Numerical Investigation of wavy channel using several Nanofluids

Bharat Naik¹*, Anand K. Hosmani¹, Shirish M. Kerur¹, Jagadeesh S. Pattanashetti¹, Vinayak Ratan¹, Chandra Bhushan²

¹Department of Mechanical Engineering, Jain College of Engineering, Belagavi, Karnataka, India
²Department of Mechanical Engineering, Babu Banarasi Das University Lucknow, India

Email: bharatnaik.bgm@gmail.com

Abstract. This study investigates the effect of nano-fluids in enhancing heat transfer. These nano-fluids contain nanoparticles (Ag, CuO, Fe, Al₂O₃ and Tin) in volume fraction ranging between 2%-5%. Two-dimensional numerical simulation has been conducted on wavy channel using ANSYS Fluent. Two dimensional governing equations such as mass, momentum and energy equations are solved using SIMPLE algorithm and discretized using Finite Volume Method. The results show that there will be enhancement of heat transfer rate as the nanoparticle volume concentration increases and from the present study it is clear that silver-water nanofluid gives better results as compared to other nanoparticles.

1. Introduction
Heat transfer is an important phenomenon which plays a vital role in various fields of engineering applications such as IC engines, power plants, refrigeration system, heating and ventilation air conditioning systems, aerospace sector etc. Increasing the rate of heat dissipation is an important task in design and development of these systems, which can be achieved by the usage of extended surfaces on to the periphery of the hot surface. Conducted a numerical simulation of wavy micro channel using two phase models based on Lagrangian approach for base fluid and Eulerian approach for the nanoparticle and identified that the deviation of two approaches is due to the non-homogeneous dispersion of nanoparticle in the main domain. Also shown that, Nusselt number increases as the volume fraction increases and decrease in the diameter of the particle [1].Carried an experimental study on forced convection flow of different nano-fluids with varying flow rates through a corrugated wavy channel for the measurement of heat transfer coefficient and the pressure drop across the channel and the results so obtained indicates the augmentation of heat transfer with the large drop in pressure[2].Investigated the heat transfer performance of the micro channel using the nanofluid with nonporous graphene in an aqueous solution as base hot fluid and with the varying flow rates and waviness the enhancement of the heat transfer coefficient is achieved at the expense of pressure drop[3]. Presented the work on numerical analysis of fluid flow and heat transfer between air and the wavy channel, studied the effect of pressure drop on the flow velocity and computed the local Nusselt number and the heat transfer coefficient. Further, compared the results so obtained with that of the 2D rectangular channel such that in an optimum range of Reynolds number, the wavy channel gave better enhanced results than the other [4]. performed a numerical investigation in a channel with lower and upper corrugated plate with a constant heat flux conditions using nano-fluids, used FVM approach for the CFD simulation with k-ε Turbulent.
model for the Reynolds number in the range 5000-20000. For varying volume fractions and diameters of the SiO₂ nanoparticle, the simulation results yield the enhancement of Nusselt number and heat transfer rate [5]. Studied the influence of TiO₂ nanoparticle in water on the performance of a horizontal wavy duct, considering laminar flow of fluid by CFD analysis. Simulation results identifies that, concentration of nanoparticles and the Reynolds number plays a vital role in the enhancement of Nusselt number and heat transfer. However, the drop in pressure also intensifies leading to high pumping power [6]. In the present study a 2D sinusoidal wavy channel is considered and simulations are carried out by using ANSYS Fluent. Different Nanofluids like Ag, CuO, Al₂O₃, Fe and Tin are being used with the volume concentration 2%-5% in water as a base fluid to predict the influence of these nanofluids on the heat transfer characteristics of the water flowing over the channel. By the application of necessary boundary conditions for laminar flow field, governing equations are solved to determine the heat transfer rate and its implications on the drop in pressure in the flow field.

2. Model description
The model of a wavy channel used in the present analysis is given in Fig.1 (a). Wavy channel consists of two sinusoidal wavy walls and is bounded by straight sections at inlet and outlet.

![Figure 1a. Geometric model of a wavy channel](image1a.png)

![Figure 1b. Detailed view of meshed region showing the inflation layers near the walls of wavy passage with Φ = 0° phase shift](image1b.png)

Table 1. Geometry parameters of the wavy channel.

| Parameter                  | Value |
|----------------------------|-------|
| Length of Channel (L)      | 0.2 (m) |
| Width of Channel (H)       | 0.01 (m) |
| Wavelength (λ)             | 0.04 (m) |
| Hydraulic diameter (Dh)    | 0.02 (m) |
| Phase Shift (Φ)            | 0°     |

2.1 Grid Independence Test
Five different meshes were tried, to evaluate the number of elements essential. To test the grid independence, the grid sizes 8932, 10500, 12467 and 15672. It is found that after 15672 elements, further increase in elements provides less than 2% variation in pressure drop which is taken as a criteria for grid independence.

2.2 Governing equations
The flow is laminar, steady state, incompressible and two dimensional. The mass, momentum and energy equations can be shown, respectively, as:
\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0
\]  

(1)

\[
\rho_{nf} \left( \frac{\partial u}{\partial x} + \nu \frac{\partial u}{\partial y} \right) = -\frac{\partial p}{\partial x} + \mu_{nf} \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right)
\]  

(2)

\[
\rho_{nf} \left( \frac{\partial v}{\partial x} + \nu \frac{\partial v}{\partial y} \right) = -\frac{\partial p}{\partial y} + \mu_{nf} \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right)
\]  

(3)

\[
u \frac{\partial T}{\partial x} + \nu \frac{\partial T}{\partial y} = k_{nf} \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right)
\]  

(4)

The viscosity of nanofluid is determined from the Drew and Passman correlation [7] using the following equation.

\[
\mu_{nf} = \mu_{bf} (1 + 2.5\phi)
\]  

(5)

The density is determined from the Choi correlation [8] using the following equation

\[
\rho_{nf} = (1 - \phi) \rho_{bf} + \phi \rho_{p}
\]  

(6)

The heat capacity is determined from the Xuan and Roetzel correlation [9] using the following equation

\[
(C_p)_{nf} = \frac{(1 - \phi)(\rho C_p)_{bf} + \phi (\rho C_p)_{p}}{\rho_{nf}}
\]  

(7)

The thermal conductivity is determined from the Maxwell-Garnett’s correlation [10] using the following equation.

\[
\frac{k_{nf}}{k_{bf}} = \frac{k_p + 2k_{bf} + (k_p - k_{bf})\phi}{k_p + 2k_{bf} - (k_p - k_{bf})\phi}
\]  

(8)

2.3 Boundary conditions

Fully developed and uniform temperature of the inflow were applied as boundary condition at the channel entry. At lower and upper wavy wall slip conditions and constant wall temperature were applied. At the outlet boundary, the exit pressure was fixed as atmospheric.

2.4 Validation

![Graph showing pressure drop versus Reynolds number for different studies](image)

Figure 2. Comparison between present study and A. Chakravarty [4]
Fig. 2 shows the comparison between our study and the study presented by A. Chakravarthy. The graph is plotted between Reynolds number and the pressure drop. It can be seen that there is a very close correlation between our study and the earlier study. It can be observed that the deviation at a few places exists, but it is less than 2% which is acceptable. Hence the work carried out by us and A. Chakravarthy are matching. This validation is done for air that is used as the working medium. Since our work very closely matches with the earlier work, it concludes that our methodology followed is correct. Hence we proceeded ahead to carry out similar simulation using nano-fluids as the working medium.

3. Results and Discussions

![Figure 3a. Static temperature contour](image)

![Figure 3b. Velocity Contour](image)

In order to do the simulations for determination of fluid flow regime, Reynolds number based on hydraulic diameter of the channel was calculated. The hydraulic diameter Dh for a sinusoidal wavy channel is calculated as: \( Dh = 2 \times h \), where h is the height of channel. The default width of 1 m for 2D geometry was taken for the calculation of hydraulic diameter and Reynolds number. Further, the simulations for determination of pressure drop were performed for the laminar flow regime. The inlet velocities were varied from 0.2 to 1.6 m/s in a step of 0.2 and the effect of corresponding Reynolds number on the pressure drop and heat flux in the wavy channel is as shown in below Figures. The figure 4 (a), (b), (c), (d) and (e) represent the influence of Reynolds number on drop in pressure and the wall heat flux for various nanofluids with water as a base fluid. For varying the volume concentration of nanofluids from 2% to 5%. The results show that, drop in pressure intensifies up to 33.33% for Ag nanoparticle, 18.18% for CuO nanoparticle, 17.39% for Iron as a nanoparticle, up to 20.83% for Al\(_2\)O\(_3\) and 4.10% for Tin as a nanoparticle respectively in the laminar regime (Reynolds number up to 2000). Similarly, the enhancement in the wall heat flux up to 10.14% for Silver, 8.57% for CuO, 9.35% for Iron, 8.42% for Al\(_2\)O\(_3\) and 11.85% for Tin as a nanoparticle is observed by the variation of their volume concentration from 2% to 5% respectively.
Figure 4a. Effect of Ag-water nanofluid on drop in pressure and wall heat flux in the laminar flow regime (Reynolds no. between 0 to 2000)

Figure 4b. Effect of CuO-water nanofluid on drop in pressure and wall heat flux in the laminar flow regime (Reynolds no. between 0 to 2000)

Figure 4c. Effect of Fe-water nanofluid on drop in pressure and wall heat flux in the laminar flow regime (Reynolds no. between 0 to 2000)
4. Conclusion

Numerical simulation on a 2D sinusoidal wavy channel was performed using ANSYS Fluent software to understand and predict the impact of various nanofluids on the heat transfer characteristics. Based on the results so obtained, it is important to note that, increasing the volume concentration from 2% to 5% enhances the heat transfer rate at the wall of a wavy channel. Meanwhile, the drop in pressure also increases as result of which the pumping power required would be more. In particular, silver nanoparticle in water gives better heat transfer characteristics then the remaining. As an overall outcome of this study insist, one to make use of nanoparticle to enhance the thermal conductivity of the base fluid such that the heat transfer rate could be accordingly amplified with a compromise on the drop in pressure.

5. Index

| Symbol | Description                  | Subscript     |
|--------|------------------------------|---------------|
| \( \lambda \) | wavelength of channel (m) |               |
| \( D_h \)    | hydraulic diameter of channel (m) | \( b_f \)   | base fluid |
| \( \Phi \)   | phase shift (deg)            | \( n_f \)    | nanofluid  |
| \( C_p \)  | specific heat capacity       | \( p \)      | particle   |
| \( \phi \)  | volume fraction               |               |
6. References
[1] Rostami J, Abbassi A and Harting J 2018 Heat transfer by nanofluids in wavy channels, Advanced Powder Technology 29 (18), P.925-933
[2] Khoshvaght-Aliabadi M, Zamzamian S A and Hormozi F 2014 Wavy channel and nanofluids effect on performance of a plate fin heat Exchanger, International Journal of Thermophysics and Heat transfer
[3] Anvari A, Javahardeh K and Meibodi M E 2018 Performance evaluation of a new nanofluid through micro channel heat exchangers, Chemical engineers’ transactions, P. 973-978
[4] Chakravarti A 2017 Numerical Analysis of fluid flow and heat transfer in 2D sinusoidal wavy channel, students conference, czech technical university in Prague
[5] Majdi H and Abed A M 2014 Effect of Nanofluid on performance of a corrugated channel Within out of phase arrangement, International Journal of Scientific and Technology Research 3(1).
[6] Gadhaban S A, Aun S H A and Jehhef K A 2020 Numerical Modelling of fluid flow and heat transfer using TiO2-water nanofluid in wavy channel, IOP Conference Series-Material science and Engineering 881 012162
[7] Drew D A and Passman S L 1999 Theory of Multicomponent Fluids, Springer
[8] Das S K, Choi S U S, Patel E H 2006 Heat Transfer in Nanofluids-A Review Heat Transfer Engineering 27(10), P. 3-19
[9] Xuan Y and Wilfried R 2000 Conceptions for Heat Transfer Correlation of Nanofluids, International Journal of Heat and Mass Transfer 43 (19), P.3701-3707
[10] Maxwell J C 1881 Treatise on Electricity and Magnetism, second ed., Clarendon Press, Oxford University, UK.
[11] Naik B, Soudagar M E M, Thomas M, Dasurkar K, Alloli O, Hossain F and Alloli M 2020 Numerical Investigation of double pipe heat exchanger with different Nano-fluids, IOP Conference series: Earth and Environmental Science 573 012030