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Numerical Stability Analysis for a Stationary and Translating Droplet at Extremely Low Viscosity Values Using the Lattice Boltzmann Method Color-Gradient Multi-Component Model with Central Moments Formulation

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Abstract. Multicomponent models based on the Lattice Boltzmann Method (LBM) have clear advantages with respect to other approaches, such as good parallel performances and scalability and the automatic resolution of breakup and coalescence events. Multicomponent flow simulations are useful for a wide range of applications, yet many multicomponent models for LBM are limited in their numerical stability and therefore do not allow exploration of physically relevant low viscosity regimes. Here we perform a quantitative study and validations, varying parameters such as viscosity, droplet radius, domain size and acceleration for stationary and translating droplet simulations for the color-gradient method with central moments (CG-CM) formulation, as this method promises increased numerical stability with respect to the non-CM formulation. We focus on numerical stability and on the effect of decreasing grid-spacing, i.e. increasing resolution, in the extremely low viscosity regime for stationary droplet simulations. The effects of small- and large-scale anisotropy, due to grid-spacing and domain-size, respectively, are investigated for a stationary droplet. The effects on numerical stability of applying a uniform acceleration in one direction on the domain, i.e. on both the droplet and the ambient, is explored into the low viscosity regime, to probe the numerical stability of the method under dynamical conditions.

AMS subject classifications: 76-XX

Key words: Lattice Boltzmann method, multicomponent flow, numerical stability, low viscosity.

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1 Introduction

The numerical modeling of multiphase/multicomponent fluids is still a challenge and the Lattice Boltzmann Method (LBM) has shown great potential in this field [1]. Several models for simulating multiphase/multicomponent flows using the LBM have been proposed over the last three decades, including the color gradient (CG) model [2], the pseudopotential model [3], the free-energy model [4] and the mean-field model [5]. In the current work we focus on exploring the capabilities of a recent formulation of the CG model, i.e. the central moments formulation as proposed by [6], which promises increased numerical stability while retaining physical accuracy of the standard CG model formulation [7]. To explore the limits of this formulation in terms of accessible parameter range and the strength of the spurious currents produced around a droplet-ambient interface, we simulate firstly a quiescent droplet in a cubic domain with periodic boundary conditions. Although the system is stationary, spurious currents will arise due to discretization errors, concentrated mainly near to the droplet-ambient interface [8,9]. Therefore the simulated system is not perfectly static, as it should, despite the droplet being stationary. The kinetic energy, E_{kin}, is non-zero due to the presence of spurious currents, which we measure for a variety of parameters, such as material properties, droplet radius and simulation domain size.

Firstly, the viscosities of the droplet and surrounding ambient are pushed down to the point where physical accuracy is severely compromised, in order to find the limits to which the viscosity parameters can be pushed. We also consider the effect of small-scale anisotropy on the total kinetic energy E_{kin}, caused by the finite sized spacing between grid-points, Δx, adopted for simulations in LBM. By running several simulations with increasing droplet radius, $R = 8$, 12, 16, we can quantify the effect of this small-scale anisotropy, which is essentially a resolution effect. Furthermore we investigate the effect of large-scale anisotropy, caused by using periodic boundary conditions. In this setup the droplet is influenced by itself, but not equally in every direction, e.g. across the diagonal of the simulation domain, the distance of the droplet to itself is greater than across the horizontal. To quantify this effect we increase domain sidelength L, while keeping R constant, thereby increasing the distance from the droplet to the surrounding boundaries to investigate the influence of L on E_{kin}.

Finally we consider the case of a translating droplet put in motion by accelerating the entire domain, i.e. droplet and ambient, in one direction. This is done for varying densities, viscosities and acceleration values. Through this procedure we quantify a stable and unstable regime for a droplet in a moving frame of reference, thereby testing Galilean invariance of the system.

2 Numerical method: Color-gradient with central moments formulation