NEGF2015-61

Investigation of cold to hot heat transfer in a nano step geometry

Amir-Mehran Mahdavi[1], **Ehsan Roohi**[*2]
[1]a.m_mahdavi@yahoo.com
[2]eh.roohi@gmail.com

KEY WORDS

DSMC, Rarefied flow, cold to hot transfer, separation zone.

ABSTRACT

In this paper we investigate the cold to hot phenomena at the nano step geometry. This geometry is applied in nano devices where straight channels with various diameters are connected to each other. The DSMC approach has been used to model nitrogen gas through this geometry. We observed that there is a thermal separation zone in which heat lines deviate their direction toward the inlet of step. This zone can affect total gas behavior. The results show that big thermal separation zone can force heat lines to move from cold regions to hot ones (see Fig. 1-c and 1-d) As is shown, the temperature decreases suddenly at X/L=0 because of flow expansion and a cold region appears. Heat lines originating from hotter walls enter this area; however, they are deflected toward the hotter region near the inlet

To understand the details of this process, the constitutive laws of the linearized Boltzmann theory has been used[1]. These set of equations take into account the dependency of the gas thermal conductivity on the temperature. As Kn and temperature variations are small in our case, the use of the constitutive laws of weakly nonlinear equations derived by Sone[1] is justified. In these equations, the heat flow vector Q is given as follows:

$$Q = Kn^{**}Q_1 + Kn^{**2}Q_2 + Kn^{**3}Q_3 \tag{1}$$

$$Q_1 = 0 \tag{2}$$

$$Q_2 = -\frac{5}{4}\gamma_2 \frac{\partial \tau^{**}}{\partial x_i} \tag{3}$$

$$Q_3 = -\frac{5}{4}\gamma_2 \frac{\partial \tau^{**}}{\partial x_i} - \frac{5}{4}\gamma_5 \tau^{**} \frac{\partial \tau^{**}}{\partial x_i} + \frac{1}{2}\gamma_3 \frac{\partial^2 u^{**}}{\partial x_j^{\,2}} \tag{4}$$

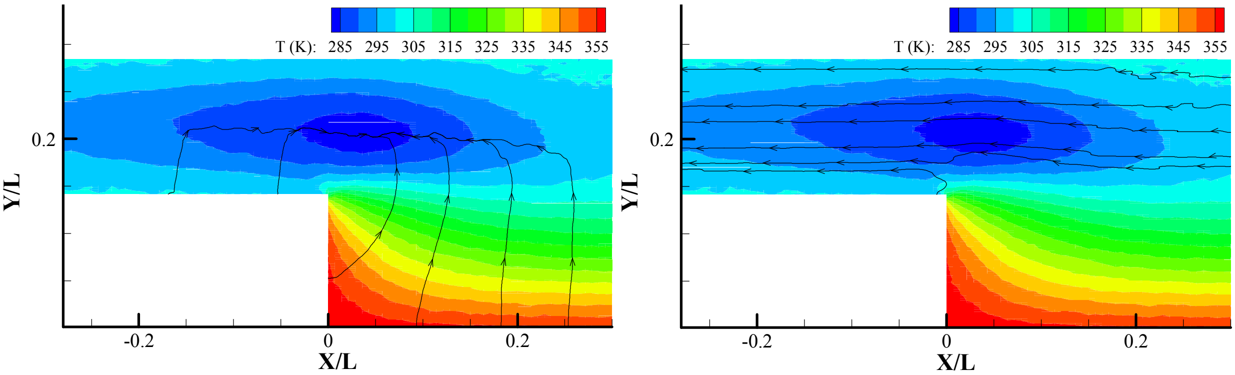
The employed parameters are defined as follow:

$$Kn^{**} = Kn\frac{\sqrt{\pi}}{2} \tag{5}$$

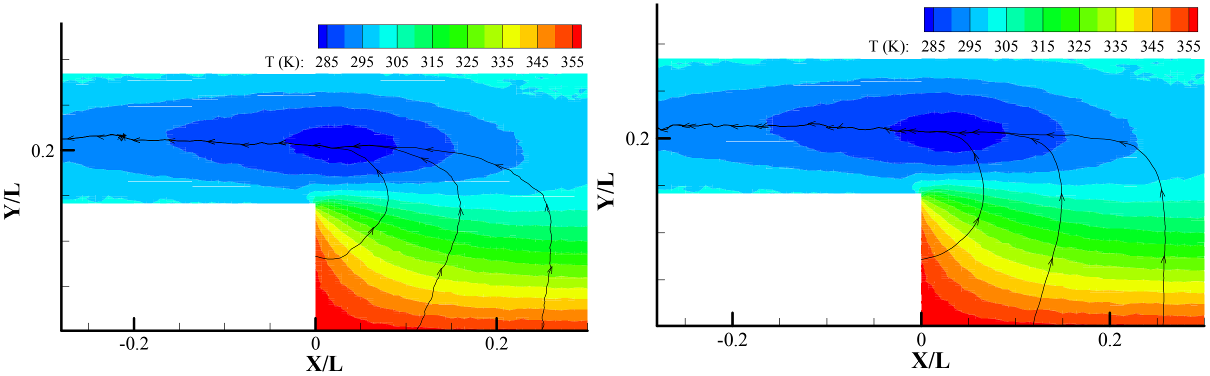
$$\tau^{**} = \frac{T - T_0}{T_0}, u_i^{**} = \frac{u_i}{\sqrt{2RT_0}}, x_i = \frac{X_i}{L} \tag{6}$$

The coefficients used in Eq. (7) are set as $\gamma_2 = 1.9222$, $\gamma_3 = 1.9479$ and $\gamma_5 = 0.9611$ [1]. The results of this theory show good agreement with DSMC results at small Knudsen numbers. Numerical results

show that the magnitude of the $\frac{\partial^2 u_i^{**}}{\partial x_j^{2}}$ term is greater than the other parameters in Q_3. Therefore this theory states that there are two main factors, i.e., Fourier effect and second derivative of velocity which determine the heat lines behavior. The balance between these two terms determines the heat direction. The effect of these two terms are shown in Fig. 1-a and b. Our results show that second derivative of velocity is more dominant where the temperature gradient is weak. It means that if the differences between gas and wall temperature is low, the Fourier term will have little effect and second derivative of velocity determines the heat lines. This causes cold to hot heat transfer (see Fig. 1-b). The results of all terms in equation (4) is shown in Fig. 1-c and compared with DSMC solution (Fig. 1-d). The effect of inlet temperature have been investigated as well. We observed that cold to hot heat transfer can occur in the cases in which inlet temperature nears to the wall temperature. As is shown in equation (4) at these cases the effect of Q_2 becomes weak and therefore the effect of $\frac{\partial^2 u_i^{**}}{\partial x_j^{2}}$ in Q_3 is more dominant. Our results show that at high wall temperatures the cold to hot transfer vanishes.



(a) Heat lines of $-\frac{\partial \tau_s^{**}}{\partial x_i}$ term (b) Heat lines of $\frac{\partial^2 u_i^{**}}{\partial x_j^{2}}$ term



(c) Heat line from Eq. (4) (d) DSMC Heat lines

Figure 1:): Heat lines plotted in the zoomed view of the step geometry

References and Citations

[1] . Sone, Y., *Molecular gas dynamics theory, techniques, and applications*, Brikhauser, 2007.
[2] . Mahdavi, M., Le, N., Roohi, E., White, C., Thermal rarefied gas flow investigations through micro/nano backward-facing step: Comparison of DSMC and CFD subject to hybrid slip and jump boundary conditions, *Numerical Heat Transfer*, Part A: Applications, Vol. 66, 733–755, 2014.
[3] . Bao F, and Lin J.Z., Continuum Simulation of the Microscale Backward-Facing Step Flow in a Transition Regime, *Numerical Heat Transfer*, Part A, Vol. 59: pp 616–632, 2011.
[4]. 3. Beskok A., Validation of a new velocity-slip model for separated gas miroflows, Numerical Heat Transfer, Part B, Vol. 40, 451-471, 2001.