

Experimental quantification of local counterdiffusion effects on the gas-liquid mass transfer performance on a microscale

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Highlights

- Local counterdiffusion effects on mass transfer performance of fine bubbles
- Microscale mass transfer phenomena
- Laser-induced Fluorescence

1. Introduction

The quantification of counterdiffusion effects on the mass transfer performance in aerated bioreactors is of special interest when utilising fine bubble aeration. The liquid bulk of the reaction medium in an aerated bioreactor can contain a range of dissolved gases, which diffuse into the gaseous phase and, thus, influence the desired mass transfer performance of the process gas. This effect gains relevance especially for fine bubble aeration [1], where bubbles with diameters smaller than $d = 100 \mu\text{m}$ [2] are used. For these bubbles, the increase in Laplace pressure with decreasing diameter becomes relevant and influences the mass transfer significantly due to the resulting higher partial pressure inside the bubbles [1,3]. Therefore, the mass transfer performance of fine bubbles is sensitive towards the bubble size. A previous study on volumetric mass transfer coefficients $k_{L,a}$ in a stirred tank reactor has shown that the counterdiffusion effects play an enormous role for fine bubble aeration, as visible in Figure 1 [1].

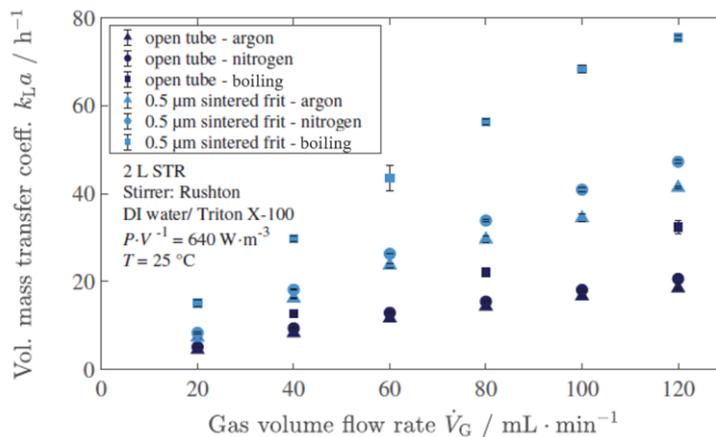


Figure 1. Volumetric mass transfer coefficient in a stirred tank reactor for fine bubble aeration (sintered frit) and macroscopic aeration (open tube) using different degassing measures for the dynamic degassing method [1].

By measuring the volumetric mass transfer coefficient in a reactor using a range of degassing methods, as in [1], the counterdiffusion effects can be quantified on a global scale. However, to deepen the fundamental understanding of these effects and therefore enable further process optimization, studies on a local microscale are desired and, thus, conducted within the current project.

2. Methods

To gather information about the local counterdiffusion effects on the mass transfer performance from single oxygen bubbles, their shrinking rates and the concentration fields of the dissolving oxygen into water are measured with Laser-induced Fluorescence (LIF). By varying the degassing method of the

water, the counterdiffusion effects can be evaluated, as done in [1] on a global scale. As a reference system, the water is degassed physically by boiling and subsequent cooling to ambient conditions for the measurements. On the other hand, different stripping gases (argon, helium and nitrogen) are used to compare the impact of their counterdiffusion into the oxygen bubble. The concentration fields captured with LIF are quantified by a pixel-wise calibration using the Stern-Volmer equation, which couples the measured fluorescence intensity to a concentration of the desired species oxygen. This way, the change in the evolution of the concentration field of dissolved oxygen can be compared for different degassing methods and, hence, the impact of counterdiffusion can be studied. The shrinking rate is evaluated by the change in bubble size and can directly be linked to the mass transfer performance and, therefore, counterdiffusion.

For these measurements, a novel set-up is used. The Lightsheet Fluorescence Microscope (LSFM, *Rapp Optoelectronics GmbH*, Wedel, Germany) with an open periphery combines microscopic imaging with a laser lightsheet with a thickness of $w = 5 \mu\text{m}$ at the focal point and a wavelength of $\lambda = 488 \text{ nm}$, which excites the oxygen-sensitive fluorescent dye dichlorotris(1;10phenanthrolin)ruthenium(II)hydrat. By comparing the resulting shrinking rates and the concentration fields, the counterdiffusion effects and the effects of the Laplace pressure can be quantified on a local scale.

3. Results and discussion

Figure 2 shows an exemplary concentration field of dissolved oxygen around an oxygen bubble with an approximate diameter of $d = 200 \mu\text{m}$ captured with the set-up described above. The fluorescence of the dye is quenched when in contact with oxygen and, therefore, dark areas around the bubble in Figure 2 indicate the presence of dissolved oxygen. In the scope of the current study, different degassing methods of the water are used and, applying a pixel-wise calibration of the images, a comparison of the quantitative concentration fields as well as the shrinking rates provides insights into the local counterdiffusion effects.

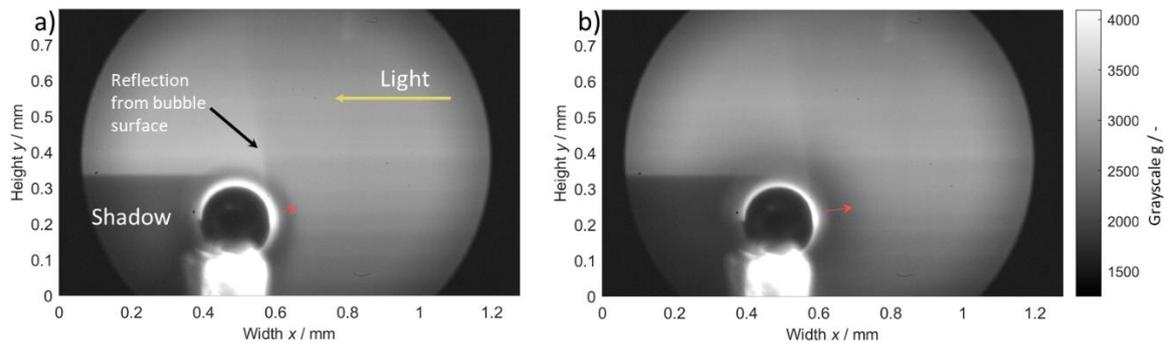


Figure 2. Oxygen bubble in water using argon as stripping gas with $\Delta t = 8 \text{ s}$ between a) and b). The dark halo around the bubble, resulting from a quenching of the fluorescence, indicates the presence of dissolved oxygen. Comparing a) and b), the evolution of the dissolved oxygen concentration field over time can be observed, as indicated by the red arrows.

4. Conclusions

Conclusions on the counterdiffusion effects will be drawn within the scope of the described study.

References

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Keywords

Fine bubbles; counterdiffusion; microscale mass transfer phenomena; Laser-induced Fluorescence

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