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# Three-Dimensional Simulation of Helium Gas Flow in an Aluminum Heat Sink with Rectangular Microchannel in Slip Flow Regime

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**ABSTRACT:** In the present work, for the first time, gas flow with considering slip velocity and temperature jump boundary condition is studied in a heat sink consisting of rectangular fins and microchannels with calculating conjugated heat transfer. In this paper, helium gas flow with Knudsen number between 0.048 to 0.06 has been studied. Heat flux applied to the bottom of the aluminum heat sink is 500W/m2. The governing equation for fluid flow has been discretized using second-order upwind method and solved with using the Coupled algorithm in Ansys-Fluent commercial software. Results show that inlet and local Knudsen numbers decrease with increasing pressure ratio and also local Poiseuille number decreases with increasing inlet Knudsen number. Also, with increasing inlet Knudsen number (reduction of pressure ratio), first the average Nusselt number decreases and then increases. In this case, the average Nusselt number decreases about 54.4% with increasing Knudsen number from 0.006 to 0.024 and the average Nusselt number increases with increasing Knudsen number from 0.024 to 0.048. With increasing Knudsen number, thermal resistance increases continuously. The results show that with increasing inlet Knudsen number, slip and temperature jump coefficients increase.

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## 1. INTRODUCTION

Flow in microchannels is one of the important subjects in fluid mechanics and industry. Zhu and Liao [1] investigated forced convective heat transfer for gas flow in a microchannel with different cross sections. They studied the slip flow and temperature jump regime using the orthonormal function method. Then, as a sample, they focused on investigating the heat transfer characteristics of rectangular and triangular microchannels. They indicated that the average Nusselt number in the slip flow regime is smaller than no-slip flow regime. Hooman [2] studied air heat transfer and entropy generation in micro electro mechanical systems (a. plate microchannel b. circular microchannel) in the slip flow regime, analytically. The results showed that: 1. With increasing velocity, entropy generation increases. 2. Increasing Prandtl number enhances Nusselt number and entropy generation. 3. Increasing Knudsen number increases Nusselt number and entropy generation. Shkarah et al. [3] studied laminar, developed, and steady-state flow in a 3D microchannel. The used aluminum, silicon, and graphene as substrate materials. Their results showed that graphene most effectively decreases the thermal resistance.

The most previous studies on heat transfer are related to liquid flow and slip condition is ignored in them. But in this paper, slip flow of incompressible and ideal helium gas is studied. Also, the conduction in the solid parts of the heat sink is considered.

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## 2. PROBLEM DESCRIPTION

The geometric configuration of the microchannel heat sink is shown in Fig. 1. The dimensions of the microchannel and rectangular fins are shown in Fig. 2. As it is shown in Fig. 2, the heat sink consists of 11 rectangular microchannels separated by 10 fins. The size of the microchannels and fins is equal. Heat flux of 500 W/m$^2$ is applied at the bottom plate of the heat sink that the electronic chip assumed directly attached to the base plate of the heat sink. Helium gas is considered incompressible and ideal.

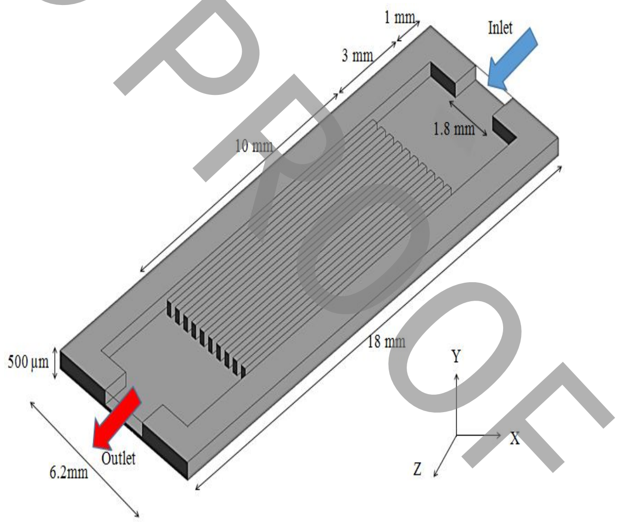


**Fig. 1. Geometry of microchannel heat sink with direct inlet and outlet.**

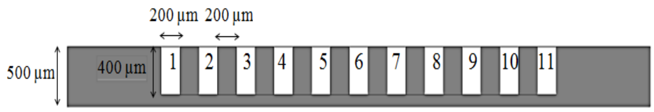


**Fig. 2. Fin and microchannel dimensions (The created cross section at $z$ =9mm)**

## 3. GOVERNING EQUATIONS

The governing equations in the fluid and the solid parts of the heat sink are:

$$\frac{\partial}{\partial x}(\rho u)+\frac{\partial}{\partial y}(\rho v)+\frac{\partial}{\partial z}(\rho w)=0 \tag{1}$$

$$\frac{\partial}{\partial x}(\rho uu)+\frac{\partial}{\partial y}(\rho vu)+\frac{\partial}{\partial z}(\rho wu)=-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial u}{\partial z}\right) \tag{2}$$

$$\frac{\partial}{\partial x}(\rho uv)+\frac{\partial}{\partial y}(\rho vv)+\frac{\partial}{\partial z}(\rho wv)=-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}\left(\mu\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial v}{\partial z}\right) \tag{3}$$

$$\frac{\partial}{\partial x}(\rho uw)+\frac{\partial}{\partial y}(\rho vw)+\frac{\partial}{\partial z}(\rho ww)=-\frac{\partial p}{\partial z}+\frac{\partial}{\partial x}\left(\mu\frac{\partial w}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial w}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial w}{\partial z}\right) \tag{4}$$

$$\frac{\partial}{\partial x}(\rho uT)+\frac{\partial}{\partial y}(\rho vT)+\frac{\partial}{\partial z}(\rho wT)=\frac{\partial}{\partial x}\left(\frac{k}{c_p}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{k}{c_p}\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{k}{c_p}\frac{\partial T}{\partial z}\right) \tag{5}$$

$$\frac{\partial}{\partial x}\left(k_s\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_s\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_s\frac{\partial T}{\partial z}\right)=0 \tag{6}$$

Slip velocity boundary condition at the gas-solid interface for walls in Y-Z plane is:

$$w_{\mathrm{w}}-w_{\mathrm{g}}=\left(\frac{2-\sigma_v}{\sigma_v}\right)\mathrm{Kn}\,L_c\left(\frac{\partial w}{\partial n}\right)\approx\left(\frac{2-\sigma_v}{\sigma_v}\right)\frac{\lambda}{\delta}(w_{\mathrm{g}}-w_c) \tag{7}$$

The temperature jump boundary condition at the gas-solid interface for walls in the Y-Z plane is:

$$T_{\mathrm{w}}-T_{\mathrm{g}}=\left(\frac{2-\sigma_T}{\sigma_T}\right)\mathrm{Kn}\,L_c\left(\frac{\partial T}{\partial n}\right)\approx 2\left(\frac{2-\sigma_T}{\sigma_T}\right)\frac{\lambda}{\delta}(\mathrm{T_g}-T_c) \tag{8}$$

Indexes of Nusselt number and thermal resistance of the heat sink substrate to the heat flux are used for evaluating the microchannel heat sink performance. The average Nusselt number is defined as:

$$Nu=\frac{hD_h}{k_f} \tag{9}$$

Thermal resistance as another index of thermal performance is obtained via:

$$R_{th}=\frac{T_{\mathrm{w,max}}-T_{in}}{q_w W_{hs} L_{hs}} \tag{10}$$

## 4. RESULTS AND DISCUSSION

The variation of average Nusselt number with Knudsen number depends on variations slip velocity and temperature jump. The presence of slip velocity on the walls increases the heat transfer, therefore with increasing Knudsen number, due to increasing slip velocity, average Nusselt number increases. Also, the presence of temperature jump on the walls decreases the heat transfer, therefore with increasing Knudsen number, due to increasing temperature jump, the average Nusselt number decreases. Fig. 3 shows the average Nusselt number and thermal resistance in terms of inlet Knudsen number. As indicated in Fig. 3, with increasing inlet Knudsen number from 0.006 to 0.024 the average Nusselt number 54.40% decreases and with increasing inlet Knudsen number from 0.024 to 0.048 the average Nusselt number 5.42% increases. In the present study, for the Knudsen number smaller than 0.024, the effect of the temperature jump is superior to slip velocity and for the Knudsen number bigger than 0.024, the effect of slip velocity is superior to temperature jump. As indicated in Fig. 3, with increasing inlet Knudsen number, thermal resistance increases continuously, because with increasing Knudsen number flow pressure and also gas velocity decreases, therefore convection heat transfer decreases and thermal resistance increases. Results show that with increasing inlet Knudsen number from 0.006 to 0.048 thermal resistance 966.34% increases.

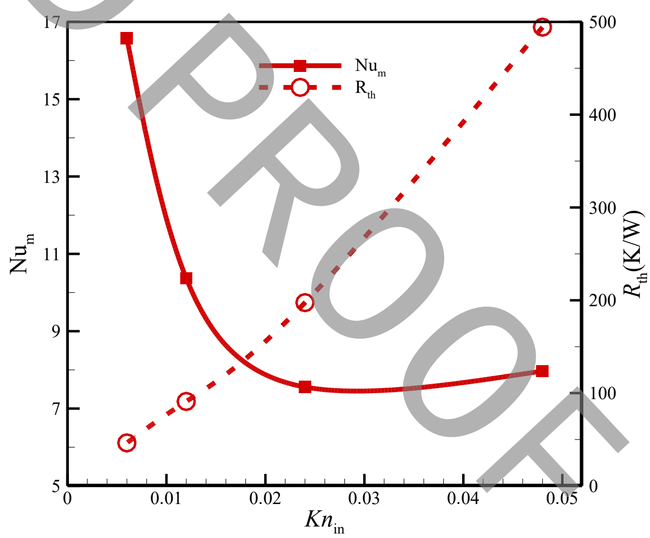


**Fig. 3. Variation of average Nusselt number and thermal resistance with inlet Knudsen number.**

## 5. CONCLUSION

The summary of the results are as follows:

1. With increasing the inlet Knudsen number, velocity slip and temperature jump increases.

2. With increasing the inlet Knudsen number from 0.006 to 0.012 and from 0.012 to 0.024 the average Nusselt number decreases 37.45% and 27.10%, respectively and with increasing inlet Knudsen number from 0.024 to 0.048 the average Nusselt number increases 5.42%.

3. With increasing the inlet Knudsen number from 0.006 to 0.048 thermal resistance increases 966.34%.

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