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Mesolevel Analysis of Hydrodynamics of Flow Over Hydrophobic Surfaces

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Abstract

In this study, hydrodynamics of flow over a super-hydrophobic surface was investigated using Lattice Boltzmann method. Lattice Boltzmann method is a meso-level approach, to capture the mico-level details in the flow regime. From the numerical analysis it was found that, an effective mixing was induced in the flow domain with the introduction of hydrophobic surfaces in the channel. The cross stream velocity fields induced potentially proves its capability to create induced mixing in the channel. The result was found to be in fine agreement with the results in the literature. The exceptional capability of reducing the pumping power makes this modification more acceptable.

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Keywords: Hydrophobic surface; Lattice Boltzmann method; microchannel; slip flow.

1. Introduction

With the miniaturization of machines and electronic equipment, cooling has become one of the major challenges. Microchannel and heat pipe technology are effectively used in modern days to meet these challenges. A notable feature common to this micro devices is that they have large surface area to volume ratio. This property of these equipments makes them different from macro level flow devices. Since flow through these channels suffers

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from heavy viscous drag and results in high pumping power. To meet this challenge the idea of coating the channel walls by hydrophobic surfaces has been investigated since 2006.

Choi et al.[1] analyzed the effect of slip in hydrophilic and hydrophobic microchannel. Slip length found to vary approximately with shear rate. It was also found that the uncertainty may occur in the experiment due to nanometer sized uncertainty in the channel. Tretheway et al.[2] analyzed the effect of slip flow in microchannel. It was found that presence of fluid slip at hydrophobic walls resulting in formation of nano-bubbles at the surface.

Choi et al.[3] analyzed the effect of slip and friction reduction in nano-grate super-hydrophobic surfaces in microchannel and reported greater effect was found when slip is parallel to flow condition than in the parallel direction. Nano-grated super hydrophobic surfaces not only reduce friction but also enable control over the slip. Davies et al.[4] reported a notable reduction in friction factor and enhancement in friction factor with increase of cavity to rib length ratio and with increase of hydraulic diameter of the channel.

Niu et al.[5] reported a work on thermal LBM model with diffuse scattering. It was concluded that LBM as a good tool for predicting micro-fluidic behaviour with thermal effects for low Knudsen number flows. Zade et al.[6] studied the effect of variable physical properties on flow and heat transfer characteristics of simultaneously developing slip flow in rectangular microchannel was numerically investigated. It was found that even at low temperature difference, friction and heat transfer coefficient vary considerably.

Navid et al.[7] analyzed the effect of wettablity and aspect ratio of rectangular micro channels. It was found that with increase of surface wettablity pressure drop in laminar regime found to reduce. Mohammad and Alireza in 2011 [8] studied on the ability of hydrophobic walls in reducing drag in turbulent channel flow and it was found that near the walls turbulence structures are modified with stream wise slip velocity and a noticeable effect on turbulence structure when slip length is greater than a certain value.

Liu and Guo[9] studied pressure driven flow in a long microchannel using LBM. In this work author takes into account of gas wall collision effect and reported LBM as a useful tool to capture flow behaviour in transition regime. Vishal Anand [10] in 2014 reported a work on slip effect on heat transfer and entropy generation in a pressure driven flow in a microchannel. It was found that the thermally fully developed flow with viscous dissipation of a non-Newtonian fluid occur through a microchannel and slip parameter only affect the advection of fluid momentum and not its diffusion.

Guillermo et al.[11] found that an optimum value of heat flux that can be applied in the wall of microchannel with minimum entropy generation. It was found that an optimum value of both slip length and wall to fluid thermal conductivity ratio at which entropy generation become maximum, found to decrease with wall heat flux. Derby et al. [12] analyzed the heat transfer enhancement obtained in a microchannel with hydrophobic and hydrophilic patterns. It was reported that 3.2 to 13.4 times rise in condensation in the microchannel walls occur with the introduction of hydrophobic walls.

Tan and Liu[13] reported a work on flow and heat transfer in microchannel. The effect of electric potential and slip flow in heat transfer in microchannel was studied. It was found that streaming potential affect the flow and decreases the heat transfer rate while wall slip effect tends to increase the flow velocity and enhances the heat transfer.

Wang et al. [14] reported an effective boundary condition called Immersed boundary Lattice Boltzmann method (IBLBM). It was found that conventional no-slip boundary condition cannot fully implement flow properties and some stream lines enter solid boundary. This drawback is overcome in this method by modifying flow velocity at boundary dependent points.

Ranjith et al.[15] analyzed hydrodynamics of flow through two dimensional parallel plate microchannel with periodic hydrophobic strips using dissipative particle dynamics. Symmetric and anti-symmetric strips were analyzed and it was found that anti-symmetric strips cause a finite velocity component towards center of the channel. This cross stream velocity field generated enhances mixing in micro channels. Sharafatmandjoor et al. [16] presented a scheme to implement no slip boundary condition. It was found that the method proposed present a faster solution procedure in comparison with bounce back scheme. Arash[17] used specular reflective bounce back for the simulation of slip condition at the boundary. Benzi[18] analyzed the hydrodynamic characteristics' of flow over hydrophobic using Lattice Boltzmann method.

From the preceding literatures it was found that, with the introduction of hydrophobic walls, the pressure drop reduces and with an increase in heat transfer enhancement in the channel. It was also found that this effect is