Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 50(2) (2018) 85-88
DOI: 10.22060/mej.2016.857

Investigation of the Effect of Velocity Slip and Temperature Jump on the Heat Transfer of Nanofluid in a Microchannel Under Constant Heat Flux with Lattice Boltzmann Method

A. Alipour Lalami, M. Kalteh*

Mechanical Engineering Department, University of Guilan, Rasht, Iran

ABSTRACT: In this article, the effect of velocity slip and temperature jump on the flow and heat transfer characteristics of Al_2O_3 – Water nanofluid in a microchannel with insulated upper wall and constant heat flux on the lower one, is investigated using the lattice Boltzmann method. The problem is solved at Re equal to 5, for base fluid and nanofluid with 0.02 and 0.04 volume fractions, no-slip and slip conditions with 0.04 and 0.1 slip coefficients and also at 5 to 50 nm nanoparticle diameters. The results show that, in general, using the hydrophobic surfaces in addition to making a considerable reduction in wall shear stress, somewhat increases the heat transfer efficacy at uniform wall heat flux condition that can not be seen in the constant wall temperature situations. Also, it is shown that the effect of temperature jump on the average Nusselt number, is more for base fluid than the nanofluid and increases for higher slip coefficients. For nanofluid with 0.04 volume fraction, the average Nusselt number increases continuously with slip coefficient but, for base liquid, firstly it increases and then decreases.

Review History:

Received: 27 July 2016
Revised: 20 October 2016
Accepted: 27 November 2016
Available Online: 30 November 2016

Keywords:

Nanofluid
Microchannel
Temperature jump
Constant heat flux
Lattice Boltzmann method

1- Introduction

In general, liquid flow in microchannels can be considered in a continuous regime. But in some applications, liquid flow in microchannels is in slip regime [1] due to the use of hydrophobic surfaces in the vicinity of a hydrophilic liquid.

Karimipour et al. [2] investigated the forced convection heat transfer of copper-water nanofluid in a 2D microchannel with constant wall temperature in slip flow regime with lattice Boltzmann method. They found that at a constant volume fraction of nanoparticles, by increasing the slip coefficient (by considering temperature jump on the wall), Nusselt number decreases.

In the present work, the effect of velocity slip and temperature jump on flow and heat transfer characteristics of Al_2O_3–Water nanofluid in a microchannel with insulated upper wall and constant heat flux on the lower one is investigated using the lattice Boltzmann method. The main goal of the present work is to compare the results of constant heat flux boundary condition with those of the constant wall temperature case. Also in this article, the effect of nanoparticles diameter in the effective viscosity model is considered and the average shear stress and Nusselt number on the wall in different diameters (5 to 50 nm) are estimated.

2- Methodology

2- 1- Problem statement

In this article, forced convection heat transfer and fluid flow of Al2O3-Water nanofluid in a 2D microchannel with the insulated upper wall and constant heat flux imposed on the lower one is investigated. The problem is solved at a constant Reynolds number equal to 5, for base fluid and nanofluid with 0.02 and 0.04 volume fractions, no-slip and slip conditions with 0.04 and 0.1 slip coefficients and also at 5 to 50 nm nanoparticle diameters. The geometry of the problem is shown in Fig. 1. In this figure, H=50 µm and L=1 mm are height and length of the channel and W/m^2 is the imposed heat flux on the lower wall. The nanofluid enters the channel at a uniform temperature of 300 K, uniform velocity and exits the microchannel at fully developed condition (both hydrodynamically and thermally).

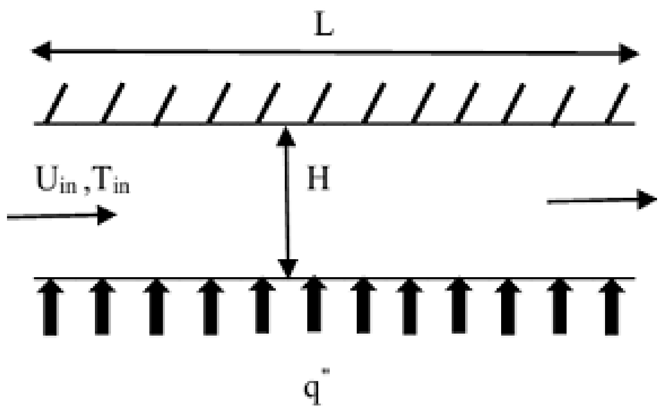

Figure 3. The geometry of the problem

2- 2- Nanofluid property models

Single phase modeling is used to simulate the nanofluid properties. For density and specific heat capacity, a two-phase mixture model is used [3]. For viscosity, Corcione model [4], in accordance with the following formula is applied:

Corresponding author, E-mail: mkalteh@guilan.ac.ir

$$\frac{\mu_{nf}}{\mu_f}=\frac{1}{1-34.8\left(\frac{d_p}{d_f}\right)^{-0.3}\varphi_p^{1.03}} \tag{1}$$

In this equation, d_p and d_f are diameters of nanoparticles and base fluid molecules, respectively.
Also for calculating the thermal conductivity coefficient of nanofluid, Chon et al.'s model [5] is used:

$$\frac{k_{nf}}{k_f}=1+0.64\varphi_p^{0.746}\left(\frac{d_f}{d_p}\right)^{0.369}\left(\frac{k_p}{k_f}\right)^{0.7476}\times Pr_f^{0.9955}Re_s^{1.2321} \tag{2}$$

In this equation, Re_S is the specific Reynolds number that is defined as follows:

$$Re_s=\frac{\rho_f K_B T}{3\pi\mu_f^2\lambda_f} \tag{3}$$

wherein K_B is Boltzmann constant and λ_f is the mean free path of the base fluid.

2- 3- Lattice Boltzmann method

The D_2Q_9 lattice model is applied in the present study. The discretized forms of hydrodynamic and thermal Boltzmann equations are written as follows [6]:

$$f_k(x+\Delta x,y+\Delta y,t+\Delta t)=f_k(x,y,t)[1-\frac{\Delta t}{\tau_f}]+\frac{\Delta t}{\tau_f}f_k^{eq}(x,y,t) \tag{4}$$

$$g_k(x+\Delta x,y+\Delta y,t+\Delta t)=g_k(x,y,t)[1-\frac{\Delta t}{\tau_g}]+\frac{\Delta t}{\tau_g}g_k^{eq}(x,y,t) \tag{5}$$

In which f_k and g_k are density distribution function and dimensionless temperature distribution function, respectively. Also, f_k^{eq} and g_k^{eq} are density equilibrium distribution function and dimensionless temperature equilibrium distribution function, respectively:

$$\Theta_k^{eq}=\omega_k\Phi[1+\frac{\vec{C}_k\cdot\vec{V}}{C_s^2}+\frac{\left(\vec{C}_k\cdot\vec{V}\right)^2}{2C_s^4}-\frac{\vec{V}\cdot\vec{V}}{2C_s^2}] \tag{6}$$

Wherein V is macroscopic velocity vector, C_k is microscopic velocity vector, C_s is the speed of sound, Φ is a scalar (density or dimensionless temperature) and Θ is distribution function of the scaler. τ_f and τ_g are relaxation time of density distribution function and dimensionless temperature distribution function, respectively.

3- Validation

For the validation of the written computer code, a comparison between the obtained average Nusselt number at the lower wall of the microchannel, with the results of Aminossadati et al. [7], at Reynolds equal to 100, for Al_2O_3-Water nanofluid is done and is shown in Table 1.

4- Results and Discussion

In Table 2 average shear stress and Nusselt number at the lower wall of the microchannel, for volume fractions equal to 0 and 0.04 (at a diameter equal to 5 nm) and slip coefficients equal to 0, 0.04 and 0.1 are shown. As can be observed from Table 2 for each volume fraction, by increasing the slip coefficient from 0 to 0.1, the average Nusselt number increases slightly. Thus, using the hydrophobic surfaces, in addition to a considerable reduction in the wall shear stress, increases the Nusselt number slightly at uniform wall heat flux conditions that can not be seen in the constant wall temperature situations in the study performed by Karimipour et al. [2].

Table 1. Comparison between the average Nusselt number in the present study and [7] at *Re*=100

Volume fraction	Average Nusselt-Present study	Average Nusselt [7]	The relative deviation (%)
0	4.167	4.171	-0.1
0.01	4.304	4.282	0.51
0.02	4.427	4.394	0.75
0.03	4.556	4.506	1.11
0.04	4.696	4.618	1.69

Table 2. Average shear stress and Nusselt number at the lower wall (for dp equal to 5 nm)

Slip coefficient	0		0.04		0.1	
Volume fraction	0	0.04	0	0.04	0	0.04
Average Nusselt	5.99	8.02	6.04	8.23	6.00	8.33
Average Shear stress (Pa)	9.00	47.29	7.20	37.79	5.55	29.13

5- Conclusions

The main results of this study are as follows:
Using the hydrophobic surfaces (with slip coefficient equal to 0.1), in addition to 38% decrease in the average wall shear stress in each volume fraction, increases the average Nusselt number, 0.08%, 1% and 3.89% for nanofluid with volume fraction equal to 0, 0.02 and 0.04, respectively.
The effect of temperature jump on the average Nusselt number at higher slip coefficients for the pure water is higher than the nanofluid.

References

[1] A. Akbarinia, M. Abdolzadeh, R. Laur, Critical investigation of heat transfer enhancement using nanofluids in microchannels with slip and non-slip flow regimes, *Applied Thermal Engineering*, 31(4) (2011) 556-565.

[2] A. Karimipour, A.H. Nezhad, A. D'Orazio, M.H. Esfe, M.R. Safaei, E. Shirani, Simulation of copper–water nanofluid in a microchannel in slip flow regime using the lattice Boltzmann method, *European Journal of Mechanics-B/Fluids*, 49 (2015) 89-99.

[3] M. Kalteh, A. Abbassi, M. Saffar-Avval, A. Frijns, A. Darhuber, J. Harting, Experimental and numerical investigation of nanofluid forced convection inside a wide microchannel heat sink, *Applied Thermal Engineering*, 36 (2012) 260-268.

[4] M. Corcione, Heat transfer features of buoyancy-driven nanofluids inside rectangular enclosures differentially heated at the sidewalls, *International Journal of Thermal Sciences*, 49(9) (2010) 1536-1546.

[5] C.H. Chon, K.D. Kihm, S.P. Lee, S.U. Choi, Empirical correlation finding the role of temperature and particle size for nanofluid (Al_2O_3) thermal conductivity enhancement, *Applied Physics Letters*, 87(15) (2005) 153107.

[6] A.A. Mohamad, *Lattice Boltzmann Method*, Springer, New York, 2011.

[7] S. Aminossadati, A. Raisi, B. Ghasemi, Effects of magnetic field on nanofluid forced convection in a partially heated microchannel, *International Journal of Non-Linear Mechanics*, 46(10) (2011) 1373-1382.

Please cite this article using:

A. Alipour Lalami, M. Kalteh, Investigation of the Effect of Velocity Slip and Temperature Jump on the Heat Transfer of Nanofluid in a Microchannel Under Constant Heat Flux with Lattice Boltzmann Method, *Amirkabir J. Mech. Eng.*, 50(2) (2018) 255-270.

DOI: 10.22060/mej.2016.857