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D.M. Nie, J.Z. Lin

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Behavior of three circular particles in a confined power-law fluid under shear

D.M. Nie[a], J.Z. Lin[a,b,]*

[a] *Institute of Fluid Mechanics, China Jiliang University, Hangzhou, China*

[b] *State Key Laboratory of Fluid Power Transmission and Control, Zhejiang University, Hangzhou, China*

ABSTRACT

We studied the interactions among three circular particles suspended in a power-law fluid undergoing confined shear flow in two dimensions. The calculations are based on our previously developed lattice Boltzmann direct-forcing/fictitious-domain method. Reynolds numbers $1 \le Re \le 20$ and power-law indices $0.5 \le n \le 1.5$ were considered. We roughly classified the particles' motion into "returning" and "passing" behaviors. We found that the particles are more likely to pass for higher Reynolds numbers or lower power-law indices, given the same flow conditions. In particular, we investigated the dynamics of the particles in shear flows and find two peaks in the horizontal fluid (drag) force for large Reynolds number or small power-law index. The first peak serves to decelerate the particles, while the second does the opposite, and might be primarily responsible for the transition from the "returning" to the "passing" behavior. We also studied the effects of the Reynolds number and the power-law index on particle velocity and streamline patterns.

Keywords: Particle suspension; Direct numerical simulation; Power-law fluid; Lattice Boltzmann Method (LBM)

1. Introduction

Particulate flows are found in numerous natural situations and industrial applications. A thorough understanding of the behavior of particles in Newtonian, as well as non-Newtonian, fluids is essential for many engineering applications, as substances encountered in the biological, food, and mining industries and chemical engineering often display shear-thinning or shear-thickening behavior. For instance, in blood flow, shear thinning has been demonstrated to be the dominant non-Newtonian property. The motion of particles suspended in these fluids is a problem that deserves greater attention.

The interaction mechanisms among multiple particles are of considerable importance in finding insights into their microstructural evolution in fluids, which is usually related to the collective behavior and self-organization of solid particles. Two kinds of simulation are commonly encountered in studies of the behavior of multiple interacting particles. One is particle sedimentation under gravity, in which rigid particles are settling in a fluid at rest; the other is particle motion confined to a simple shear flow, which is the focus of this paper. To better understand the fluid–particle and particle–particle interactions, direct numerical simulations are usually employed, because they represent the highest resolution method available to address the problem of particle motion in fluids. In this approach, one must simultaneously integrate the Navier–Stokes equations (governing the motion of the fluid) and the equations of rigid-body motion (governing the motion of the particles). These equations are coupled through the no-slip condition on the particle boundaries.

* Corresponding author. Tel./fax: +86 571 86875662.

E-mail address: mecjzlin@public.zju.edu.cn (J. Z. Lin).