Numerical investigation of the effect of including three fins inside a channel on thermo hydrodynamic behavior of nanofluid

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Abstract: This paper presents a numerical study of the flow around three fins inside a channel. The effect of including three fins on the heat transfer characteristics is studied. The effect of different parameters such as Hartmann number Ha, Reynolds number Re, Magnetic field angle γ and the nanoparticles volume fraction φ on heat transfer characteristics in the presence of fins was studied.

Keywords: Magnetic field inclination, Nanofluid, Nanoparticles, fins angle orientation, MHD, forced convection .

1. INTRODUCTION

Heat transfer and fluid flow characteristics over a channel including obstacles with different types of geometry was recently interested by researchers due to its importance in industrials applications such as cooling electronic devices and nuclear reactors. The magnetic field can control the flow and energy transport mechanism of the ferrofluid. However, the computational fluid dynamic can be used to study these phenomena. Several numerical and experimental studies are focused on two dimensional or three dimensional MHD free or forced convection flows over channels with obstacles

Sarkar et al (2013) studied MHD free and forced convection of viscous incompressible flow through a channel including magnetic field in order to examine the effect of viscosity and joule dissipations and magnetic parameter on the heat transfer characteristics. Gul et al (2015) studied MHD mixed convection of ferrofluid over a vertical channel in the presence of transverse magnetic field using water with magnetic nanoparticles Fe3O4 and non-magnetic nanoparticles Al2O3. Results shows the effect of viscosity and thermal conductivity is more important on temperature and velocity of the ferrofluids under magnetic field. Rashidi et al (2015) in their study present forced convection flow through a channel including square obstacle under magnetic field. Results show that when Stuart number increases the boundary layer increases so the heat transfer decreases. Vimala et al (2016) in there study investigated the effect of magnetic Reynolds number on velocity gradients in MHD forced convection heat transfer from cylinder including magnetic field.it is observed that average Nusselt number decreases until $N \leq 1$ and increases by increasing the interaction parameter. Sheikholeslami et al (2017) studied nanofluid forced convection in porous semi-annulus under uniform magnetic field including various shapes of nanoparticles. It observed that the increasing of Darcy number Da and Reynolds number Re the velocity of nanfluid increases. As well as the Nusselt number Nu increases by increasing the nanoparticles volume fraction and decreases when the Lorentz force increases. Sheikholeslami et al (2017) in their study use Lattice Boltzmann Method(LBM) for nanofluid flow inside a cavity including hot obstacle under magnetic field. Results show that thermal plume decreases by increasing Hartmann number. However when Darcy number and Reynolds number increases the convection was improved. Yuan et al (2018) numerically investigated forced convection heat transfer of nanofluid (MWCNT–Fe3O4/water hybrid nanofluid) under magnetic field inside a partially heated channel. Results show that Nusselt number increases as Ha increases for the heater of dominating convection mechanism but decreases for the heater of dominating conduction mechanism. Nguyen et al (2019) studied a nanofluid forced convection flow over a wavy channel with obstacles using different shapes of CuO nanoparticles in order to enhance the heat transfer. Results show that when replacing the spherical nanoparticles by the platelet the heat transfer rate increases more than 55 %. Hussain et al (2019) in their study used a computational approach using different nanoparticles in the base fluid such as Silica (SiO2), Copper (Cu) and Alumina (Al) in order to study the forced convection of nanofluid over a rotating cylinder inside a channel. Results show that the clockwise rotation of the cylinder makes the fluid move over the cylinder while the fluid moves below the cylinder in the anticlockwise case, and when the nanoparticles volume fraction increases the Nusselt number increases too. Selimefendigil el al (2019) numerically studied nanofluid forced convection within branching channel including uniforme magnetic field in order to improve the heat transfer characteristics of the separated flow in this channel. Alsabery et al (2021) present a computational analysis of nanosuspension forced convection in wavy channel in order to enhance the heat transfer. It observed that as Reynolds number increases the average velocity and the average Nusselt number increases both. However an augmentation of nanoparticles volume fraction results an increment of the temperature and the heat transfer was enhanced. Mansour et al (2021) investigated numerically MHD natural convection of a nanofluid into inclined square cavity with a cylindrical obstacle. Results show that the average Nusselt number decreases by increasing the radius of a cylindrical obstacle. Oğlakkaya et al (2023) numerically investigated forced convection flow through a channel in the presence of uniform magnetic field including a rotating cylinder in the center of the channel to show how controlling parameters and the presence of the cylinder affect heat transfer and flow characteristics. It is observed that by increasing the intensity of magnetic field the effect of rotating cylinder decreases so Nusselt number increases and the heat transfer was enhanced.

2. DESCRIPTION OF THE PROBLEM

The geometry of the physical problem is presented in the figure above; it's a channel with three fins. H is the height of the step. 13H is the length channel. A parabolic profile of velocity and uniform temperature are imposed in the inlet. Tc is the temperature of straight wall and Th is the temperature of the downstream wall. Magnetic field was located below the channel. In this paper different magnetic field inclination were calculated for different fins orientations angles.

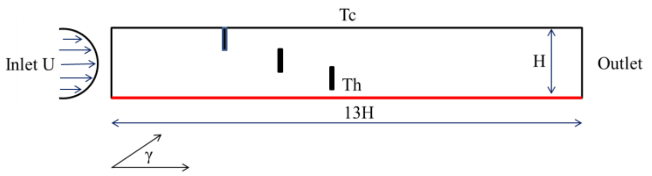


Figure 1.Geometry of the problem

2. GOVERNING EQUATIONS

The governing equations of continuity, momentum and energy are expressed as follows [1]:

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

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

$$+\sigma_{nf} B_0^2 (u \sin\gamma \cos\gamma - v sin^2 y) \qquad (2)$$

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

$$+\sigma_{nf} B_0^2 (u \sin\gamma \cos\gamma - v cos^2 y) \qquad (3)$$

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} v\frac{\partial T}{\partial y} = -\frac{\partial P}{\partial y} + \sigma_{nf}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) \qquad (4)$$

3. EFFECTIVE THERMO PHYSICAL PROPERTIES OF THE NANOFLUID [1]:

Density: $\rho_{nf} = \varphi\rho_s + (1-\varphi)\rho_f$

Dynamic viscosity: $\mu_{nf} = \mu_f(1-\varphi)^{-25}$

Thermal diffusivity: $a_{nf} = \frac{k_{nf}}{(\rho Cp)_{nf}}$

Thermal conductivity: $k_{nf} = \frac{k_s + 2k_f - 2\varphi(k_f - k_s)}{k_s + 2k_f + \varphi(k_f - k_s)} k_f$

Thermal expansion coefficient :

$(\rho\beta)_{nf} = \varphi(\rho\beta)_s + (1-\varphi)(\rho\beta)_f$

Specific heat: $(\rho Cp)_{nf} = \varphi(\rho Cp)_s + (1-\varphi)(\rho Cp)_f$

Electrical conductivity: $\sigma_{nf} = \sigma_f\left[1 + \frac{3(\sigma-1)\varphi}{(\sigma+2)-(\sigma-1)\varphi}\right], \sigma = \frac{\sigma_s}{\sigma_f}$

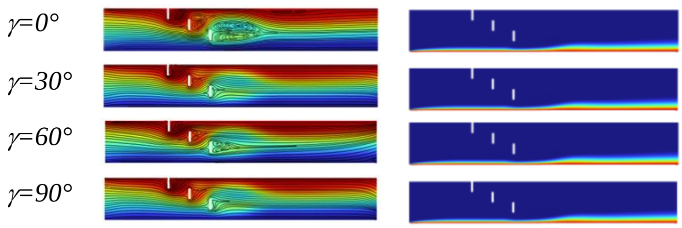
4. RESULTS AND DISCUSSION

Numerical simulations in this study are performed for various values of Hartman number Ha (Ha= 0, 25 and 50), Reynolds numbers Re (Re= 5, 10 and 100), magnetic field inclination γ (γ= 0,60 and 90), and the nanoparticle volume fraction φ (φ = 0, 0.02 and 0.04). The effects of the different parameters on the streamlines, isotherms and average Nusselt number are presented and interpreted in this study. The obtained results of streamlines and isotherms are presented in Figures. 2-4 as contour maps as well as the effect of fins angle orientation on the average Nusselt number are presented in graphs in Figures. 5 -10.

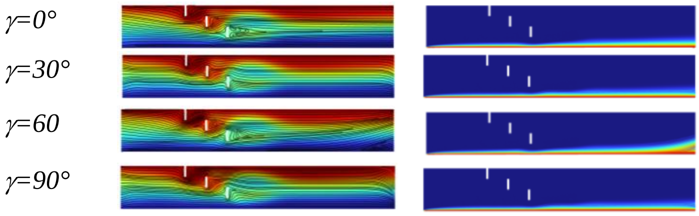
4.1 Streamlines and isotherms

4.1.1 Effect of magnetic field

a) Ha=0



b) Ha=25



c) Ha=50

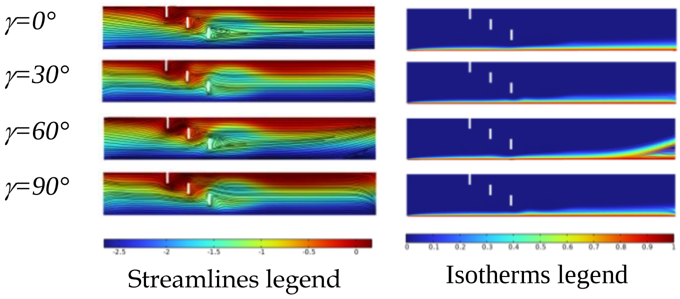


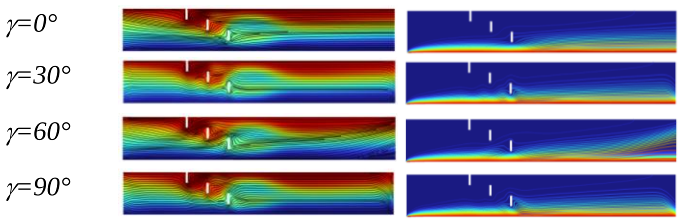
Figure 2: Streamlines and isotherms at different magnetic field inclination γ for *Ha = 0, Ha = 25, Ha = 50, Pr = 6.2, Re = 100* and *φ =0.04*

Figure 2 shows the contours of streamlines and isotherms for the variation of Hartmann number Ha=(0, 25, 50) at different magnetic field inclination angle γ=(0°, 30°, 60°,90°) at vertical fins position for Re=100, Pr=6.2 and φ=0.04.

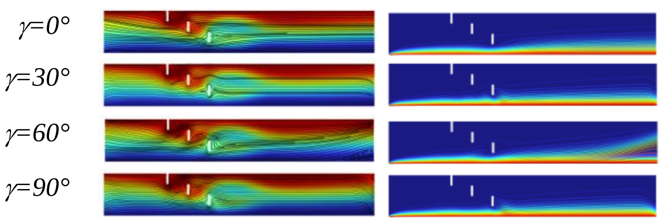
The fluid makes a strong flow at the inlet and at the top wall and weak flow at the bottom wall. At Ha=0 the nanofluid with important velocities around fins. As observed in contours velocity is more strong around the third fin, caused a separation of the flow that disappear at Ha=50 for γ=90°, the separation of the flow affect the heat transfer at the heated wall where the ferrofluid concentrates and the contact with the heated wall is better. However the isotherms begin to extend toward the top wall so the thermal boundary decreases and the heat transfer will be enhanced

4.1.2 Effect of inlet velocity

a) Re=5



b) Re=10



c) Re=100

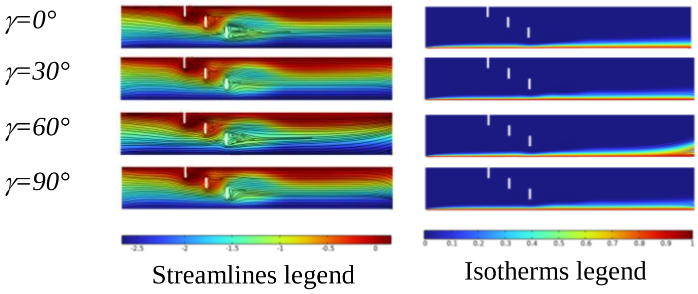
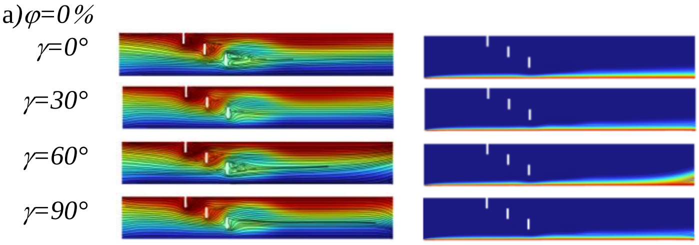


Figure 3: Streamlines and isotherms at different magnetic field inclination γ for Re=5, Re=10, Re=100, Pr = 6.2, Ha = 25, and φ = 0.04

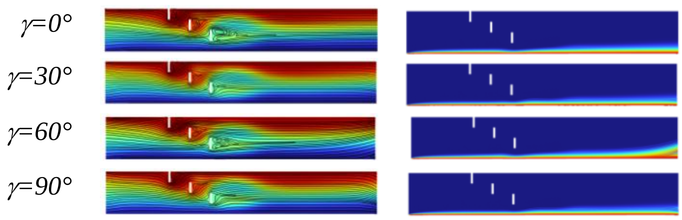
Figure 3 illustrate the stream function distribution as well as streamlines and isotherms for different Reynolds number Re=(5, 10, 100) at different magnetic field inclination γ=(0°, 30°, 60°,90°) at vertical fins position for Ha=25, Pr=6.2 and . For all angle γ Reynolds number increases, inertial force begin dominate, so the flow becomes faster at the nanofluid fins intersection. When Reynolds number increases the flow accelerates at the intersection of vertical fins to make a concentration of nanofluid at Re=100 to improve the heat transfer. For the isotherms contours the increase of Reynolds number generates a decreases of thermal boundary thickness witch enhance the heat transfer.

4.1.3 Effect of nanoparticles volume fraction

a)*φ=0%*



b)*φ=2%*



c)*φ=4%*

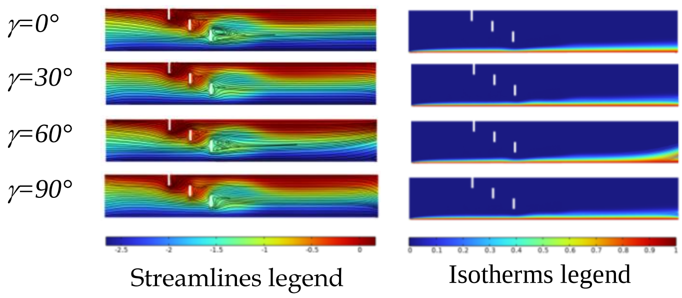


Figure 4. Streamlines and isotherms at different magnetic field inclination γ for φ= 0, φ=0.02, φ=0.04, Re = 100, Ha = 25, Pr = 6.2

Figure 2 shows the contours of streamlines and isotherms for the variation of nanoparticles concentartion φ =(0, 0.02, 0.04) at different magnetic field inclination angle γ=(0°, 30°, 60°,90°) at vertical fins position for Re=100, Ha=25 and Pr=6.2. It is observed that for all fin orientation angle when the nanoparticles volume fraction increases the heat transfer increases too and this is due to the thermal conductivity of the nanoparticles. At vertical fin position the thermal boundary layer decreases so the heat transfer is enhanced.

4.2 Effect of different parameters on average Nusselt number Nu_av:

Qualitative analyses has been focused in this section to show the effect of fins angle orientation on average Nusselt number for different parameters such as Hartmann number Ha, Reynolds number Re and nanoparticles volume fraction φ.

4.2.1 Effect of fins angle orientation α on average Nusselt number Nu_av at different Hartmann number:

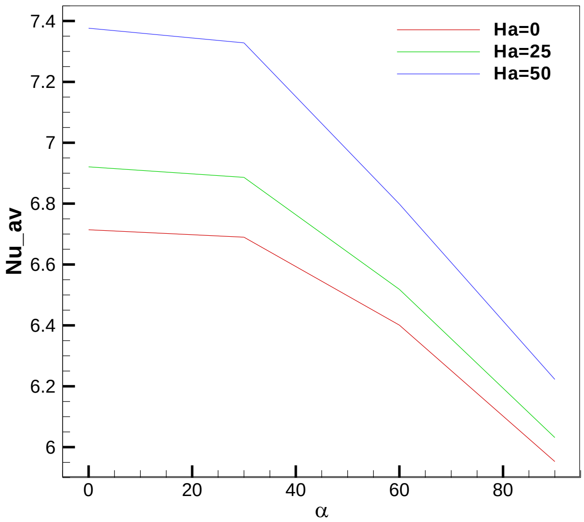


Figure 5: Average Nusselt number variation with fins orientation angle α at different Hartmann numbers Ha

Figure 5 demonstrate the effect of fins orientation angle α on average Nusselt number at different Hartmann number Ha. In this study we consider the vertical fins orientation is α=0° and the fins orientation was on the anticlockwise direction α=(30°, 60°, 90°) . Figure shows that at α=0° the average Nusselt number decreases by increasing Hartmann number, physically that is due to the presence of the Lorentz force, this force curb flow and the convection decreases too. When the fin orientation angle increases the average Nusselt number decrease for that we note that the vertical position of fin is the good position to improve the heat transfer in the absence of magnetic field.

4.2.2 Effect fins angle orientation α on average Nusselt number Nu_av at different Reynolds number:

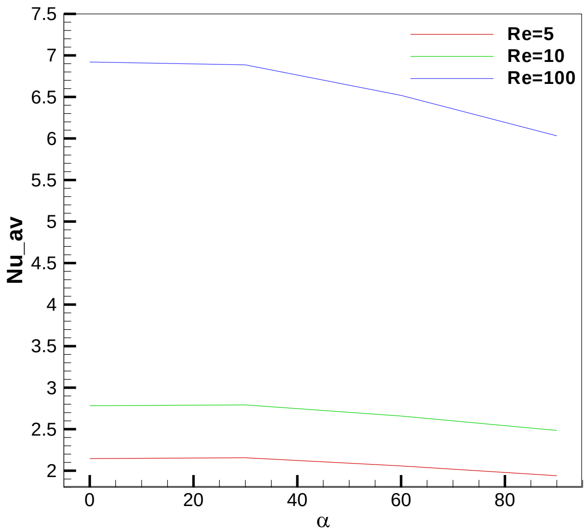


Figure 6: Average Nusselt number variation with fins orientation angle α at different Reynolds numbers Re

The effect of fins orientation angle α on average Nusselt number at different Reynolds number is shown in figure 6.It is observed that the average Nusselt number increases by increasing Reynolds number and took the maximum value 6.9 for Re=100 at vertical fins position witch assures good contact of the nanofluid with the heated wall to improve the heat transfer.

4.2.3 Effect fins angle orientation α on average Nusselt number Nu_av at different nanoparticles concentration φ:

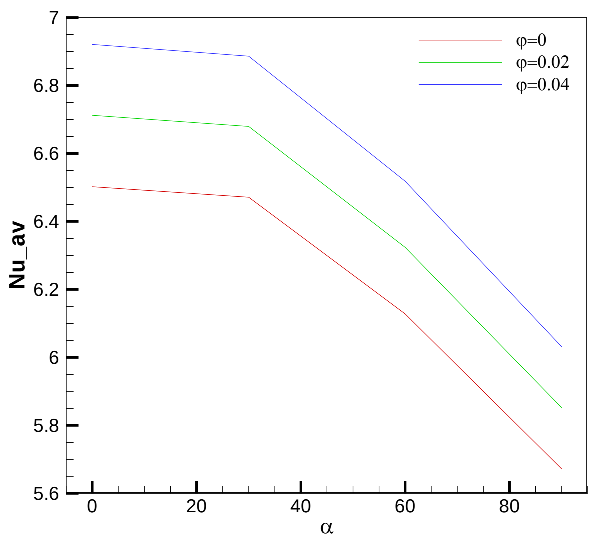


Figure7: Average Nusselt number variation with fins orientation angle α at different nanoparticles volume fraction φ

Fig. 9 displays profiles of the variation of the average Nusselt number for various values of fins orientation angle α at different nanoparticles volume fractions φ .In this figure we note that as nanoparticles volume fraction increase the average Nusselt number increases too until the maximum value equal to 7.9 for vertical fin position at φ=0.04. This is due to nanoparticles thermal conductivity that increases as the volume fraction of the nanoparticles is concentrated at the bottom by the fin in a vertical position favoring the contact with the heated wall, which generates an improvement of the heat transfer rate.

5. CONCLUSIONS

In the present numerical study, the forced magnetohydrodynamic convection of the laminar flow of nanofluid inside a channel comprising three fins has been studied. The finite element method has been used to solve the flow governing equations and wide ranges of governing parameters were considered. The following conclusions can be derived from the numerical simulation:

- The increase of the Hartmann number slows down the flow of ferrofluid, decreases the average Nusselt number, the vertical fin position makes the average Nusselt achieve a maximum value.
- The average Nusselt number increases as Reynolds number increases until it reaches a maximum value at a vertical fins position.
- Variations in the volume fraction of the nanoparticles have positive effects on the average Nusselt number, which improves at vertical fin position.

REFERENCES

Sarkar, B.C., Das, S., & Jana, R. N. (2013). MHD Free and Forced Convective Flow in a Rotating Channel. International Journal of Computer Applications, (0975 – 8887), 74(18).

Gul, A., Khan, I., Shafie, S., Khalid, A., & Khan, A. (2015). Heat Transfer in MHD Mixed Convection Flow of a Ferrofluid along a Vertical Channel. PLoS ONE. 10(11): e0141213. doi:10.1371/journal.pone.0141213

Selimefendigil, F., Öztop, H.F., & Chamkha, A.J. (2019). Role of magnetic field on forced convection of nanofluid in a branching channel, International Journal of Numerical Methods for Heat & Fluid Flow, https://doi.org/10.1108/HFF-10-2018-0568

Vimala, S., Damodaran, S., Sivakumar, R., & Sekhar, T. (2016). The role of magnetic Reynolds number in MHD forced convection heat transfer. Applied Mathematical Modelling. DOI: 10.1016/j.apm.2016.02.019

S. Rashidi, J.A. Esfahani, Journal of Magnetism and Magnetic Materials 391 (2015)5–11, http://dx.doi.org/10.1016/j.jmmm.2015.04.095

Sheikholeslami, M., & Bhatti, M.M. (2017). Forced convection of nanofluid in presence of constant magnetic field considering shape effects of nanoparticles. International Journal of Heat and Mass Transfer 111, 1039–1049. http://dx.doi.org/10.1016/j.ijheatmasstransfer.2017.04.070

Yuan, M., Mohebbi, R., Rashidi, M.M.,& Yang, Z. (2018). MHD forced convection of MWCNT–Fe3O4/water hybrid nanofluid in a partially heated τ-shaped channel using LBM. Journal of Thermal Analysis and Calorimetry. https://doi.org/10.1007/s10973-018-7788-4

Sheikholeslami, M., Hayat, T., & Alsaedi, A. (2018). Numerical simulation for forced convection flow of MHD CuO-H2O nanofluid inside a cavity by means of LBM. Journal of Molecular Liquids 249 (2018) 941–948, https://doi.org/10.1016/j.molliq.2017.10.099

Hussain, S., Jamal, M., & Sameh, E.A. (2019). Hydrodynamic forces and heat transfer of nanofluid forced convection flow around a rotating cylinder using finite element method: The impact of nanoparticles. International Communications in Heat and Mass Transfer 108, 104310. https://doi.org/10.1016/j.icheatmasstransfer.2019.104310

Nguyen. T.K., Saidizad, A., Jafaryar, M., Sheikholeslami, M., Barzegar Gerdroodbary,M., Moradi,R., & Zhixiong, L. (2019). Influence of various shapes of CuO nanomaterial on nanofluid forced convection within a sinusoidal channel with obstacles. Chemical Engineering Research and Design. https://doi.org/10.1016/j.cherd.2019.04.030

Alsbery, A.I.,Hajjar, A., Sheremet,M.A., Ghalambaz, M., & Hashim, I. (2021). Impact of particles tracking model of nanofluid on forced convection heat transfer within a wavy horizontal channel,. International Communications in Heat and Mass Transfer 122, 105176. https://doi.org/10.1016/j.icheatmasstransfer.2021.105176

Mansour, M.A., Gorla, R.S.R., Siddiqa, S., Rashad, A.M., & Salah, T. (2021). IJNSNS 2021; aop, https://doi.org/10.1515/ijnsns-2020-0138

Oğlakkaya, F.S., & Bozkaya, C. (2023). MHD forced convection flow in an infinite channel with a rotating cylinder, Engineering Analysis with Boundary Elements 156, 189-198. https://doi.org/10.1016/j.enganabound.2023.07.045