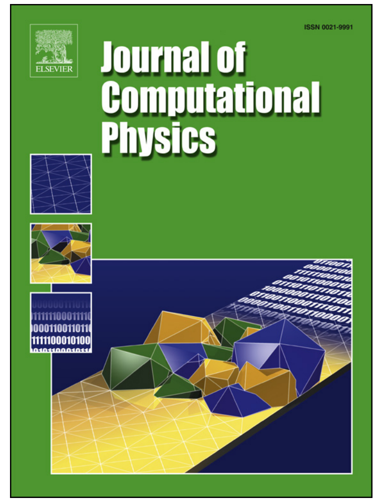

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Multiphase Flows of N Immiscible Incompressible Fluids: A Reduction-Consistent and Thermodynamically-Consistent Formulation and Associated Algorithm

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Abstract

We present a reduction-consistent and thermodynamically consistent formulation and an associated numerical algorithm for simulating the dynamics of an isothermal mixture consisting of N ($N \geqslant 2$) immiscible incompressible fluids with different physical properties (densities, viscosities, and pair-wise surface tensions). By reduction consistency we refer to the property that if only a set of M ($1 \leqslant M \leqslant N-1$) fluids are present in the system then the N-phase governing equations and boundary conditions will exactly reduce to those for the corresponding M-phase system. By thermodynamic consistency we refer to the property that the formulation honors the thermodynamic principles. Our N-phase formulation is developed based on a more general method that allows for the systematic construction of reduction-consistent formulations, and the method suggests the existence of many possible forms of reduction-consistent and thermodynamically consistent N-phase formulations. Extensive numerical experiments have been presented for flow problems involving multiple fluid components and large density ratios and large viscosity ratios, and the simulation results are compared with the physical theories or the available physical solutions. The comparisons demonstrate that our method produces physically accurate results for this class of problems.

Keywords: *reduction consistency; thermodynamic consistency; surface tension; phase field; multiphase flow; N-phase flow*

1 Introduction

This paper concerns the formulation and simulation of isothermal multiphase flows consisting of N ($N \geqslant 2$) immiscible incompressible fluids with possibly very different physical properties (e.g. densities, dynamic viscosities, and pair-wise surface tensions). Following our previous works [14, 17, 18] and with a slight abuse of notation, we will refer to such problems as N-phase flows, where N denotes the number of different fluid components in the system, not necessarily the number of material phases. Our primary concern is the reduction consistency and thermodynamic consistency in the formulation of such problems. By thermodynamic consistency we refer to the property that the formulation should honor the thermodynamic principles (e.g. mass

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