The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2023

Volume 26, Pages 375-386

IConTES 2023: International Conference on Technology, Engineering and Science

Effect of Cuo-Water Nanofluid on the Thermal - Hydraulic Behavior of Triangular Corrugated Channel

Rahima Benchabi
University of Mentouri Brothers

Ahsene Lanani
University of Mentouri Brothers

Abstract: The aim of this study is to model and simulate laminar flow and heat transfer in a triangular-corrugated duct containing a CuO-water nanofluid. Note that a temperature is imposed on the walls, the considered Reynolds number (Re) and the nanoparticle volume fraction range from 100 to 800 and 0 to 5% respectively. The basic equations were discretized using the finite volume method. Dynamic and thermal fields were obtained, as well as the Nusselt number (Nu). In addition, the influence of certain parameters (Re, nanoparticle volume fraction) was taken into account. It can be observed that the mean Nu increases with increasing Re. Furthermore, raising the nanofluid volume fraction further enhances the heat transfer. For numerical resolution, we used the FLUENT code. Finally, we note that the results are in excellent accord with experimental ones published in the literature.

Keywords: Heat transfer, Nano-fluid, Corrugated channel, Numerical simulation, Fluent

Introduction

Heat transfer is an extremely important process in industry and technology. Although it manifests itself in different forms, namely radiation, conduction and convection, the latter is the most targeted in certain well-defined fields, such as the cooling of processors, electronic components, radiators and heat exchangers in industrial processes, etc... To this end, a large number of researchers have carried out a wide range of numerical and experimental studies on the phenomena governing convection, the effect of the systems in which it takes place (geometry in particular) and the properties of the fluids involved (physico-chemical properties). Over the last few decades, numerous studies have been conducted on heat transfer to improve the thermal performance of heat exchangers. Initially, researchers studied channels by considering simple fluids. Later, they considered fluids in which nanoparticles are dispersed in a base fluid, hence the term nanofluids (Choi & Eastman, 1995). For more than a century, several researchers have attempted to use suspended metal particles to perform the heat transfer of conventional cooling fluids. The base fluid is usually water, oil or ethylene glycol (EG). Nanofluids are colloidal solutions produced by dispersing nano-sized solid particles in a base fluid. A number of these solutions have shown themselves to be highly efficient in improving heat transfer under certain circumstances. Heat transfer in a nanofluid relies on the thermophysical characteristics of the solid and liquid phases.

In recent years, the study of nanofluids has attracted a great deal of interest in the field of heat transfer. The future of these new types of fluids looks very promising. Many researchers claim that this technology has the potential to become the cooling medium of choice in many fields of application. Numerous studies have shown that nanofluids (Al_2O_3, CuO, SiO_2, ZnO, etc...) have received a lot of interest because of their better heat transfer compared to conventional heat transfer fluids such as water, oil, ethylene glycol, etc..., especially since numerical and experimental studies on this type of problem are quite recent. A lot of numerical and experimental research has been carried out in this field to enhance the heat transfer in heat exchangers. A numerical study is given by Ahmed et al, (2013a). This study concerns a laminar flow in forced convection based on the Al_2O_3-water nanofluid in a wavy triangular duct. The authors show that the Nu rises with Re and nanoparticle volume fraction. From this study, the authors conclude that the use of a nanofluid in a corrugated triangular channel is a good choice. Ahmed et al (2014a) numerically studied the heat transfer characteristics of the CuO-water nanofluid by considering a straight duct and then a corrugated channel. Also, the authors were interested in the effect of nanoparticle volume fraction and Re on temperature, velocity and Nu. The authors find that the average Nu rises with nanoparticle volume fraction and Re for the three examined corrugations (sinusoidal, triangular and trapezoidal). To improve heat transfer, Abed et al. (2015) considered a corrugated channel with various nanofluids, (Al_2O_3, CuO, SiO_2 and ZnO). The authors showed that of the four considered nanofluids, SiO_2 provides the best heat transfer enhancement. In numerical and experimental studies, Ahmed et al. (2015a) focused on improving heat transfer in a corrugated duct by utilizing SiO_2 as nanoparticles. In this study, the authors considered three corrugated channels (trapezoidal, sinusoidal and straight channel). Their results reveal that average Nu increases with nanoparticle volume fraction, and that the trapezoidal channel provides the greatest heat transfer, followed by the sinusoidal and straight channels. Ahmed et al, (2015b) conducted a numerical investigation involving turbulent forced convection flow. The used wavy channel is triangular and the flow considered contains nanoparticles (Al_2O_3, CuO, SiO_2 and ZnO). The authors showed that the best nanofluid was SiO_2, followed by Al_2O_3, ZnO and finally CuO. A numerical investigation concerning the influence of nanoparticles on the heat transfer of flow in a sinusoidal channel is carried out by Heidary & Kerman, (2010). The influence of Re, nanofluid volume fractions and amplitude on the local mean Nu and coefficient of friction has been investigated. The impact of various variables like amplitude, channel wavelength, volume fractions of the nanofluid under consideration and Re on velocity vectors, temperature contours, pressure drop and mean Nu are discussed and reported by Ahmed et al. (2013b). The results reveal an improvement in mean Nu as nanofluid volume fractions increase with channel amplitude, but this enhancement is associated with an increase in the pressure drop. Similarly, as pitch decreases, average Nu increases and pressure drop decreases. Numerical studies are given by Ahmed et al (2012). The authors investigated the effects of nanofluid volume fractions, channel amplitude, pitch and Re on mean and local Nusselt number, coefficient of friction, and heat transfer enhancement. The findings show that the coefficient of friction and the Nu increase with amplitude. In addition, as nanofluid volume fractions increase, the Nu rises with a slight increase in the friction coefficient.

The objective of this study is to evaluate the impact of CuO-water nanofluid on the thermal and hydraulic behavior of a triangular corrugated channel. The corrugated channel used is filled with CuO-water nanofluid. We are also trying to understand the influence of the nanofluid on the forced convection mechanism in this corrugated channel. In this context, we have used the Fluent computational code and carried out a parametric study of the thermomechanical and geometrical parameters. Numerical simulations are carried out for Re numbers ranging from 100 to 800 and for different volume fractions for the base fluid (water, $\varphi = 0$) and for CuO nanoparticles (φ ranging from 0.01 to 0.05).

Mathematical Modeling

Physical Model

Figure 1 illustrates the problem under study, which consists of a triangular corrugated channel. Our problem concerns the study of forced convection in a triangular corrugated duct. The height and total length of the triangular corrugated channel are H and L, respectively. The corrugated channel consists of ten corrugation units whose length, wavelength and corrugation amplitude are L_2, p and a, respectively. It is also assumed that the channel is charged with CuO-water nanofluid of uniform size and shape. The thermophysical characteristics of CuO nanoparticles and water are shown in Table 1.

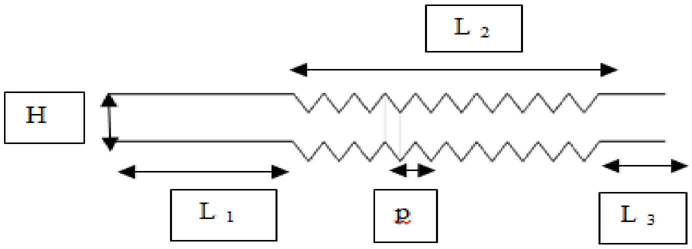


Figure 1. Studied configuration

Table 1. Thermo physical properties of nanoparticles and water

	ρ[Kg m^{-3}]	Cp[J Kg^{-1} K]	K[W m^{-1} K^{-1}]	[Kg m^{-1}s^{-1}]
Water	996.5	4181	0.613	0.001
CuO	6500	533	17.65	_

Governing Equations

The governing equations are:

Continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (1)$$

x - Momentum equation

$$\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=\frac{1}{\rho_{nf}}\left[-\frac{\partial P}{\partial x}+\mu_{nf}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)\right] \quad (2)$$

y - Momentum equation

$$\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=\frac{1}{\rho_{nf}}\left[-\frac{\partial P}{\partial y}+\mu_{nf}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)\right]$$
(3)

Energy equation

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{K}{\rho_{nf}C_{pnf}}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial x^2}\right) \quad (4)$$

Boundary Conditions

Channel Inlet

The velocity component is obtained from Re based on the hydraulic diameter.

$$u_{nf}=\frac{\mu_{nf}\times R_e}{D_h\times\rho_{nf}} \quad (5a)$$

- Cold constant temperature is imposed.

Channel Outlet

$$\frac{\partial u}{\partial x}=0,\frac{\partial v}{\partial x}=0,\ \frac{\partial T}{\partial x}=0 \quad (5b)$$

Walls of Corrugated Channel

$$u=v=0$$
(5c)

Nanofluid Property

Density

$$\rho_{nf}=(1-\varphi)\,\rho_f+\varphi\rho_P \quad (6)$$

Heat Capacity

Most studies done in the literature use one of the two models given by Pak & Cho, (1998) or Xuan & Roetzel, (2000). The later model is given by:

$$(\rho\ Cp)_{nf} = (1-\varphi)\ (\rho\ Cp)_f + \varphi(\rho\ Cp)p \tag{7}$$

Effective Dynamic Viscosity

Two models are proposed, Brinkman, (1952) and Corcione, (2010). The second is evaluated by the following correlation:

$$\frac{\mu_{nf}}{\mu_f} = \frac{1}{1-34{,}87\left(\frac{d_p}{d_f}\right)\varphi^{1.03}} \tag{8}$$

Where: dp is the diameter of the CuO particle and df that of the base liquid.

Effective Thermal Conductivity

Thermal conductivity plays a very important role in heat transfer (Choi & Eastman (1995); Eastman at al., (1996); Frouillat et al., (2011); Maxwell, (1881); Hamilton & Crosser, (1962). In this work, the used conductivity is that introduced by Maxwell (1881).

$$K_{nf} = \frac{(k_p+2k_{f)} - 2\varphi(k_f-k_p)}{(k_p+2k_{f)} + \varphi(k_f-k_p)}.K_f \tag{9}$$

Where: K_{nf} is the thermal conductivity of the nanofluid; k_f that of the base fluid; k_p that of solid particles and φ the volume fraction.

Numerical Method

The FLUENT code was applied to calculate the flow characteristics of the used fluid. For our study, the mesh chosen is based on quadratic cells. The accuracy and stability of our simulation results depend on the quality of the mesh, so a test of mesh independence on the solution was carried out for different numbers of nodes.

Results and Discussion

The numerical findings are derived for a two-dimensional flow of the CuO-water nanofluid They are presented in the form of velocity, pressure, temperature, velocity profile, variation of the Nu as a function of Re and nanoparticle volume fraction.

Independence Mesh

The influence of the mesh has been considered in order to obtain satisfactory solutions. To demonstrate the impact of the mesh size on the numerical findings, three mesh sizes (310131; 446825 and 607973) were tested in the flow regime and presented in the form of the local variation of the Nu, the heat transfer coefficient, the velocity profiles, the temperature at $Re = 500$ and a nanoparticle volume fraction, $\varphi = 0.05$.

Figures 2 and 3, show that the three meshes have an identical appearance and that the profiles are insensitive to the numbers of nodes. In order to minimize the computational burden, the considered mesh in this study is 446825 for Re varying from 100 to 800 and volume fractions between 0% and 5%. The grid independence test revealed that grid 446825 guarantees a satisfactory solution.

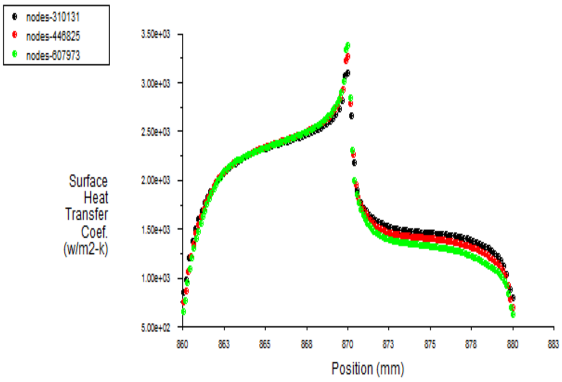


Figure 2. Variation of heat transfer coefficient with $Re = 500, \varphi = 0.05$ for different meshes

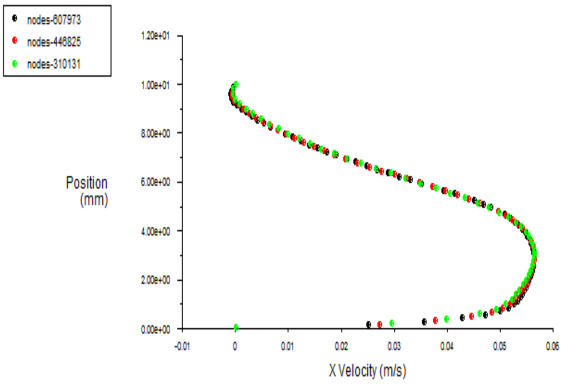


Figure 3. Profiles of the velocity horizontal component at $x = 0.860$ with $Re = 500, \varphi = 0.05$ for different meshes

Code Validation

Simulation validation is required to verify the precision of the findings obtained by the Fluent CFD code. A comparison of our results was made with the study by Ahmed et al, (2014a) which considered a triangular corrugated channel and a constant temperature imposed on the corrugated walls. Figure 4 shows the evolution of average Nu as a function of Re for a triangular corrugated channel using a volume fraction $\varphi = 0.05$. It can be seen that Nu is influenced by Re and that an increase in Re leads to a rise in Nu.

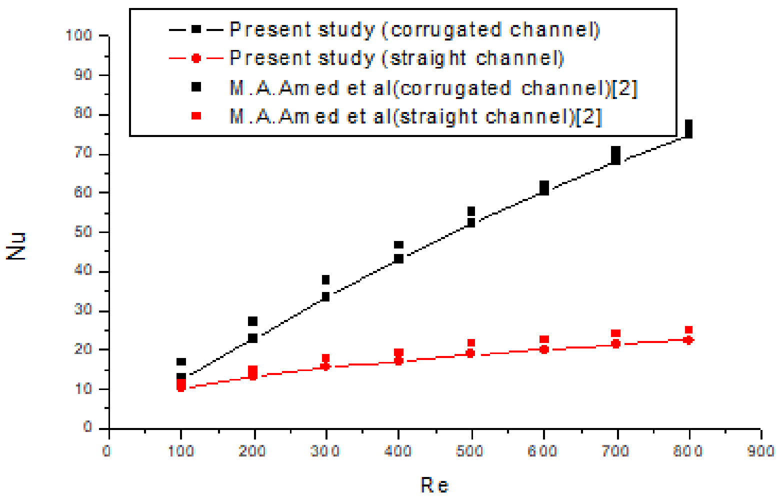


Figure 4. Variation of mean Nu versus Re at $\varphi = 0.05$

In addition, the Nu numbers for the triangular channel are much higher than those for the smooth channel. We also note that there is good accord with the findings of Ahmed et al. (2014a). Figure 5 shows the change in Nu versus various volume fractions at $Re = 300$. It can be seen that an increase in volume fraction leads to a rise in Nu. It is also observed that the Nu values are greater than those of the smooth channel. Moreover, there is good agreement between the numerical results obtained by this simulation and those of Ahmed et al. (2014a).

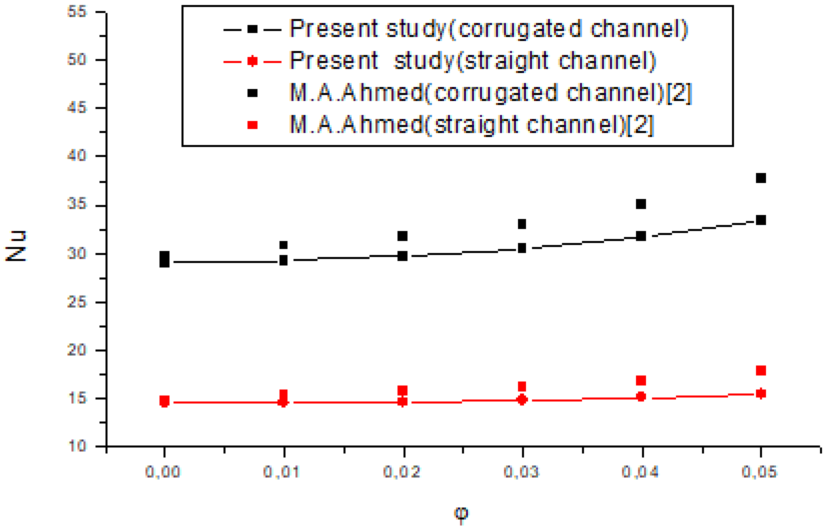


Figure 5. Variation of mean Nu versus volume fractions at $Re = 300$

Results and Discussion

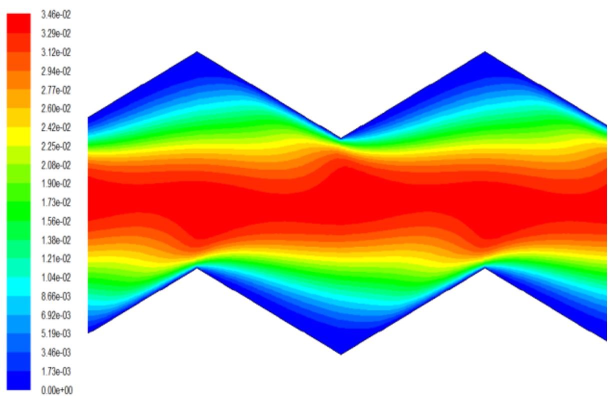
The numerical findings are obtained for various Reynolds numbers which vary between 100 and 800 and different volume fractions, φ ranging from 0% to 5%. The effect of Re and volume fractions on flow and heat transfer will be analyzed in this numerical study.

Reynolds Number Effect

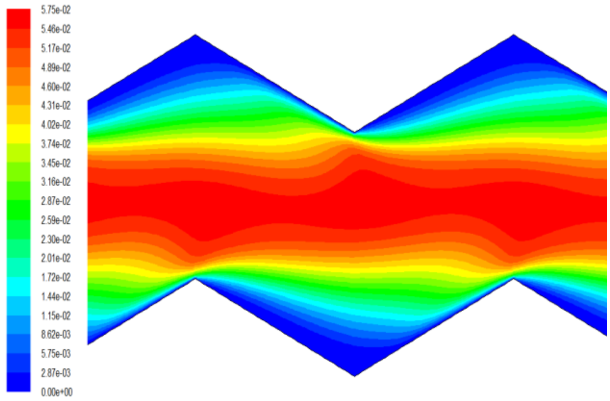
The dynamic and thermal fields are presented for various Reynolds numbers at a volume fraction $\varphi = 5\%$.

a- Dynamic Field

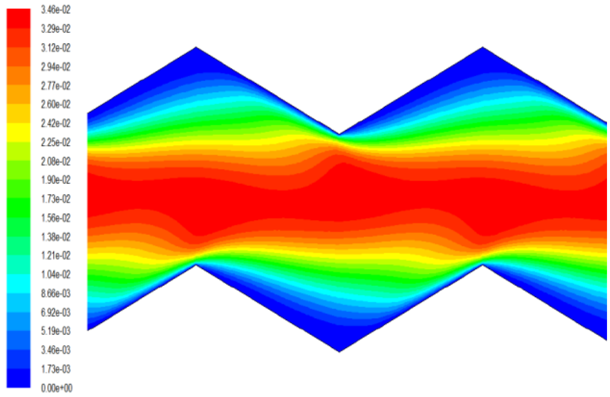
Figure 6 a, b, c illustrates the contours of the average velocity for various at a volume fraction $\varphi = 0.05$. We see a central flow with velocities more and more important as the Reynolds number increases. These velocities decrease to zero near solid walls, thus the non-slip condition is satisfied.



(a)



(b)



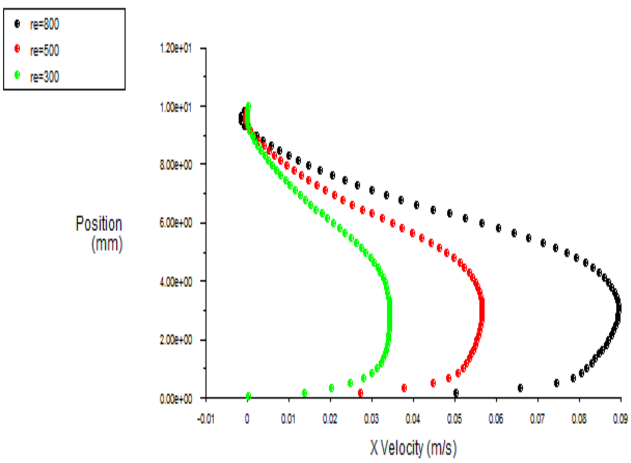
(c)

Figure 6. Velocity contours at $\varphi = 0.05$

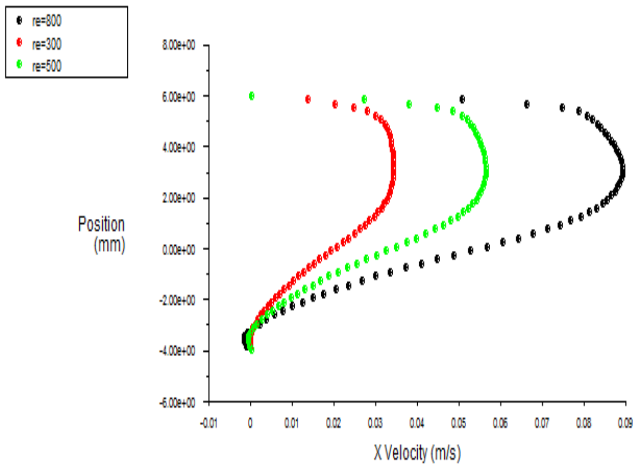
$(a) Re = 300$ $(b)\ Re = 500$ $(c)\ Re = 800$

Thick dynamic boundary layers are seen along the upper wall corresponding to dunes, and along the lower wall in valleys where fluid velocities are low, and recirculation zones are present. We also note that the rate of thickening of the boundary layers becomes greater as the Re increases. Recirculation zones appear in the troughs of dunes and valleys. These zones grow in size as the Re increases.

The velocity profiles for various Re with $\varphi = 0.05$ at the stations $x = 0.860\,m$ and $x = 0.870\,m$ are represented by figure 7 a, b. We notice the appearance of negative velocities. This is due to the emergence of recirculation zones in the hollows of the dunes and valleys and that they are more and more important in increasing Reynolds number.



(a)



(b)

Figure 7. Profiles of the horizontal component of the velocity at $\varphi = 0.05$ for various Re
$(a)\ x = 0.860\ m \qquad (b)\ x = 0.870\ m$

b- Thermal field

Figure 8 shows the change in mean Nu versus Re for the triangular wavy channel filled with CuO and water. We can see that the Nu is influenced by the Re. We also find that increasing Re leads to an increase in Nu, and that Nu values for CuO nanoparticles are greater than those for water.

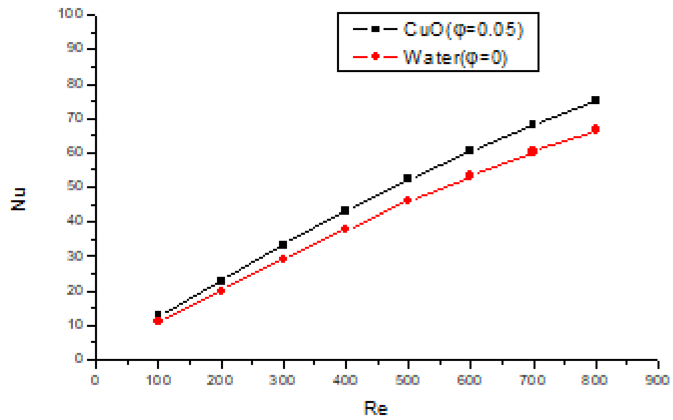


Figure 8. Change of the Mean Nu vs Re

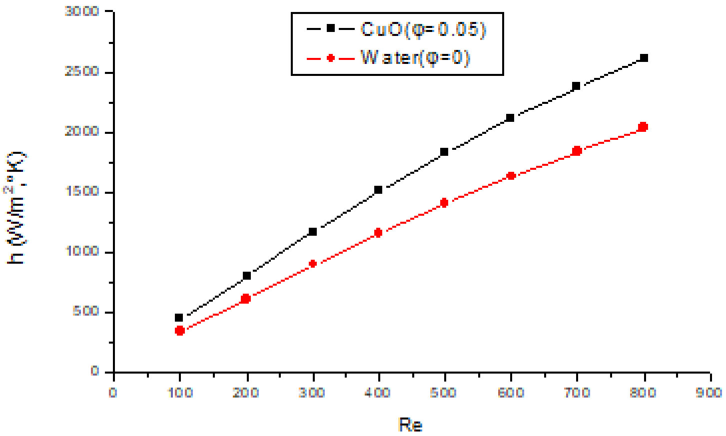
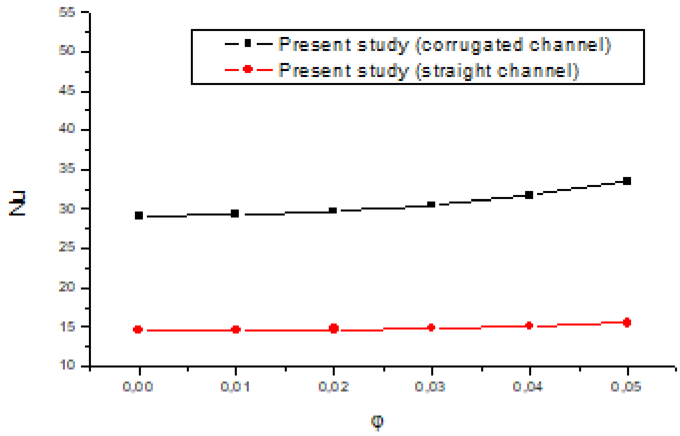


Figure 9. Change of the heat exchange coefficient vs Re

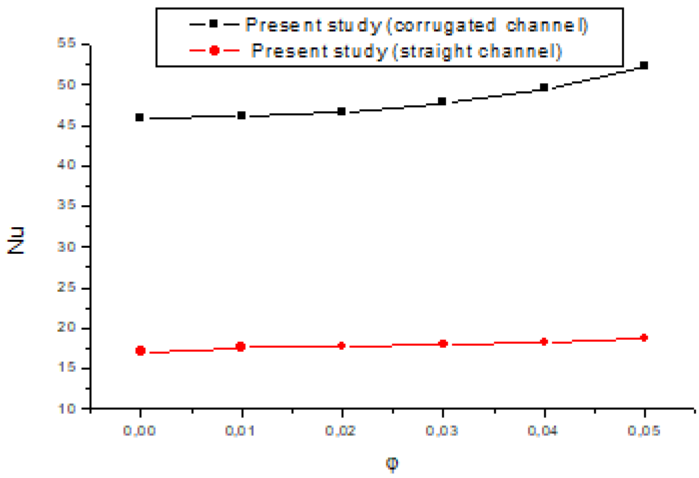
The evolution of the heat exchange coefficient versus Re for CuO and water is shown in Figure 9. The thermal coefficient h rises with increasing Re. The values of h for CuO are also large compared with those for water.

Volume Fraction Effect

Figure 10 a, b reveals the impact of volume fractions on average Nu at $Re = 300$ and $Re = 500$ for corrugated and smooth channels. It can be seen that an improvement in volume fractions causes an increase in Nu. This is explained by the improved thermal conductivity of the base fluid. It can also be observed that the Nu values of the wavy channel for the different volume fractions are much greater than those of the smooth one, due to the appearance of recirculation zones in the wavy channels, which improve heat transfer between the cold fluid in the channel and the hot fluid near the channel walls. It can also be seen that increasing the Reynolds number generates a very significant increase in Nu values. This is caused by the growing volume of recirculation zones.



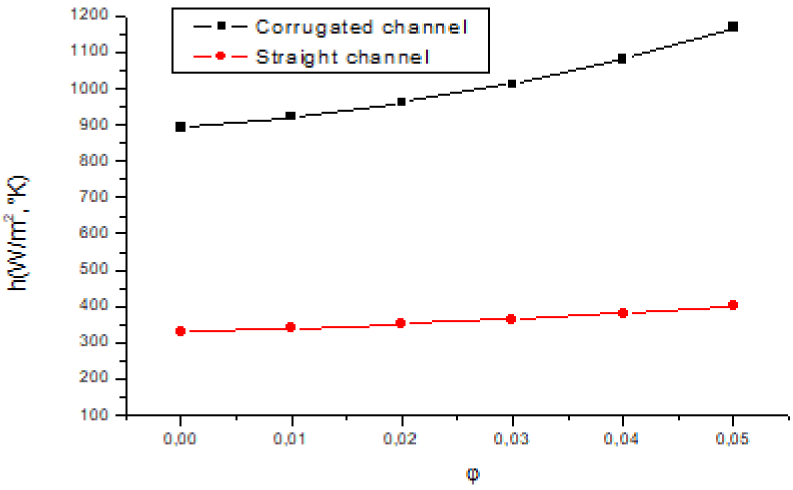
(a)



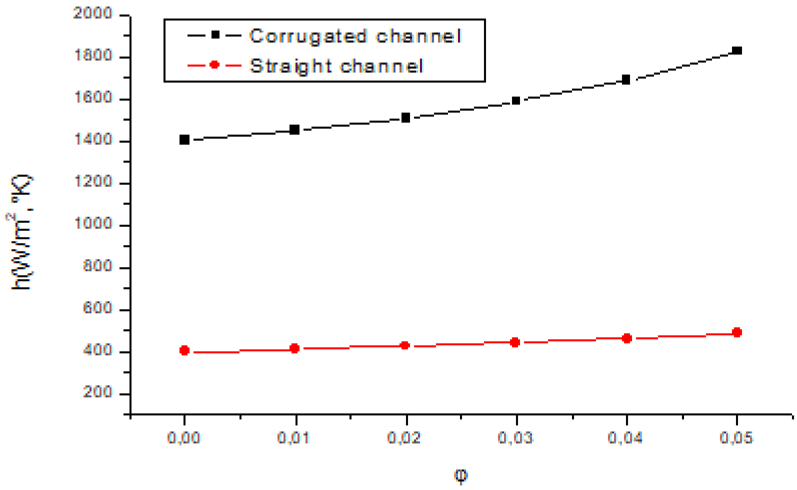
(b)

Figure 10. Variation of the mean Nu as a function of volume fractions
(a) $Re = 300$; (b) $Re = 500$

The impact of volume fractions on the heat exchange coefficient at $Re = 300$and $Re = 500$ is shown in Figure 11 a, b for the corrugated and smooth channels. We see an increase in the coefficient h with increasing volume fractions. This is due to the increase in the Nu and the improved thermal conductivity of the nanofluid. The values of the exchange coefficient are larger than those of the smooth channel, and are very significant as the Re increases. Figure 12 illustrates the change in mean Nu versus Re for various volume fractions. It can be seen that the improvement in heat transfer increases with increasing volume fractions and Reynolds number, as the addition of nanoparticles to the base fluid (water) improves the thermal conductivity of the fluid and hence the increase in heat transfer.



(a)



(b)

Figure 11. Variation of the heat exchange coefficient vs volume fractions
(a) $Re = 300$; (b) $Re = 500$

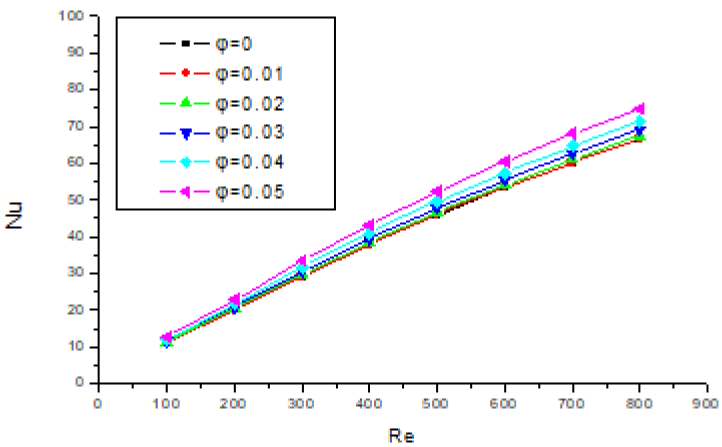


Figure 12. Change of the mean Nu vs Re for various volume fractions

The variation of the heat exchange coefficient for various volume fractions as a function of Re at $Re = 300$ and $Re = 500$ is illustrated in Fig. 13 a, b for the corrugated and smooth channels. An increase in the thermal coefficient h is noted with increasing volume fractions as well as Reynolds number, as fluid velocity is an important factor in heat transfer.

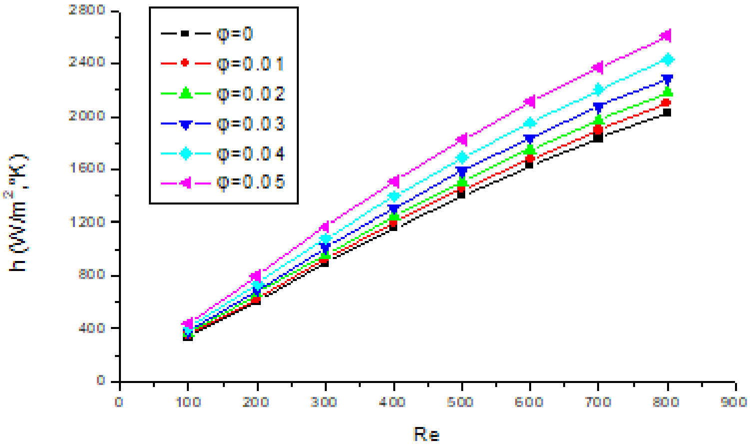


Figure 13. Variation of heat exchange factor as a function of Re for various volume fractions

Conclusions

In this work, a numerical investigation of convective heat transfer has been presented in a wavy channel filled with a mixture of water and nanofluids. The geometric configuration of the physical model is a triangular corrugated channel whose walls are subjected to an imposed temperature. Numerical simulations are also carried out for Re ranging from 100 to 800 and for various volume fractions for the base fluid (water, $\varphi = 0$) and for the CuO nanoparticle (φ ranging from 0.01 to 0.05). The basic equations are solved using the finite volume method and the numerical resolution is performed by the CFD code FLUENT. We noted that our numerical simulation procedure was confirmed by comparing our findings with those published in the literature, and good concordance was observed. The main outcomes are summarized below:

- Increasing the Reynolds number improves forced convection flow.
- Increasing the nanofluid volume fraction enhances heat transfer.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

* This article was presented as a poster presentation at the International Conference on Technology, Engineering and Science (www.icontes.net) held in Antalya/Turkey on November 16-19, 2023.

* This research was partially supported by the Algerian MESRS. Project research N°: A11N01UN250120200005.

References

Abed, A. M., Sopian, K., Mohammed, H. A., Alghoul, M. A., Ruslan, M. H., Mat, S., & Al-shamani, A.N. (2015). Enhance heat transfer in the channel with V-shaped wavy lower plate using liquid nanofluids. *Case studies in Thermal Engineering*, *5*, 13-23.

Ahmed, M. A., Yusoff, M. Z., & Shuaib, N. H. (2012). Numerical investigations on the heat transfer enhancement in a wavy channel using nanofluid. *International journal of Heat and Mass Transfer, 55,* 5891-5898

Ahmed, M. A., Yusoff, M. Z., & Shuaib, N. H. (2013b). Effect of geometrical parameters on the flow and heat transfer characteristics in trapezoidal-corrugated channel using nanofluid. *International Communications in Heat and Mass Transfer, 42,* 69-74.

Ahmed, M. A., Yusoff, M. Z., Ng, K. C., & Shuaib, N. H. (2014a). Effect of corrugation profile on the thermal-hydraulic performance of corrugated channels using CuO-Water nanofluid. *Case studies in Thermal Engineering, 4,* 65-75.

Ahmed, M. A., Yusoff, M. Z., Ng, K. C., & Shuaib, N. H. (2014b). The effect of wavy-wall phase shift on thermal-hydraulic performance of Al_2O_3-Water nanofluid flow in sinusoidal-wavy channel. *Case studies in Thermal Engineering, 4,* 153-165.

Ahmed, M. A., Yusoff, M. Z., Ng, K. C., & Shuaib, N. H. (2015a). Numerical and experimental investigations on the heat transfer enhancement in corrugated channels using SiO2-Water nanofluid. *Case studies in Thermal Engineering, 6,* 77-92.

Ahmed, M. A., Yusoff, M. Z., Ng, K. C., & Shuaib, N. H. (2015b). Numerical investigations on the turbulent forced convection of nanofluids flow in a triangular-corrugated channel. *Case studies in Thermal Engineering, 6,* 212-225.

Ahmed, M. A., Yusoff, M. Z., Shuaib, N. H., & Ng, K. C. (2013a). A numerical study of laminar forced convection flow of Al_2O_3 - water nanofluid in triangular-corrugated channel. *ICEE.* Putrajaya, Malaysia

Brikman, H. C. (1952). The viscosity of concentrated suspensions and solutions. *The Journal of Chemical Physics, 20,* 571-581.

Choi, S.U.S., & Eastman, J. A. (1995). Enhancing thermal conductivity of fluids with nanoparticles. *ASME-Publ-Fed, 231,* 99-106.

Coorcione, M. (2010). Heat transfer features of buoyancy-driven nanofluids inside rectangular enclosures differentially heated at the sidewalls. *International Journal of Therm. Science, 45,* 1536-1546.

Eastman, J. A., Choi, S.U.S., Li, S., Thompson, L. J., & Lee, S. (1996). Enhanced thermal conductivity through the development of nanofluids. *MRS Proceeding, 457,* 3.

Frouillat, S., Bontemps, A., Ribeiro, J. P., Gruss, J. A., & Soriano, O. (2011). Hydraulic and heat transfer study of SiO_2 /Water nanofluids in horizontal tubes with imposed wall temperature boundary conditions. *International Journal of Heat and Fluid Flow, 32,* 424-439.

Hamilton, R. L., & Crosser, O. K. (1962). Thermal conductivity of heterogeneous two component systems. *Industrial and Engineering Chemistry Fundamentals, 1*(3), 187-191.

Heidary, H., & Kermani, M. J. (2010). Effect of nanoparticles on forced convection in sinusoidal-wall channel. *International Communications in Heat and Mass Transfer, 37,* 1520-1527.

Maxwell, J. A. (1881). *A treatise on electricity and magnetism* (2nd ed.). Oxford: Clarendon Press.

Pak, B. C., & Cho, Y. I. (1998). Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. *Exp. Heat Transfer, 11,* 151-170.

Xuan, Y. M., & Roetzel, W. (2000). Conceptions for heat transfer correlation of nanofluids. *International Journal of Heat Mass Tranfer, 43*(19), 3701-3707.

Author Information

Rahima Benchabi
University of Mentouri Brothers
Constantine 1, 25000 Algeria
Contact e-mail: rbenchabi*@yahoo.fr*

Ahsene Lanani
University of Mentouri Brothers
Constantine 1, 25000 Algeria

To cite this article:

Benchabi, R., & Lanani, A. (2023). Effect of CuO-water nanofluid on the thermal - hydraulic behavior of triangular corrugated channel. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 26,* 375-386.