Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 51(4) (2019) 1-4
DOI:

# Numerical Heat Transfer by Nanofluids in Wavy Walls Microchannel Using Dispersion Method

J. Rostami[1*], A. Abbassi[2], M. Saffar-Avval[2]

[1] Department of Mechanical Engineering, Razi University, Kermanshah, Iran
[2] Department of Mechanical Engineering, Amirkabir University of Technology, Tehran Iran

**ABSTRACT:** In this paper, conjugate heat transfer in wavy microchannels filled with nanofluid is studied numerically. To simulate the nanofluids, dispersion and homogeneous methods in single-phase model and Eulerian-Lagrangian method in two-phase model are used. Homogeneous method underestimates the experimental results. Then, nanofluid simulated by two-phase model using an Eulerian-Lagrangian approach. Then its results are used to find the unknown parameter in the conduction relation of nanofluid in dispersion method. Nanofluids are water-Cu or water-$Al_2O_3$ suspensions with a particle diameter of 100-150nm and a volume fraction of up to 2%. The three-dimensional governing equations including continuity, Navier-Stokes and energy equations are solved by the well-known semi-implicit method for pressure-linked equations. The governing equations for particles are solved by a 4th order Runge-Kutta algorithm. Due to the 3 dimensional governing equation, four equations including velocity components and energy should be solved for all particles. The computer program has been written in parallel processing method. Then a super computer with several central processing units should be used. Using dispersion method is as simple as homogeneous method but has accuracy as two-phase Eulerian-Lagrangian method.

**Review History:**

Received:
Revised:
Accepted:
Available Online:

**Keywords:**

Nanofluid
One phase model
Dispersion method
Two-phase model
Eulerian-Lagrangian method



## 1- Introduction

According to higher thermal conductivity of the metal nano particles, adding them to the base fluid will improve the thermal conductivity of the working fluid. The nanofluid properties have been presented by many researchers [1-5]. However these relations have been obtained experimentally but none of them can predict the results of nanofluid in heat transfer problems. Then researchers examined two phase model [6-10]. They found that the results of two phase model are closer to the experimental data [6-10]. But, two phase model with Eulerian-Lagrangian method needs the parallel processing in programming and a super computer with several Central Processing Units (CPUs). Need to the complicated facilities made this method so expensive. Instead, the dispersion method is cheaper and faster. In this paper nanofluid heat transfer in wavy walls microchannel has been studied numerically. Finally a correlation has been presented for each nanofluid.

## 2- Methodology

### 2- 1- Governing equations

Geometrical parameters have been obtained in our previous paper [11].

The three dimensional governing equations for one phase model are continuity, momentum and energy. Due to using the body fitted mesh for wavy walls microchannel, the governing equations transferred to the curvilinear coordinates [12]:

Continuity:

$$\frac{\partial u^c}{\partial \hat{\imath}}+\frac{\partial v^c}{\partial \varsigma}+\frac{\partial w^c}{\partial \text{æ}}=0, \tag{1}$$

Corresponding author, E-mail: jrostami@razi.ac.ir

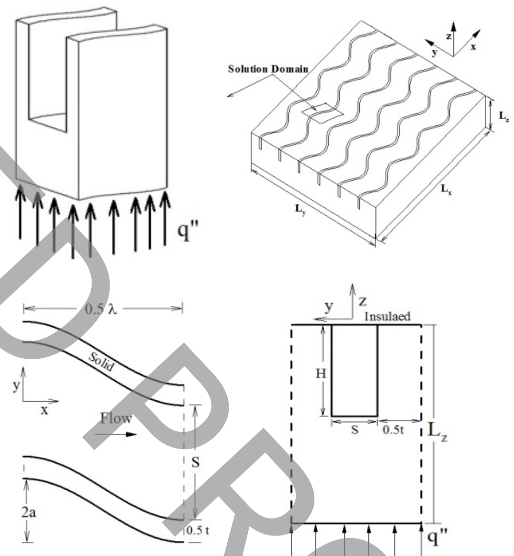


**Fig. 1. Geometry of microchannel**

Momentum:

$$\begin{aligned}&\frac{\partial u^c\psi}{\partial \xi}+\frac{\partial v^c\psi}{\partial \eta}+\frac{\partial w^c\psi}{\partial \zeta}=\\&\frac{\partial}{\partial \xi}\left[\frac{Jq_{11}}{\mathrm{Re}}\psi_{\xi}\right]+\frac{\partial}{\partial \xi}\left[\frac{J}{Pe}(q_{12}\psi_{\eta}+q_{13}\psi_{\zeta})\right]+\\&\frac{\partial}{\partial \eta}\left[\frac{Jq_{22}}{Pe}\psi_{\eta}\right]+\frac{\partial}{\partial \eta}\left[\frac{J}{Pe}(q_{12}\psi_{\eta}+q_{13}\psi_{\zeta})\right]+\\&\frac{\partial}{\partial \zeta}\left[\frac{Jq_{33}}{Pe}\psi_{\zeta}\right]+\frac{\partial}{\partial \zeta}\left[\frac{J}{Pe}(q_{13}\psi_{\xi}+q_{23}\psi_{\eta})\right].\end{aligned} \tag{2}$$

Energy in fluid:

$$\frac{\partial u^c T}{\partial \xi}+\frac{\partial v^c T}{\partial \eta}+\frac{\partial w^c T}{\partial \zeta}= \frac{\partial}{\partial \xi}\left[\frac{Jq_{11}}{Pe}T_\xi\right]+\frac{\partial}{\partial \xi}\left[\frac{J}{Pe}(q_{12}T_\eta+q_{13}T_\zeta)\right]+ \frac{\partial}{\partial \eta}\left[\frac{Jq_{22}}{Pe}T_\eta\right]+\frac{\partial}{\partial \eta}\left[\frac{J}{Pe}(q_{12}T_\eta+q_{13}T_\zeta)\right]+ \frac{\partial}{\partial \zeta}\left[\frac{Jq_{33}}{Pe}T_\zeta\right]+\frac{\partial}{\partial \zeta}\left[\frac{J}{Pe}(q_{13}T_\xi+q_{23}T_\eta)\right]. \quad (3)$$

## 2- 2- Solution method

The governing equations for fluid and solid body are solved using the finite volume technique on a collocated grid. In this arrangement, all parameters such as velocity components ($u,v,w$), pressure and temperature are located at the same nodes. The hybrid differencing [13] is used for the approximation of the convective terms. For velocity and pressure the Semi-Implicit Method for Pressure-Linked Equations (SIMPLE) algorithm [14] employed. The grid points are generated in a non-uniform manner with a higher concentration of points close to the walls. To eliminate the checkerboard pressure due to using a collocated grid, the Rhie and Chow [15] interpolation is used in the pressure correction equation. After solving the fluid, the equations for the particles are solved by a 4th order Runge-Kutta method.

## 3- Results and Discussion

The problem has been solved by three methods including homogeneous and dispersion method in one-phase model and Eulerian-Lagrangian method in two-phase model. Increased Thermal conductivity of nanofluid is presented as follow [16]:

$$k_d=C_d\rho_{nf}Cp_{nf}.(\frac{A_c}{D_h^2}).\frac{\mathrm{Re}\,\mu}{\rho_f}\frac{10^{-5}}{d_p^a}\varphi^b\left|\nabla\times u\right| \quad (1)$$

Where $C_d$ is unknown parameter and it should define by experimental method. Due to lack of experimental results, $C_d$ is obtained by adjusting the results of dispersion method and Eulerian-Lagrangian method. Unknown parameters in Eq. (1) is presented in Table 1.

**Table 1. Unknown parameters in dispersion method**

| Particle | $a$ | $b$ | $C_d$ |
|---|---|---|---|
| Cu | 0.71 | 1 | $1.25-9.387\times10^{-5}(\mathrm{Re}-190)^2$ |
| $Al_2O_3$ | 0.1 | 0.55 | $3.837-3.9\times10^{-4}(\mathrm{Re}-200)^2$ |

As shown in Figs. 2 and 3, results show that the Nusselt number in dispersion method and the Eulerian-Lagrangian methods are in a good agreement. But, the results on homogeneous method underestimate the results of two phase model.

## 4- Conclusions

In this paper unknown parameters to calculate the thermal conduction of nanofluid in dispersion method have been defined by adjusting the results of dispersion method and Eulerian-Lagrangian methods in the wavy walls microchannels.

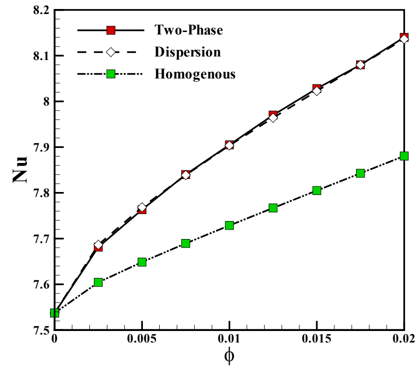


**Fig. 2. Nusselt number for water-Al2O3 with Dp=150nm, Re=150**

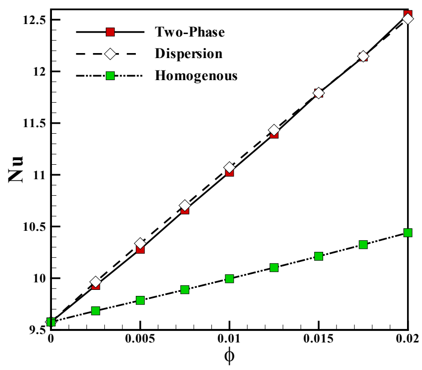


**Fig. 3. Nusselt number for water-Cu with Dp=100nm, Re=200**

## References

[1] Maiga, S., E., B., Nguyen, C., T., Galanis, N., Roy, G., Mare, T., and Coqueux, M., 2006, "Heat Transfer Enhancement in Turbulent Tube Flow Using $Al_2O_3$ Nanoparticle Suspension", *International Journal of Numerical Method for Heat and Fluid Flow*, 16 (3), pp. 275-292.

[2] Patel, H., Sundararajan, T., Pradeep, T., Dasgupta, A., Dasgupta, N. and Das, S. K., 2005, "A Micro-convection Model for Thermal Conductivity of Nanofluids", *Journal of Physics*, 65 (5), pp. 863-869.

[3] Brinkman, H. C., 1952, "The Viscosity of Concentrated Suspension and Solution", *the Journal of Chemical Physics,* 20, pp. 571-581.

[4] Chon, C., Kihm, K., Lee, S., Choi, S., 2005, "Empirical correlation finding the role of temperature and particle size for nanofluid $Al_2O_3$ thermal conductivity enhancement", *Applied Physics Letter* 87.

[5] Corcione, M., 2011, "Empirical Correlating equations for predicting the effective thermal conductivity and dynamic viscosity of nanofluids", Energy Conversion and Management, 52, pp. 789-793.

[6] Mirzaei, M., Saffar-Avval, M., Naderan, H., 2014, "Heat Transfer Investigation of Laminar Developing Flow of Nanofluids in a Microchannel Based on Eulerian-Lagrangian Approach", The Canadian Journal of

Chemical Engineering, 92, pp. 1139-1149.

[7] Bianco, V., Chiacchio, F., Manca, O., Nardini, S., 2009, "Numerical Investigation of Nanofluids Forced Convection in Circular Tubes", Applied Thermal Engineering, 29, pp. 3632-3642.

[8] Wen, D., Zhang, L., He, Y., 2009, "Flow and Migration of Nanoparticle in a Single Channel", Heat and Mass Transfer, 45, 1061-1067.

[9] He, Y., Men, Y., Zhao, Y., Lu, H., Ding, Y., 2009, "Numerical Investigation into the Convective Heat Transfer of TiO2 Nanofluids Flowing through a Straight Tube Under the Laminar Flow Conditions, Applied Thermal Engineering, 29, 1965-1972.

[10] J. Rostami and A. Abbassi, 2016, "Conjugate heat transfer in a wavy microchannel using nanofluid by two-phase Eulerian–Lagrangian method", Advanced Powder Technology, 27, 9-18.

[11] Rostami, J., Abbassi, A., Saffar-Avval, M., 2015, "Optimization of Conjugate Heat Transfer in Wavy Walls Microchannels", Applied Thermal Engineering, 82, 318-328.

[12] 12-Raisee, M., 1999, "Computation of Flow and Heat Transfer Through Two- and Three-Dimensional Rib-Roughed Passages, PhD Thesis, Department of Mechanical Engineering, University of Manchester (UMIST).

[13] Patankar, S. V., and Spalding, D. B., 1972, "A Calculation Procedure for Heat, Mass and Momentum Transfer in Three-Dimensional Parabolic Flows", International Journal of Heat and Mass Transfer, 15, pp. 1787-1806.

[14] Spalding, D. B., 1972, "A Novel Finite Difference Formulation for Differential Expressions Involving Both First and Second Derivatives", Journal of Numerical Methods for Engineering, 4, pp. 551-559.

[15] Rhie, C. M., Chow, W. L., 1983, "Numerical Study of the Turbulent Flow Past an Airfoil with Trading Edge Separation", AIAA Journal, 21 (11), 1525-1535.

[16] Mokmeli, A., Saffar-Avval, M., 2010, "Prediction of Nanofluid Convective Heat Treansfer Using the Dispersion Model", International Journal of Thermal Sciences, 49, pp. 471-478.

Please cite this article using:

J. Rostami, A. Abbassi, M. Saffar Avval, Numerical Heat Transfer by Nanofluids in Wavy Walls Microchannel Using Dispersion Method, *Amirkabir J. Mech. Eng.*, 51(4) (2019) 1-4.

DOI: