume. However, a sensitivity analysis showed that the bubble diameter and oxygen partitioning results were not sensitive to the volume reduction in the range of 1-100 μL/L. The oxygen partitioning determined in this study suggests that oxygen in a ultrafine bubble suspension mostly exists in a dissolved form, and the key role of the ultrafine bubbles is to maintain the partial pressure higher than the atmosphere to keep the dissolved oxygen supersaturated.