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Technical Note

Investigation of convective heat transfer through constant wall heat flux micro/nano channels using DSMC

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ABSTRACT

In this research, convective heat transfer of the argon gas flow through a micro/nano channel with uniform heat flux wall boundary condition is investigated using the direct simulation Monte Carlo (DSMC) method. Both of the hot wall ($q_w > 0$) and the cold wall ($q_w < 0$) cases are considered. Implementation of wall heat flux in the DSMC method is performed using the recently developed "iterative" technique. Our investigation considers heat transfer behavior in both of slip and transition flow regimes. We investigate the influence of rarefaction, i.e., Knudsen number, and viscous dissipation, i.e., Brinkman number, on the Nusselt number behavior. We use the generalized hard sphere (GHS) collision model to consider accurate variation of the heat conductivity with the temperature. The DSMC solutions for the Nusselt number are compared with different analytical expressions reported in the literature with suitable accuracy through the slip regime. We observe that the dependency of the Nusselt number on the Knudsen number decreases in nanochannels as Knudsen number increases into the transition regime, i.e., Nusselt number approaches nearly a constant value as Knudsen number goes beyond 1. Additionally, it is shown that the Nusselt number is a weak function of the Brinkman number.

1. Introduction

During the past decades, direct simulation Monte Carlo (DSMC) method has been widely used to investigate flow fields ranging from hypersonic spacecrafts to small scale micro/nano systems [1]. Rapid development in high temperature power, propulsion and high density power electronics has introduced new opportunities and challenges in developing high temperature heat exchangers (HTHE) which are expected to exceed 2500 K [2]. An important issue in future development in micro/nano systems is applying efficient techniques to control thermal condition within allowable operating limits due to high power densities which are expected to exceed 25 W/cm^2 [3]. Because of decreasing in medium's density in small size geometries, flow rarefaction, i.e., Knudsen number, has a significant impact on the heat transfer. Kn number is defined as the ratio of the gas mean free path to the characteristic length of the geometry,

$$Kn = \lambda / H \tag{1}$$

Based on the generalized hard sphere (GHS) model, the mean free path of the gas is defined as follows

$$\lambda = \sqrt{\frac{\pi m}{2kT}}\left(\frac{\mu}{\rho}\right) \tag{2}$$

Small geometry size makes it important to take into account viscous dissipation. Viscous dissipation is usually considered in the Brinkman number (Br), which is the ratio of the viscous heat generation to the external heating:

$$Br_q = \frac{\mu u_b^2}{q_w 2H} \tag{3}$$

Both of Kn and Br numbers depends on the gas viscosity, which is a function of the gas temperature. This dependency will be further discussed in Section 2.

A key characteristic of the heat transfer behavior of a system is the Nusselt number (Nu), defined as follows:

$$Nu = \frac{2q_w H}{k(T_w - T_b)} \tag{4}$$

where the bulk temperature (T_b) is defined as

$$T_b = \frac{\int_A \rho u_x T dA}{\int_A \rho u_x dA} \tag{5}$$

There are a wide set of studies considering micro/nano channel flows in the slip flow range and beyond, i.e., Refs. [4–6]. Also there are theoretical and numerical investigations around the topic of

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