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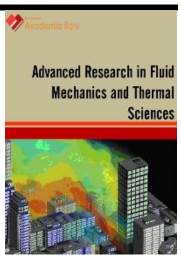

A Numerical Investigation of Laminar Hybrid Nanofluid Flow Inside Circular Straight Minitube

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ABSTRACT

This present work represents a numerical approach using concepts of computational fluid dynamics. The intension of the work is to consider single-phase to identify the various aspects of the concentration of nanoparticles with various flow inputs. Output was focused on heat transfer(convective) and friction factor under fully developed laminar flow. Experiments were conducted with a circular straight minitube. Reynolds number was altered from $400 \leq Re \leq 1200$ under constant heat flux around the minitube. The hybrid nanofluid used considered using Multiwall carbon nanotube (MWCNT)/ Titanium Oxide (TiO_2) nanoparticles at a fixed mixed ratio 20:80, with water acting as base fluid. In total, two volume fractions 0.01% and 0.05% were focused. The results indicate that as the increment in both volume fraction as well as Reynolds number shall promote Nusselt number. While reduction in friction factor was noted with increment in Reynolds number.

1. Introduction

Impact of nanotechnology is gaining high importance not just in the medical sector but also finds a key role in various streams of modern-day engineering applications. Generally, liquids are used as moving materials to carry away heat from the source. Some of the popular liquids included water and oils. Oils and water are preferred because of low thermal conductivity [1-2]. Optimizing properties such as thermo- physical of the fluid is an important aspect. Some of which include density and viscosity, these can be considered as an effective way to lower the energy consumption [3-4]. The first successful attempt to come out with a solid-liquid mixture was proposed by Maxwell [5-6]. The intention of his work was based on enhancing the thermal conductivity of the base fluid to the best possible extent. In getting better thermal conductivity there were some issues like erosion and

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losses due to pressure drop [7-8]. Thus, to develop better and efficient heat exchangers, the involvement of nanofluids can be an ideal choice. The word “nanofluid” was first termed by Choi *et al.,* [9].

This fluid is basically composed of water which acts as a base fluid, while nanometer sized particles were distressed. The range of particles was from 1-100 nm. Particles can be made of metals like copper or aluminum. A good amount of enhancement in thermal properties was found out when nanoparticles with higher thermal conductivity were mixed with the base fluid [9-10]. Later, Li *et al.,* [11] worked with copper oxide-water nanofluid. The intension of the work was to consider heat transfer coefficient and to consider various flow performances. A convective heat transfer study was conducted with a straight tube by maintaining a uniform heat transfer conditions on the boundaries. This study also focused on laminar and turbulent flow conditions at various flow rates. The results from this work made a clear conclusion on improvement in heat transfer performance and thereby gives a direct impact on friction factor. This friction factor showed good agreement with respect to water. While Tsai *et al.,* [12] worked with conventional heat pipe using nanofluid. Their area of research was on the investigation of gold with deionized water nanofluid. Heat pipe used was having 6 mm diameter and 170 mm long. Results indicate that with the use of nanofluid there is a direct lowering in thermal performance in pipe, in relation with base liquid. Moraveji and Hejazian [7] worked with a numerical approach for a case of fully developed turbulence model. They focused on heat convection concepts with nanofluid. Their domain involves a straight channel. They used concepts of computational fluid dynamics without the impact of the magnetic field. In addition, the variation of Re was 3000 and 22000. The method involves magnetic nanofluid with ferric oxide as fine nanoparticles. The nanoparticles possess diameter of 36 nm. While base fluid was water. Three different volume concentrations were used, namely; 0.02 %, 0.1 % and 0.6 %. The intension of the work was not just to relate the Nusselt number, but also and friction factor was involved, which turns out to be under acceptable limits. Sundar *et al.,* [13] focused heat transfer behavior with forced convection. The intension was to consider the turbulent approach of nanofluid flow inside a tube. The work carried out was completely experimental with magnetic nanoparticles of ferric oxide in water. The volume concentrations were in the range from 0 to 0.6 %. Experimental trials were conducted with a variation of Re starts from 3000 and varied up to 22000. Results indicate a new correlation between Nusselt number and friction factor. In addition, thermal performance improvement was noted to be 30.93 %. Presented research work basically highlights the modeling of 3D laminar flow with hybrid nanofluid at fix mixed ratio 20:80 with different volume fractions. Importance was given on numerical investigation using CFD tools (ANSYS FLUENT). Computation domain involves a horizontal straight minitube. The main intention of this work is to study the performance of hybrid nanofluid by volume fraction. While Re was varied from 400 to 1200 with a surrounded heat flux across minitube.

2. Mathematical Modeling

Presented work adopts Three-dimensional approach using computational fluid dynamics model. Where in nanofluid was modeled with the laminar flow within a circular domain. Single phase concepts with uniform conditions were enabled. Various properties of nanofluid were given as input, some of them include density, thermal conductivity, and viscosity. The behavior of the fluid was considered to be as continuous in nature. While the preliminary governing equations include continuity, momentum and energy. These equations are as follows

Conservation of mass

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

Conservation of momentum

$$\nabla.(\rho v) = -\nabla\rho + \nabla.(\tau) \tag{2}$$

Conservation of energy

$$\nabla.(\rho V C_p T) = \nabla.(\lambda\nabla T - C_p \rho v) \tag{3}$$

2.1 Significance of Hybrid Nanofluid

The significant relations of the nanofluid properties can be related as follows [14]

Density

$$\rho_{hnf} = (1-\varphi)\rho_{bf} + \varphi\rho_{p1} + \varphi\rho_{p2} \tag{4}$$

Heat Capacitance

$$C_{hnf} = \frac{(1-\varphi)\rho_{hf}C_{hf} + \varphi\rho_{p1}C_{p1} + \varphi\rho_{p2}C_{p2}}{\rho_{hnf}} \tag{5}$$

where ρhnf and $Chnf$ are noted as density and specific heat respectively, φ is overall volume concentration. The thermal performance of hybrid nanofluid are co related as follows [15]. While thermal conductivity can be formulated as given below.

Thermal conductivity

$$k_{hnf} = k_{bf}(1 + 10.5\varphi)^{0.1051} \tag{6}$$

Viscosity

$$\mu_{hnf} = \mu_{bf}(1 + \frac{\varphi}{12.5})^{6.356} \tag{7}$$

The various properties of the hybrid nanofluid MWCNT/TiO_2 at fixed mixed ratio 20:80 are tabulated in Table 1.

Table 1
Thermo-physical properties of MWCNT/TiO_2 hybrid nanofluid

Volume fraction (%)	Density (kg/m3)	Specific heat (J/kg.K)	Thermal conductivity, k (W/m.K)	Vicosity, μ (kg/m-s)
0.01	1065.5	3933.2	0.6144	0.000984
0.05	1327.5	3190.6	0.6356	0.000912

M=meter, J=joule, kg=kilogram, s=seconds, K=Kelvin

2.2 Physical Model

A 3D circular minitube that has been examined in this study where the inner diameter, D = 0.3 mm with wall thickness, t= 0.3 mm and length, L= 0.3 m while the applied surrounding heat flux, q of 17900 W/m2 is shown in Figure 1 below.

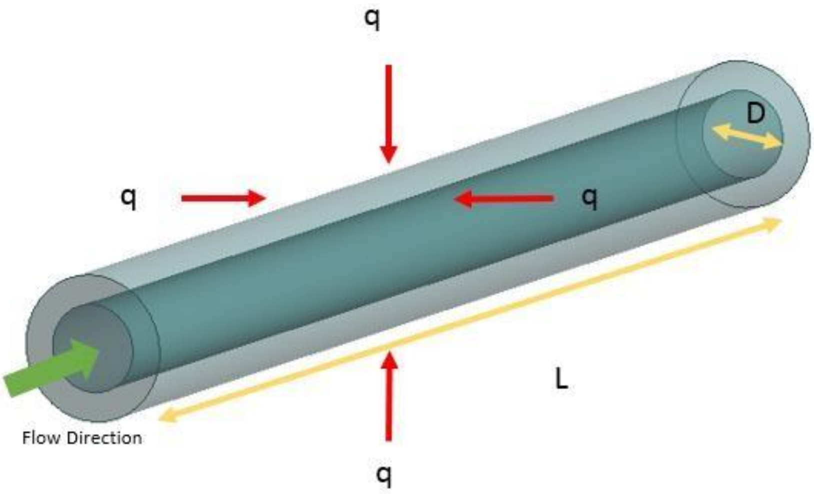

Fig. 1. 3D model

2.3 Boundary Conditions

A construction of circular minitube was devoted with inlet and the profiles of uniform axial velocity (V) was given as input. While temperature (T) was kept at 300k. Based on trails different uniform axial velocities were varied. At the of minitube exit area, the fully developed laminar conditions were adopted with all axial derivatives as zero. The behavior of minitube outer surface are considered to be adiabatic in nature. The other two important aspects include non-slip conditions and uniform heat flux was also enabled. In addition, assumptions also include continuum approach of nanofluid with characteristics of Newtonian. The behavior of the fluids was always taken as incompressible. Since the tube is cylindrical in nature the symmetric approach was enabled to reduce computation time. Finally, the physical properties were unaltered.

2.4 Numerical Method Implementation and Dependency Test Validation

The present work consists of cynical minitube which was kept at constant heat flux. Flux was kept at constant value surrounding of the tube wall. Before carrying out of the complete simulation, the computational domain was tested for better result accuracy and time effectiveness. In the case, four different mesh size models were modeled using ANSYS Software. Of all the four meshes only one suitable mesh is selected for the simulation model. The output values indicating Nusselt number were used in an independence test. Mesh points were selected based in trial and error with the following values from 37370, 253792, 644712, and 709917. Generated values from the meshing elements were carried out to come up with the best possible size. Which can be used to determine the variation of results and also the dependency of grid independency test. The interdependency of Nusselt number can be generated as below.

$$h = \frac{q}{T_{inner\,wall} - T_{mean\,fluid}} \tag{8}$$

$$Nu = \frac{h\,x\,D}{k} \tag{9}$$

where q and h refer to generated heat flux as well as value of heat transfer coefficient repetitively.

While, D along with k indicate proposed hydraulic diameter of the domain and thermal conductivity repetitively. While, T for temperature. T can be referred to the inner wall as well as mean fluid. The results produced indicate a decent agreement with element numbers more than 600,000. Thus, mesh size was shortlisted as 644,712 for entire simulation work. In addition, to ensure the validity of this simulation analysis of three dimensional circular straight minitube, data validation was done for the accuracy of the result. The data is validated against Shah equation [16] with the Nusselt number evaluated and plotted in Figure 2 as a function of longitudinal distance, z. It was very much evident that the variation differences between the output of the present work with shah equation were under acceptable limits.

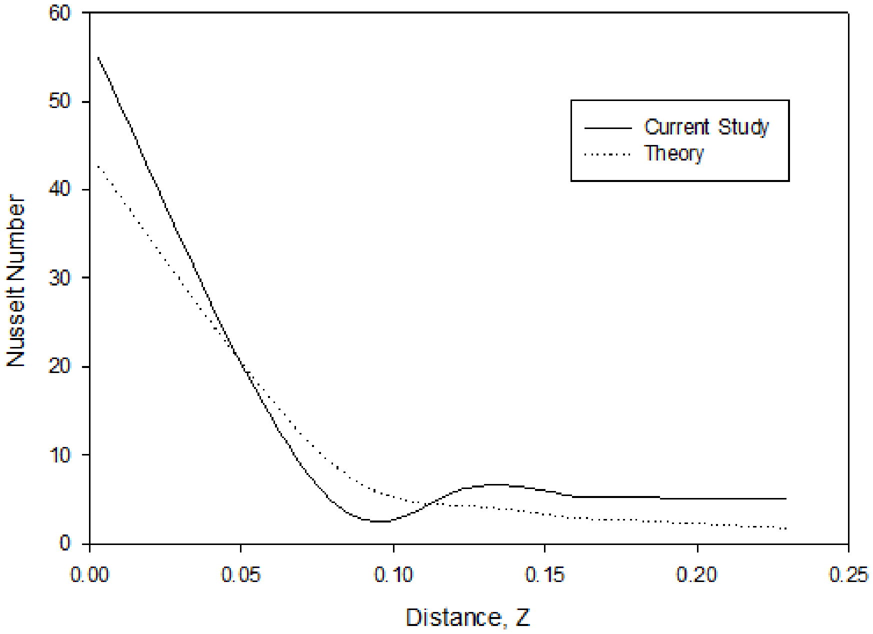

Fig. 2. Theory Nusselt number vs current study

3. Results and Discussion

In this study, heat transfer performance in minitube with surrounded heat flux is analyzed based on Nusselt Number. The generated outcome with a single-phase simulation for considers vol. fraction = 0.01% & 0.05% were performed with Reynolds number ranging from 400 to 1200.

3.1 Relation Between Nanoparticle Volume Fraction, Heat Transfer Coefficient and Nusselt Number

Figure 3 represents a plot of avg heat transfer coefficient versus Re for various volume fractions of the nanoparticles. Figure 4 represents a plot of average Nusselt number with Re for different volume fractions.

The brief outcome from the present work reveals that an increment in both Re and volume fraction of nanoparticles shall promote enhancement in the value of Nusselt number. As preferred Eq. (6), it can be noted that nanofluid with higher volume fraction has better capabilities of thermal performances. Which shall boost heat transfer phenomenon. In case, with 0.05 % of vol fraction and Re of 1000, it can be noted that the mean heat transfer coefficient shall reach a value of 9.8 %, which is much larger than compared to the water. The base fluid is pure water in the present case.

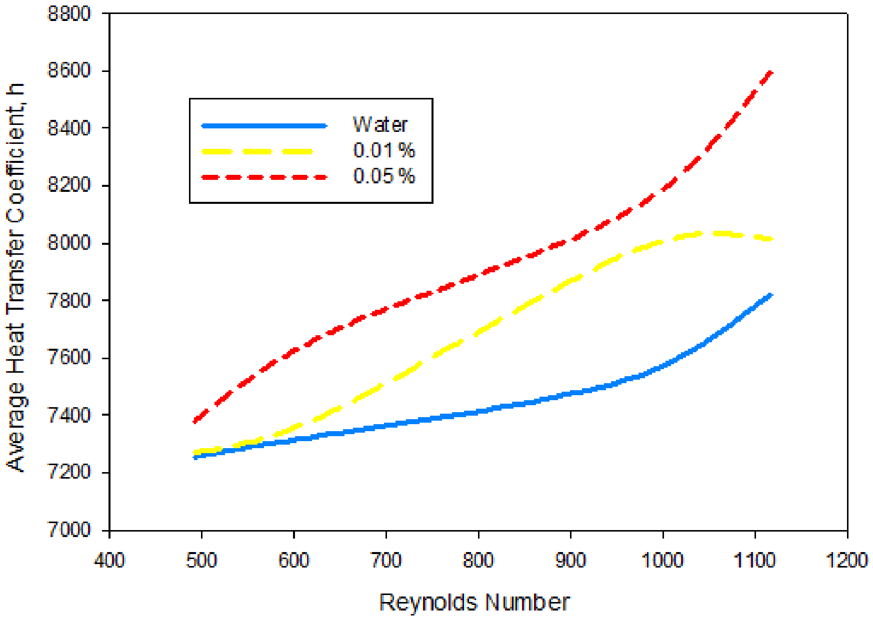

Fig. 3. Values of average heat transfer coefficient with Reynolds number

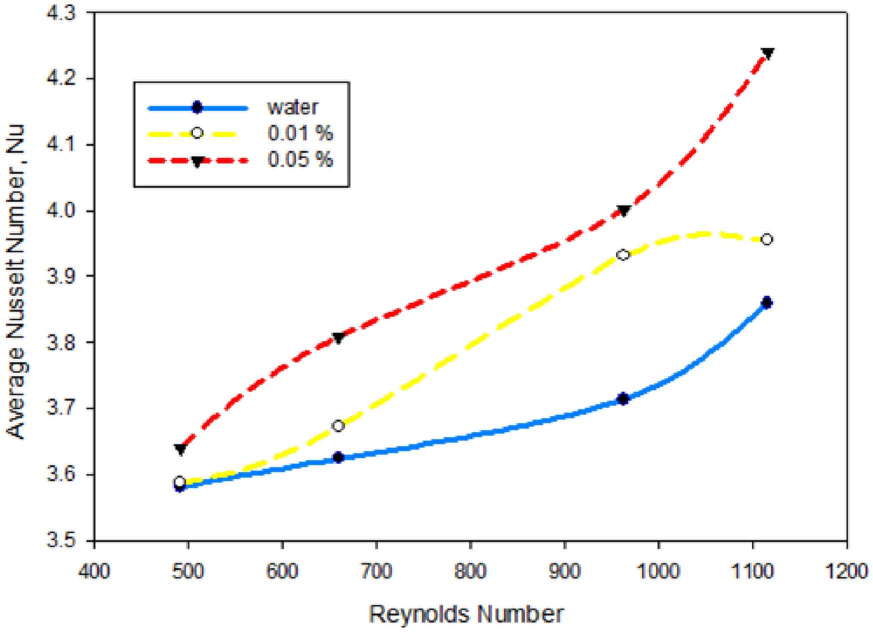

Fig. 4. Values of average Nusselt number with hybrid nanofluid concentrations

3.2 Impact of Nanoparticle Volume Fraction with Friction Factor

Figure 5 show the variation of friction factor of different concentration MWCNT/TiO_2 hybrid nanofluid. It can be obvious from the plot that, the values of friction factor for minitube dips as Re gets more value.

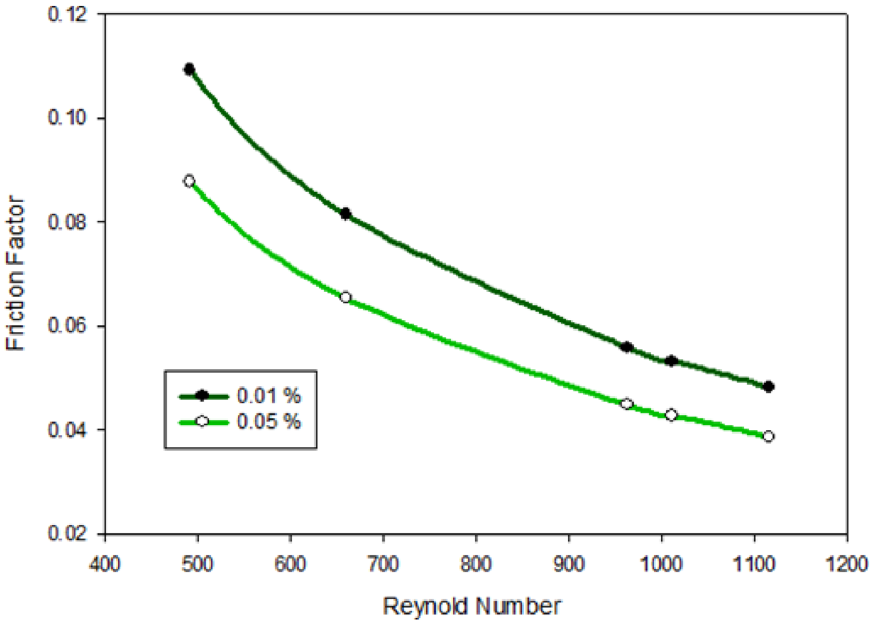

Fig. 5. Variation of friction factor of different concentration MWCNT/TiO_2 hybrid nanofluid

4. Conclusions

In conclusion, the presented works use commercial software called ANSYS Fluent to perform an investigation of the effect of fluid flow rate as well as hybrid nanofluid concentration on the average Nusselt number. In addition, friction factor was also involved. The approach was done numerically by involving CFD concepts. Results indicate an increase both Nusselt number as well as the amount of heat transfer was mainly depended on two parameters namely; an increment of Re and vol concentration of nanoparticles. In addition, the friction factor is inversely related to the Re. Finally, by considering simulation technique, it can be implied that Nusselt number prediction was based on the dimensionless numbers.

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