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Improving the Heat Transfer using Fe3O4 Nanoparticles Suspended in Water Flow through Circular Tube

Hamed J. Hussain
State Company for Gas Filling and Services/ Qadisiyah branch
Corresponding Author E-mail: hamedjh76@gmail.com

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Abstract

The new class of pressure drop and heat transfer enhancement through pipes and heat exchangers is defined a nano-fluid. The applications of this process are the cooling of oil inside heat exchanger and the flow of oil into the pipe line. In this work, the prediction of heat transfers and friction factor in a heated tube is studied. ANSYS software of CFD simulation through the geometrical problem undertaken was utilized. The Fe3O4 nanoparticles suspended in pure water has been adopted to flow through the test rig under ranges of nanoparticles mass concentrations and Reynolds number 1% to 4% and 4000 to 10000 respectively. The numerical results show that the friction factor and heat transfer enhancement increase as increase of nanoparticles mass concentrations 23% and 4% respectively. Additionally, the heat transfer is increased and the friction factor is decreased as increase of Reynolds number. It was concluded that Nusselt number increases due to add the solid nanoparticles to the water but slightly increases of pumping power. These obtained results are validated with the available data in the literature.

Keywords: Heat Transfer, Nano-fluid, Oil Flow, FLUENT, CFD analysis.

1. Introduction

The nanofluid forced convection through tube is more interesting subject to many scholars [1-4]. The improving of oil recovery is promising approach by using environment-friendly nanoparticles to be as an innovative-alternative for chemical methods [5].

A number of investigators studied the prediction of pressure drop and Nusselt number for different types of TiO2, CuO, Al_2O_3 and ZrO_2 solid nanoparticles suspended in liquid with

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different concentration, sizes and temperatures. Deviation between their data and others has been observed due to different size or synthesis methods.[6]

The insertion of twisted tape was investigated within/ without alumina nanoparticles suspended in pure water experimentally. It was observed that enhancement of heat transfers and slightly increasing of friction factor. It was concluded a new correlation for the evaluation of friction factor and Nusselt number through pipes without and with inserting tapes. [7]

The improving of Nusselt number for alumina nanoparticles suspended in pure water through a circular tube with constant wall temperature numerically. Their results indicated a good matched with the other researchers' data. [8]

Tetania and alumina nanoparticles suspended in pure water flow through a horizontal heated tube under turbulent flow condition were studied numerically [9]. CFD analysis has been employed for solving the continuity, momentum and energy equations of horizontal test section and thermos-physical properties of nano-fluids. Numerical analysis indicated the heat transfer enhancement due to add nanoparticles volume fractions and validation process of the numerical model.

The alumina nanofluid flow was placed under turbulent flow through a heated pipe numerically. It was found the enhancement of heat transfer increases due to add solid nanoparticles mass concentrations and Reynolds number [10]

Some authors has [11] investigated the effect of pipe shape on friction factor and Nusselt number by using nanoparticles dispersed in pure water under turbulent flow. They were concluded the Nusselt number increased as increasing of nanoparticles volume concentrations, whereas the friction factor was slightly increased.

In this work, predictions of Nusselt number and pressure drop have been studied by using ANSYS software of CFD simulation. It will expect to improve heat transfer by using Fe3O4 nanoparticles dispersed in base fluid flow in a circular pipe. The nanoparticles volume fractions and Reynolds number are 1% to 4% and 4000 to 10000 respectively.

1.1 CFD Simulation

The study undertaken is included a CFD model to simulate the forced convection heat transfer through a circular heated pipe by ANSYS software that might be solved the governing

Open Access
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equations. The physical model of test section was drawing and meshing by selecting the size of length and radius 150 and 32 respectively as shown in Figure (1).

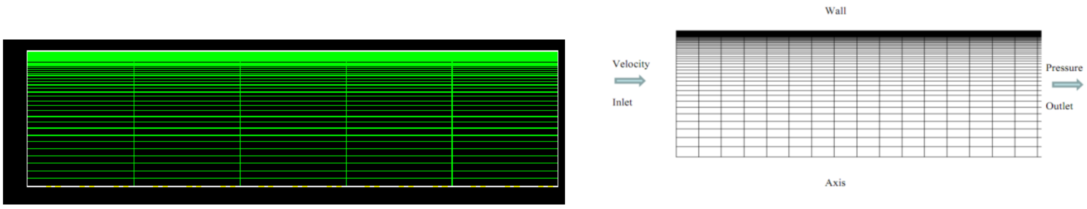

Fig. (1): Mesh generated and boundary conditions.

1.1.1 Governing equations

This study is considered that a heated pipe and continuity, momentum and energy equations that govern the problem undertaken as following [12]:

$$\nabla \cdot (\rho_{nf} . u) = 0 \quad (1)$$

$$\nabla \cdot (\rho_{nf} u u) = -\nabla P + \nabla \cdot (\mu_{nf} \nabla u) \quad (2)$$

$$\nabla \cdot (\rho_{nf} C_{nf} u T) = \nabla \cdot (k_{nf} \nabla T) \quad (3)$$

These equations have been solved iteratively by adopting the separation solver and an equation of correction pressure that employed to ensure the mass conservation and momentum. The method of pressure treatment is a SIMPLE scheme employing k-ε model due to high Reynolds number and turbulent viscous flow. The converged solutions of this simulations steps of the governing equations is less than 10^{-6} residuals [13].

The verification process of numerical data of nano-fluid were performed by comparing the data with available data of pure water. The friction factor with Blasius Eq. (4) and heat transfer with Dittus Boelter Eq. (5) for comparing data as following [14]:

$$f = \frac{0.316}{Re^{0.25}} \quad (4)$$

$$Nu = 0.035 * Re^{0.8} * Pr^{0.4} \quad (5)$$

Open Access
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It was found that 150 x 32 grids showed an optimum result due to a steady result linearly and hence this mesh size has been considered for finding all the solving steps as illustrated in Figure (2).

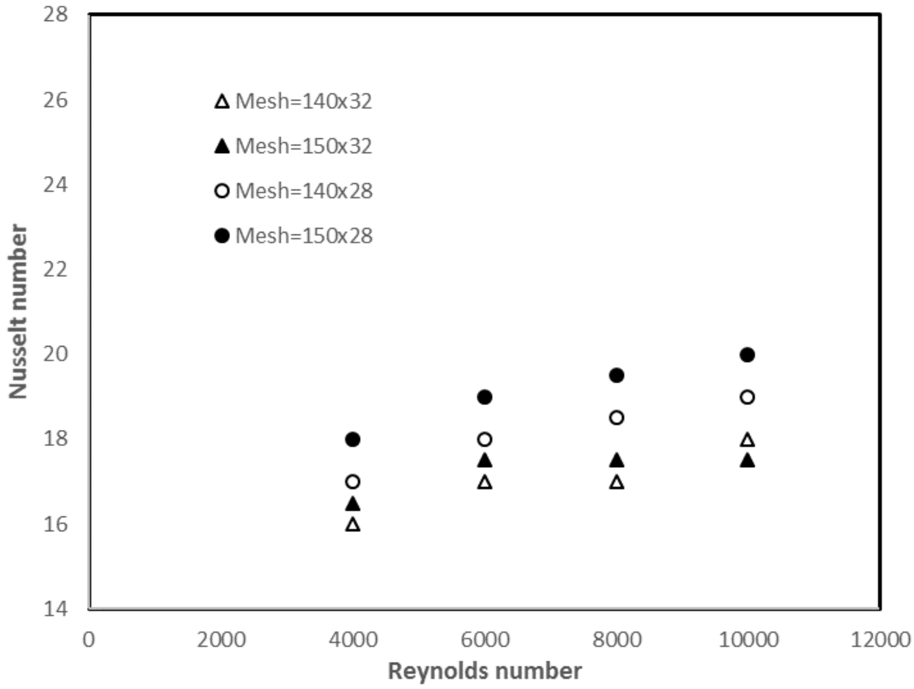

Fig. (2): Optimum mesh selected.

1.1.2 Thermophysical properties

Eq. (6) includes the mass fraction (φ) evaluation as [15]:

$$\varphi = \left(\frac{m_p}{(m_p + m_f)} \right) * 100 \tag{6}$$

Where: (m_p) and (m_f) are the nanoparticles mass and pure H2O respectively. Furthermore, the specific heat capacity (C_{nf}) and density (ρ_{nf}) of nano-fluids is estimated as shown below [15]:

$$\rho_{nf} = \left(\frac{\phi}{100} \right) \rho_p + \left(1 - \frac{\phi}{100} \right) \rho_f \tag{7}$$

$$C_{nf} = \frac{\frac{\phi}{100} (\rho C)_p + \left(1 - \frac{\phi}{100} \right) (\rho C)_f}{\rho_{nf}} \tag{8}$$

The effective nanoparticles viscosity and thermal conductivity that dispersed in pure water can be evaluated as [15]:

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$$k_{nf} = \left[\frac{k_p + 2k_{m-}2\varphi(k_w - k_p)}{k_p + 2k_{w+}\varphi(k_w - k_p)}\right] k_w \quad (9)$$

$$\mu_{nf} = (1 + 2.5\Phi)\mu_f \quad (10)$$

The thermos-physical properties of pure water and solid nanoparticles are presented in Table (1).

Table (1) Both pure water and solid nanoparticles properties.

Medium	Cp, (J/kg.k)	μ, (Pa.s)	k, (W/m.k)	ρ, (kg/m^3)	T (K)
Water	4182	0.001	0.6	998.2	293.15
Fe_3O_4 [15]	670	-	80.4	5180	293.15

1. Boundary conditions

The nano-fluids mass fractions are (1, 2, 3 and 4%) at 30°C have been utilized as input fluid. water has been employed as working fluid for comparison purposes as a verification process. CFD studies by using ANSYS software is adopted with inlet velocity known at the inlet of the system. k-ε method of turbulent intensity (*I*) is employed as an initial guess of turbulent flow conditions.

Depending on the formula [14]:

$$I = 0.16(Re)^{-1/8} \quad (11)$$

The turbulent intensity for each case was calculated. Where *Re* is Reynolds number which will be assumed 4000 to 10000. The exit point of flow boundary condition is assumed as outlet flow. The pipe walls are assumed to be zero roughness height as perfectly smooth with 6300 W/m^2 constant wall heat flux boundary.

2. Results and Discussion

2.1 Pure water without nano-fluid:

The numerical results are compared with the results available in the literature. Figure (3a) shows the friction factor of pure water under turbulent flow which was compared with Blassius Eq. (4) [3] as a solid black line. It was found results of friction factor in acceptable limit.

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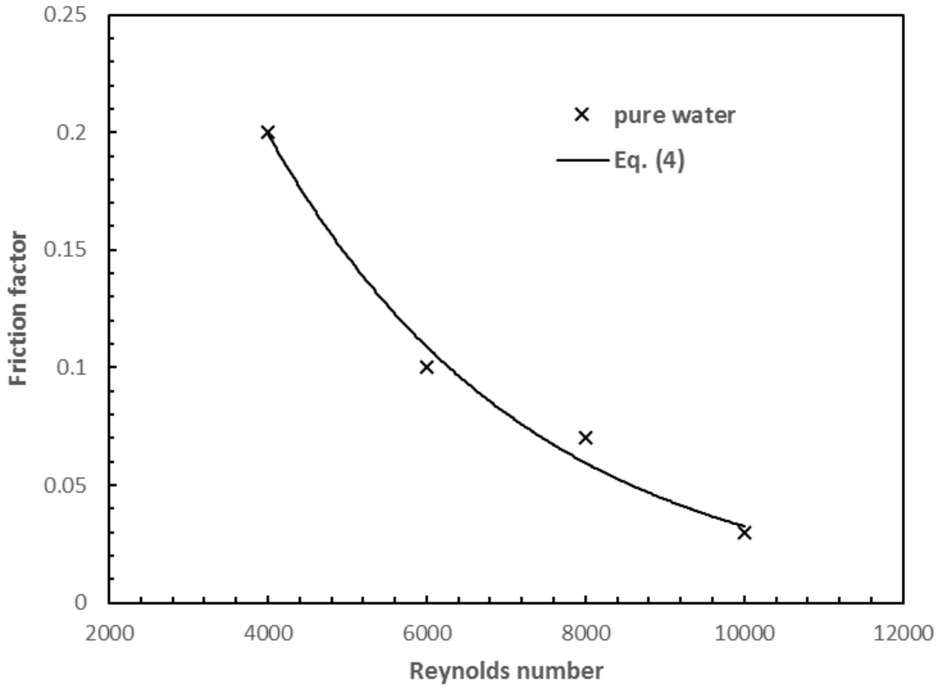
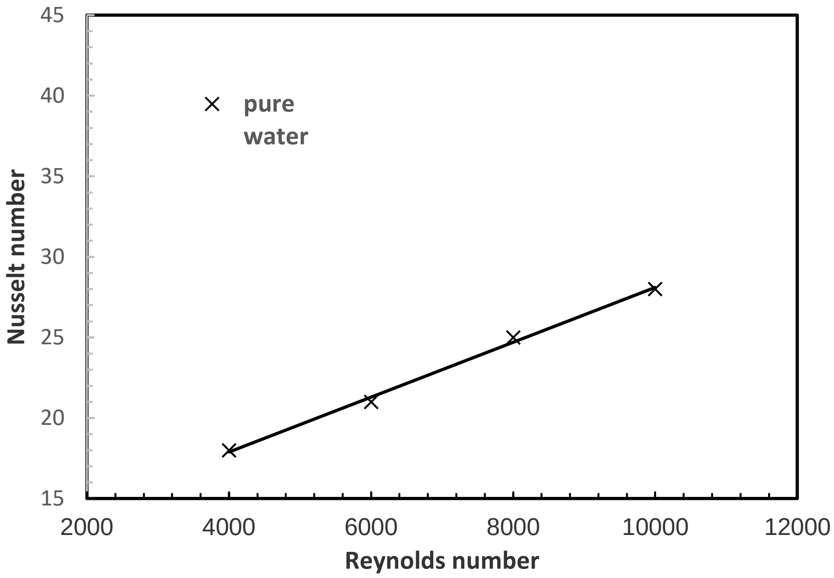
Likewise, Figure (3b) indicates a comparison of Nusselt number data with results of Dittus-Boelter correlation [12]. It was observed good agreement between them with deviation less than 4%.



(a) Friction factor with Reynolds number for pure water.



(b) The effect of Reynolds Number on Nusselt Number for pure water.

Fig. (3): Comparison of CFD analysis data with equations.

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No. 36, September 2022, pp. 92-103

P- ISSN: 2220-5381
E- ISSN: 2710-1096

2.2 The effect of Nano-fluid:

Figure (4) shows the effect of Reynolds number and nano-fluid mass concentrations on friction factor. It can be seen that friction factor is decreasing as Reynolds number increases but increasing as increase of nano-fluid mass concentrations. The increasing of friction factor is generated from the solid nanoparticles that flowing through the pipe which may lead to result a shear strength and momentum [15].

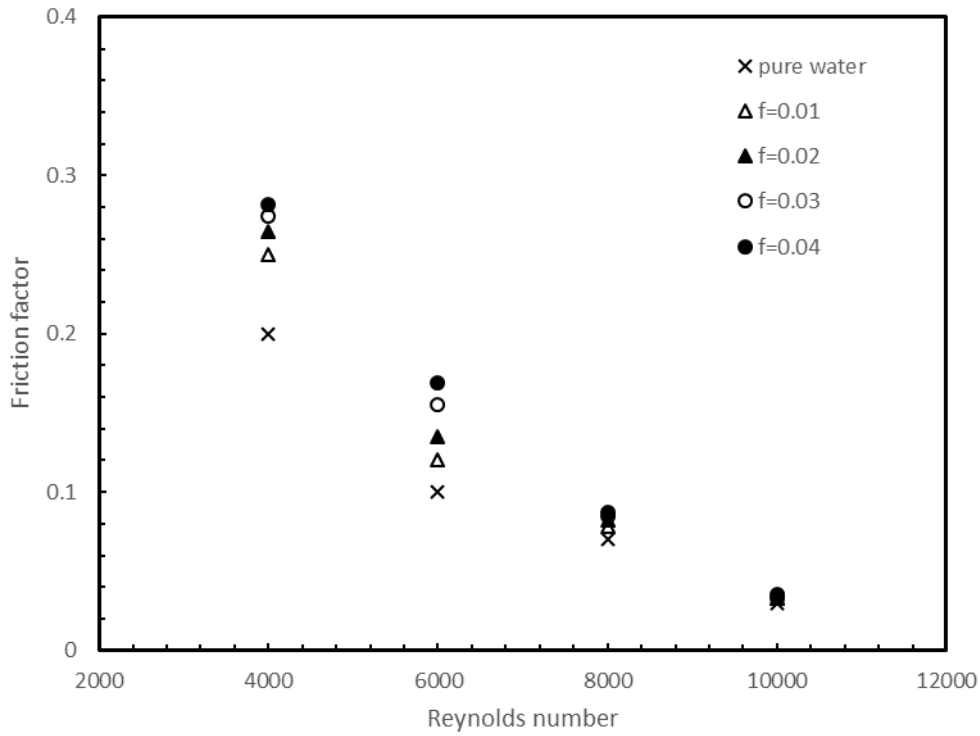

Fig. (4) The influence of nanofluid mass concentrations on friction factor with different Reynolds number.

Figure (5) is demonstrated that the influence of nano-fluid volume concentrations and Reynolds number on heat transfer. It can be seen that the increasing of Nusselt number due to increase of both nano-fluid mass concentrations and Reynolds number. The reason of increasing Nusselt number is the Brownian motion that led the particles to be in different direction of flow or inverse direction of flow to generate more resistance against flow [15].

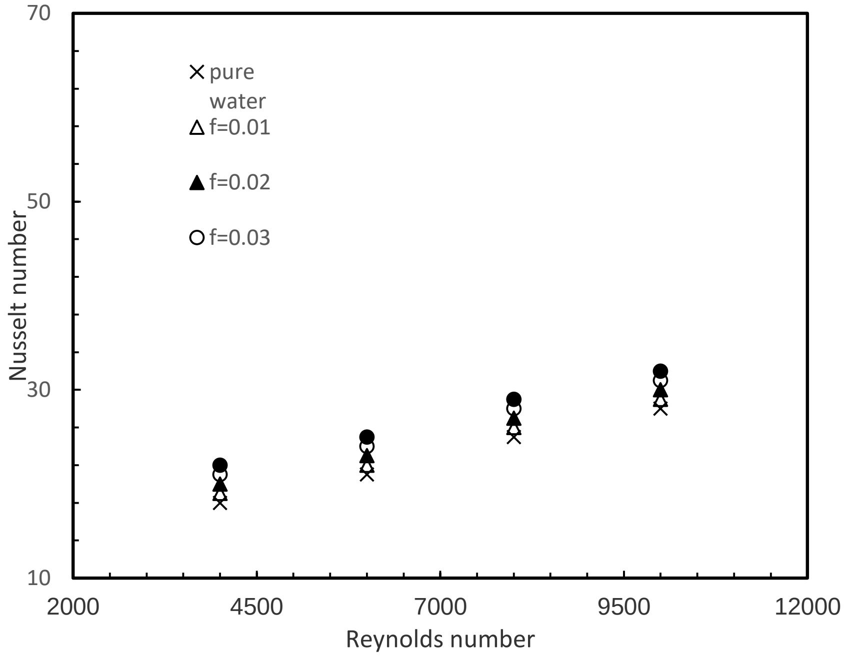

Fig. (5): The effect of nanofluid mass concentrations on Nusselt number with Reynolds number for.

Validation of friction factor data from numerical study of Fe3O4 nano-fluid with the data available in the literature is performed as illustrated in Figure (6). The numerical data of friction factor is agreed with the other researchers' data and the deviation is less than 5%. Deviation between CFD analysis and experimental results may be generated from the different of size diameter of nanoparticles or synthesis method of nanoparticles.

Figure (7) shows that Nusselt number data of numerical study for Fe3O4 nanoparticles suspended in pure water compared with Nusselt number data of other researchers available in the literature. It was observed that there are agreement good-matched and the deviation is not more than 4%.

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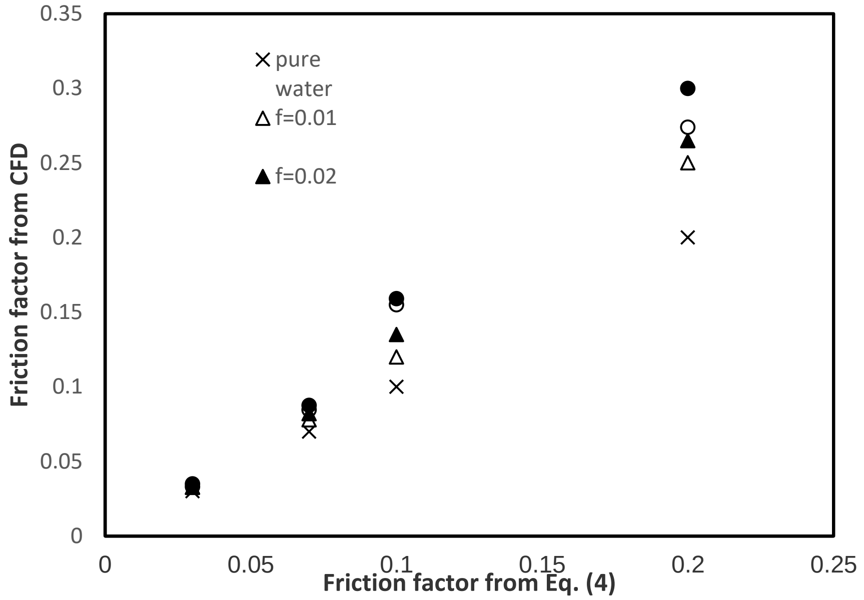

Fig. (6): CFD data of friction factor validation with Blassius equation for different nano-fluid mass concentration.

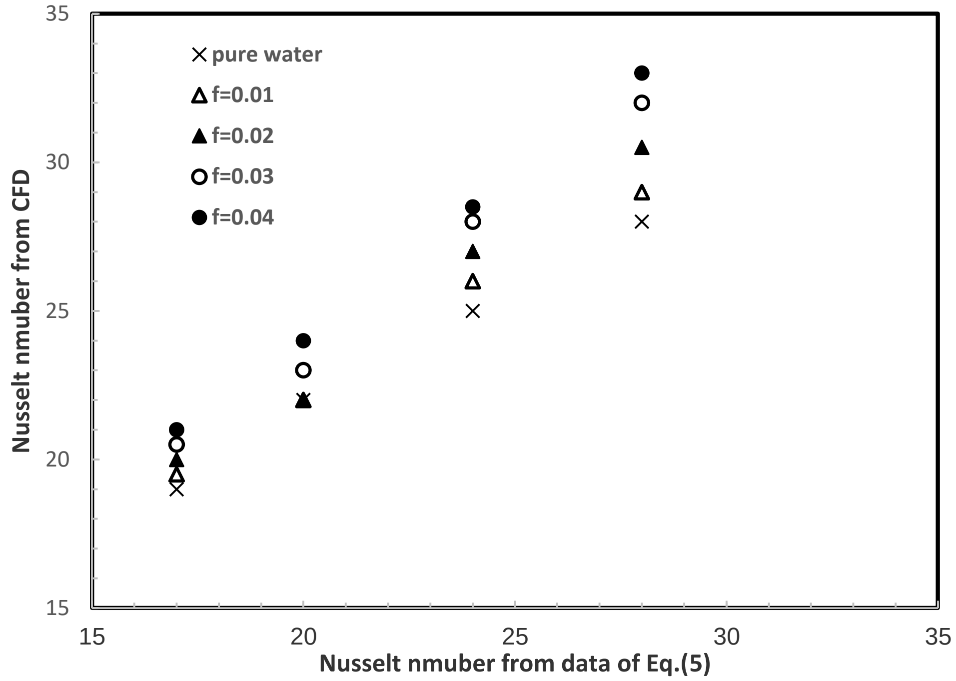

Fig. (7): Validation of CFD data with Dittus-Boelter equation for nanofluid mass concentrations.

Open Access
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3. Conclusions

In this work, CFD analysis has been conducted by using ANSYS software for solving governing equations numerically.

Both heat transfer enhancement and friction factor data of Fe3O4 nanofluid through a heated circular pipe has been considered. It was summarized the conclusions of the numerical study as following:

- The friction coefficient is decreasing as increase of flow rate or Reynolds number but increasing with increase of nanofluid mass concentrations and the numerical results agreed with equations of liquids.
- Nusselt number is increasing as increase of mass concentrations and Reynolds number and there is a good agreement with correlations of Dittus Boelter.
- Validations of Nusselt number and friction factor have been conducted by comparing data with other researchers' data available in the literature.

Nomenclatures

C	specific heat capacity	*Pr*	Prandtle Number ($C.\mu/K_{eff}$)
D	diameter (m)	*U*	velocity (m/s)
E	energy (W)	μ	Viscosity (N.s /m^2)
F	friction factor	ρ	Density (kg/m^3)
K	thermal conductivity (W/m.°C)	τ	Shear stress (N/m^2)
H	convection heat transfer coefficient(W/m^2.°C)	ϕ	Volume fraction
Keff	effective thermal conductivity (W/m.°C)	*Subscripts*	
Nu	Nusselt Number ($h . D/K_{eff}$)	*P*	solid particle
P	pressure (N/m^2)	*0*	liquid phase
Re	Renolds Number ($\rho. u. D/K_{eff}$)	*eff*	effective

Open Access
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