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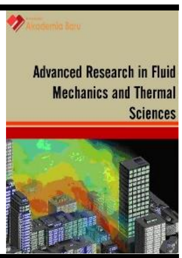

Enhancement of Nanofluid Heat Transfer in Elliptical Pipe and Helical Micro Tube Heat Exchanger

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ABSTRACT

This manuscript offers three-dimensional turbulent flow *with a single-phase* of different nanofluids with different pitch of copper elliptical tube and helical micro pipe heat exchanger device is proposed numerically investigated to determine the effect on the heat transfer coefficient, friction factor and thermal performance factor. It is very difficult and time-consuming if these analyses could be carried out experimentally. The proposed approach utilized simultaneous passive heat transfer improvement via incorporate the geometry impact using nanofluids influx within the elliptical helical micro pipe. The approach has several notable merits, namely, minimize the overall volume and cost of the heat exchanger. The tests are carried out using. computational fluid dynamics (CFD) simulations (ANSYS- eighteen) to resolve the governing equations of mass, momentum, and energy employing a finite element method (FLM) two types of nanoparticles ZnO, SiO_2 and water as a base fluid with various volume fractions ($1\% - 2\%$), diameters of nanoparticles ($dp = 25nm$) and Reynolds number ranging from 4000 to 20000 in a constant tube surface area of helical micro pipe with different pitch and diameter (10, 14 and 18 mm). From the simulation work, it was discovered that when Reynolds number and nanofluid volume fraction increases Nusselt number increase, likewise the results show that ZnO with volume fractions of 2% offered utmost Nusselt number. Whereas, the uppermost value of thermal performance factor gained at pitch and diameter 18 mm.

1. Introduction

Heat transfer augmentation techniques are very important to save energy and using ideal energy sources. It's the process of increasing the performance of a heat transfer system. Different enhancements techniques have been broadly classified as passive and active techniques. While the active techniques rely on an external source of power in order to perform heat transfer, the passive techniques, on the other hand, rely only on changes related to the heat exchanger itself. For instance, Coiled tubes, Swirl flow devices and fluid additives (Nanofluids) are among the methods that are used as a passive technique [1-4]. Helically coiled heat exchangers are usually given priority over double

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pipe heat exchangers. Thus, several researches have been mentioned that use the helical coil as a main technique [5-18]. However, most of these experiments are conducted using water as the base fluid, which has a low thermal conductivity. This leads to the usage of other types of fluids and liquids that can be used to improve heat transfer. Based on these findings the presence of nanoparticles increases the thermal conductivity without significant changes to the chemical and physical properties of the base fluid by dispersion of these nanoparticles in the base fluid [19, 20]. Furthermore, the thermal boundary layer thickness is reduced because of the non-uniform distribution of the thermal conductivity and viscosity caused by the Brownian movement of the nanoparticles. In addition, Nanoparticles display significant steadiness, higher heat transfer capabilities, and reduced particle clogging. Micro heat exchangers will be a vital part of advanced technology such as electronic devices, space, and defense technology [21-24]. These requirements can be satisfied by the incorporation of micro heat exchangers dealing with nanofluids. These nanofluids play an essential role in the improvement of thermophysical properties by which the desired consequence of heat transfer rate and pressure drop can be accomplished. [25–27]. On the other hand, a search of the literature revealed that limited studies have focused on numerical and experimental studies of the convective heat transfer of using elliptical helical microtube heat exchanger, the major focus of this research is to study the heat transfer and fluid flow characteristics induced by technique using novel configurations of elliptical helical micro tube inserts In order to improve heat transfer coefficient.

2. Model Description and Numerical Method

2.1 Physical Model and Grid

Commercial computer program ANSYS-Fluent 18 is used to create the model and grid of elliptical pipe and helical microtube heat exchanger with copper shell tube diameter of 25.45 mm OD, and length of 500 mm. The coil diameter (Dc) and pitch (Pc), (Dc) to (Pc) ratio is 1. The tetrahedrons method with an element of Quad/Tri is selected to mesh as shown in Figure 1 and Figure 2. Moreover, geometric parameters are listed in Table 1. Working fluids (water, SiO_2 and, ZnO nanofluid).

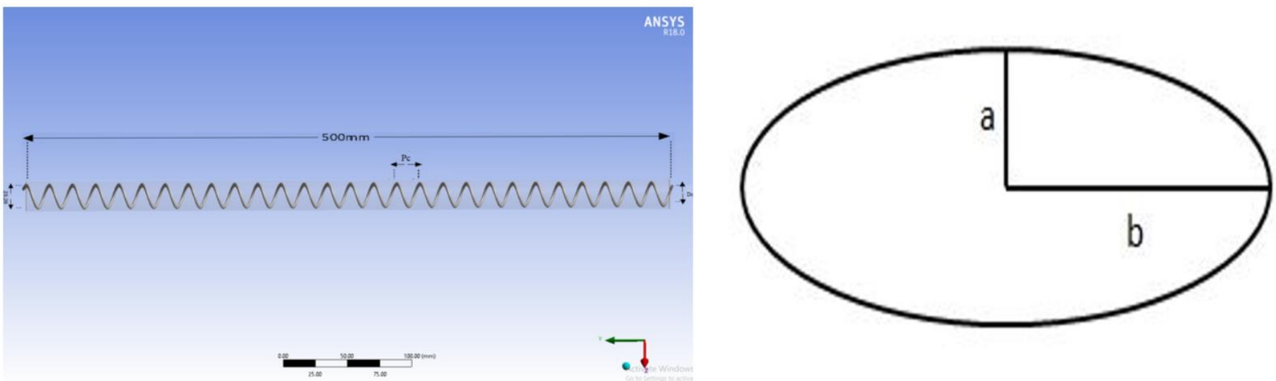

Fig. 1. Micro elliptical tube heat exchanger model and cross section

Table 1
Geometric parameters

Heat Exchanger	Pc mm	Dc mm	No of turns	a mm	b mm
1	18	18	28	0.511	1.1
2	14	14	36	0.511	1.1
3	10	10	50.5	0.511	1.1

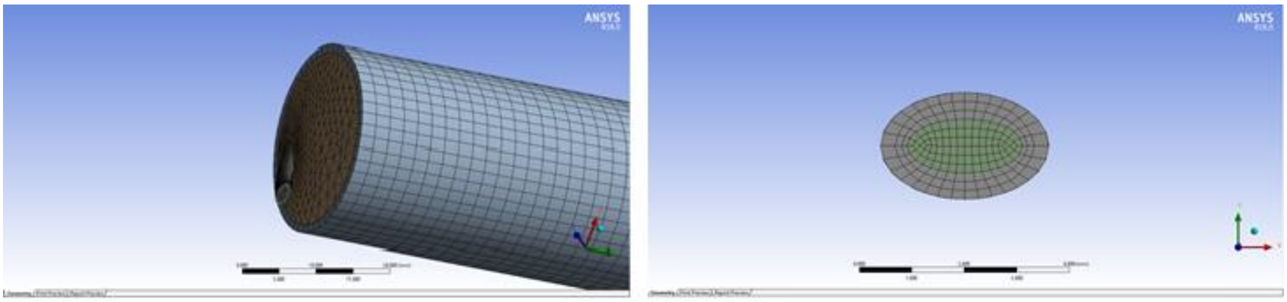

Fig. 2. Grid for Micro elliptical tube heat exchanger model and cross section

2.2 Governing Equation and Boundary Conditions

In order to simplify the numerical model, some suppositions are adopted as follows

(i) the nanofluid is Newtonian and incompressible, (ii) turbulent flow, (iii) the nanoparticles are assumed to be spherical (iv) single-phase model is utilized (v) the thermophysical properties for the nanofluid is constant, Water is employed as test fluid, steady-state, homogeneous with negligible result of viscous heating. The single-phase homogeneous flow governing equations inclusive of the turbulent phrases as follow [28]

Continuity

$$\nabla.(p_m v) = 0 \tag{1}$$

Momentum

$$\nabla.(p_m\, w) = -\nabla P + \nabla.[\tau - \tau_t] + p_m \tag{2}$$

Energy

$$\nabla.(p_m\, v c_p T) = \nabla.(\lambda_{eff}\, \nabla T - c_p\, p_m\, \overline{v} t) \tag{3}$$

The boundary conditions are as following: Inlet shell and the elliptical micro coiled pipe insert temperature determined 298 and 360 K respectively. With turbulent flow (Re= 4000-20000) of water and nanofluid through the elliptical micro coiled tube insert, turbulent flow (Re=5000) of water through shell pipe. Fluid in the outlet adjusts free and the gauge pressure was 0 Pa. the assumption is that the shell is thermal isolation.

2.3 Numerical Method and Grid Independence

In this research, the governing equations numerically are resolved by using ANSYS- Fluent 18. The equations for mass, momentum, and energy of preservation are resolved by utilizing the FLM. For determining the pressure field in the program SIMPLE algorithm was employed. Elliptical micro coil tube with the pitch of 18, 14 and 10 mm have meshed with three varying elements of 5010432, 5516738 and 509345 elements. It had been discovered that the numerical results predicted do not differ beyond 5516738 nodal points (i.e.) the perfect solution is grid-independent beyond 5516738 elements.

2.4 Nanofluid Properties

Thermos-physical properties for nanofluid of this study were calculated utilizing the follows equations [29,30]

For density

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_{np} \tag{4}$$

where ϕ Is the volume fraction of nanoparticle, ρ_f is the density of the based fluid and ρ_{np} is the density of solid nanoparticles.

For heat capacity

$$(\rho c_p)_{nf} = (1-\phi)(\rho c_p)_f + \phi(\rho c_p)_{np} \tag{5}$$

where C_{p_s} and C_{p_f} are the heat capacity of the solid particles and base fluid respectively.

For thermal conductivity

$$K_{static} = K_{static} + K_{Brownian} \tag{6}$$

$$K_{static} = K_f \left[\frac{(K_{np}+2K_f)-2\phi(K_f - K_{np})}{(K_{np}+2K_f)+2\phi(K_f - K_{np})}\right] \tag{7}$$

$$k_{Brwnian} = 5 * 10^4 \beta\phi\rho_f C_{p_f}\sqrt{\frac{KT}{2}} f(T,\phi) \tag{8}$$

where $1.9526(100\emptyset)^{-1.4594}$, $8.4407(100\emptyset)^{-1.07304}$ are the value of β for SiO_2 and ZnO respectively. Boltzmann constant: $k = 1.3807 * 10^{-23} J/K$

$$f(T,\phi) = (2.8217 * 10^{-2}\, \phi + 3.917 * 10^{-3}\,)\left(\frac{T}{T_0}\right) + (-3.669 * 10^{-2}\phi - 3.391123 * 10^{-3})$$

For viscosity

$$\mu_{eff} = \mu_f \times \frac{1}{1-34.87\left(\frac{dp}{df}\right)^{-3} \times \phi^{1.03}} \quad (9)$$

$$d_f = \left[\frac{6M}{N\pi\rho_{f_0}}\right]^{1/3} \quad (10)$$

where M is the molecular weight of base fluid, N is the Avogadro number = 6.022*10^{23} mol^{-1}, ρ_{f_0} is the mass density of the based fluid calculated at temperature T_o=293K.

3. Results

3.1 Effect of Micro Coil Pitch

The numerical analysis was conducted within an elliptical tube and helical micro pipe heat exchangers with different pitch (10, 14 and 18) mm utilize the water as a working fluid in cases like this. Figure 3, 4 and 5 show the variance of Reynolds number with Nusselt number, skin friction factor and thermal performance, Figure 3 depicts all the data to be able to compare the effect of various pitches on Nusselt number at various Reynolds number. From this figure, it is clearly show that the utmost Nusselt number may be accomplished by utilizing pitch 10 mm followed by pitch 14 mm and then pitch 18 mm, because of maximum curvature in minimum pitches. Via diminishing the micro-coil pitch, the torsion of pipe increment and powerful minor flow is generated in pipe aspect. These flows enhance the heat transfer rate in helical tubes. From Figure 4, it is obvious that with increase Reynolds number and the coil pitch the torsion of the elliptical helical micro pipe and friction factor decreases, because of stream mixing between the fluid and pipe wall caused by torsion of the micro-coil lead to the wall shear stress will be increased. Figure 5 displays the Thermal performance factor for different coil pitch with different Reynolds number. From the result, it was clearly seen that with increase Reynolds number and coil pitch. The thermal performance factor increase for the whole case and the higher thermal performance factor was found for coil at pitch 18 than others because of the powerful vortex flow produced along the coil.

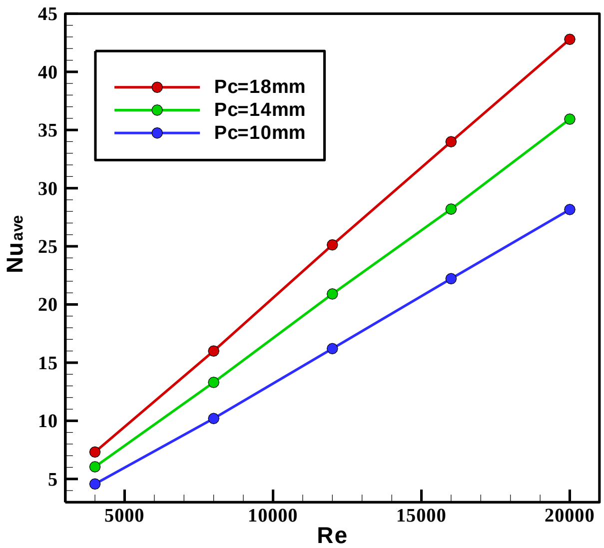

Fig. 3. The vertical and horizontal axes represent average Nusselt Number (Nu_{ave}) & Reynolds Number (Re) respectively with various micro coil pitch

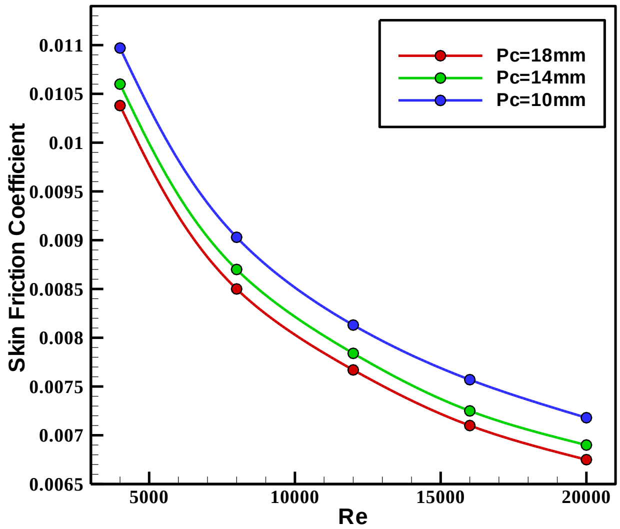

Fig. 4. The vertical and horizontal axes represent average Skin friction coefficient (SK_f) & Reynolds Number (Re) respectively with various micro coil pitch

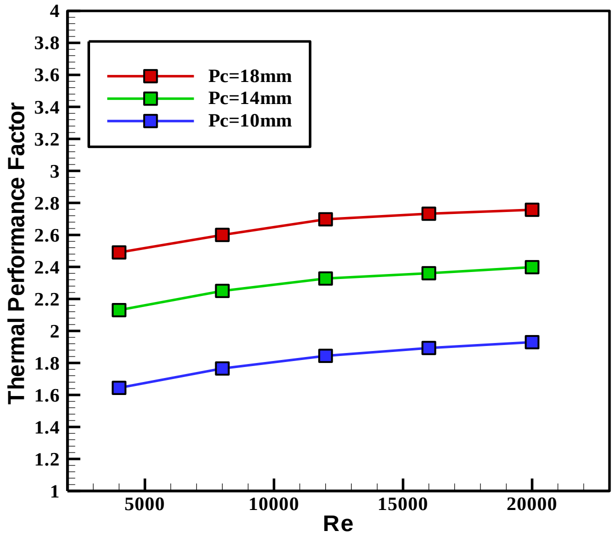

Fig. 5. The vertical and horizontal axes represent thermal performance factor (η) vs. Reynolds Number (Re) for various micro coil tube pitch

3.2 Effect of Nanofluid

In this study, two various kinds of nanoparticles which that are SiO_2 and ZnO with water as a basics liquid are being utilized .to study the impact of various nanofluids on the heat exchange improvement and the other parameter of the device of heat transfer ought to be constant. The variation of heat transfer coefficient with several Reynolds number is appeared in Figure 6 with utilizing different kinds of nanofluids at volume fraction 1% and practical diameter 25 nm of nanoparticle at elliptical pipe and helical micro tube heat exchanger with pitch (18 mm) in this case. As shown in Figure 6, the heat transfer factor of nanofluids is uppermost than that of the water and increases with Reynolds number as the existence of nanoparticles led to an increment of thermal conductivity [31-36]. Eventually, ZnO nanofluid gave a better heat transfer factor in contrast to the others. Figure 7 displays the variance of the skin friction factor with various Reynolds number. It tends to be clearly observed that the skin friction coefficient decreases with the increment of the Reynolds number. Among the fluids tested, the presence of nanoparticles in the base fluid led to a little increment in the skin friction factor due to the increment in the working fluid's viscosity. This means that the wall shear stress increment with the increment of the nanoparticles concentration [37].

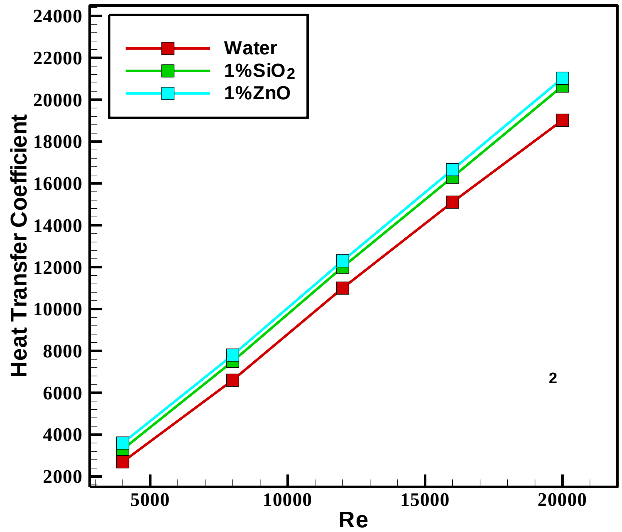

Fig. 6. The vertical and horizontal axes represent heat transfer coefficient (h) vs. various Reynolds Number (Re) with various type of nanofluids with 1% vol

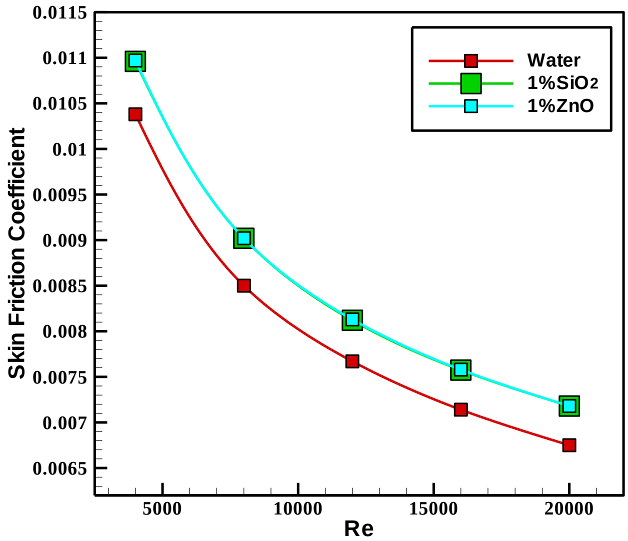

Fig. 7. The vertical and horizontal axes represent skin friction coefficient (SK_f) vs. Reynolds Number (Re) for different type of nanofluids with 1% vol

3.3 Effect of Nanoparticle Concentrations

The nanoparticles used were experimented in various concentrations. Thus, the effects of these concentrations are analyzed in this section. Figure 8 depicts the Nusselt Number and how it is affected by changes to the volume fractions. In this study, the Reynolds number varies from 4000 to 20000 and the nanoparticle concentration in the range of 1-2% is investigated. Based on results, the observation indicates that ZnO nanofluid with maximum volume fractions of 2% has the maximum surface heat transfer coefficient at all Reynolds numbers, it has been found that there is about 17%, enhancement in heat transfer coefficient for 0.2 % vol of ZnO nanoparticles in base fluid at Reynolds number 20000 as compared with the value for the base fluid. In fact, because the ZnO nanofluid has the highest thermal conductivity when compared to the other nanofluids, at that point, it tends to be inferred that increment the thermal conductivity of the fluid can ultimately lead to an improved heat transfer enhancement. Pure water has zero volume fractions and provides the lowest surface heat transfer coefficient. Another observation indicates that the heat transfer coefficient has a direct relationship with the Reynolds number. Figure 9 depicts the Reynolds number and its relationship with the skin friction coefficient. The results indicate that the relationship is opposite and at higher Reynolds number, we have lower skin friction coefficient. In the concentration range studied, there was no observed effect on the skin friction coefficient.

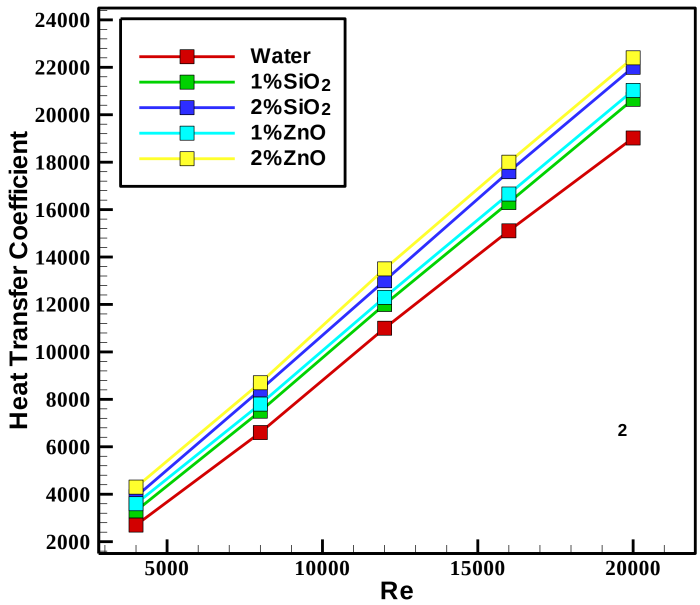

Fig. 8. The vertical and horizontal axes represent heat transfer coefficient (h) vs. various Reynolds Number (Re) with various type of nanofluids with 1-2% vol

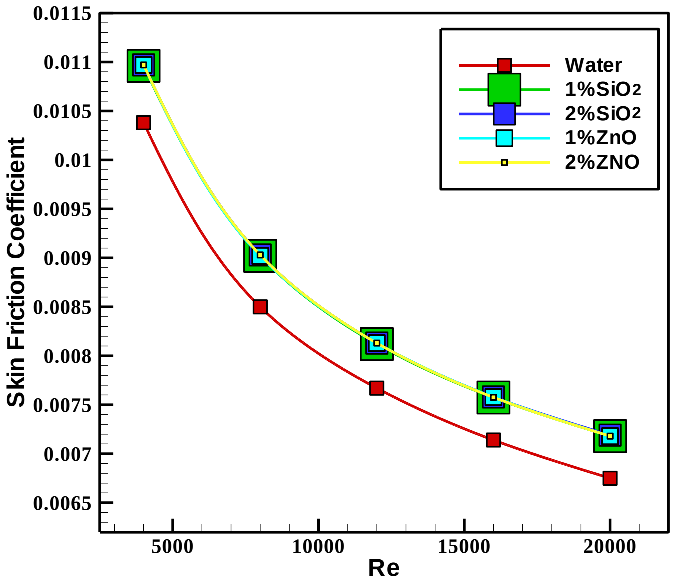

Fig. 9. The vertical and horizontal axes represent skin friction coefficient vs. Reynolds Number (Re) for different type of nanofluids with 1-2% vol

4. Conclusions

A different coil pitch (10, 14 and 18 mm) was used to enhance the heat transfer rate of turbulent flow in elliptical pipe and helical micro tube heat numerically studied. Water and nanofluids like ZnO-water and SiO_2-water as the operating fluids. From the numerical simulation, The Nusselt number and skin friction factor had been got. The subsequent conclusions had been drawn as follows

i. The elliptical helical microtube with ZnO has a higher heat transfer factor and there is no impact on skin friction factor by all nanofluids types.
ii. The increase of nanoparticle concentration obtains an increase in the Nusselt number, heat transfer factor and there is no impact on skin friction facto.
iii. Nusselt number, heat transfer factor are increment with Reynolds number and decrease in skin friction factor with Reynolds number.

Eventually, it tends to be inferred that ZnO-water is the better working fluid using with elliptical helical micro that obtain the better heat transfer improvement at 2% concentration, nanoparticle diameter of 25 nm and Reynolds number of 20000. Looking into the future, an experimental study can be conducted to validate the numerical results of this study, this work can be considered significant due to the fact that minimize the overall volume of heat exchanger lead to decrease the pumping power required for a given heat transfer process.

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