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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary (approx.800 English Words)

The Lattice Boltzmann Method (LBM) has become a popular alternative for fluid flow simulations, especially for large-scale computations. However, the conventional LBM cannot simulate violent two-phase flows with a high-density ratio and Reynolds number, such as dam breaking problems. In this thesis, a novel cumulant LBM is developed to overcome this limitation. The proposed method is also employed to simulate a turbulent bubbly pipe flow with a high-density ratio and Reynolds number, the first of its kind in Direct Numerical Simulations (DNS) of turbulent bubbly flows. Additionally, we study foam formation simulations with thin films, offering possibilities for future applications.

Chapter 1: Introduction
The background, scope, literature review, objective, and significance of this thesis are described. In this thesis, we studied liquid-gas two-phase flow simulations. The conventional Computational Fluid Dynamics (CFD) methods that solve the incompressible Navier-Stokes equations have limited success in simulating these problems, especially for large-scale computations. In this thesis, LBM is employed as it is efficient for large-scale simulations. However, the conventional LBM cannot simulate two-phase flows with a high-density ratio and a high Reynolds number. Therefore, a novel cumulant LBM was developed to simulate the problems.

Chapter 2: Basic theory
The prerequisite knowledge for developing the proposed cumulant LBM, including the conventional LBM and its improved collision models such as Multi Relaxation Time (MRT) and cumulant models, are described. The summary of interface-capturing schemes such as Volume of Fluid (VOF), Level Set (LS), and phase-field methods are given. Finally, the momentum-based and velocity-based formulations of two-phase LBM are described.

Chapter 3: Cumulant LBM for Violent Two-phase Flows
We proposed a cumulant LBM to simulate violent two-phase flows. Detail description of the proposed cumulant LBM is given, which includes the two-phase LBM for hydrodynamics, the conservative phase-field LBM, and the second-order filter based-on cell's Peclet number. The proposed cumulant LBM has been validated on several non-violent two-phase flow problems, such as Rayleigh-Taylor instability, rising bubbles, and droplet splashing on a thin film. The results show good agreements with both computational and experimental references. The proposed cumulant LBM was then applied to simulate the dam-breaking and liquid jet breakup with a high-density ratio and high Reynolds number, which cannot be solved by conventional two-phase LBM. The results show good agreements with computational references. The cumulant LBM is more diffusive due to the filter's application; however, more accurate results can be obtained by increasing the resolution and tuning the filtering criteria.

Chapter 4: Cumulant LBM for Turbulent Bubbly Flows
The cumulant LBM was also employed as a DNS solver to study the dynamics of turbulent bubbly flows. In the past, the problems were simulated in a limited setting, namely, turbulent bubbly channel flows with low-density ratio and low Reynolds number. The present study aims to overcome these limitations and simulate a turbulent bubbly pipe flow of a water-air system with a high-density ratio and high Reynolds number. The problem is simulated without filtering, and a multi-phase field model with improved active parameter tracking is introduced to simulate dispersed bubbles. The proposed cumulant LBM has been applied to a turbulent bubbly pipe flow of a water-air system with a high Reynolds number ($\gamma \approx 831.7$, $Re_\tau = 55.6$. The first and second-order statistics were calculated, and the results agree reasonably well with the

experiment. As suggested by these results, the turbulent statistics are sensitive to change in bubble properties, void fraction, and Reynolds number; therefore, simulating the real flow condition is necessary.

Chapter 6: Cumulant LBM for Foam Simulations
Additionally, we applied our cumulant LBM to simulate foam formation. The problem is difficult to simulate because of its multi-scale and multi-physics nature. In this study, we employed cumulant LBM with a multi-phase field model to simulate stable thin liquid films. The iterative pressure projection method was introduced to reduce the compressibility error in the simulation. We have stably simulated 3D foam formation with 200 air bubbles in water ($\gamma \approx 831.7$, $\eta = 55.6$, $\alpha = 12.5\%$) and show the foam formation's behavior.

Chapter 7: Conclusions
We conclude this thesis and give recommendations for future works. We can simulate the violent two-phase flows such as dam breaking ($\gamma \approx 1000$, $Re \approx 7.9\times105$) using LBM for the first time. The results agree well with the experiment, where the difference in dimensional surge-front and water-height are about 5% and 1%, respectively. The turbulent bubbly pipe flow of the water-air system with a high Reynolds number ($\gamma = 831.7$, $Re_\tau = 550$) has been stably simulated. The results agree well with the experiment, where the root mean square of error of bubble distribution, mean streamwise velocity, and streamwise velocity fluctuation are about 12%, 4%, and 13%, respectively. The proposed method is promising for future complex two-phase flow simulations.