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Research Article

Numerical simulation on performance evaluation among metal and oxide based nanofluids for power savings application of a circular tube

Md Insiat Islam RABBY[1,*], Farzad HOSSAIN[2], S. A. M. Shafwat AMIN[3], A. K. M. Sadrul ISLAM[4]

[1]*Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia, Selangor, Malaysia*
[2]*Department of Mechanical and Production Engineering, Islamic University of Technology, Board Bazar, Gazipur, Bangladesh*
[3,4]*Department of Mechanical Engineering, Military Institute of Science and Technology, Mirpur Cantonment, Dhaka, Bangladesh*

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ABSTRACT

The advancement of heat transfer techniques is a challenge to the researcher in this era. Implementation of nanotechnology is one of the potential techniques which enhance the heat transfer rate in a significant amount. Subsequently, nanotechnology can reduce the requirement of pumping power. However, suspension of nanoparticle with liquid to produce a new working fluid called nanofluid which has better thermal and fluid dynamic properties in comparison to pure liquid is introduced as a typical nanotechnology technique in the heat transfer area. In this study, the thermal performance of two categories of nanofluids metal-based (Cu-water and Ag-water) and oxide-based (Al_2O_3-water, CuO-water, BeO-water) with 1–5% volume fractions have been analysed for the laminar flow region of a circular tube which is fully developed under 2D control volume finite element method. The heat transfer was analysed for a range of Reynolds numbers from 100 to 1000 with a constant heat flux of 500 W/m^2 applied on the tube wall. For evaluating the performance among nanofluids, the Figure of Merits (FOM), pumping power, Nusselt number enhancement ratio, and heat transfer coefficient ratio of the base fluid and nanofluids have been calculated and compared. The computational results show that in terms of Nusselt number and heat transfer coefficient, all nanofluids provide higher enhancement compared to pure water. Meanwhile, for this higher enhancement, nanofluids required significantly lower pumping power in comparison to pure water. However, the power has been saved 86.26% for Ag-water nanofluid, 72.84% for Cu-water, 42.36% for CuO-water, 40.99% for Al_2O_3-water, and 26.58% for BeO-water. Between the mentioned two categories of nanofluids, metal-based nanofluids provide the highest heat transfer enhancement and lowest pumping power requirement compared to oxide-based because of their higher thermal conductivity and other fluid and

***Corresponding author.**
*E-mail address: insiatislam8@gmail.com

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thermal properties. For clearing the enhancement of heat transfer rate over-pumping power, a dimensionless number FOM has been calculated whereas metal-based nanofluids provide the highest value of FOM (1.863 for Ag-water nanofluid) in comparison to oxide-based (1.266 for BeO-water). In the meantime, the comparison between nanofluids also reveals that among all the nanofluids, metal-based Ag-water nanofluids provide the highest heat transfer enhancement and oxide-based BeO-water provide the lowest heat transfer enhancement in terms of pumping power requirements. Lastly, the study concluded that suspension of metal-based nanoparticles with base fluid has better capability to save pumping power (86.26% for Ag-water nanofluid) by providing the highest enhancement of heat transfer rate whereas oxide-based nanoparticles show the lowest capability to save pumping power (26.58% for BeO-water) compared to the base fluid.

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INTRODUCTION

Basically from the past couple of decades, the utilisation of nanotechnology and nanoparticles in various sections is highly praised and introduced. Nanoparticle is most often utilised for making nanofluids because when it mixes with a base fluid like water, engine oil, ethylene, etc., these nanofluids show higher thermophysical properties like density, viscosity, thermal conductivity and lower specific heat capacity in comparison to base fluids. Because of these competitive properties, these nanofluids are utilised in heat transfer enhancement applications which provides us better performance in the heat exchangers, air, refrigeration system, and numerous industries sector. Besides the heat transfer enhancement application, nanofluids are also saved energy because nanofluids required lower power at the time of pumping in comparison to base fluids in order to get the same amount of heat transfer. Solid particles vary small amounts of nano-size and shape (1 nm to 100 nm) is generally utilised in order to produce nanofluids. Normally, almost all researchers used oxide-based nanoparticles like Al_2O_3, CuO, ZnO, TiO_2, MgO, Fe_2O_3, etc. in their research more. Besides these particles, some are also used Cu, Al, Zirconium, SiC, etc. However, maximum researchers only studied the heat transfer enhancement and they didn't show the justification of this enhancement with pumping power requirement and other performance parameters. On the other hand, there is no research paper that shows which type of nanofluid is more effective- pure metal, oxide, or others. That's why in this study, pure metal and oxide-based nanoparticles are used in order to compare their performance on the basis of performance parameters and the required power for pumping. The available researches concerned with heat transfer by utilising nanofluids are described below.

Saha and Paul [1] carried out their study on convective turbulent flow through a tube by using aluminium oxide-water and titanium oxide-water-based nanofluid. In their study, they took different size of nanoparticles (10nm to 40nm) and took volume concentration of particles up to 6%. The results show that they have got higher heat exchange rate and higher ratio of wall shear stress at 6% volume concentration and between these two nanofluids, Al_2O_3-water provides more rate of heat transfer than TiO_2-water. Duangthongsuk and Wongwises [2] analysed heat transfer of a circular tube at wall by using TiO_2-water nanofluid. The heat flux was considered uniform and the result indicates that by increasing the length of the tube, the heat transfer coefficient has been decreased and with the increment of Reynolds number, the coefficient of heat transfer has been increased. Minea [3] investigated water-based Al_2O_3 nanoparticles under turbulent convective flow through a circular tube and found that enhancement of heat transfer depends on volume concentration, type of nanoparticles and Reynolds number. Rea et al. [4] led an investigation on the convective warmth exchange and weight drop of alumina–water and zirconium–water nanofluids in a tube for laminar flow which width is 4.5-mm (inward). But from their discoveries, no deviation has been observed in convective heat exchange and weight drop of nanofluid. Heris et al. [5] played out an exploratory investigation to decide the loss of pressure and transfer of heat qualities of Al_2O_3-water and CuO-water nanofluids through a triangular conduit under constant/uniform heat flux at laminar flow area. Their outcomes demonstrated that, at similar/constant volume concentration and Reynolds number, utilising CuO nanoparticles is less beneficial than Al_2O_3 nanoparticles.

Yu et al. [6] worked with SiC-water nanofluid for turbulent flow and a comparison parameter the Figure of the merit which is denoted by heat transfer enhancement and pumping power ratio. Their result showed that SiC-water nanofluid provided the value of FOM 0.8 and Al_2O_3-water nanofluid provided the value of FOM 0.6. It indicates that SiC-water nanofluid is more favourable in the case of pumping power penalty. Yu and Liu [7] studied on convective thermal performance investigation of nanofluids (Al_2O_3-water and Al_2O_3-polyalphaolefin) for cooling applications and their result reveals that in the case of constant pumping power condition, the nanofluid's and the base fluid's overall effectiveness will not be changed significantly when the hydrodynamic and the thermal performances both are considered. Sarkar [8] carried out his research work on performance analysis of the nanofluids (Al_2O_3, TiO_2, CuO, and Cu) as a cooling application for cooled gas cooler (shell-and-tube) in CO_2 refrigeration cycle which is transcritical. The research shows that the effectiveness of nanofluid is suitable to utilize as a coolant in the gas cooler in order to improve the performance of the CO_2 refrigeration cycle. Ehsan et al. [9] made an investigation on the savings of energy of heat exchanger and they found that TiO_2-water, CuO-water, and Al_2O_3-water required minimum volumetric flow rate and pumping power in comparison to pure water for constant heat transfer coefficient. Ingole et al. [10] investigated the pumping power of car radiators by using Al_2O_3-water nanofluid and they found that 2% volume concentration Al_2O_3-water needed 23.81% less pumping power in comparison to pure water. In another related work, Hatton and Turton [11] investigated heat transfer in the thermal entry length with laminar flow between parallel walls at unequal temperatures. Al-Kouz et al. [12] carried out their investigation at a constant wall temperature with low-pressure gaseous nanofluid through the entry area of a circular tube wherein they demonstrated that there is no significant impact on the heat transfer characteristics at the presence of nanoparticles volume concentration less than 0.03. Hence, by increasing this volume concentration beyond 3%, and enhancement of the average Nusselt number is obtained. Another researcher Karimzadehkhouei et al. [13] investigated the effect of inlet temperature for alumina-water nanofluid for thermally developing and hydrodynamically developed zone of laminar fluid flow whereas their results indicated that inlet temperature effects for thermally developing regions were more resulted and significant. Beside them, Singh et al. [14], Iyahraja et al. [15], Rabby et al. [16], He et al. [17], Kapıcıoğlu and Esen [18], Kaya et al. [19], Ekiciler et al. [20] also examined the impact of nanofluids on laminar convective heat transfer and their results also indicate the enhancement and improvement of heat transfer characteristics by the utilisation of nanofluids.

Hussein et al. [21] investigated the thermal and flow field characteristics of laminar steady mixed convection flow and observed the decrement of local Nusselt number with the increment of inclination angle and solid volume fraction. Mohammed et al. [22] examined buoyancy-opposing laminar mixed convection in a vertical duct and found that SiO_2 nanofluid has the highest Nusselt number at the highest buoyancy level and the decrement of skin friction coefficient occurred with the increment of Reynolds number and Prandtl number. Ahmed et al. [23] examined the thermal and flow field characteristics of the laminar steady mixed convection flow in a square lid-driven enclosure and found the decrement of average Nusselt number and the heat source occurred with the increment of heat source length whereas the increment of average Nusselt number and the heat source occurred with the increment of solid volume fraction. Kareem et al. [24] investigated mixed convection heat transfer of nanofluids in a lid-driven trapezoidal cavity and found that all types of nanofluids have higher Nusselt numbers in comparison to pure water. Their investigation also showed that SiO_2–water has the highest Nusselt number followed by Al_2O_3–water, TiO_2–water, and CuO–water. Al-Rashed et al. [25] performed three-dimensional numerical simulations on a cubical cavity utilising the finite volume method and found that the increment of the generation of thermal entropy occurred with the increment of nanoparticles concentration for all Richardson numbers. Ahmed et al. [26] investigated steady laminar two-dimensional magnetohydrodynamic mixed-convection flow in trapezoidal enclosures and found that the increment of average Nusselt number occurred with the decrement of Richardson number and the increment of solid volume fraction whereas the decrement occurred with the increment of heat source length.

Al-Rashed et al. [27] conducted an investigation on the effects of the inclination angle of an external magnetic force on the natural convection inside a cubical cavity and found that the increment of heat transfer occurred with the increment of the concentration of CNT particles and Rayleigh number. Pordanjani et al. [28] reviewed the application of nanofluids in heat exchangers for saving energy and observed that heat transfer has been improved significantly in most cases which save energy and reduce heat exchanger volume. Mashayekhi et al. [29] examined the enhancement of heat transfer of Water-Al_2O_3 nanofluid in an oval channel and found the highest heat transfer coefficient in CCI-inward which is around 17% higher than the plain tube. Qi et al. [30] conducted an experiment on thermo-hydraulic performance of TiO_2-H_2O nanofluids in triangle tubes and found enhanced heat transfer in twisted tape tubes in comparison to smooth tubes. They also found better exergy efficiency with Reynolds number greater than 5000. Sajid and Ali [31] reviewed recent heat transfer applications of nanofluids and found that the boundary layer thickness and particle clustering reduce with the presence of nanoparticles which significantly improve the characteristics of heat transfer of the system. He also observed a comparatively higher heat transfer rate in the nanofluids having smaller size nanoparticles. Mahian et al. [32] reviewed the heat transfer characteristics of nanofluids and found that the two-phase mixture model is comparatively easier to approach which usually gives results that are closer to experimental data.

Literature shows so much research on nanofluids in heat transfer application but still, the identification of most effective nanofluids and performance evaluation of nanoparticles between metal-based and oxide-based are not properly evolved for saving pumping power. In the current study, two types of nanoparticles, i.e. metal-based (pure Cu and Ag) and oxide-based (Al_2O_3, CuO, and BeO) were used to mix with water which a working fluid to prepare nanofluids. For 1% to 5% volume fractions of all nanoparticles, heat transfer enhancement ratio, Nusselt Number enhancement ratio, pressure loss, pumping power, and Figure of merits have been found out to evaluate performance and identify the most effective nanoparticles.

PHYSICAL MODEL & BOUNDARY CONDITIONS

In order to investigate the rate of heat transfer and corresponding pumping power, constant heat flux is applied on both surfaces of a two-dimensional tube. For investigating the nanofluid performance through a tube, a numerical analysis has been performed by the application of the renowned commercial computational fluid dynamics software ANSYS Fluent. The flow is considered laminar and a two-dimensional circular sharp pipe with 5mm diameter and 750 mm length is presented. At the tube wall boundary, a uniform constant 500 W/m^2 heat flux is exerted and the tube wall is considered to be in no-slip condition. At the tube inlet, the inlet velocity and constant temperature are set as boundary conditions to allow the fluids to flow at a uniform temperature of 303 K. At the tube outlet, pressure outlet is considered as a boundary condition. The parameters of heat exchange and fluid dynamics are released after making thermal and hydrodynamic enhancement of the fluid stream. Measurements are computed beyond the entrance length of x/D=60. To determine the heat transfer characteristics and pumping power, the surface and bulk temperatures were examined at a distance of 750 mm from the inlet to the outlet, and pressures were also measured at lines which were situated around 725 mm and 715 mm from the inlet.

Numerical Method

Computational fluid dynamics software ANSYS (Fluent) commercial software is utilised for this numerical analysis. Utilising a control volume method, solution of all the governing equations for momentum, mass, energy, and laminar quantities is done. At the inlet, laminar inlet velocity and at the outlet, boundary pressure outlet is considered. Under relaxation factors 0.4 for pressure, 0.72 for momentum equation, 0.97 for energy equation and 0.8 for density equation are considered for the circular tube. Al_2O_3-water, Cu-water, Ag-water, CuO-water and BeO-water nanofluids with different particle volume fractions (1, 2, 3, 4, and 5%) are tested with a Reynolds number 600 and constant heat transfer coefficient 600 W/m^2-K and then results are compared with every used nanofluid.

Governing Equation

For forced convection under the steady-state and laminar flow condition, the expression of governing equations for continuity, momentum and energy is written as follows:

Continuity equation: In steady flow, the amount of mass within the control volume under remains constant, and thus the conversation of mass for nanoparticles can be written as:

Continuity equation: In steady flow, the conservation of mass for nanoparticles can be written as:

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

Here, u and v are the velocity of the fluid at x and y directions respectively.

Momentum equation: For laminar flow, the momentum equation is:

Momentum equation: For laminar flow, the X-momentum and Y-momentum equations are:

X-momentum equation,

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \qquad (2)$$

Y-momentum equation,

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \qquad (3)$$

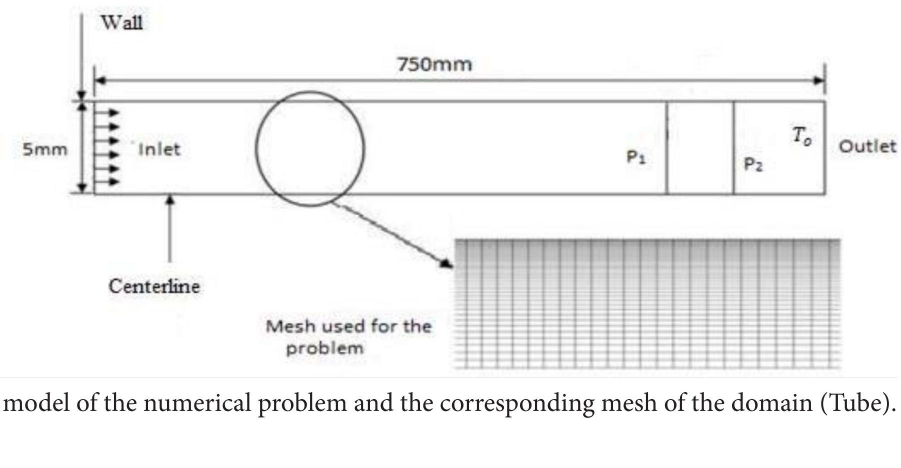


Figure 1. Physical model of the numerical problem and the corresponding mesh of the domain (Tube).

Here, ρ is the density and μ is the viscosity of fluids.

Energy Equation: Energy can be transferred by heat, work, and mass only, the energy balance for a steady-flow control volume can be express as:

$$\rho_{nf} C_{P_{nf}} \left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} \right) = k_{nf} \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \quad (4)$$

Here, C_p is the specific heat at constant pressure, k is the thermal conductivity and T is the temperature of fluids.

Thermal and Fluid Dynamics Analysis

The Reynolds number for the flow of nanofluid is expressed as:

$$Re = \frac{\rho_{nf} U_{av} D_h}{\mu_{nf}} \quad (5)$$

The rate of heat transfer,

$$Qnf = m_{nf} C_{P_{nf}} \Delta T \quad (6)$$

Here, m_{nf} is the mass flow rate of nanofluid and $C_{P_{nf}}$ is the specific heat of nanofluid at constant pressure.

The average heat transfer coefficient h_c is given by:

$$h_c = \frac{Q_{nf}}{A_w (\Delta T)} \quad (7)$$

Here, A_w is the surface area of the circular tube.

The temperature difference between the wall and the tube is calculated as:

$$\Delta T = \frac{(T_w - T_o) - (T_w - T_i)}{ln\left(\frac{T_w - T_o}{T_w - T_i} \right)} \quad (8)$$

The average Nusselt number is defined as follows:

$$Nu = \frac{h_c D_h}{K_{nf}} \quad (9)$$

Friction factor Dracy-Weisbach equation:

$$f = \frac{64}{Re} \quad (10)$$

The pumping power per unit length is given by:

$$W = \frac{(\pi / 4) D^2 U_{av} \Delta P}{L} \quad (11)$$

Here, differential pressure difference: $\Delta P = \frac{fL\rho U^2}{2D_h}$ (12)

Nusselt number enhancement ratio: $\frac{Nu_{nf}}{Nu_{bf}}$ (13)

Overall heat transfer coefficient enhancement ratio:

$$\frac{h_{nf}}{h_{bf}} \quad (14)$$

Figure of Merit: $FOM = \left(\frac{h_{nf}}{h_{bf}} \right) \left(\frac{W_{bf}}{W_{nf}} \right)$ (15)

Thermo Physical Properties of Nanofluids

Dynamic Viscosity: There are several equations for dynamic viscosity; among them, we utilize Maiga [33] equation for Al_2O_3 and Chen [34] equation for Ag-water, Cu-water, CuO-water, and BeO-water. The equation can be expressed as:

Maiga equation: $\mu_{nf} = (1 + 7.3\phi + 123\phi^2)\mu_f$ (16)

Chen equation: $\mu_{nf} = \mu_{bf}[1 + 10.6\phi + (10.6\phi)^2]\mu_f$ (17)

Thermal Conductivity: There are several thermal conductivity equations; among them, we utilize Maxwell (1073) mode equation for all nanofluids, which is given by:

$$K_{nf} = \frac{K_p + 2K_{bf} + 2(K_p - K_{bf})\phi}{K_p + 2K_{bf} - (K_p - K_{bf})\phi} \times K_{bf} \quad (18)$$

Density: For calculating the density of all nanofluids, Xuan and Roetzel [35] equation has been used:

$$\rho_{nf} = \rho_p \phi + \rho_{bf}(1 - \phi) \quad (19)$$

Specific Heat: For calculating specific heat of all nanofluids, Pak and Cho [36] equation has been used:

$$C_{nf} = (1 - \phi)C_w + \phi C_p \quad (20)$$

Grid Independence Test

For grid independence investigation, working substance has been taken as water and the simulation was run at Reynolds number 600. Grid independence test was carried out to discover the optimum grid size for the present study. Five diffident grid sizes (500 × 20, 800 × 25, 900 × 30, 1000 × 35 and 1200 × 40) were tested to find out the effect

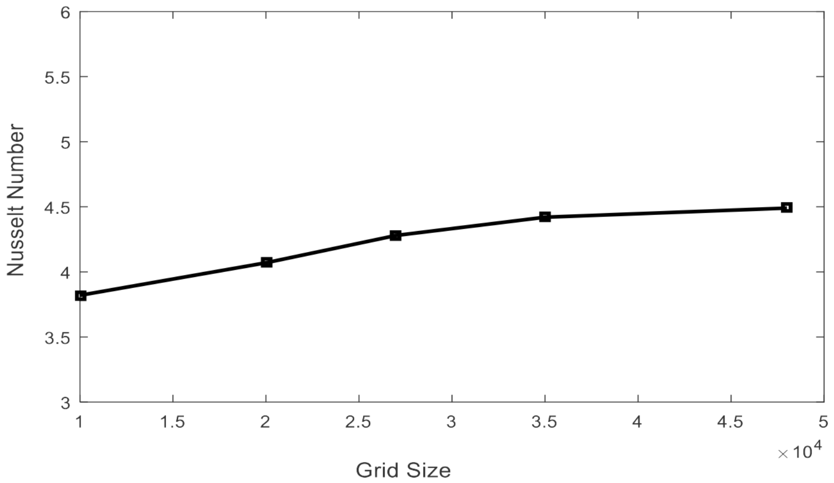


Figure 2. Variation of Nusselt Number for different grid sizes.

on the Nusselt number calculated at a distance of 750 mm which is shown in Figure 2.

From Figure 2, it is found that there is no significant change in the Nusselt number beyond the grid size of 1000 × 35 and at this grid, the Nusselt number is very close to 4.36. Therefore for the present study, the grid size of 35000 was used to perform all the simulations.

Code Validation Test

For laminar tube flow, water has been moved through the tube at constant heat flux and uniform speed. Reynolds number within the range of 100–1000 has been examined in order to calculate Nusselt number and heat transfer coefficient, whereas Reynolds number within the range of 100-1000 has been examined in order to calculate friction factor. At fully developed zone, a comparison is made among the local Nusselt number obtained from Shah and London [37] theoretical equation which is shown in Figure 3(a), also used to calculate heat transfer coefficient that showed in Figure 3(c). It gives a good agreement with only 2% error for Nusselt number and 1.5% error for heat transfer coefficient which are a constant. Additionally, the friction factor obtained at the fully developed zone is compared with the Darcy-Weisbach equation which is shown in Figure 3(b) and it gives only 1.5% error. The correlation developed by Shah Equation [37] for laminar tube as follows:

$$Nu = 1.302\left(\frac{x^*}{2}\right)^{-\left(\frac{1}{3}\right)} - 0.5, \qquad x^* \le 0.003 \qquad (21)$$

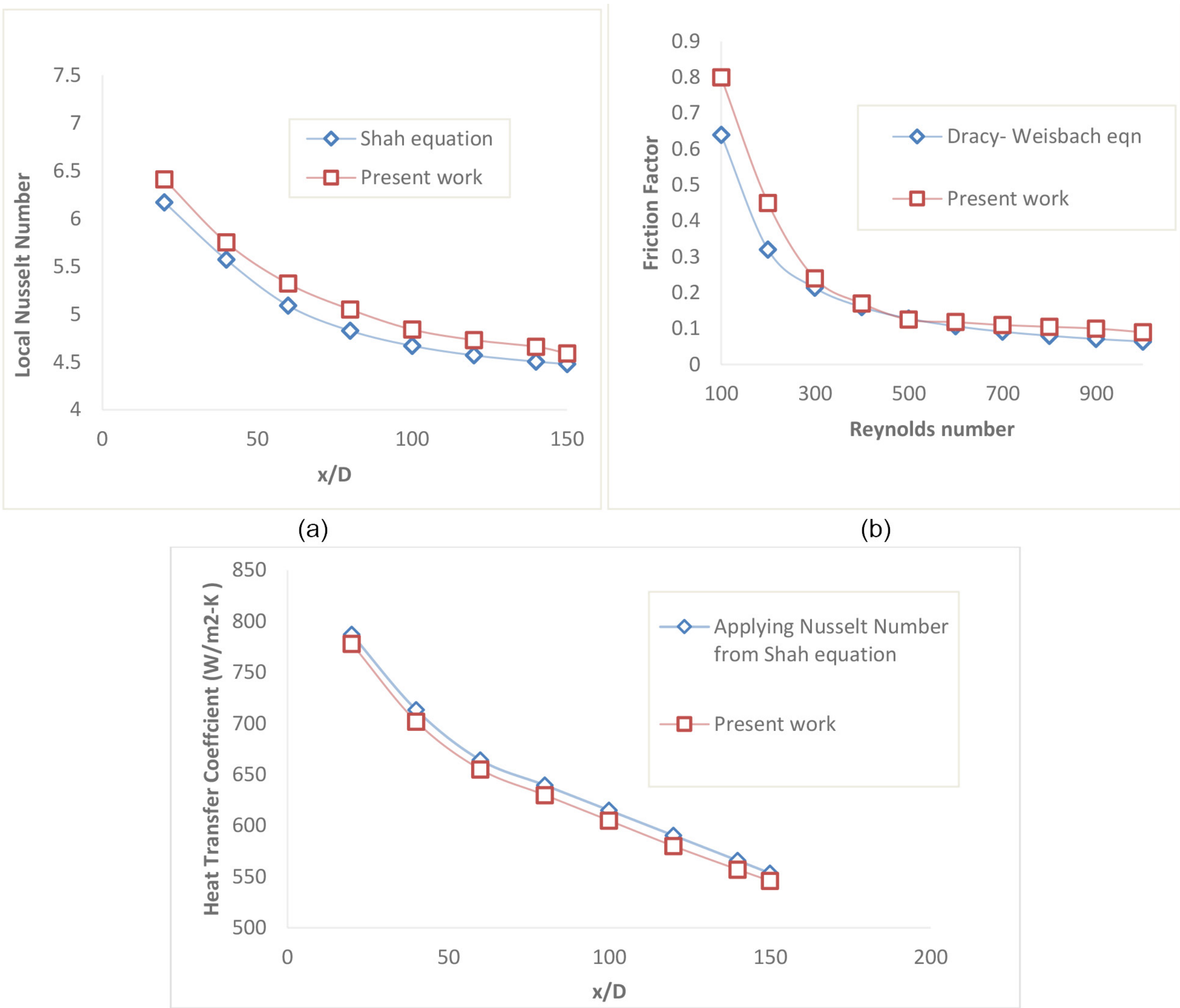
$$Nu = 4.364 + 0.263\left(\frac{x^*}{2}\right)^{-0.506} e^{-41\left(\frac{x^*}{2}\right)}, \qquad x^* > 0.03 \qquad (22)$$

$$Where, \qquad x^* = \frac{2(x/D)}{Re\,Pr}$$

RESULTS AND DISCUSSION

The Nusselt number enhancement ratio of nanofluids in comparison to water is presented in Figure 4 with (a) constant Reynolds number 600 and (b) constant heat transfer coefficient 600 W/m^2-K. The Figure 4(a) demonstrated that with the presence of volume concentration of nanoparticles in water higher enhancement of Nusselt number ratio between nanofluids and base fluid has been noticed whereas this ratio of BeO nanoparticles is the highest compared to others. Due to the highest thermal conductivity and specific heat of BeO in comparison to others is the main reason for this enhancement. At the volume of each Figure, fraction 0 represents the value which is obtained by using water. However, at constant heat transfer coefficient, the ratio between nano and base fluid indicates a different view in Figure 4(b) in comparison with Figure 4(a). With the presence of nanoparticles, the ratio of Nu_{nf}/Nu_{bf} has been decreased rapidly compared to pure water which indicates that by adding volume concentration same heat transfer coefficient can be achieved at lower Reynold number of nanofluids. In details, to get 600 W/m^2-K heat transfer coefficient pure water required 960 Reynolds number whereas 3% Ag nanoparticles required only 540 Reynolds number. Therefore, in case of Figure 4(b), the decrement of Nu_{nf}/Nu_{bf} ratio indicates better heat transfer enhancement and the lowest value represent the highest heat transfer rate. Moreover, from Figure 4(b), Ag nanoparticles provided the lowest value of Nu_{nf}/Nu_{bf} therefore, in this viewpoint Ag provides the highest heat transfer rate which totally conflicts with Figure 4(b). Therefore, to clear this conflict and to identify the highest heat transfer provided nanofluids, other fluid dynamic parameters are calculated and prescribed in the Figures and table below.

Hence, the heat transfer coefficient of nanofluid is generally influenced by the thermal conductivity of the nanoparticles. Higher thermal conductivity indicates a higher heat transfer coefficient but the density and viscosity



(c)

Figure 3. Comparison of Local Nusselt number, friction factor and heat transfer coefficient of present work with (a) Shah equation [37] for Local Nusselt Number (b) Dracy-Weisbach equation for friction factor of different Reynolds number and (c) heat transfer coefficient which was calculated by using Nusselt number from Shah equation.

of nanoparticles also affect its value which is clearly observable in the following Figures and table. In Figure 5(a), the comparison of h_{nf}/h_{bf} of all nanofluids is presented. From the results, it is clear that BeO-water provides more enhancements and Al_2O_3-water shows less enhancement ratio at constant Reynolds number 600 in comparison to others. On the contrary, Figure 5(b) represents the pressure loss with volume fraction at 600 W/m^2-K heat transfer coefficient. The result reveals that BeO-water shows the highest pressure loss and Ag-water shows the lowest pressure loss in comparison to others. The above discussions represent the heat transfer enhancement only but to get this enhancement, the required amount of energy is also an important parameter that actually helps to justify the performance among all nanofluids. We can get this by measuring the pumping power and FOM at constant heat transfer coefficient which is shown in Figures 6 and 7. The results from Figure 6 show that at a constant Reynolds number of 600, pumping power requirements are increased with the increment of volume fraction and BeO-water required the highest power and Ag-water required the lowest power in comparison to all. On the other hand, at constant heat transfer coefficient 600 W/m^2-K, the pumping power requirement has been decreased with the increment of volume fraction of nanoparticles. So, in order to get the same rate of heat transfer, the more we add nanoparticles, the more pumping power requirement will be decreased and this is the big advantage of using nanofluid. In this case, among

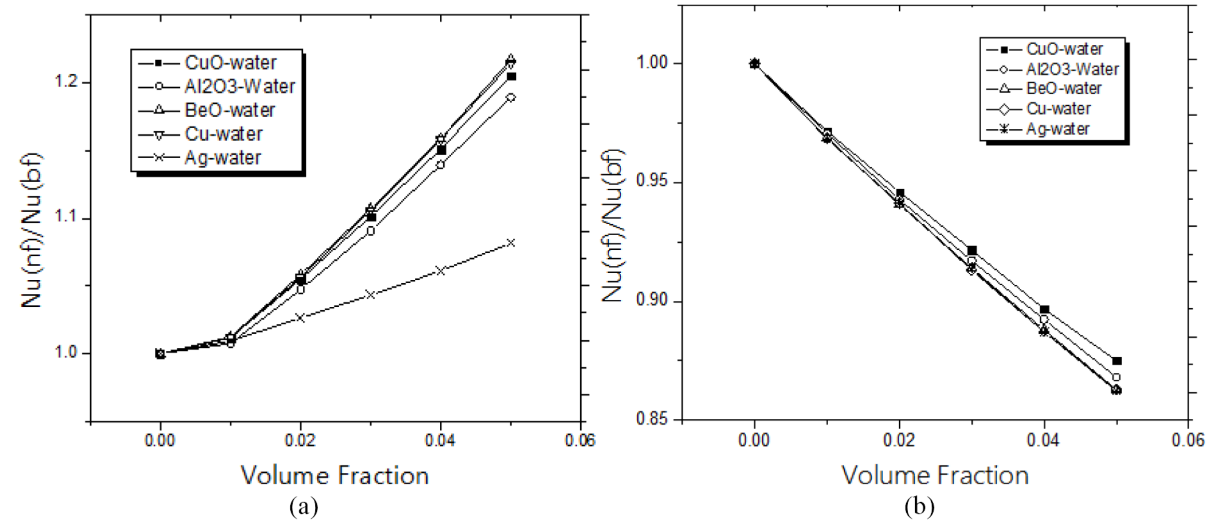


Figure 4. Variation of Nusselt Number Enhancement with volume fraction at (a) constant Reynolds number and (b) constant heat transfer coefficient.

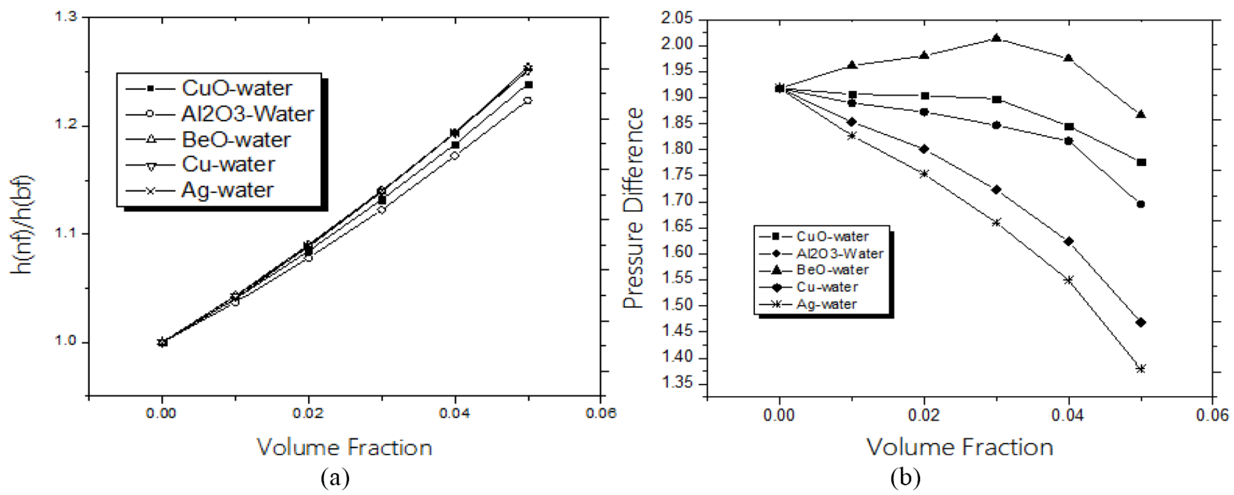


Figure 5. Effect of nanoparticles volume fraction on (a) heat transfer coefficient enhancement ratio and (b) pressure difference (Pa/m).

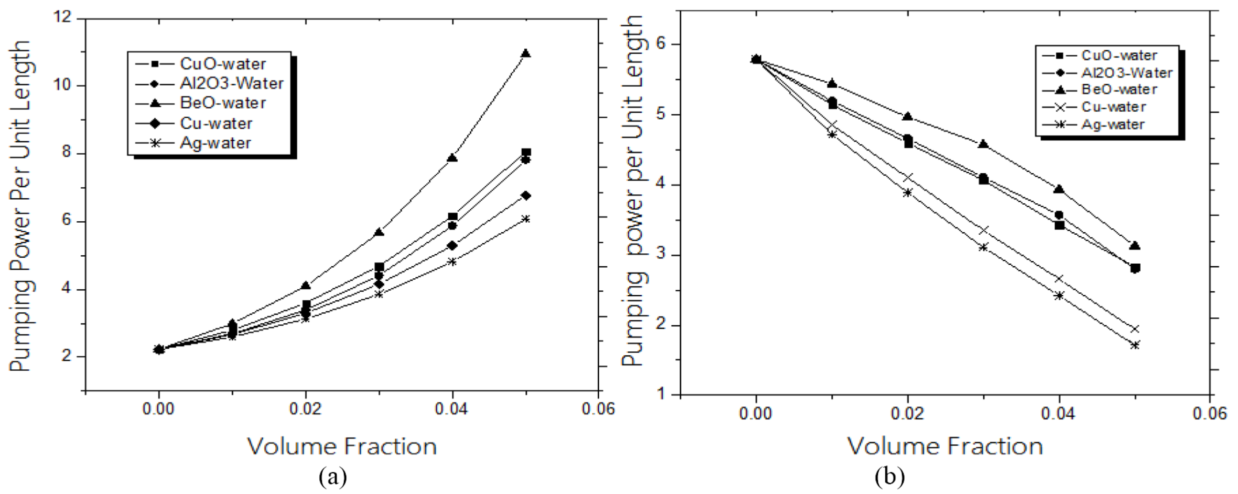


Figure 6. Effect of volume fraction on pumping power per unit length (KW/m) at (a) constant Reynolds number and (b) constant heat transfer coefficient.

all the nanofluids, Ag-water required the lowest power and BeO-water required the highest power. To justify the performance of the used nanofluids, another performance parameter FOM has been calculated which is the ratio of heat transfer rate and required pumping power indicates the more enhancement of its higher value and here, Ag-water nanofluid shows the highest value of FOM and BeO-water provides the lowest value at both constant Reynolds number and constant heat transfer condition at Figure 7. This behaviour is occurred due to the highest density of Ag nanoparticles and meanwhile, the lowest density of BeO nanoparticle's in comparison to other nanoparticles which affect the fluid's velocity and flow behaviour.

To understand the performance parameters properly and identify the best nanofluids among all the used nanofluids in this study Table 1 has been presented. From Table 1, it is clear that in order to get the same amount of heat transfer rate, the energy has been saved 86.26% by Ag-water nanofluid, 72.84% by Cu-water, 42.36% by CuO-water, 40.99% by Al_2O_3-water, and 26.58% by BeO-water. On the other hand,

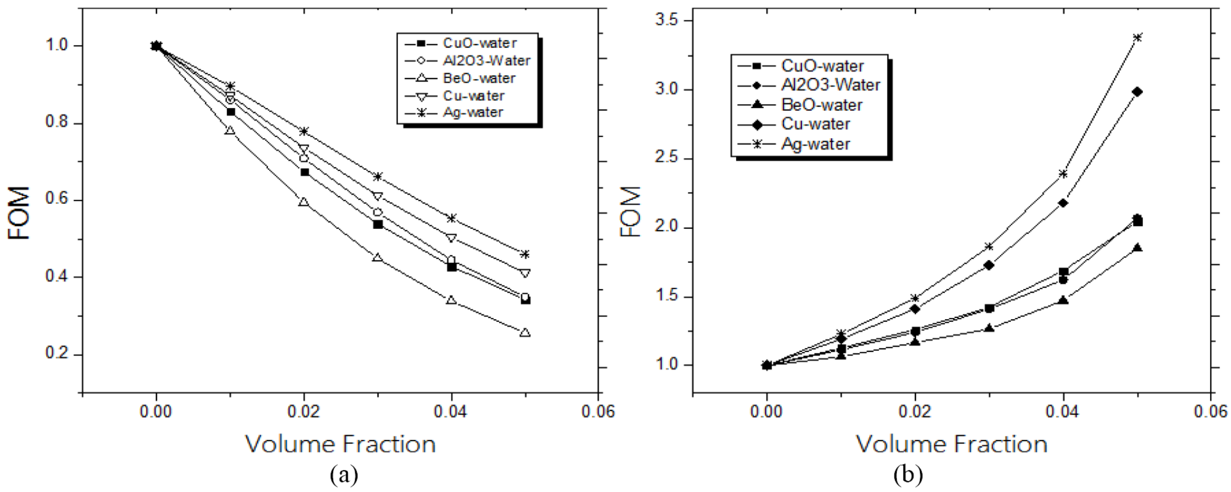


Figure 7. Variation of FOM with volume fraction at (b) constant Reynolds number and (a) constant heat transfer coefficient.

Table 1. Performance Comparison between all used nanofluids

Type of Fluid parameter	Water	3% Al_2O_3	3% CuO	3% BeO	3% Cu	3% Ag
Heat Transfer Co efficient (W/m^2-K)	600	600	600	600	600	600
Reynolds number	960	580	560	540	540	540
Nusselt Number	4.897	4.62	4.75	5.07	4.34	4.18
Density (Kg/m^3)	996	1085.22	1161.12	1056.12	1234.11	1281.12
Pressure loss (Pa/m)	1.91779	1.84678	1.89787	2.01336	1.7229	1.65976
Pumping power per unit length (W/m)	5.9726426	4.108583652	4.0689721	4.566245	3.351421	3.109973
Power advantage (W/m)	0	1.684059	1.723671	1.216298	2.441214	2.68267
Power advantage (%)		40.99	42.36	26.58	72.841	86.26
FOM	1	1.41	1.424	1.266	1.729	1.863
Velocity (m/s)	0.153831	0.113105	0.109191	0.11576	0.099064	0.095429
Volumetric flow rate (m^3/s)	$3.02E^{-6}$	$2.2247E^{-6}$	$2.14397E^{-6}$	$2.27294E^{-6}$	$1.94512E^{-6}$	$1.87375E^{-6}$
Reduction in volumetric flow rate (%)	0	35.7	40,9	32.9	53.3	61.2
Mass Flow rate (Kg/s)	$3.01E^{-3}$	$2.41E^{-3}$	$2.49E^{-3}$	$2.500497E^{-3}$	$2.400492E^{-3}$	$22.395695E^{-3}$
Reduction in Mass flow rate (%)	0	24.6	20.8	20.4	25.39	25.6

the value of FOM is 1.863 for Ag-water nanofluid, 1.729 for Cu-water, 1.424 for CuO-water, 1.41 for Al_2O_3-water, and 1.266 for BeO-water. Besides this, Ag-water nanofluid's reduction rate of volumetric flow rate, pressure loss, and mass flow rate is higher in comparison to others. So if we consider overall parameters and results, then it is clear that Ag-water nanofluid provides more enhancement and BeO-water provides less enhancement compared to others on the basis of considering pumping power requirement FOM and reduction of volumetric and mass flow rate.

However, higher thermal conductivity, heat capacity, density, and lower viscosity are the standard properties for fluids that are worked in heat transfer application (Chand et al. [38], Kasmani et al. [39], Rabby et al. [40]). Nanofluid basically introduced because of its higher thermal conductivity, heat capacity, density, and lower viscosity compared to traditional fluids (Hussein and Mustafa [41], Wen [42], Corcione [43], Belhadj et al. [44]). After analysing the above results, it appears that metal-based nanoparticles show more enhancements in heat transfer compared to oxide-based, higher thermal conductivity, heat capacity, density and lower viscosity of metal-based nanoparticles is the main reason for this phenomenon. Higher thermal conductivity and density mainly help the fluids to transfer more heat and reduce pressure loss which increases the heat transfer rate by reducing pumping power requirement as well. Therefore, metal-based nanoparticles provide more enhancement and power-saving advantages compared to oxide-based.

CONCLUSION

In the present work, three oxides based on different nanofluids Al_2O_3-water, CuO-water, BeO-water, and two pure metal-based nanofluids Cu-water and Ag-water have been studied through a typical circular tube to observe the performance among them on the basis of heat transfer enhancement and the pumping power benefits. For this purpose, 1–5% volume fraction of these nanoparticles were mixed with water to analyse the performance parameters and required pumping power of all nanofluids. Results demonstrated that the presence of nanoparticle volume fractions in a base fluid provides better enhancement of heat transfer (Nusselt number and heat transfer coefficient) with comparatively lower utilisation of pumping power. At constant heat transfer coefficient, 26% to 86% power advantages have been achieved by using this 3% volume fraction of nanoparticles in the base fluid which is water whereas pure metal-based nanoparticles are more beneficial than oxide-based nanoparticles. The thermal conductivity, specific heat, and density of the metal nanoparticles are comparatively higher than oxide-based particles which are mainly responsible for this better performance of metal-based nanoparticles. However, between metal-based nanoparticles, Ag provides more energy-saving benefits (86.26%) compared to Cu (72.84%) on the other hand between oxide-based nanoparticles, CuO show higher power savings advantages (42.36%), and BeO show lower advantages (26.58%) compared to Al_2O_3 nanoparticles in the heat transfer application. Additionally, other parameters such as volumetric flow rate and mass flow rate were reduced by using nanoparticles especially Ag nanoparticles provide the highest reduction and BeO nanoparticles provide the lowest reduction compared to others. Therefore, after analysing data from this study, it can be concluded that metal-based nanoparticles provide more heat transfer enhancement compared to oxide-based nanoparticles in terms of pumping power advantages whereas Ag nanoparticles show the highest power-saving advantages and BeO nanoparticles show the lowest power-saving advantages in the heat transfer application.

NOMENCLATURE

ϕ	Volume concentration
T	Temperature (°C or K)
U_{av}	Average inlet velocity (m/s)
D_h	Hydraulic diameter (m)
m	Mass flow rate (kg/s)
k	Thermal conductivity ($Wm^{-1} K^{-1}$)
μ	Viscosity ($kg{\cdot}m^{-1}{\cdot}s^{-1}$)
h	Average heat transfer coefficient ($Wm^{-2}K^{-1}$)
ΔT	Temperature difference (°C or K)
C_p	Specific heat at constant pressure ($J.mol^{-1}.K^{-1}$)
Δp	Pressure difference (Pa or N/m^2)
W	Pumping power (KW)

Subscripts

i	Inlet
o	Outlet
W	Wall
nf	Nanofluid
bf	Basefluid
p	Particle size

AUTHORSHIP CONTRIBUTIONS

Concept: Md Insiat Islam Rabby; Design: Md Insiat Islam Rabby; Supervision: A. K. M. Sadrul Islam; Materials: Md Insiat Islam Rabby, Farzad Hossain; Data: Md Insiat Islam Rabby, Farzad Hossain, S. A. M. Shafwat Amin; Analysis: Md Insiat Islam Rabby, Farzad Hossain, S. A. M. Shafwat Amin, A. K. M. Sadrul Islam; Literature search: Md Insiat Islam Rabby, Farzad Hossain; Writing: Md Insiat Islam Rabby, Farzad Hossain, S. A. M. Shafwat Amin; Critical revision: Md Insiat Islam Rabby, Farzad Hossain, A. K. M. Sadrul Islam

DATA AVAILABILITY STATEMENT

No new data were created in this study. The published publication includes all graphics collected or developed during the study.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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