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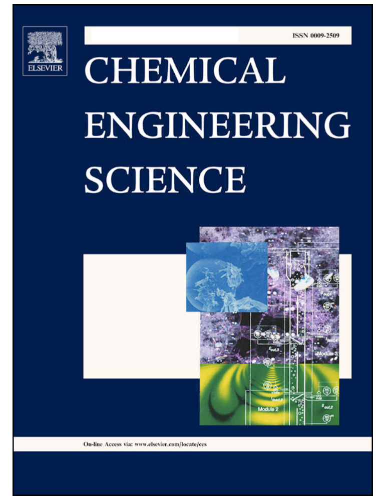

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Bidan Zhao, Junwu Wang

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Unification of particle velocity distribution functions in gas-solid flow

Bidan Zhao[a,b], Junwu Wang[a,*]

[a]*State Key Laboratory of Multiphase Complex Systems, Institute of Process Engineering, Chinese Academy of Sciences, P.O Box 353, Beijing 100190, P. R. China*
[b]*University of Chinese Academy of Sciences, Beijing, 100049, P. R. China*

Abstract

Continuum models have been extensively used in CFD simulation of gas-solid flow, which is usually closed with a kinetic theory of granular flow for particulate phase stresses and a correlation for interphase drag force. Particle velocity distribution function (PVDF) is the cornerstone of kinetic theory of granular flow and the PVDFs in gas-solid flow can be Maxwellian, bimodal and/or non-Maxwellian with an overpopulated high-energy tail, depending on the physical nature of gas-solid flow. Here we theoretically show that the different PVDFs can be unified under the umbrella of a recently proposed kinetic theory framework (Wang, et al., AIChE Journal, 2016, 62 (8), 2649-2657) and the root of different PVDFs lies in the different characteristics of mesoscale structures. Validation of theoretical analysis is then carried out by comparing the theoretical prediction with experimental and DNS data available in literature. The findings of present study offer a possibility of developing a unified kinetic theory for gas-solid flows.

Keywords: Fluidization; Gas-solid flow; Kinetic theory; Granular flow; Clustering structure; Particle velocity distribution function

Introduction

Gas-solid flow can be widely found in industry, such as coal combustion and fluid catalytic cracking (Yang, 1998). Correct understanding of the hydrodynamics of gas-solid flow is essential for proper scale-up and design of many multiphase chemical reactors, such as gas-fluidized beds. However, the analysis is notoriously difficult, because of the coexistence of multiple spatio-temporal scales, the strongly coupled interactions between different scales, the close relationship between transport properties and the dynamically multiscale heterogeneous structures (Li and Kwauk, 1994; Van der Hoef et al., 2008; Li et al., 2013).

In addition to experiment and theory, computational fluid dynamics (CFD) has emerged as an effective tool in studying the hydrodynamics of gas fluidization and exploring the underlying mechanism of gas-solid flows (Gidaspow, 1994; Van der Hoef et al., 2008; Ge et al., 2011). Various simulation techniques have been developed in order to study the gas-solid flow at different spatiotemporal scales, among of which continuum model (Gidaspow, 1994; Enwald et al., 1996; Jackson, 2000; Gidaspow et al., 2004; Wang, 2009; Syamlal and Pannala, 2011) is one of the most popular methods in industrial applications. The governing equations of continuum model can be obtained using various averaging methods, which are then usually closed with a kinetic theory of granular flow for particulate phase stresses (Gidaspow, 1994) and a drag force correlation for inter-phase drag force, such as Gidaspow's drag model, EMMS drag model or filtered drag model (Gidaspow, 1994; Wang et al., 2008; Igci et al., 2008; Li et al., 2013; Milioli et al., 2013).

In kinetic theory, particle velocity distribution function (PVDF) is the cornerstone to develop the constitutive relationship of continuum models. Therefore, extensive studies have been devoted to it, it was found that PVDFs in fluidized beds can be Maxwellian, bimodal and/or non-Maxwellian distribution with an overpopulated high-energy tail with respect to the standard Maxwellian distribution (Ichiki and Hayakawa, 1995; Fiedler et al., 1997; Leszczynski

*Corresponding author
Email address: `jwwang@ipe.ac.cn` (Junwu Wang)