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Dec. 2009, Volume 3, No.12 (Serial No.25) Journal of Materials Science and Engineering, ISSN 1934-8959, USA

Lattice Boltzmann modelling of microchannel flow*

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Abstract: A lattice Boltzmann algorithm to model the fluid flow in microchannel is developed. The details in determining the parameters critical for lattice Boltzmann application in microchannel flow are provided. The results from a 9-bit square lattice Boltzmann model are in good agreement with recent analytical data for a pressure-driven microchannel flow in slip flow regime. The differences between the predicted and the analytical for pressure gradients along the channel are well comparable. Results suggest that the lattice Boltzmann model described here is an effective computational tool for predicting more complex microfluidic systems that might be problematic using conventional methods.

Key words: lattice Boltzmann equation; distribution function; microchannel; Knudsen number

1. Introduction

In the past few years, many of the researchers have diverted their attention to the microflow area. Examples of microflow applications are microchannel heat exchanger, mirco-electro-mechanical systems (MEMS), micro blood pump, etc.[1-4] Those applications have their characteristic length scales in micrometer. To understand all of these applications, simulation of micro flow is needed to predict the flow behaviors and the evaluation process has to be carried out before product fabrication of these micro devices.

For a microsystems, the continuum hypothesis of Navier-Stokes (NS) equations cannot be applied due to the mean free path of molecules which almost comparable to the characteristic length scales of the system[5]. The continuum flow assumption only holds until Kn = 0.01, where Kn is the Knudsen number describes the ratio of the mean free path, λ to the characteristic length, L. The continuum assumptions break down in rarefaction when Kn beyond this limit. In the range of 0.01< Kn < 0.1, known as slip-flow regime, the application of Navier- Stokes equation still valid under the constraint of slip velocity on the solid boundary. For 0.1 < Kn < 10, flow is considered in the transition regime. The rarefaction effect is critical in this regime and no longer valid for Navier-Stokes solution. At Kn > 10, flow is considered completely at free molecular level.

Direct simulation of Monte Carlo (DSMC) method has been widely used to simulate micro flow. This method is a particle-based method and able to simulate the flow for low until high Knudsen number. However, DSMC is shadowed by its long computational time even to solve small physical geometry. Recently, Lattice Boltzmann Method (LBM), a numerical method based on particle distribution function, becomes an alternative choice in solving micro flow phenomenon. The LBM is the outcome from the frustration on lattice gas automata (LGA) method. LBM derives the Navier-Stokes equation from statistical behavior of particles dynamics. Besides that, LBM does not evaluate the evolution of particles in the certain field and deal directly with the number of mesh points and the lattice model. Therefore, LBM has been proved as an efficient and fast computational approach compared to DSMC method.

In the present study, the authors demonstrate the capability of LBM to simulate the behavior of fluid flow in micro regime. Pressure driven problem, where the pressure at inlet and outlet are always fixed during

* **Acknowledgment:** The authors acknowledge the University Teknology Malaysia and Malaysia government for supporting this research activity.

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