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An IBM-like numerical approach for mass transfer across deformable and semipermeable membranes in fluid flows

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ABSTRACT

Mass transfer across deformable and semipermeable membranes is encountered in plenty of biomedical systems such as oxygen bio-transport across red blood cell membrane in human body, and also involved in various industrial applications such as water desalination processes, food processing and petrochemical systems. The mass flux through such membranes is related to the solute concentration difference across the membranes. This causes technical challenges for numerical simulations, especially for deformable membranes in fluid flows. To address these concerns for the mass transfer across a membrane interface, the immersed membrane method (IMM) is proposed in this research. Unlike the typical explicit boundary methods that require the domain on the two sides of the membrane to be treated separately, IMM can solve the mass transfer with a uniform numerical scheme over the same Eulerian mesh grid without any sophisticated membrane treatment and thus the mesh regeneration for deformable membranes is avoided. In IMM, the sharp interface is replaced with an immersed layer of fluid along the membrane, however, of an extra mass transfer resistance based on the membrane permeability. To validate our developed boundary method, we test several benchmark and demonstration cases with flat and curved interface membranes in both steady and unsteady states, and satisfactory agreement is observed between our numerical results and the analytical solutions of these cases.

Keywords: Mass transfer, Immersed membrane method, Immersed boundary method, Deformable membranes, Semipermeable membranes, Computational heat and mass transfer.