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Conjugate Heat Transfer of Nanofluid Flow Inside A Micro– Wavy Channel

Hussein Jamal Hussein
hussein.enp65@student.uomosul.edu.iq

Amir Sultan Dawood
asdawood@uomosul.edu.iq

Mechatronics Engineering Department, Collage of Engineering, University of Mosul

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ABSTRACT

Conjugate heat transfer method is utilized in this work for numerically studying the laminar two-dimensional forced convective heat transfers related to the aluminum oxide-water nano-fluid in horizontal micro wavy channel also the impact of adding nano-particles for constant heat flux applied at bottom the channel، The study assumed that the nanofluid is subject to the single phasic hypothesis that treats the basic fluid (H_2O) and nanoparticles (Al_2O_3) as a homogeneous mixture and that the nano-fluid is incompressible and it has steady and laminar flow. The considered Reynold number and the nano particle volume fraction have been in a range between (500 and 2,000) and 2% respectively. Use the (ANSYS FLUENT 2020 R1)software, which is one of the programs regarding the computational fluid dynamics (CFD), and Finite volume method (FVM) is selected to solve the governing equations For ensuring the accuracy of results, the CFD result were verified with modern theoretical equation. In this research four models are examined numerically, The first model is a flat channel and only water is flowing through it, The second model is a wavy channel and only water is flowing through it, The third model is a flat channel where the nanofluid consisting of water and nanoparticles (aluminum oxide) passe through it, and the fourth model is a wavy channel in which the nanofluid consisting of water and the nanoparticles (AL_2O_3) passes through the channel for three different values of Reynolds number (500,1400,2000) and concentration of (2%) nanoparticles. A micro-wavy channel represents an optimal state among all examined cases and with regard to all the Reynolds numbers. Furthermore, the best Performance evaluation criterion (PEC) is recorded for the case of wavy channel with nanofluid for Reynolds number equaling 2000. At Re = 2000 with 2% as volume concentration, the value related to heat transfer coefficient equal to (4603.61) when using the nanofluid due to dispersion factors, Brownian motion, and nanoparticles that are responsible for enhancing heat transfer. The presence of wavy channel and nanofluid flow enhance the nusselt number and improve heat transfer to fluid. It is noticed that when Reynolds number increases the pressure drop increases, the thermal resistance decreases, the heat transfer coefficient increases. The addition of waves in the channel and nanoparticles increased the number of Nusselt and thus improved heat transfer.

Keywords:

Conjugate Heat transfer; Nanofluid; Wavy channel; Computational fluid dynamics (CFD)

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1- Introduction:

The conjugate heat transfer (CHT) can be defined as a process that describes the processes involving temperature variations within fluids and solids, due to thermal interaction between the solids and fluids. Thermal energy exchange between both physical bodies has been referred to as Heat Transfer study; the transferred heat rate is directly proportionate to the difference of the temperature between bodies. The Conjugate heat transfer in Micro-channels is a major research topic because of its extensive engineering applications.

Conjugate heat transfer in Micro-channels is one of the most common research topics due to its extensive engineering applications. Most attention to heat transfer problems is two cases regarding heat flux and uniform temperature of the wall. In the past decades, many cooling technologies were followed to the high heat dissipation rate requirements as well as maintaining low junction temperature with regard to the electronic components. For improving the heat transfer surfaces, several technologies were utilized for increasing the heat transfer. As known, Heat is a form of energy, which is responsible for moving molecules inside the material, as its movement increases with increasing temperature, which is responsible for moving molecules inside the material, as its movement increases with increasing temperature, which leads to its expansion referred to as the thermal expansion. In addition, the heat was moving constantly and moving between the objects, since it is moving from the body with maximum heat to the body with minimum heat till their temperature become equal [1].

In general, methods for improving heat transfer can be divided into three parts: Active methods, Passive Methods and Compound Methods, which is a combination of the first and second methods. Most methods of improving heat transfer are limited to the continuous restriction of thermal conductivity regarding the conventional fluids. The perfect properties of nanomaterial from the enhanced thermal conductivity and the long-term stability have stimulated various studies for examining the nanofluids flowing and thermal behavior [2-7] . In this investigation, the computational technique is carried out to study flow behavior analysis, pressure drop characteristic and enhancement of heat transfer in three-dimensions smooth pipe and circular corrugated tube (circular sectional area rings are inserted around the tube).Result indicated that the dynamic pressure profile and velocity profile in corrugated tube is non-uniform as compared to profile in smooth pipe, the high pressure value is existed at the outer pipe the reason behind that is due to the losses in the tube The shape of flow in tube changes based on the corrugate ring radius diameter. The maximum dynamic pressure is concentrated at the centre of tube due to the high velocity take place in this region. [8].

Ramiar and Ranjbar [9] numerically examined the Laminar 2D forced convective heat transfer related to Al2O3 water and CuO water nano-fluids in a horizontal micro-channel, taking into account the axial conduction effect in liquid and solid regions, and dynamic viscosity and various values of the thermal conductivity. In addition, results are showing that using nanoparticles (NPs) with high thermal conductivities is going to intensify enhancements regarding the heat transfer characteristics and insignificantly increasing the wall's shear stress. The acquired results are showing further steep change in the Nusselt number concerning low diameters and high Nusselt number's values via reducing the NP diameter. Through using conduction number as a criterion, results specified that adding NPs is going to increase the axial conduction effects in considered geometry.

Abdullah et al. [10] Studied the fluid flow as well as heat transfer related to NPs in the micro channel heat sink with V-type inlet/outlet arrangements for various nanofluid types were used as working fluids that were Al_2O_3, SiO_2, CuO and ZnO dispersed in the pure water as base fluid, while the results are specifying that SiO2 nanofluid showed maximum heat transfer rate in comparison with the other tested nano-fluids. To increase NP volume fraction and reducing the NP diameter improves the value of the Nusselt number. In addition, a coefficient of pressure drop did not significantly changes via utilizing a nanofluid with different NP diameters and different volume fractions. In addition, results are indicating that the nanofluid might improve the performance related to microchannel heat sink MCHS with the V-shaped inlet/outlet arrangement.

Rashid et.al.[11] reviewed numerically studies on comparisons of two phase as well as a single phase of the heat transfer as well as flow field regarding copper water nanofluid in the wavy channels. CFD prediction is utilized for flow prediction and heat transfer of single phase and three distinctive two-phase models (Eulerian, VOF and mixture). Also, the temperature, velocity and heat transfer coefficient distributions were examined. Also, the results are showing that the difference between temperature field in single-phase model and the 2-phase model were great compared to the ones in hydrodynamic field. Furthermore, it has been indicated that coefficient of heat transfer predicted through single phase model is improved via an increase in volume fraction of NP with regard to all Reynolds numbers; whereas for 2-phase models, in a case where Reynolds number has been low, the increase in NP volume fraction is going to enhance heat transfer coefficient in middle and wavy channel front, yet a reduction along the wavy channel.

Niceno And Nobile [12] presented numerically study, on 2D steady as well as time dependent fluid flow, and heat transfer via periodic, wavy channels was studied numerically, with regard to a fluid with 0.70 Prandtl number, via utilizing unstructured co volume technique. The 2 geometrical configurations taken into account, arc-shaped channel and sinusoidal channel were providing no or little augmentation in the heat transfer, compared to parallel plate channel, in the steady flow regimes at low values of the Reynolds number. The both configuration have high-pressure drop compared to that related to parallel plate channel within totally developed flow conditions. In terms of unsteady regime, the results they reach at approximately(Re=175–200) in terms of sinusoidal channel, while for arc-shaped channel it is (Re=60–80), the two geometries are showing a considerable increment in a rate of the heat transfer, up to 3 times concerning maximum Reynolds number examined, such increment has been high for arc shaped flow passage, yet was accompanied via high friction factor compared to that of sinusoidal channel.

Bhattacharya, Chakraborty and Samanta, [13] In this research, the conjugate heat transfer technique was utilized for studying (numerically) the laminar forced convective heat transfer properties that are related to Al_2O_3/H_2O nano-fluid flowing in silicon MCHS of rectangular cross section with the use of thermal dispersion model. In addition, the results were provided with regard to thermal resistance that researches were carried out for determining the number in 3-D conjugate process of heat transfer. With regard to micro-scale dimensions including metallic oxide, based nano-fluid, it was identified that utilizing the nano-fluid enhances MCHS efficiency through decreasing fin (i.e. conductive) thermal resistance.

NANOFLUID:

The concept of a nanofluid indicates The formulation by researchers at the Argonne National Laboratory in 1995 that a new type of thermal transfer fluid could be created by adding nano-particles or non-metallic particles in main fluid [14]. Conventional pure fluids have great potential for enhancing heat transfer. It is a new class of fluids that consists of adding very small particles (Usually less than 100 nanometers) (nanometers $=10^{-9}$ meter) to conventional fluids.

1-Density :

The density of the nano-fluid can be found with the use of the equation [Pack and Cho] [15] **.**

$$\rho_{nf} = \theta\rho_p + (1-\theta)\rho_{bf} \qquad \text{………(1)}$$

2-Specific heat:

The specific heat at constant pressure of the nanofluid can be found by using the researcher's equation[Khanafar] [16].

$$cp_{nf} = \frac{(1-\theta)(\rho cp)_{bf}+\theta(\rho cp)_p}{\rho_{nf}} \qquad \text{…….(2)}$$

3-Dynamic viscosity:

The researcher [Corcione] [17] has developed an experimental relationship to calculate the nano-fluids' dynamic viscosity on a basis of a large size of the experimental data for a number of studies as shown below:

$$\frac{\mu_{nf}}{\mu_{bf}} = \frac{1}{1-34.87\left(\frac{d_p}{d_{bf}}\right)^{-0.3}\theta^{1.03}} \qquad \text{......………(3)}$$

$$d_{bf} = 0.1\left(\frac{6M}{N\,\pi\,\rho_{bf0}}\right)^{1/3} \qquad \text{…......……(4)}$$

4- Thermal conductivity:

The researcher [Corcione] [17] has developed an experimental relationship for calculating the Nano-fluids' thermal conductivity on a basis of large amount of the experimental data for a number of studies as shown below:

$$\frac{K_{nf}}{K_{bf}} = 14.4\,Re^{0.4}Pr^{0.66}\left(\frac{T}{T_{fr}}\right)^{10}\left(\frac{K_p}{K_{bf}}\right)^{0.03}\theta^{0.66} \quad (5)$$

$$Re = \frac{\rho_{bf}\,u_B\,d_p}{\mu_{bf}} \qquad \text{…......……(6)}$$

$$\tau_D = \frac{d_P^2}{6D} = \frac{\pi\,\mu_{bf}d_p^3}{2K_bT} \qquad \text{....…......…(7)}$$

$$u_B = \frac{2K_bT}{\pi\,\mu_{bf}d_p^2} \qquad \text{…....……..(8)}$$

$$Re = \frac{2\,\rho_{bf}\,K_bT}{\pi\,\mu_{bf}^2\,d_p} \qquad \text{…....……..(9)}$$

LIST OF SYMBOLS

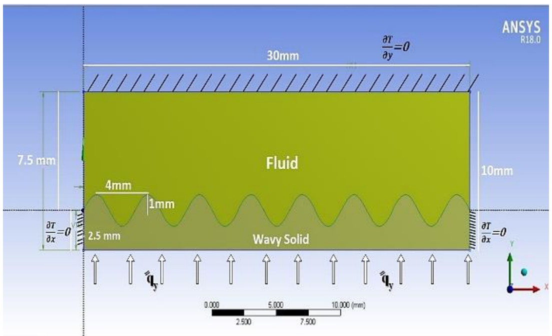
Θ	Volume fraction of nanoparticles, %	T_{fr}	Freezing temperature, K	q″	Heat flux, W/m2
ρ	Density, kg/m3	k	Thermal conductivity, W/m.K	VOF	Volume of fluid
μ	Dynamic viscosity, m2/s	d	Diameter, m	A	Section area, m2
π	Pi	M	Molecular weight, mol	*f*	Friction factor
cp	Specific heat capacity, J/kg.K	N	Avogadro constant, mol-1	Pr	Prandtl number (Pr = $\frac{\mu . cp}{k}$)
τ_D	Time required to cover the movement	Re	Reynolds number (Re = $\frac{\rho\ u\ D}{\mu}$)	CFD	Computational fluid dynamics
u_b	Brownian speed			bf	Base Fluid
Φ	Thermal resistance, K/W	Nu	Nusselt number (Nu = $\frac{h.D}{k}$)	nf	Nanofluid

PHYSICAL AND THERMAL PROPERTIES OF NANOFLUIDS:

Use the (ANSYS FLUENT 2020 R1) , software which is one of the CFD programs. The finite volume approach has been chosen for solving the governing equations. The numerical procedures for a program (ANSYS 2020 R1) are divided into five parts, which are **:**Firstly, Draw the Engineering model with the required dimensions and determine the direction of the flow. Secondly, The distribution of the grid points over the parts of the space all drawn, so the best distribution of points must be chosen, and at this stage a procedure is performed Grid Independent Test. thirdly, Set and choose the governing equations if the program contains a large number of equations that cover most types of flow and heat transfer. Determine the type of fluid used and the metal, enter the boundary conditions for the studied space, and choose the solution method, as an algorithm was chosen from the solution methods as it corrects velocity and pressure simultaneously. Take Consider that simulation is considered to be convergent when the result of an error of all equations is less than(10^{-10}). Fourthly, run the solution. Fifthly, Results. More information about the solution algorithms used in the (ANSYS FLUENT 2020.R1) program can be found at the source [18]**.**

SCHEMATIC ILLUSTRATION OF THE MICRO-WAVY CHANNEL:

The mathematical model, which has been utilized in this work of conjugated heat transfer through a microchannel, fully developed flow through the whole length of the channel. The temperature distributions of the moving fluid inside the channel are presented in different sections for all cases and through a sinusoidal wave shaped channel. The issue which is under consideration includes a steady, forced laminar convection flow and heat transfer of the nano-fluid which flows within a two-dimensional microchannel. The microchannel of height *H* is equal to 10 mm and a length *L* is equal to 30 mm. The lower part of solid conducting wall of sinusoidal shape of 3.5 mm thickness (measured from the top of the wave to the lower base of the solid wall), the wavelength L_w is 4 mm, the wave height (amplitude) *a* is 1 mm, and its lower straight base is kept at constant heat flux. The upper wall is straight solid and is kept at constant low temperature. AL2O3-water nano-fluid gets into channel in a constant velocity and a constant 293K temperature, and many different Reynolds number from 500 to 2,000 was taken under consideration. The solid area is made of the silicon (k_s = $120 Wm^{-1}K^{-1}$). The geometry is illustrated in Fig.



(1).

Figure (1) Illustration of Micro-Wavy Channel

ASSUMPTIONS:

To facilitate the study of any problem, put assumption to solve equations and obtain logical results and Governing equations. In this work, the following assumptions have been made:

1- The nanofluid is a single-phase approach as the basic fluid treats water (H_2O) and nanoparticles Aluminum oxide (AL_2O_3) as a homogeneous mixture.

2- The flow condition is fully developed laminar flow, Newtonian nanofluid and incompressible.
3- The studied case is in a state of steady, as there has not been any change with time.
4- A constant heat flux is imposed at the bottom of solid channel wall.
5- The upper wall and the two side walls of the solid area are insulate (adiabatic).
6- Nano-particles used with a diameter of 20 nanometers with volumetric concentrations 2%.
7- The thermal conductivity, specific heat, viscosity and density of nano-fluid are calculated at the entry temperature and for each volumetric concentration.
8- Heat transfer by radiation is neglecting.

GOVERNING EQUATIONS:

The equations (mass conservation, momentum conservation, and energy conservation) are the basis for representing engineering issues and solving them all in the area of heat transfer and fluid mechanics based on the assumptions previously mentioned, so the governing equations are according to the following:

i) Mass Conservation Equation:

$$\frac{dp}{dt} + \rho_{nf}\,\vec{\nabla}.\,\vec{V} = 0 \quad \text{.................(10)}$$

The density change is neglect, the governing equation are as follows:

$$\nabla.\vec{V} = 0 \quad \text{……………..(11)}$$

ii) Momentum Equation:

$$\frac{d\vec{V}}{dT} = \vec{A} - \frac{1}{\rho_{nf}}\nabla P + \frac{\mu_{nf}}{\rho_{nf}}\nabla^2\vec{V} \quad \text{...………(12)}$$

If we neglect external body forces, the momentum equation is:

$$(\vec{V}.\nabla)\,\vec{V} = -\frac{1}{\rho_{nf}}\nabla \mathrm{P} + \frac{1}{\rho_{nf}}\nabla.(\mu_{nf}\nabla\vec{V}) \quad \text{…….(13)}$$

iii) Energy Equation:

$$\frac{DT}{Dt} = \frac{\mu_{nf}}{\rho_{nf}CP_{nf}}\Phi + \frac{1}{\rho_{nf}CP_{nf}}\nabla.K_{nf}\nabla T \quad \text{……(14)}$$

If the term of the viscous dissipation is neglected, then, the equation of the energy will be:

$$(\vec{V}.\nabla)\,T = \frac{1}{(\rho\, c_p)_{nf}}\nabla.(K_{nf}\nabla T) \quad \text{………..(15)}$$

For the solid region the energy equation is:

$$K_s\,\nabla^2 T = 0 \quad \text{……………(16)}$$

Thermal Resistance (Φ):

It is the temperature difference ratio between the 2 material faces to the heat flow rate per the unit of area.

$$\Phi = \frac{T_{ave} - T_{in}}{A_S.q} \quad \text{……………….(17)}$$

T_{ave} : Average temperature, T_{in} : Fluid inlet temperature.

Performance evaluation criterion (PEC) :

The PEC defined as the ratio of heat flow rate transferred to the required pumping power in the system. PEC is the heat transfer and the hydro-dynamics are most critical aspects. They may be compared with a global energy method, with the use of PEC that has been characterized as the ratio of heat flow rate which is transferred to required power of pumping in a system.[19].

$$PEC = \frac{m\,c_p(T_i - T_o)}{v\,\Delta P} \quad \text{…………(18)}$$

It is calculated from the following relationship as well :

$$f = 2\,\Delta P\,\frac{D}{L}\,\frac{1}{\rho_{nf}\,U_{ave}^2} \quad \text{……………..(19)}$$

$$PEC = \frac{(Nu_{ave}/Nu_{ave,0})}{\left(\frac{f}{f_0}\right)^{1/3}} \quad \text{………..........(20)}$$

f_0 , $Nu_{ave,0}$: Symbolize magnitude in the absence of vortices and the nanofluid.

Pressure drop (ΔP):

The drop in the pressure ($\Delta p = p_1 - p_2$) is directly associated with the power of pumping for maintaining the flow, for laminar flow the pressure drop can be obtained from:

$$\Delta p = \frac{32\mu L V_{ave}}{D^2} \quad \text{………..(21)}$$

The pressure drop for a channel that has L length as follows:

$$\Delta P = f\,\frac{L\rho U^2}{2d} \quad \text{………..(22)}$$

For laminar flow:

$$f = 64/Re \quad \text{……………(23)}$$

BOUNDARY CONDITIONS:

These conditions must be present to solve any differential equation, but they must be consistent logical and based on engineering assumptions appropriate to the nature of the mathematical model.

1- Velocity Inlet: The Inlet nanofluid temperature is 293K and the velocity of the nano-fluid flow at entry is dependent on the Reynolds number (Re).also (u =U , v = w = 0 , $T = T_{in}$ = 293 K $0 \le y \le H$).

2- Pressure Outlet: The pressure of the nanofluid at exit is equal to zero and the flow is fully developed ($\frac{\partial u}{\partial x} = \frac{\partial v}{\partial x} = \frac{\partial T}{\partial x} = 0$).

3- Top and two side walls: the top wall is adiabatic, and the side walls have been considered insulated.

4- Bottom surface: No slip condition for every solid surface, Fluid flow at the wall no-slip (u = v = 0) at $x = 0$, $y = 0$, and y =H, For solid area, constant and uniform heat flux is applied from bottom (1000 W/m^2).

$$q'' = -k_s \frac{\partial T_S}{\partial y} , \quad y = -H_s$$

$$\frac{\partial T_S}{\partial x} = 0 , \quad x=0 , x= L$$

5- The boundary condition of conjugate heat transfer for the interface between the 2 areas will be

$$k_s \left(\frac{\partial T_S}{\partial y}\right)_{solid} = k_{nf} \left(\frac{\partial T_f}{\partial y}\right)_{nanofluid} , \quad y= 0.$$

CHECKING THE VALIDITY OF THE COMPUTATIONAL FLUID DYNAMICS (CFD):

To ensure the validity of the (ANSYS FLUENT 2020.R1) software, it because necessary to check of the program and its ability to give approximated results, Therefore, Nusselt's theoretical equation was chosen and the results of the theoretical equation were compared to results of simulation (CFD) and the results obtained from the program (ANSYS FLUENT 2020.R1) with the theoretical equation were convergent and the difference between them was very small with 5.5% theoretically. As shown in the following figure(2) .

The analysis has considered the laminar heat transfer, fully developed and the uniform heat-flux, it may be seen that local Nusselt number can be computed as:

$$Nu_x = \frac{0.4637\, Re_x^{\frac{1}{2}} Pr^{\frac{1}{3}}}{\left[1+\left(\frac{0.0207}{Pr}\right)^{2/3}\right]^{1/4}} \qquad Re_x < 2200 \;\ldots(24)$$

Therefore, Nusselt's theoretical equation (24), as is cited in the Churchill. Bernstein [20].

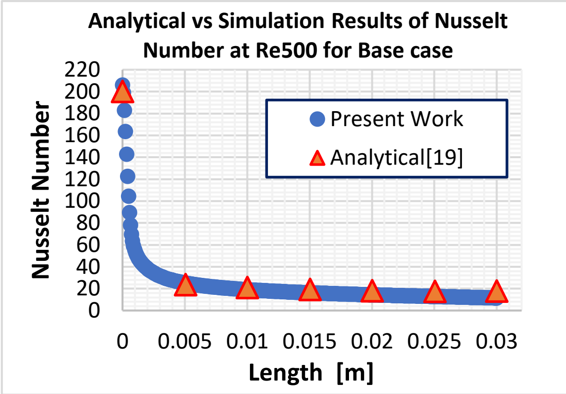
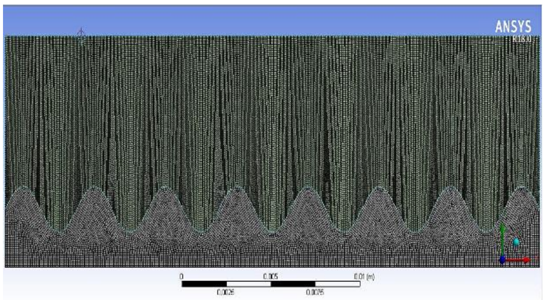


Figure (2) the Analytical results with the theoretical Simulation Nusselt Number along the channel

GRID GENERATION:

Meshing of complex geometry makes the approach of the finite element a powerful way for solving the problems of the boundary value, which occur in various engineering applications. Fig. (3).



The figure (3) Wave Mesh Structure of element for the mode

WAVY CHANNEL WITH NANOFLUID:

A grid independent test was performed before taking the numerical readings, as the channel was divided into several values representing the number of elements, and at the minimum tested value for Reynolds number is (500), the number of elements were chosen (54,000) as the results became stable and Converging, as shown in the figure(3) .

Figures (4),(5),(6) and (7) show a contour of velocity, temperature, pressure and Dynamic pressure at (Re. = 500) along the wavy channel respectively.

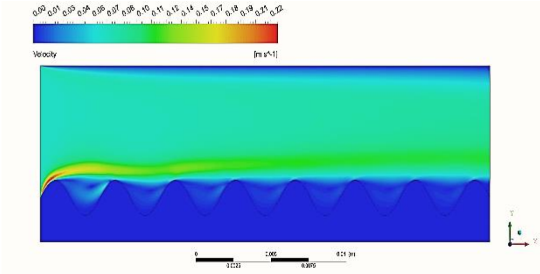


Figure (4) a two-dimensional view for velocity contour within the channel at (Re = 500)

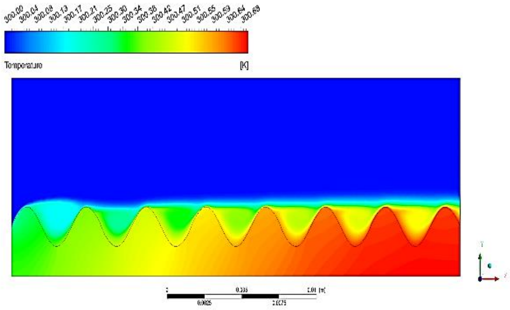


Figure (5) a 2-D view of the temperature contour inside the channel at (Re = 500)

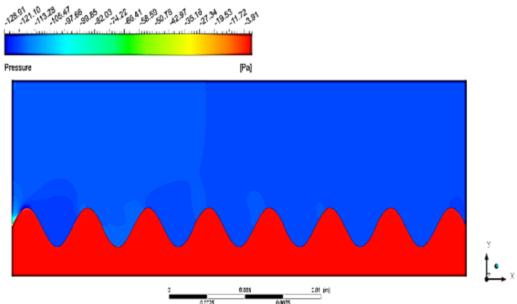


Figure (6) a 2-D view of the pressure contour inside channel at (Re = 500)

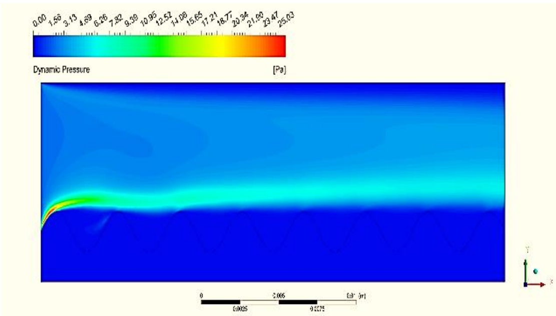


Figure (7) a 2-D view of the dynamic pressure contour inside the channel at (Re = 500)

Figures (8),(9) and (10) show The relationship between Reynolds number and each of the pressure drop(Δp), thermal resistance(Φ), Nusselt number and coefficient of heat transfer (h) respectively. Figure (11) the (fr) along the channel.

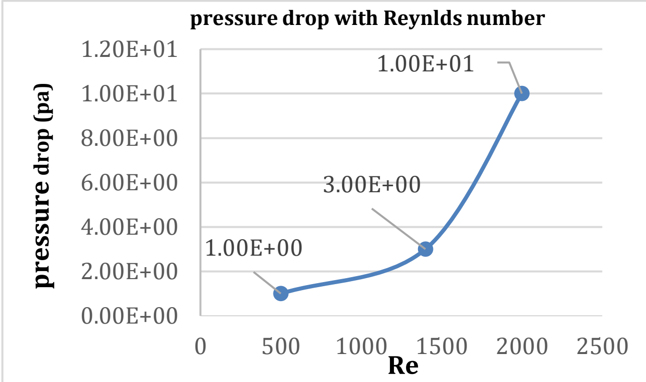


Figure (8) show the correlation between pressure drop and Reynolds number for Nanofluid with Wavy channel

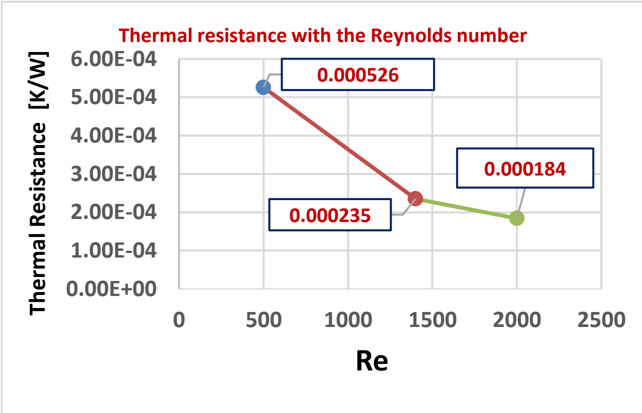


Figure (9) show the correlation between thermal resistance and Reynolds number for Nanofluid with Wavy channel

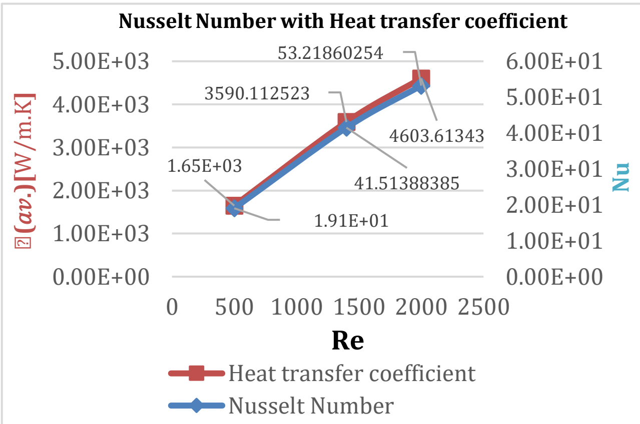


Figure (10) show the correlation between Nusselt number and the coefficient of heat transfer with Re. for Nanofluid with Wavy channel

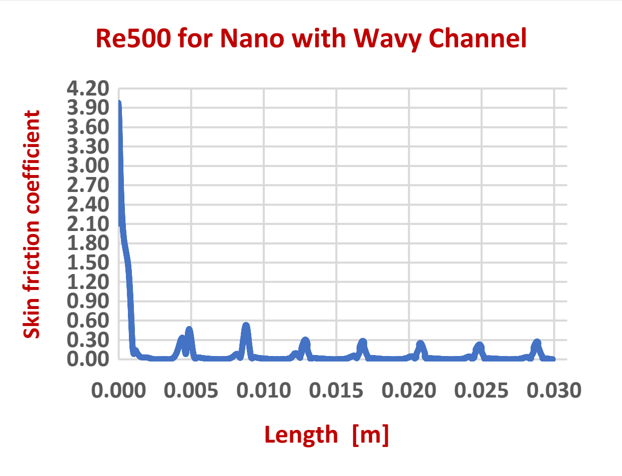


Figure (11) the coefficient of friction (fr) along the channel at (Re = 500)

COMPARISON OF THE STUDIED CASES AND CONCLUSIONS:

Pressure and Pressure drop:

Pressure drop can be described as a very significant parameter for studying fluid flow and heat transfer in laminar flow, which has to do with the capacity and fullness of the pump, And its impact on the value of the PEC. The pressure drop increases as the number of Reynolds increases, and we notice the highest pressure drop when using water in an ideal state and the lowest pressure drop when using the wave channel, and it comes after when using the wave channel with nanofluid and we notice the pressure drop increases when adding the nanofluid due to the increase in the fluid concentration as a result of the increase in the nano-fluid viscosity.

Skin friction coefficient:

the highest friction coefficient value is in the (entrance region), which is an area where the flow is thermally incomplete because the thickness of the adjacent layer is the lowest possible in the entry region and the value of the friction coefficient increases when adding nanoparticles as well as when The presence of waves.

Heat transfer coefficient:

the lowest heat transfer coefficient value for the flat channel of water and the highest heat transfer coefficient value for wave channel in the presence of the nanofluid at (Re = 2000). An enhancement in heat transfer coefficient has been noticed when adding nanoparticles, and the improvement increases with increasing the concentration of nanofluid.

Nusselt number:

The highest value of Nusselt number is in the entry region, and the flow in the distant regions from the entry is thermally complete, so the value of Nusselt remains constant and the use of nanoparticles increased the number of Nusselt.

Performance evaluation criterion (PEC):

PEC that increases with increasing Re and increases (PEC) with increasing nanomaterial concentration.

CONCLUSIONS

The most important conclusions and recommendations reached in this study that summarize a two-dimensional simulation of heat transfer and fluid flow in a Micro- channel with several flat and wave shapes as well as the effect of added nanoparticles (AL2O3), and after discussing all the shapes resulting from this study, the most important conclusions were reached. Included in this research according to the following:

1- A micro-wavy channel represents the optimal state among of all studied cases and for all Reynolds numbers.
2- The wavy channel showed the lowest pressure drop compared to the other studied cases.
3- The pressure drop increases, the thermal resistance decreases, the heat transfer coefficient increases, and the performance coefficient increases with the increase of Reynolds number.
4- The change of Re affects the amount of heat transferred from the channel surface to the fluid in the inlet zone (entrance region), which is a region where the flow is thermally incomplete due to the fact that the thickness of the adjacent layer is as small as possible in the entry area, and the flow in the distant regions is thermally complete, so the value of the inflow remains there The use of waves and nanoparticles increased

the number of nanoparticles in all these regions.

5- The greatest value of performance (PEC) is obtained is from wavy channel in at Reynolds number (Re = 2000).

6- There is a rise in pressure drop when using the nanofluid if modern equations are used that give results near to laboratory results, if the high-pressure drop due to the added nanomaterial causes an increase in the viscosity of the nanofluid, and this increase is offset by a rise in the heat transfer coefficient.

7- Reynolds number At (2000) and a (2%) volume concentration, the amount of heat transfer rate was equal to (4603.61) when using the nanofluid due to dispersion factors, Brownian motion, and nanoparticles that are responsible for enhancing heat transfer.

8- The addition of waves in the channel and nanoparticles increased the number of Nusselt and thus improved heat transfer.

References

[1] Meteorology Today: "An Introduction to Weather Climate،، and the Environment C. Donald Ahrens".

[2] A.E Bergles. , "Enhanced heat transfer: endless frontier, or mature and routine. Paper C565/082/99. Proceedings of the UK National Heat Transfer Conference, Heriot-Watt University. IMechE, Bury St Edmunds, September." 1999.

[3] M.R. Salem, R.K. Ali, R.Y. Sakr and K.M. Elshazly، "Experimental Study on Convective Heat Transfer and Pressure Drop of Water-Based Nanofluid Inside Shell and Coil Heat Exchanger، PhD Dissertation، Faculty of Engineering at Shoubra, Benha University, Cairo, Egypt, June2014,DOI:10.13140/RG.2.2.31958.75846."

[4] H.I Abu-Mulaweh. ،"Experimental Comparison Between Heat Transfer Enhancement Methods in Heat Exchangers, The International Journal of Mechanical Engineering Education, vol. 31(2), pp. 160–167,2003."

[5] A.E. Bergles, "Techniques to Enhance Heat Transfer," in Handbook of Heat Transfer, 3rd ed., W. M. Rohsenow, J. P. Hartnett, Y. I. Cho, Eds., McGraw-Hill, New York, pp. 11.1–11.76, 1998.

[6] A. Dewan, P. Mahanta, K. Sumithra Raju and P. Suresh Kumar, "Review of Passive Heat Transfer Augmentation Techniques," Proc. Instn Mech. Engrs، Vol. 218, Part A: J. Power and Energy, A04804 © IMechE 2004.

[7] A.N. Mahureand and V.M. Kriplani, "Review of Heat Transfer Enhancement Techniques," International Journal of Engineering Research and Technology, ISSN 0974-3154, vol. 5(3), pp. 241–249, 2012.

[8] A.R. Al-Obaidi, Investigation of fluid field analysis، characteristics of pressure drop and improvement of heat transfer in three-dimensional circular corrugated pipes, Journal of Energy Storage 26 (2019) 1-21.

[9] A.Ramiar and A. A. Ranjbar "Two-Dimensional Variable Property Conjugate Heat Transfer Simulation of Nanofluids in Microchannels،" Journal of Nanoscience, Vol. 13, Article No.217382, pp.1-9, 2013.

[10] A. Abdollahi , H.A. Mohammed , Sh.M. Vanaki , A. Osia and M.R. Golbahar aghighi "Fluid flow and heat transfer of nanofluids in microchannel heat sink with V-type inlet/outlet arrangement," Alexandria Engineering Journal, 56, 161–170, 2017.

[11] M. M. Rashidi, A. Hosseini, S. Kumar and Freidoonimehr "Comparative numerical study of single and two-phase models of nanofluid heat transfer in wavy channel, "Applied Mathematics and Mechanics, English Edition, Springer-Verlag Berlin Heidelberg, 2014.

[12] B.Niceno And E.Nobile "numerical analyisis of fluid flow and heat transfer in periodic wavy channels، "International Journal of Heat and Fluid Flow vol.22,156-167, 2001.

[13] P.Bhattacharya, A.N. Samanta, and S.Chakraborty, "Numerical study of conjugate heat transfer in rectangular microchannel heat sink with Al2O3/H2O nanofluid," Heat and Mass Transfer, vol. 45, no. 10, pp. 1323–1333, 2009.

[14] S. Senthilraja, M. Karthikeyan and R. Gangadevi، "Nanofluid Applications in Future Automobiles: comprehensive Review of Existing Data" , Nano-Micro Lett.2, pp. 306-310.2010.

[15] B. C.Pack, and Cho, Y. I., Hydrodynamic and Heat Transfer Study of Dispersed Fluids with Submicron Metallic Oxide Particles, Experimental Heat Transfer, vol. 11, no. 2, pp. 151–170, 1998.

[16] Khanafar, Vafai and Lightstone, M., Buoyancy-Driven Heat Transfer Enhancement in a Two-Dimensional

Enclosure Utilizing Nanofluids, International Journal of Heat and Mass Transfer, vol. 46, No.19, pp. 3639-3653, 2003.

[17] M.Corcione, Rayleigh–Bénard Convection Heat Transfer in Nanoparticle Suspensions, International Journal of Heat and Fluid Flow، vol. 32, pp. 65–77, 2011.

[18] ANSYS FLUENT Workbench User's Guide; Release 12.1. ANSYS, Inc. Cecil Township, Washington County, PA, USA, 2009.

[19] H. E. Ahmed and M. Z. Yusoff, "Thermal enhancement of triangular duct using compound of vortex generators and nanofluids," Heat Transfer Engineering, 2017.

[20] S. W. Churchill and Ozoe., "Correlations for Laminar Forced Convection in Flow a Flat Plate and in Developing and Fully Developed Flow in an Isothermal Tube،" ASME J. Heat Transfer, 95, pp. 416–419, 1973.

إنتقال الحرارة المقترن لتدفق المائع النانوي داخل قناة صغرى متموجة

حسين جمال حسين
hussein.enp65@student.uomosul.edu.iq

امير سلطان داؤود
asdawood@uomosul.edu.iq

قسم الهندسة الميكانيكية، كلية الهندسة، جامعة الموصل

الخلاصة

تم استخدام نهج نقل الحرارة المقترن في هذا العمل لدراسة عددية لنقل الحرارة بالحمل الحراري القسري الثنائي الأبعاد لأوكسيد الألومنيوم -السائل النانوي الأساس(الماء) في قناة أفقية متموجة صغيرة، فضلا عن ذلك تم دراسة تأثير إضافة الجسيمات النانوية لتدفق الحرارة الثابت أسفل القناة، افترضت الدراسة أن المائع النانوي يخضع لفرضية احادي الطور يعامل السائل الأساسي (H_2O) والجسيمات النانوية (Al_2O_3)كمزيج متجانس وأن المائع النانوي غير قابل للانضغاط وجريانه مستقر وطباقي، وعدد رينولدز وتركيز حجم الجسيمات النانوية تعتبر في حدود (500-2000)و٪2 على التوالي. تم استخدام برنامج انسزز فلونت (ANSYS FLUENT 2020 R1)وهو أحد برامج ديناميكا الموائع الحسابية(CFD)، وتم اختيار طريقة الحجم المحدود(FVM) لحل المعادلات الحاكمة. ولضمان دقة النتائج تم التحقق من المعادلات النظرية الحديثة ومقارنتها مع برنامج المحاكاة CFD. في هذا البحث تم فحص أربعة نماذج عدديًا، النموذج الأول هو عبارة عن قناة صغيرة مسطحة ويتدفق الماء فقط من خلالها. النموذج الثاني فهو عبارة عن قناة صغيرة متموجة ويتدفق الماء فقط من خلالها. النموذج الثالث هو عبارة عن قناة صغيرة مسطحة حيث يمر السائل النانوي المكون من الماء والجسيمات النانوية عبره. وكان النموذج الرابع عبارة عن قناة صغيرة متموجة يمر فيها السائل النانوي المكون من الماء والجسيمات النانوية (AL_2O_3) عبر القناة لثلاث قيم مختلفة لأعداد رينولدز(500،1400،2000) وتركيز (٪2) من الجسيمات النانوية، تمثل القناة الصغيرة المموجة الحالة المثلى من بين جميع الحالات المدروسة ولجميع أرقام رينولدز. يتم تسجيل أفضل معيار لتقييم الأداء (PEC) لحالة القناة المتموجة ذات الموائع النانوية لرقم رينولدز الذي يساوي (2000). وعند Re=2000 بتركيز حجمي (٪2)كانت قيمة معامل نقل الحرارة تساوي (4603.61) عند استخدام الموائع النانوية بسبب عوامل التشتت والحركة البراونية والجسيمات النانوية المسؤولة عن تعزيز نقل الحرارة. كما توصلت الدراسة الى ان وجود القناة المتموجة وتدفق السوائل النانوية يعزز عدد نسلت ويحسن انتقال الحرارة إلى السائل.

الكلمات الدالة:
نقل الحرارة المترافق، المائع النانوي، قناة متموجة، ديناميكية الموائع الحسابية