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

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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\textsubscript{2}O\textsubscript{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.

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 \cite{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 \cite{6-10}. They found that the results of two phase model are closer to the experimental data \cite{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 \cite{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 \cite{12}:

\begin{align}
\frac{\partial u^c}{\partial t} + \frac{\partial v^c}{\partial \xi} + \frac{\partial w^c}{\partial \zeta} &= 0, \\
\frac{\partial \rho u^c}{\partial t} + \frac{\partial \rho u^c u^c}{\partial \xi} + \frac{\partial \rho u^c v^c}{\partial \eta} + \frac{\partial \rho u^c w^c}{\partial \zeta} &= F_{\xi} + \sigma_{\xi}, \\
\frac{\partial \rho v^c}{\partial t} + \frac{\partial \rho v^c u^c}{\partial \xi} + \frac{\partial \rho v^c v^c}{\partial \eta} + \frac{\partial \rho v^c w^c}{\partial \zeta} &= F_{\eta} + \sigma_{\eta}, \\
\frac{\partial \rho w^c}{\partial t} + \frac{\partial \rho w^c u^c}{\partial \xi} + \frac{\partial \rho w^c v^c}{\partial \eta} + \frac{\partial \rho w^c w^c}{\partial \zeta} &= F_{\zeta} + \sigma_{\zeta}.
\end{align}

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Fig. 1. Geometry of microchannel

Momentum:
\begin{align}
\frac{\partial u^c}{\partial t} + \frac{\partial v^c}{\partial \xi} + \frac{\partial w^c}{\partial \zeta} &= 0, \\
\frac{\partial \rho u^c}{\partial t} + \frac{\partial \rho u^c u^c}{\partial \xi} + \frac{\partial \rho u^c v^c}{\partial \eta} + \frac{\partial \rho u^c w^c}{\partial \zeta} &= \frac{\partial}{\partial \xi} \left( \frac{\mu \partial u^c}{\partial \xi} \right) + \frac{\partial}{\partial \eta} \left( \frac{\mu \partial u^c}{\partial \eta} \right) + \frac{\partial}{\partial \zeta} \left( \frac{\mu \partial u^c}{\partial \zeta} \right) + F_{\xi} + \sigma_{\xi}, \\
\frac{\partial \rho v^c}{\partial t} + \frac{\partial \rho v^c u^c}{\partial \xi} + \frac{\partial \rho v^c v^c}{\partial \eta} + \frac{\partial \rho v^c w^c}{\partial \zeta} &= \frac{\partial}{\partial \xi} \left( \frac{\mu \partial v^c}{\partial \xi} \right) + \frac{\partial}{\partial \eta} \left( \frac{\mu \partial v^c}{\partial \eta} \right) + \frac{\partial}{\partial \zeta} \left( \frac{\mu \partial v^c}{\partial \zeta} \right) + F_{\eta} + \sigma_{\eta}, \\
\frac{\partial \rho w^c}{\partial t} + \frac{\partial \rho w^c u^c}{\partial \xi} + \frac{\partial \rho w^c v^c}{\partial \eta} + \frac{\partial \rho w^c w^c}{\partial \zeta} &= \frac{\partial}{\partial \xi} \left( \frac{\mu \partial w^c}{\partial \xi} \right) + \frac{\partial}{\partial \eta} \left( \frac{\mu \partial w^c}{\partial \eta} \right) + \frac{\partial}{\partial \zeta} \left( \frac{\mu \partial w^c}{\partial \zeta} \right) + F_{\zeta} + \sigma_{\zeta}.
\end{align}
Energy in fluid:
\[
\frac{\partial v T}{\partial \xi} + \frac{\partial v T}{\partial \eta} + \frac{\partial v T}{\partial \zeta} = \nabla \cdot \left[ \frac{J_q}{Pe} \right] + \nabla \cdot \left[ \frac{J_{T v}}{Pe} \right] + \nabla \cdot \left[ \frac{J_{T z}}{Pe} \right] + \nabla \cdot \left[ \frac{J_{T \eta}}{Pe} \right] + \nabla \cdot \left[ \frac{J_{T \xi}}{Pe} \right] + \nabla \cdot \left[ \frac{J_{T \zeta}}{Pe} \right].
\]

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]:

\[
k_a = C_d \rho_a C_p_a \left( \frac{D_p}{D_h} \right) \frac{Re}{\mu} \times 10^{-5} \nabla \times u
\]

where \(C_d\) is an unknown parameter and it should be defined 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>
<thead>
<tr>
<th>Particle</th>
<th>(a)</th>
<th>(b)</th>
<th>(C_d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>0.71</td>
<td>1</td>
<td>1.25 (\times 9.387 \times 10^{-5}) (Re=190)²</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.1</td>
<td>0.55</td>
<td>3.837 (\times 3.9 \times 10^{-5}) (Re=200)²</td>
</tr>
</tbody>
</table>

As shown in Figs. 2 and 3, results show that the Nusselt number in dispersion method and the Eulerian-Lagrangian method 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.

References
Chemical Engineering, 92, pp. 1139-1149.


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