JASMAC

Conference of the Japan Society of Microgravity Application

PS14

三重長さスケールを有する多孔質媒体を用いた基板上停留気泡群の受動的除去機構の提案

Proposal of a passive removal mechanism for substrate-attached bubble clusters using a porous medium with triple length scales

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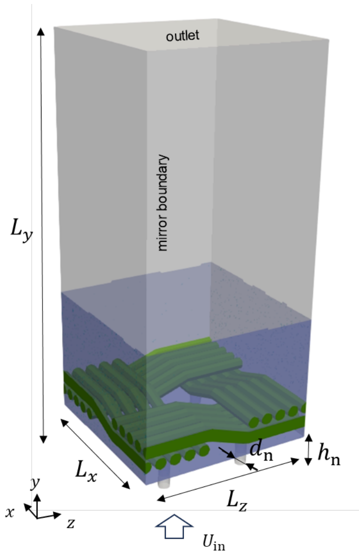
Bubble removal is a critical challenge in various engineering systems, especially under microgravity conditions, where buoyancy-driven detachment is absent. In electrochemical devices such as water electrolyze, bubbles generated on reaction surfaces tend to adhere, reducing the effective reaction area and severely degrading system performance. Although active methods such as vibration, forced convection, and electric fields have been proposed, these approaches increase system complexity and energy consumption. This study proposes a completely passive mechanism for bubble removal from the substrate by employing a triple-length-scale porous media.

Figure 1 illustrates the computional domain. The system consists of a porous media with triple-length scales (macro, meso, and micro) positioned on a substrate, and is designed to passively remove gas bubbles that are generated and remain on the substrate without relying on external forces. The domain is a liquid-filled rectangular space, where gas bubbles nucleate at designated sites on the substrate and are transported upward through the porous structure with different spatial scales. The macro pore serve as the main escape pathways for detached bubbles, while the meso pores facilitate lateral motion and coalescence of bubbles. In addition, the micro pore supply liquid to the substrate, generating a Young–Laplace pressure gradient along the curved gas–liquid interface that drives bubble deformation, movement and coalecences. Figure 2 illustrates the bubble detachment processes for different gas inlet configurations (i)–(iii). In the figure, the red color represents the gas phase, while the substrate and the porous media are shown in light gray. The liquid phase is omitted for clarity of visualization. The normalized time, t^*, is difined as $t^* = \frac{\sigma}{\mu_l L} \cdot t$, where μ_l is viscosty of liquid, σ is surface tension, and L is the hight of porous mat. In the case of (i), bubbles generated from an inlet located in the macro-pore region coalesced with smaller bubbles as they moved from the micro- to meso-pore regions, eventually detaching as a single large bubble. In the case of (ii), bubbles generated from multiple inlets placed in the micro-pore region traveled through the meso-pore region and coalesced near the macro-pore region, forming a single large bubble that subsequently detached. In the case of (iii), bubbles generated from an inlet located in the meso-pore region grew and merged into a single large bubble in the macro-pore region before detaching. In all cases, the bubbles exhibited a common behavior of migrating and coalescing across different spatial scales, eventually detaching. These results demonstrate that the porous structure with triple-layer length scales effectively promotes bubble accumulation and removal.



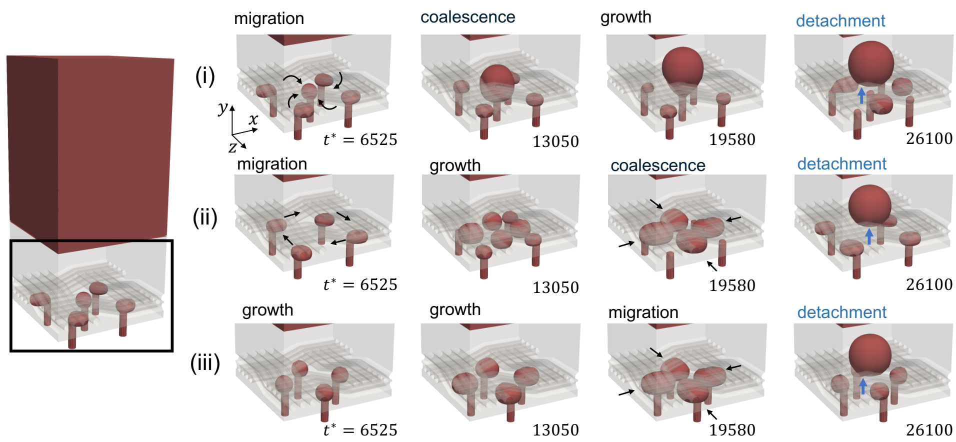


Figure 1. Computional domain: a rectangular domain containing a triple-length scale porous

Figure 2. Temporal evaluation of bubble detachment behavior under different nucleate-sites location: (i) micro- and macro-pore case, (ii) micro-pore case, and (iii) meso-pore case

Acknowledgement

This research was partially supported by the Grant-in-Aid for scientific Research (B) (Grant No.: 24K00824) from the Japan Society for the Promotion of Science (JSPS). One of the authors, MI, acknowledges the Advanced Centre for Computational Materials Science (ACCMS), Kyoto University, for providing their supercomputer resources (JFY2024 & 2025) for the part of the present simulations.

References

1) Angulo, A., et al., "Influence of bubbles on the energy conversion efficiency of electrochemical reactors," Joule, 4.3 (2020): 555–579.

2) Brackbill, J. U., D. B. Kothe, and C. Zemach, "A continuum method for modeling surface tension," Journal of Computational Physics, 100.2 (1992): 335–354.

3) Hirt, C. W., and B. D. Nichols, "Volume of fluid (VOF) method for the dynamics of free boundaries," Journal of Computational Physics, 39.1 (1981): 201–225.

4) Kim, P. J., et al., "Tailoring catalyst layer interface with titanium mesh porous transport layers," Electrochimica Acta, 373 (2021): 137879.

5) Wu, L., et al., "A dual-layer flow field design capable of enhancing bubble self-pumping and its application in water electrolyzer," Chemical Engineering Journal, 488 (2024): 151000.

6) Yuan, S., et al., "Bubble evolution and transport in PEM water electrolysis: Mechanism, impact, and management," Progress in Energy and Combustion Science, 96 (2023): 101075.