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Particle Scale Numerical Simulation on Momentum and Heat Transfer of Two Tandem Spheroids: an IB-LBM Study

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Abstract. The cold fluid flowing over two hot spheroids placed in a tandem arrangement was numerically studied via a GPU-based immersed boundary-lattice Boltzmann method (IB-LBM) model. The drag coefficient and average Nusselt number of both the two spheroids were obtained with the main influencing factors investigated. To validate the IB-LBM model, several numerical case studies containing one and two spheres were firstly conducted to reach the good agreement with the previously reported data. Then, a number of simulations were further carried out which were designed by changing the particle aspect ratio ($1.0 \leq Ar \leq 4.0$) and inter particle distance ($1.5 \leq \ell \leq 7.0$, where $\ell = L/D$, D stands for the volume-equivalent sphere diameter) as well as the Reynolds number ($10 \leq Re \leq 200$). Their influence on the momentum and heat transfer characteristics between the solid and fluid phases was fully discussed. Numerical results show that, for all the considered Reynolds numbers and aspect ratios, the individual and total drag coefficients and average Nusselt number increase with the inter particle distance. The inter particle distance has greater influence on the drag coefficient and average Nusselt number of the trailing particle than the leading one. The drag coefficient and average Nusselt number of the trailing particle are far less than the leading one under the same working conditions. The prediction correlations for the drag coefficient and average Nusselt number of both the two spheroids were established with low deviations. At last, the influence of the relative incidence angles between the two tandem spheroids on the momentum and heat transfer was studied. It is shown that the relative incidence angles play significant roles due to the change of the frontal area of the leading spheroid with these angles.

AMS subject classifications: 76T25, 68U20

Key words: Drag coefficient, average Nusselt number, IB-LBM, spheroids, inter particle distance, relative incidence angle.

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1 Introduction

1.1 Background

The fluid flowing over solid particles with different temperature is one of the most encountered phenomenon in both engineering applications and daily life. In these processes, the important information that people care about and use for the scaling design and configuration optimization of the current devices is the momentum and heat transfer between the two phases which are usually characterized by two dimensionless parameters, namely the drag coefficient (Cd) and average Nusselt number (Nu), respectively. Previous work has demonstrated that several important factors play key roles in influencing on Cd and Nu, such as the Reynolds number, particle shape with its orientation and surroundings [47]. Therefore, understanding the contribution of each factor and combining all these information to predict Cd and Nu accurately are of paramount importance to provide optimization policy on the operating parameters and energy efficiency.

Two spheroids in a tandem arrangement are a typical case of the afore-mentioned system to dig the mechanism governing the complex representations. In such cases, a tuning on the Reynolds number, aspect ratio, inter particle distance and relative incidence angle makes it possible to construct different working conditions and evaluate corresponding Cd and Nu, quantitatively. On the one hand, the leading particle exerts great influence on the force evolution and heat transfer of the second particle because of the inhibition to the fluid flow. On the other hand, due to the adjunction of the trailing particle, a significant effect is brought on the evolution of the recirculation wake of the leading particle especially when the inter particle distance between the two particles is very small. In the previous studies, the researchers have paid much attention on the momentum and heat transfer of an isolated particle and the drag force of two tandem spheroids. However, there is a gap left to describe how these factors affect the heat transfer characteristics of two tandem particles. Especially, the effect of the relative incidence angles between the two spheroids is mainly ignored before. All these facts motivate the current research.

1.2 Previous work

There have been many studies on the momentum and heat transfer for an isolated particle immersed in a fluid which have been reviewed in our previous paper [13]. Here, only a brief story is given followed by a detailed version on the two particle cases. Yuge [45] and Klyachko [19] carried out experimental studies on this topic at very small Reynolds and Grashof numbers followed by the study of Chen and Mucoglu [4] at higher Reynolds and Grashof numbers. Juncu [12] investigated the transient heat transfer from two types of spheroids to a steady stream of viscous flows. Hölzer and Sommerfeld obtained the drag, lift and moment coefficients of six kinds of particles with different shapes through numerical simulation [8]. The lattice Boltzmann method (LBM) simulations were conducted to simulate the fluid flow over various non-spherical particles and improve the