Journal of Solid and Fluid Mechanics (JSFM), 14(3): 31-33, xxxx

Shahrood University of Technology

Journal of Solid and Fluid Mechanics (JSFM)

DOI: 10.22044/jsfm.2024.14036.3828

Manufacturing Engineering of Iran

Modeling the hydraulic-thermal performance of a sinusoidal semi-porous channel with nanofluid flow and magnetic field

Nejat Sheikhpour[1], Arash Mirabdolah Lavasani[2], Gholamreza Salehi[3]

[1] PhD graduate, Department of Mechanical Engineering, Central Tehran Branch, Islamic Azad University, Tehran, Iran
[2,3] Assoc. Prof., Department of Mechanical Engineering, Central Tehran Branch, Islamic Azad University, Tehran, Iran
*Corresponding author: arashlavasani@iauctb.ac.ir

Received: 08/01/2024 Revised: 31/05/2024 Accepted: 23/06/2024

Abstract

In this study, the hydraulic-thermal performance of a semi-porous wave channel with nanofluid flow and applied magnetic field has been evaluated. The magnetic field is perpendicular to the channel. In this design, single-phase, incompressible and permanent nanofluid flow is considered. The ranges of Hartmann number and Darcy number are $0 \leq Ha \leq 10$ and $10^{-5} \leq Da \leq 10^{-2}$, respectively. Magnesium oxide nanoparticles have been investigated in four different volume fractions (0, 2, 4 and 5%). The governing equations are solved by the finite volume method. Based on the obtained results, increasing the volume fraction of nanoparticles and channel wave improves heat transfer. At constant Reynolds number, increasing the number of wave channels from 4 to 6 resulted in a 7.8% decrease in thermal hydraulics. The increase in permeability in the porous medium has increased the Nusselt number and reduced friction. The best thermal hydraulic performance is 10.08 at Darcy number 0.01 and the lowest is 0.52 at Darcy number 0.0001. Also, the presence of magnetic field has a positive effect on thermal performance. The results of this study can be useful in the design of heat exchangers.

Keywords: Thermal hydraulic performance, Numerical analysis, wavy channel, Magnetic field, Semi-porous channel.

1. Introduction

Investigating forced heat transfer in channels has been considered due to its many industrial applications For example, heat exchangers, heat boilers, solar collectors, power converters, micro heat exchangers, catalytic converters and even car radiators can be mentioned. [1] The performance of this thermal equipment can be optimized by using nanoparticles, corrugation of the walls, porous medium, magnetic force, etc.

In the past years, investigating heat transfer with the presence of nanofluid, magnetic field, porous medium has been the subject of many researches. Arora and Gupta [2] experimentally evaluated heat transfer and pressure drop of nanofluid in a tube. They observed that the volume fraction and volume flow of the nanofluid increase Nusselt. Yaerramlle et al. [3] studied the combined heat transfer of nanofluid in a porous channel. In their work, the convective heat transfer increased with increasing the height of the porous space inside the channel. Bhattacharyya et al [4] simulated the heat transfer and nanofluid flow in a small corrugated channel in the presence of an external magnetic field. The results of their work showed an increase in heat transfer with magnetic fields. Benos and Sarris [5] studied the convective heat transfer rate of a nanofluid in a geometry with a magnetic field. In their work, the presence of a magnetic field enhanced the convective heat transfer. Mohammadi et al. [6] investigated the effect of magnetic field on forced convection heat transfer in a cylindrical duct. The result of their work showed that the presence of nanofluid and magnetic field increases Nusselt. Sheikhpour et al. [7] investigated the effect of magnetic field and porous medium on convective heat transfer in a wave channel. Their results show that Reynolds number, porous medium and magnetic field have a positive effect on heat transfer.

According to the studies conducted in general, some of the most important innovations of this research are:

-The non-uniform heat flux applied to the location (sinusoidal) on the wall of the channel is wave-shaped.

-Investigating the simultaneous effect of magnetic field, wall wave porous medium and nanofluid on the hydraulic-thermal performance coefficient of a wavy channel.

This study is in the field of feasibility and investigation of increasing the thermal efficiency of the corrugated channel of a heat exchanger designed with magnetic field, porous medium and nanofluid flow.

2. Problem Statement

The geometry of a wave channel, saturated with nanofluid, is semi-porous and under the influence of a uniform magnetic field Porous materials inside the channel are near the walls. The geometry of the problem is shown in Figure 1.

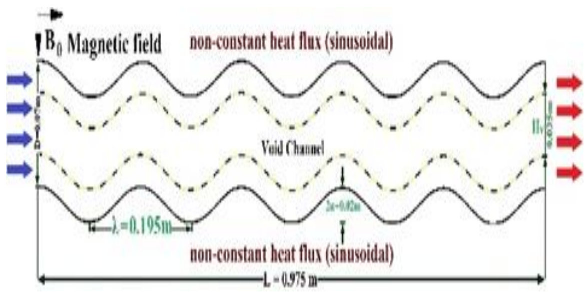

Figure 1. Wave channel with porous medium and magnetic field

3. Governing Equations and Numerical Simulation Method

The governing equations for analyzing the velocity field and temperature distribution include the equation of conservation of mass, the equations of motion in the x and y directions, and the equation of energy conservation. Equations (1) to (4) respectively show the equations of conservation of mass, conservation of momentum (speed of movement) and finally the equation of conservation of energy in two dimensions [1, 2].

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho_{nf}}\frac{\partial p}{\partial x}+\vartheta_{nf}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\frac{1}{\rho_{nf}}\mu_{nf}\frac{u}{K_{porous}} \tag{2}$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho_{nf}}\frac{\partial p}{\partial y}+\vartheta_{nf}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)-\frac{\sigma_{nf}}{\rho_{nf}}B_0^2 v-\frac{1}{\rho_{nf}}\mu_{nf}\frac{v}{K_{porous}} \tag{3}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k_m}{\rho_{nf}cp}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

The convective heat transfer coefficient is calculated using the following equation [5].

$$h=\frac{Q''}{(T_W-T_{bulk})} \tag{5}$$

In this regard, T_w is the channel wall and T_{bulk} is the temperature of the nanofluid mass. Also, Q", the applied heat flux. The local Nusselt number is obtained from equation (6) [10].

$$Nu_{local}=\frac{h_{local}D_h}{k_{nf}} \tag{6}$$

The average Nusselt number is defined as follows.

$$Nu_{avg}=\frac{1}{L}\int_0^L Nu_{local}dx \tag{7}$$

The friction coefficient can be calculated by equation (8) [11].

$$f=\frac{2\Delta P D_h}{L\rho_{nf}V^2} \tag{8}$$

Thermal hydraulic performance (total system efficiency) will be calculated according to equation (9). This relationship is used to check and achieve ideal conditions [12].

$$PEC=\frac{\left({Nu}/{Nu_0}\right)}{\left({f}/{f_0}\right)^{1/3}} \tag{9}$$

In this relation, Nu_0 and f_0 are the Nusselt number and the friction coefficient of the reference state, respectively.

In this study, the governing equations (continuity, momentum and, energy) are discretized by the finite volume method and turned into a set of algebraic equations. Numerical simulation is performed with steady, incompressible, and Two-dimensional (2D) conditions. The pressure-based solver and the Couple algorithm were used because they had high accuracy. To discretize the pressure term and convection sentence in the equation of momentum and other terms of the equations, the standard method, and the second order upwind, respectively, as well as in the coupling between the pressure and velocity fields, the SIMPLE method was used. Method Least-squares Cell-Based has been used for gradient components. To obtain the effect of magnetic field and porous medium on heat transfer, the energy equation was also solved.

4. Independence from Meshing

The independence process of the results compared to the calculation was carried out for the porous wave channel and its results are shown in Figure 2. In Figure 2, local Nusselt numbers are plotted for four meshes of different sizes. This figure shows that mesh 3 is accurate. That is, the Nusselt number for mesh 3 has very little changes compared to mesh 4. Therefore, mesh number 3 is selected as the optimal mesh.

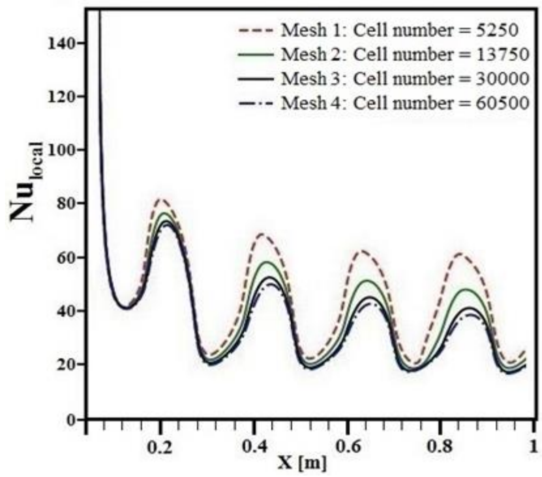

Figure 2. Independence from Meshing

5. Discussion and results

In figure 3, the performance coefficient (PEC) of the waveform channel is compared with the channel. By comparing these two geometries, it is clear that the coefficient of performance of the wave channel is higher than that of the flat channel in all Reynolds numbers. So that at Reynolds 600, the thermal efficiency of the wave channel is about 18% higher than that of the flat channel. The reason for this is that the wall wave causes a change in the boundary layer by changing the regime and increases the convective heat transfer.

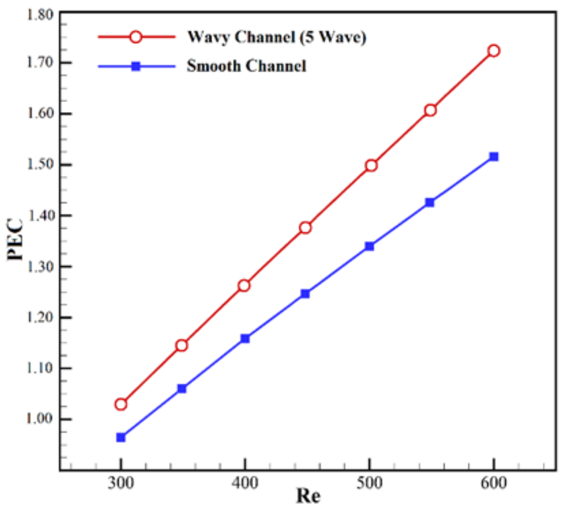

Figure 3. Comparison of hydraulic-thermal performance coefficient of wave channel with flat channel

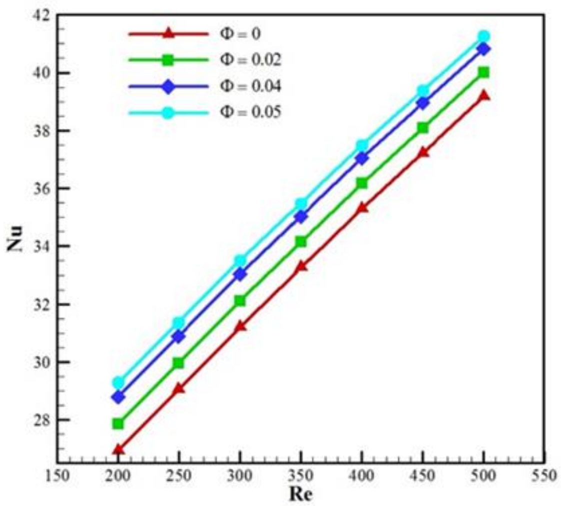

Figure 4. Effect of volume fraction of nanoparticles on Nusselt number in the wave channel and in the Reynolds range of 200 to 500

Figure 4 shows the effect of volume fraction of nanoparticles on Nusselt. It is clear that the Nusselt number increases with the increase of the Reynolds number and the volume fraction of nanoparticles. The reason for this is that convective heat transfer increases with increasing particle volume fraction. The trend of increasing this value is higher at higher Reynolds with a higher volume fraction of nanoparticles. At low Reynolds, molecular collisions decrease and decrease the conductivity of the nanofluid.

6. Conclusion

In this research, the effect of various cases on hydraulic-thermal performance in a channel has been analyzed. The results of this research are summarized as follows:

1- Injecting nanoparticles improves heat transfer.

2- The thermal hydraulic performance of the channel increases with the increase in volume fraction of nanoparticles.

3- Increasing the channel wave has a positive effect on increasing the Nusselt number. In other words, by increasing the number of channels and creating eddy currents, the flow regime and the boundary layer change and the convective heat transfer increases.

4- By changing the value of the Hartmann number (magnetic field strength), the temperature near the wall increases and the ability to absorb heat from the wall and the hydraulic-thermal performance improve.

5- By reducing the Darcy number (reducing permeability), hydraulic-thermal performance (PEC) always decreases.

7. References

[1] Saidur, R. Leong, K. Y. and Mohammed, H. A. A review on applications and challenges of nanofluids. *Renew Sustain energy Rev*, 15 (2011) 1646–1668.

[2] Arora, N. Gupta, M. An experimental study on heat transfer and pressure drop analysis of Al_2O_3/water nanofluids in a circular tube. *Materials Today: Proceedings*, 69 (2022) 199-204.

[3] Yaerramlle, V. Premachandran, B. and Talukdar, P. Mixed Convection from a Heat Source in a Channel with a Porous Insert: A Numerical Analysis Based on Local Thermal Non-Equilibrium Model. *Thermal Science and Engineering Progress*, 25 (2021) 101010.

[4] Bhattacharyya, S. Sharma, AK. Vishwakarma, DK. Goel, V. Influence of magnetic baffle and magnetic nanofluid on heat transfer in a wavy minichannel. *Sustainable Energy Technologies and Assessments*, 56 (2023) 102954.

[5] Benos, L. and Sarris, I.E. Analytical Study of the Magnetohydrodynamic Natural Convection of a Nanofluid Filled Horizontal Shallow Cavity with Internal Heat Generation. *International Journal of Heat and Mass Transfer*, 130 (2019) 862-873.

[6] Mohammadi, S. Azimi, N. and Khazaei M. CFD simulation of the effect of magnetic field on convective heat transfer and ferrofluid flow inside a pipe. *Journal of Modeling in Engineering*, 20 (2022) 155–166.

[7] Sheikhpour N, Mirabdolah Lavasani A, Salehi G (2022) Study the Effects of Magnetic Field and Porous Medium on Heat Transfer and Flow of a Nanofluid in a Wavy Channel. *Journal of Modeling in Engineering*, 20 (71): 13–25.

[8] Nouri R, Gorji-Bandpy M, Domiri Ganji D. Numerical investigation of magnetic field effect on forced convection heat transfer of nanofluid in a sinusoidal channel. *Modares Mechanical Engineering*, 14 (2014) 43-55.

[9] Ashorynejad H.R. and Zarghami A. Magnetohydrodynamics flow and heat transfer of Cu-water nanofluid through a partially porous wavy channel. *International Journal Heat Mass Transf*, 119 (2018) 247-258.

[10] Nazari, S. and Toghraie, D. Numerical simulation of heat transfer and fluid flow of Water-CuO Nanofluid in a sinusoidal channel with a porous medium. *Physica E*, 87 (2017) 134–140.

[11] Kays, W.M. and London, AL. Compact heat exchangers. 3rd ed. Melbourne. *Kreiger Publishing*, 1984.

[12] Khoshvaght-Aliabadi, M. Influence of different design parameters and Al_2O_3-water nanofluid flow on heat transfer and flow characteristics of sinusoidal-corrugated channels. *Energy Convers Manage*, 88 (2014) 96–105.