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Simulation of the reconstruction of the boundary layer by moving cylinders

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Abstract

In this paper, the reconstruction of the boundary layer of the fluid in the channel is studied by lattice Boltzmann method (LBM). By comparing the distribution of velocity in the channel, the conclusion that LBM has the feasibility and superiority in dealing with moving boundary is obtained. Based on this, physical model of moving square cylinders with different height are set up to simulate the effect on the thickness of boundary layer, and the results indicate that the thickness of the boundary layer decreases with the cylinders' height increasing in the given range. Furthermore, double cylinders model is also set up, and the results show that the optimal interval distance of the cylinders is between 90 and 140 lattice unit. It is found that the moving cylinders have significant effect on the thickness of the boundary layer, which will change the fluid flow and enhance the heat transfer.

Keywords: Lattice Boltzmann method; moving cylinders; reconstruction; the optimal interval distance; thickness of boundary layer

1. Introduction

Application of heat transfer enhancement technology is an important issue in engineering problems such as compact heat exchangers, cooling of electronic equipments, nuclear reactor fuel rods, cooling towers, chimney stacks and offshore structures, because it can improve the efficiency of heat exchange and consequently reduce the energy consumption. Thus enormous works have been done analytically, experimentally and numerically.

Many authors devoted their effort to the effect of arrangement of cylinder in the equipments, on the fluid flow

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and heat transfer. Saha et al. (2003) found that the thermal performance factor increases with the increase in pitch of the cylinders. Sharman et al. (2005) analyzed flows over two tandem cylinders using collocated unstructured computational fluid dynamic code. Lu et al. (2012) simulated the fluid flow pass two square cylinder in a tandem arrangement and investigated heat transfer around the two cylinders. Kotcioglu et al. (2011) indicated that hexagonal pin-fins can lead to an advantage in term of heat transfer enhancement via experiments. Shi et al. (2015) presented an analysis of convective heat transfer in fluid flow. It can be observed that the nature of the flow and heat transfer depend strongly on the arrangement of cylinders.

In the meantime, some works focused on the effect of agitation on the fluid flow and heat transfer. Chang et al. (2015) performed the lattice Boltzmann simulation for the convective heat transfer problems of three types of motion of impeller stirred tank. Agrawal et al. (2015) made experiments to study heat transfer augmentation of a channel flow by active agitation and surface mounted cylindrical pin fins. Yoon et al. (2009) presented a numerical investigation of the characteristics of the two-dimensional laminar flow around two rotating circular cylinders in side-by-side arrangements. Yan et al. (2008) studied and simulated a viscous fluid flowing past a rotating isothermal cylinder with heat transfer by the lattice Boltzmann method.

The lattice Boltzmann method (LBM) is a mesoscopic numerical simulation method. In the LBM, the well-known BGK model which makes the LBE a linearized form is often adopted by Bhatnagar et al. (1954) and He et al. (1997). In our work, considering the effect of the arrangement of cylinders and agitation on the fluid flow and heat transfer, we present a numerical investigation of the effect of square cylinders moving from the left to the right in the channel on the boundary layer, and then analyse the contribution to the heat transfer.

2. Physical model and numerical method

2.1. Physical model

In the design and manufacture of heat exchange equipment, the plug-in technology is a simple and effective way to damage the boundary layer. However, it is possible to form a reflow area in the rear of the static spoiler, and that can hinder convection heat transfer. Therefore, this paper hopes to drive the spoiler movement mechanically to destroy the reflow area. As shown in Fig. 1, a square cylinder moves from left to right along the lower wall.

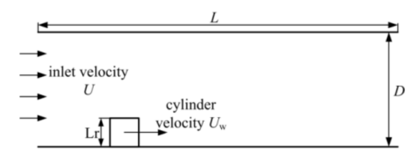

Fig. 1. Physical model of moving square cylinder.

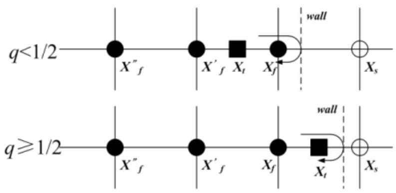

Fig. 2. 1D projection of regular lattice and curved boundary.

2.2. Lattice Boltzmann method

The fundamental principle of the lattice Boltzmann model use distribution functions $f(\boldsymbol{x},t)$ based on kinetic theory to simulate the flow field at the mesoscopic scale. The density distribution function $f(\boldsymbol{x},t)$ represents the probability of the particles at position $\boldsymbol{x}$ and at time t moving with a velocity $\boldsymbol{e}_i$ during the interval time Δt along each lattice line (i.e. direction $\boldsymbol{i}$). And LBM has second order accuracy for Navier-Stokes equation. The lattice Boltzmann equation (LBE) is an explicit time-marching finite-difference representation of the continuous Boltzmann equation in phase space and time. The LBE incorporating the single relaxation BGK approximation is given by Qian et al. (1992):

$$f_i(\boldsymbol{x}+\boldsymbol{e}_i\Delta t, t+\Delta t) - f_i(\boldsymbol{x},t) = \omega[f_i^{eq}(\boldsymbol{x},t) - f_i(\boldsymbol{x},t)] \quad (1)$$

where, $\omega = 1/\tau$ denotes the relaxation factor, $c_s = c/\sqrt{3}$ is the speed of sound, and $c = \Delta x/\Delta t$. The kinematic