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NUMERICAL SIMULATION AND ANALYSIS OF SIZE INEQULITY ON MICROBUBBLE COALESCENCE

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Summary Microbubbles has a myriad of applications in food industry, material science, medicine, and pharmacology. We investigate the coalescence mechanism of microbubbles associated with hydrodynamics and interfacial dynamics including the temporal/spatial scales and the preferences of coalescence though computational simulation and analysis using lattice Boltzmann method (LBM). The free-energy model governed by Cahn Hilliard equation is employed in the LBM. It has been experimentally observed that there is a tendency that coalesced bubble will be placed closer to the father size bubble but the mechanism of this tendency has not be well understood. We simulate the coalescence of air bubbles in water, resulting in density difference in the order of 1000 at the air-water interface. The LBM is first validated by the relationship of Laplace pressure vs. bubble radius for a single microbubble. Then the effects of size inequality on microbubble coalescence are systematically studied by varying the radius ratio of large to small bubble from 4 to 1. The projected relative position between before and after coalescence is found to follow a power-law of the parent radius ratio, which well agrees with the recent experimental observation (Weon and Je, PRL, 2012). Meanwhile, we discover the time from the two single bubbles to coalesced one is followed the linear relationship with parent size ratio. Meanwhile, our numerical simulation captured the quick merging proses of two microbubbles in the scale of micro-second. It is shown that the merging time from the two touched parent microbubbles to a coalesced single microbubble is a linear to the reciprocal of parent radius ratio, i.e. the bigger difference of parent microbubbles, the faster coalescence.

BACKGROUND Bubble coalescence is a common phenomenon with a tendency to minimize the interface when bubbles are in touch. There has been a long history to study the mechanism of bubble coalescence through experimentation [1] and theoretical modeling [2], focusing on ideal, stagnant, and militarized bubbles in free spaces. For microbubbles, focuses have been on the bubble generation/formation. A recent review [3] provides a comprehensive and systematic description of the diverse microbubble generation methods recently developed to satisfy emerging technological, pharmaceutical, and medical demands. However, the delicate and ephemeral nature of microbubbles poses significant technical challenges to the precise quantitation of the coalescence process. In spite of the few important attempts through experimental [4] and radiological measurements [5], the underlying physics of microbubble coalescence associated with hydrodynamics and mass transfer including the temporal/spatial scales and the preferences of coalescence [5, 6], the dynamic forces between microbubbles, the bubble deformation mechanisms, and so on remain unclear.

METHODOLOGY The lattice Boltzmann method (LBM) has been known as a suitable numerical approach to simulate multiphase flow, especially when both density and viscosity ratios are high. We employed the free-energy model [7] in which Cahn Hilliard diffusion is introduced to better handle the phase interface and eliminate the unphysical parasitic currents for high accuracy. We simulate the coalescence of air microbubbles sitting in the middle of a 2-D channel filled with water, resulting in density difference in the order of 1000 at the air-water interface. The focus is on the effects of size inequality on microbubble coalescence by varying the radius ratio γ from 4 to 1(Fig. 1) with 10 cases. The radius of the large parent bubble maintains 20 μm. To ensure the reliability of the results, the LBM is first validated by the relationship of Laplace pressure vs. bubble radius for a single microbubble.

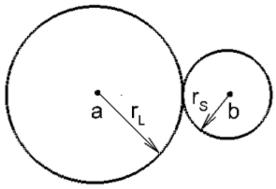

Fig. 1 Schematic of two parent air microbubbles with radius ratio $\gamma=r_L/r_s$

RESULTS AND CONCLUSION The coalescence from two touched parent microbubble to one coalesced microbubble occurs within hundreds of microseconds. We show representative microbubble coalescence with γ=1.33 for the evolution of interface shape (Fig. 2) and velocity fields (Fig. 3). The projected relative position between before and after coalescence is found to follow a power-law of the parent radius ratio, which well agrees with the recent experimental observation (Weon and Je, PRL, 2012). Meanwhile, our numerical simulation captured the quick merging proses of two microbubbles in the scale of microsecond. It is shown that the merging time from the two touched parent microbubbles to a coalesced single microbubble is a linear to the reciprocal of parent radius ratio, i.e. the bigger difference of parent microbubbles, the faster coalescence.

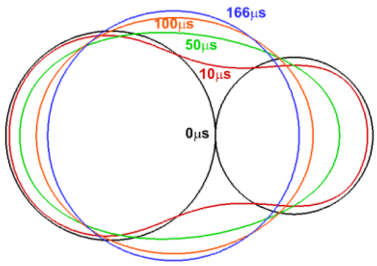

Fig. 2 Evolution of interface shape

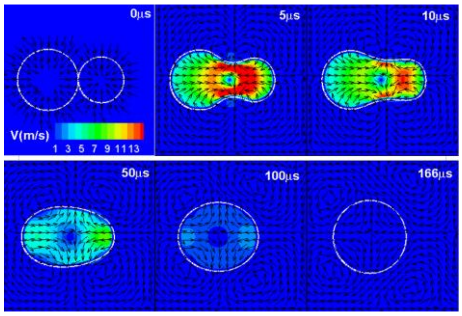

Fig.3 Evolution of velocity field

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