# Experimental Investigation for The Heat Transfer Enhancement in A Tube by Using MgO Nanofluid

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## Abstract

In this analysis, heat transfer augmentation in a tube by using 0.1% volume fraction of MgO-water nanofluid was examined. The experiment was carried out in a long copper tube of 900mm with outside and inside dimeter of 30mm and 26.6mm respectively. Two thermometers and four k-type thermocouples were used for measuring inlet-outlet temperatures of fluid and outside temperature of the tube respectively. By using rotameter flow rate was measured. A U tube manometer was used to measure the difference of pressure head between inlet and outlet section of tube. A voltage regulator constantly supplied voltage to heat a nichrome wire which were surrounded around the tube. Heat transfer coefficient, Nusselt number, friction factor, pumping power required and percentage of increase of Nusselt number were calculated. Heat transfer coefficient, Nusselt number and pumping power increased with Reynolds number. The increment of Nusselt number was 21.60% for 0.1% volume fraction of MgO-water nanofluid than that of the plain tube. It was also found that friction factor increased 1.32 times for nanofluid than that of the plain tube.

## Keywords
Heat transfer rate, Nusselt number, Nanofluid, Friction factor, Pumping power

## 1. Introduction
Various method of heat transfer augmentation techniques used nowadays. active, passive and compound techniques are the classifications of the heat transfer techniques. Heat transfer augmentation by using nanofluid and insert and have been widely used in many engineering field such as refrigeration in automotive, manufacturing industry, chemical industry, electronics, power generation etc. Concept of nanofluid was first developed about a decade ago. The concept of nanofluid was developed with some special aim such as increasing thermal conductivity of fluid. Nanofluid is a fluid which contain nanometer sized particle in a mixture with a base fluid. These types of fluid consist of colloidal suspension of nanoparticles in a base fluid. Various types of nanopowder are used to make nanofluid. Nanoparticles are made from oxides, metals, carbides and carbon nanotubes such as $TiO_2$, MgO, CuO etc. common base fluid used for nanofluid preparation are water, ethylene glycol and oil. Nanofluid shows higher convective heat transfer coefficient and higher thermal conductivity than base fluid.

### 1.1 Objectives
A few targets are detailed to introduce the general objective of the current analysis. The objectives of this analysis are:
- To study the heat transfer performance of the system using MgO nanofluid.
- To investigate the effect of Reynolds number on Nusselt number.
- To study the friction factor for nanofluid.

## 2. Literature Review
Kadhim et al. (2016) performed an experiment to analyze the effect of MgO nanofluid on heat transfer characteristics of integral finned tube heat exchanger and found that after using nanofluid thermal conductivity, heat transfer rate and density increased. Kayhani et al. (2012) performed a study on convection heat transfer and pressure drop inside a uniformly heated tube for $TiO_2$ water nanofluid. The experiment was conducted for various volume concentration of nanoparticles and observed that convection heat transfer coefficient increased with the increase of volume concentration and pressure drop increased with the increase of Reynolds number. Moraveji et al. (2012) investigated the effect of thermal efficiency of heat pipe after using $Al_2O_3$ nanofluid of 0%, 1% and 3% weight concentration of nanoparticles and found that higher concentration of nanofluids leads to the higher performance of heat pipe.

Reddy and Rao (2014) performed an experiment by using $TiO_2$ nanoparticles mixed with water and ethylene glycol combined with helical coil insert and without insert for the determination of friction factor and heat transfer co-efficient in a double pipe heat exchanger. The results showed that enhancement of convective heat transfer co-efficient depends on Reynolds number and also the concentration of nanoparticles. Vermahmoudi et al. (2014) experimentally investigated the overall heat transfer coefficient of $Fe_2O_3$ water nanofluid in an air finned heat exchanger and found that overall heat transfer coefficient enhanced with the increase of Reynolds number and concentration of nanofluid. Air Reynolds number was used in the experiment. Sundor and Sharma (2010) studied the effect of $Al_2O_3$ nanofluid and twisted tape insert in a circular tube on heat transfer characteristics and found that heat transfer enhanced for nanofluid and twist ratio of insert compared with water. Akhtari et al. (2013) carried out an investigation both numerically and experimentally in a double pipe shell and tube heat exchanger by using α $Al_2O_3$ nanofluid and found that convective heat transfer coefficients were larger after using nanofluid compared to pure water by 13.2% and 21.3% in the double pipe shell and tube heat exchanger. Chavda et al. (2014) experimented for investigation of parallel and counter flows in a double pipe heat exchanger by using nanofluid.
Hashmi and Akhavan Behabadi (2012) performed an experiment using helical coil insert, straight tube insert and CuO nanofluid for finding heat transfer enhancement. The results showed that using helical tube insert was more effective method compared to straight tube for enhancement of the convective heat transfer coefficient. The result showed that 78.4% enhancement of heat transfer coefficient happened compared to the straight tube. A conclusion was also given that nanofluid improved the performance of helical coil after performing the experiment with constant heat flux. Kumar et al. (2013) carried out an experimental investigation in shell and tube heat exchanger equipped with helical coil insert using $Al_2O_3$/water nanofluid with varying nanoparticles concentration and also found that the Nusselt number increased 56% for 0.8 volume % $Al_2O_3$ nanoparticles. By performing an experiment using $TiO_2$/water nanofluid at laminar flow conditions in helical coiled tubes, Kahani et al. (2014) concluded that due to $TiO_2$ nanoparticles heat transfer rate increased significantly. Wongcharee et al. (2011) studied on the enhancement of heat transfer by using CuO-water nanofluid and twisted tape with alternate axis. The experiment was done with different volume concentrations of nanofluid. It is found that Nusselt number increased with the increase of volume concentration and Reynolds number. Arya et al. (2019) performed an experiment on the heat transfer and pressure drop characteristics of MgO nanofluid in a double pipe heat exchanger for weight concentration of 0.1%, 0.2% and 0.3% of MgO and found that the heat transfer and pressure drop increased with the increase of concentration.

## 3. Methods

### 3.1 Preparation of Nanofluid

MgO nanoparticles and water were used for the preparation of nanofluid.  Two step preparation method was used for the preparation of the nonofluid. In this method the MgO nanopowders obtained by using different physical, mechanical or chemical process such as milling, grinding, vapour phase and sol-gel methods was used to mix directly with water. A magnetic stirring was used to keep the solution about 12 hours to achieve uniform mixing of nanoparticles with base fluid.

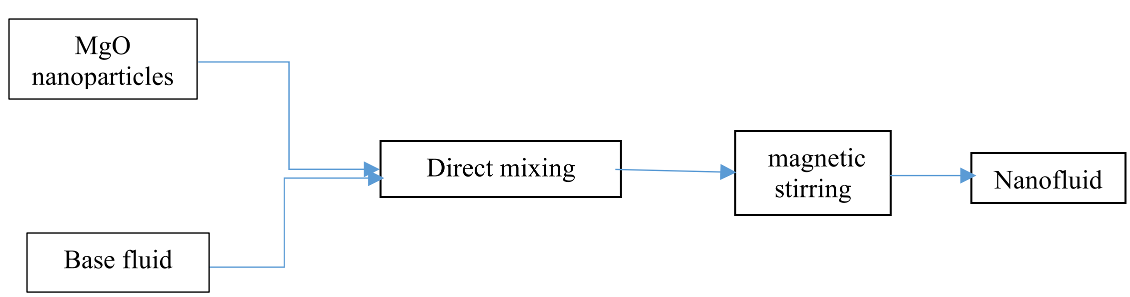


Figure 1. Nanofluid preparation procedure

### 3.2 Experimental Setup

The experiment was carried out in a long copper tube of 26.6mm inner diameter and 30mm outer diameter. The outside surface temperatures were measured by using four K-thermocouples. Water based MgO nanofluid was used for this experiment as working fluid which was contained in the tank to circulate through the tube. A voltage source was used. Constant heat flux was maintained by wrapping nichrome wire around the copper tube. A pump was also used for circulating the water through the tube.

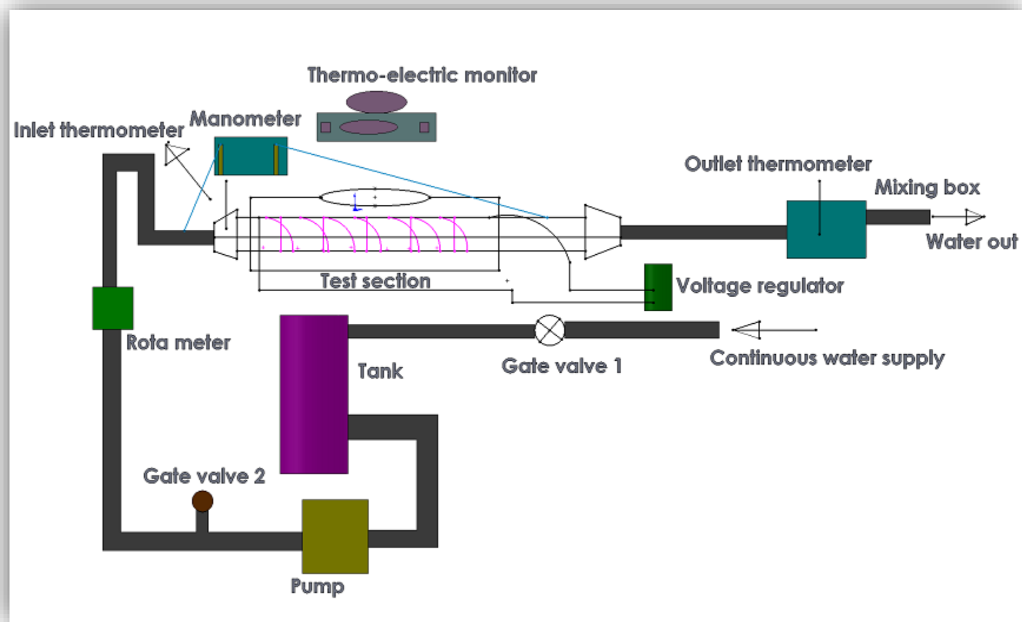


Figure 2. Schematic diagram of experimental set up

Two thermometer was used to measure the temperature of fluid at inlet and outlet section of the tube. A U tube manometer was used to measure the pressure difference between inlet and outlet of the tube. A rotameter was used to measure flow rate. The upper surface of the tube was insulated by using insulated material. The schematic diagram of the experimental setup shown in Figure 2. At first the required data for the plain tube was taken using water as working fluid. Then nanofluid was used as working fluid. The photographic view of the test section has been shown in Figure 3.

Figure 3. Photographic view of test section

## 4. Data Collection

Cross sectional area, Ax $=\frac{\pi d_i^2}{4}$ (4.1)

Inner surface area, $A_i = A_s = \pi d_i L$ (4.2)

Heat transfer rate by the heater to water was calculated by measuring heat added to the water.

Heat added to water was calculated by, $Q = mC_p(T_o - T_i)$ (4.3)

Bulk temperature, $T_b = \frac{T_O + T_i}{2}$ (4.4)

Outer surface temperature, $T_{wo} = \frac{Thermocouple\ 1 + \cdots \ldots\ldots + thermocouple\ 4}{4}$ (4.5)

Tube inner surface temperature was calculated from one dimensional radial conduction

Equation, $T_{wi}$=$T_{wo}$-Q$\frac{\ln(\frac{d_o}{d_i})}{2\pi k_{Cu}L}$ (4.6)

Convective heat transfer coefficient, h = $\frac{Q}{A_s(T_{wi}-T_b)}$ (4.7)

Velocity, $U_m$= $\frac{q}{A_x}$ , where q is the flow rate (4.8)

Reynolds Number, Re = $\frac{\rho U_m d_i}{\mu}$ (4.9)

Prandtl number, Pr =$\frac{\mu C_p}{K}$ (4.10)

Experimental Nusselt Number, $Nu_{exp}$ = $\frac{hd_i}{k}$ (4.11)

Theoretical Nusselt Number, $Nu_{th}$=$\frac{(\frac{f}{8})(Re_D-1000)Pr}{1+12.7(\frac{f}{8})(Pr^{\frac{2}{3}}-1)}$ (by Gnielinski) (4.12)

Pressure difference, $\Delta p = \Delta h \times \rho \times g$ (4.13)
Theoretical Friction Factor, $f_{th}$= $(0.79\ln Re-1.64)^{-2}$ (4.14)
Experimental friction co-efficient, $f_{exp}$ = $\frac{\Delta P}{(\frac{L}{d_i})(\frac{\rho U_m^2}{2})}$ (4.15)

Viscosity of Nano-fluid, $\mu = (1 + 2.5\varphi)\mu_b$ (4.16)
Density of Nano-fluid, $\rho_{nf} = \varphi\rho_p+(1-\varphi)\ \rho_{bf}$ (4.17)
Specific heat of nanofluid, $C_{p,nf}$ = $\frac{\varphi(\rho C_p)p+(1-\varphi)(\rho C_p)bf}{(1-\varphi)\rho_{bf}+\varphi_{\rho p}}$ (4.18)

Pumping Power, $P_m$ = $\frac{\Delta pm}{\rho}$ (4.19)

Tube outside diameter, do= 30mm; Tube inside diameter, di=26.6mm, Tube test length, L=900mm; Density of MgO =3580 kg/$m^3$, Inside surface area, $A_i$ =$A_s$= 0.0752 m², Outside surface area, $A_0$ = 0.0848 m²; Thermal conductivity of MgO, k=48.4 W/$m^2$ $^0$C; Specific heat of MgO = 877 J/kg$^0$C

Thermal conductivity of copper, k = 379 W/$m^2$ $^0$C; Cross sectional area, Ax= 5.557×$10^{-4}$ m²
Density of water, ρ = 996 kg/$m^3$; Density of Nano fluid= 998.58 kg/$m^3$; Specific heat of water, Cp = 4179 J/kg$^0$C
Thermal conductivity of water, k = 0.62 W/$m^2$ $^0$C; Specific heat of Nano fluid, Cp = 4167.1 J/kg$^0$C

Table 1. Rotameter reading at different flow rates for Plain Tube

| Experiment No | Rotameter Reading (cm) | Flow rate (ml/sec) | Flow rate ($m^3$ /sec) | Flow Rate (kg/sec) |
|---|---|---|---|---|
| 1 | 2.5 | 37.5 | 0.0000375 | 0.0375 |
| 2 | 3.5 | 52.5 | 0.0000525 | 0.0525 |
| 3 | 4.5 | 67.5 | 0.0000675 | 0.0675 |
| 4 | 5.5 | 82.5 | 0.0000825 | 0.0825 |
| 5 | 6.5 | 97.5 | 0.0000975 | 0.0975 |
| 6 | 7 | 105 | 0.000105 | 0.105 |
| 7 | 7.5 | 112.5 | 0.000113 | 0.1125 |

Table 2. Thermometer and Thermocouple reading at different flow rates (Plain Tube)

| Exp No | Inlet Temperature ($^o$ C) | Outlet Temperature ($^o$ C) | Thermo couple 1 ($^o$ C) | Thermo couple 2 ($^o$ C) | Thermo couple 3 ($^o$ C) | Thermo couple 4 ($^o$ C) |
|---|---|---|---|---|---|---|
| 1 | 26 | 29.2 | 44 | 45 | 46 | 49 |
| 2 | 26 | 29 | 43 | 44 | 44 | 47 |
| 3 | 26 | 29 | 42 | 44 | 45 | 49 |
| 4 | 26 | 28.8 | 42 | 42 | 44 | 47 |
| 5 | 26 | 28.5 | 41 | 41 | 42 | 44 |
| 6 | 26 | 28.4 | 39 | 41 | 42 | 44 |
| 7 | 26 | 28.4 | 40 | 41 | 42 | 43 |

Table 3. Rotameter reading at different flow rates for 0.1% volume fraction of MgO

| Experiment No | Rotameter Reading (cm) | Flow rate (ml/sec) | Flow rate ($m^3$ /sec) | Flow Rate (kg/sec) |
|---|---|---|---|---|
| 1 | 2.5 | 37.5 | 0.0000375 | 0.0375 |
| 2 | 3.5 | 52.5 | 0.0000525 | 0.0525 |
| 3 | 4.5 | 67.5 | 0.0000675 | 0.0675 |
| 4 | 5.5 | 82.5 | 0.0000825 | 0.0825 |
| 5 | 6.5 | 97.5 | 0.0000975 | 0.0975 |
| 6 | 7 | 105 | 0.000105 | 0.105 |
| 7 | 7.5 | 112.5 | 0.000113 | 0.113 |

Table 4. Thermometer and Thermocouple reading at different flow rates for 0.1% volume fraction of MgO

| Exp No | Inlet Temperature ($^o$ C) | Outlet Temperature ($^o$ C) | Thermo couple 1 ($^o$ C) | Thermo couple 2 ($^o$ C) | Thermo couple 3 ($^o$ C) | Thermo couple 4 ($^o$ C) |
|---|---|---|---|---|---|---|
| 1 | 22 | 24 | 31 | 31 | 31 | 35 |
| 2 | 22 | 23.8 | 30 | 31 | 31 | 33 |
| 3 | 23 | 25 | 30 | 33 | 35 | 36 |
| 4 | 24 | 26 | 31 | 35 | 35 | 36 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | 24 | .25.5 | 30 | 31 | 33 | 35 |
| 6 | 24.2 | 25.5 | 31 | 30 | 32 | 33 |
| 7 | 24.5 | 25.8 | 30 | 31 | 31 | 35 |

## 5. Results and Discussion

### 5.1 Numerical Results

Variation of heat transfer rate, convective heat transfer coefficient, experimental and theoretical Nusselt number, experimental friction factor for plain copper tube at different Reynolds number are given below

Reynolds number, Re = 2234.816~6704.449
Heat transfer rate, Q = 501.48~1128.32 W
Convective heat transfer coefficient, h = 363.93337~1056.615 W/m$^2$K
Experimental Nusselt number, $Nu_{exp}$ = 15.61393~45.33218
Theoretical Nusselt number, $Nu_{th}$ =13.5869~49.42
Experimental friction factor, fexp = 0.0326~0.205428

Variation of heat transfer rate, convective heat transfer coefficient, experimental Nusselt number, experimental friction factor for 0.1% MgO Nanofluid at different Reynolds number are given below

Reynolds number, Re = 2055.601~6166.804
Heat transfer rate, Q = 313.425~1106.788 W
Convective heat transfer coefficient, h = 465.2192~1240.989 W/m$^2$K
Experimental Nusselt number, $Nu_{exp}$ = 19.95~53.24241
Experimental friction factor, fexp = 0.0362~0.256

### 5.2 Graphical Results

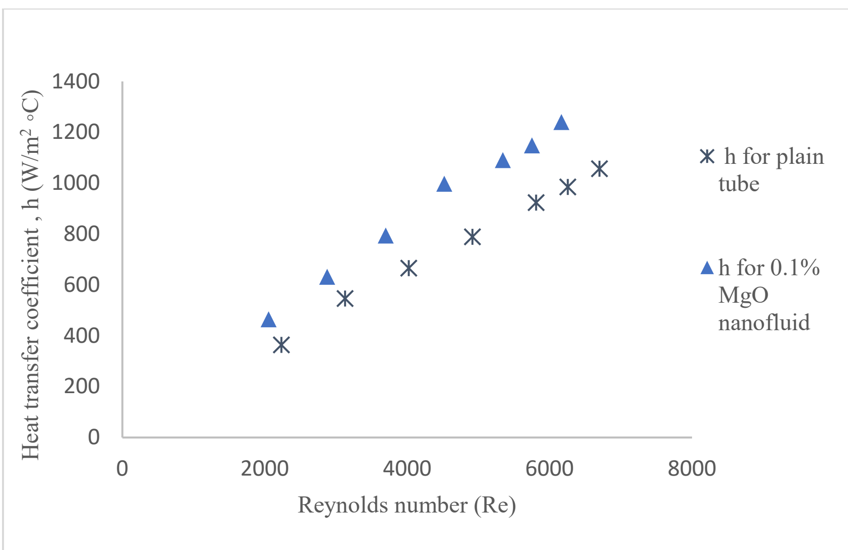


Figure 4. Variation of heat transfer coefficient with Reynolds number

Figure 4 shows the variation of heat transfer coefficient with Reynolds number for both plain tube and nanofluid. It is found that heat transfer coefficient increases with the increase of Reynolds number for both plain tube and nanofluid. When 0.1% volume fraction of MgO is used, heat transfer rate increases more than plain tube. The graphical representation shows that heat transfer rate is higher for 0.1% MgO nanofluid comparing to the plain tube. Since the nanoparticle has greater thermal conductivity than water so the overall heat transfer coefficient also increased in accordance with the conductivity of fluid.

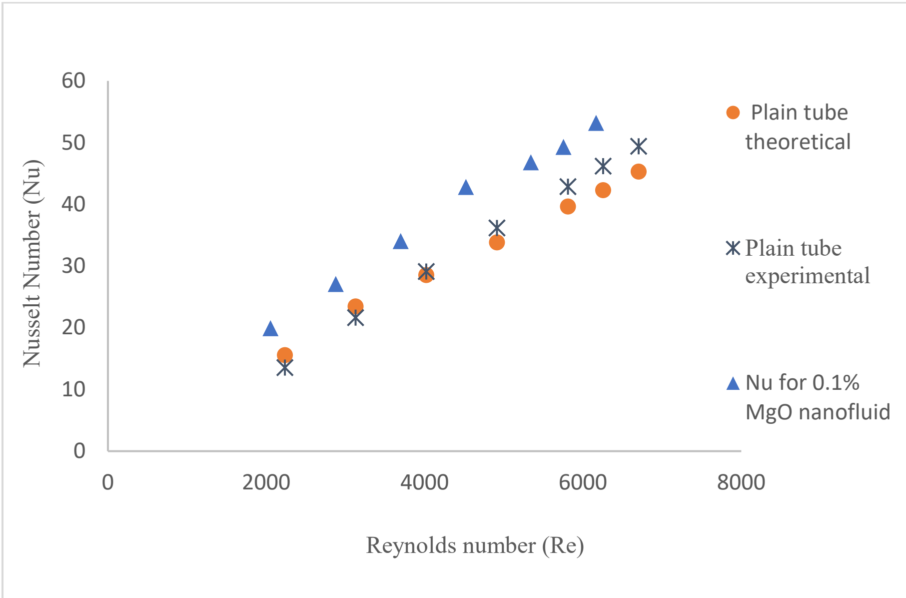


Figure 5. Variation of Nusselt number with Reynolds number

Due to the smaller dimensions, nanoparticles have a natural tendency to show a zigzag motion. It is called Brownian motion. Due to this motion, the transfer of energy in the direct nanoparticle-nanoparticle contact from the particle collision which is the partial cause of the enhancement of thermal conductivity. Interfacial layers are also created in nanofluid which show different thermophysical properties. So higher thermal conductivity is shown comparing to water that helps to enhance heat transfer coefficient. Figure 5 shows the variation of Nusselt number with Reynolds number for plain tube and 0.1% volume fraction of MgO. The Figure shows that Nusselt number increases 21.60% for 0.1% MgO than that of plain tube.

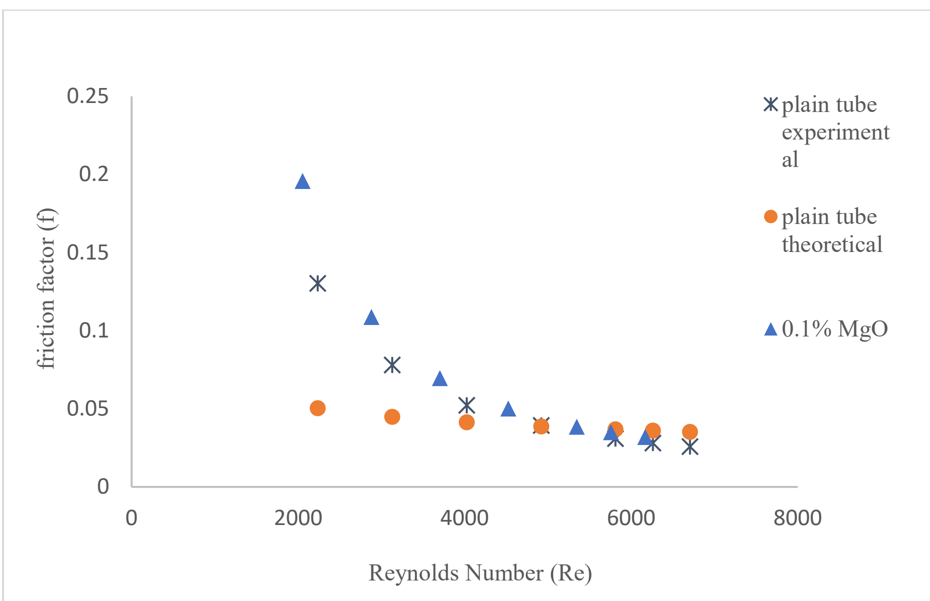


Figure 6. Friction Factor vs Reynolds number

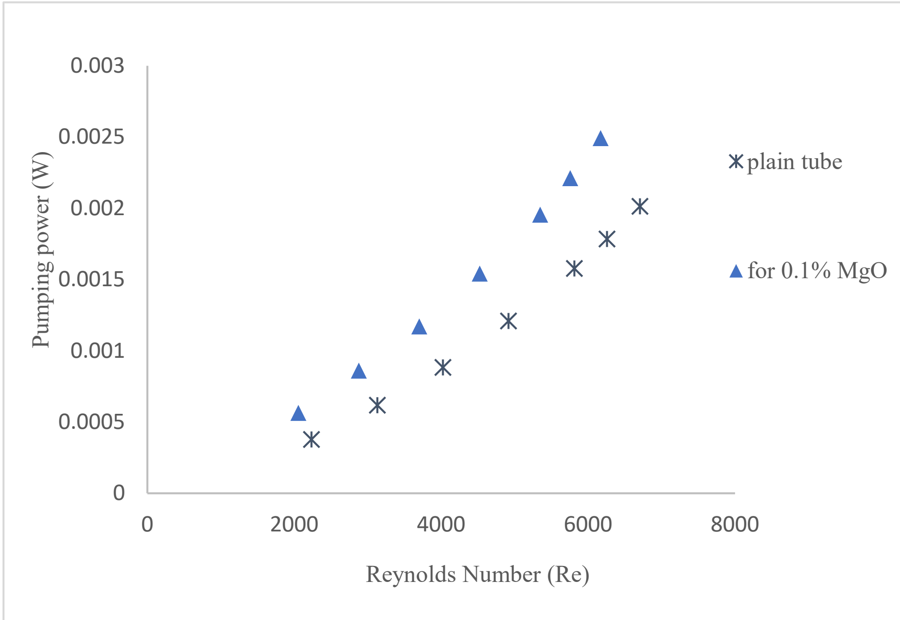


Figure 7. Pumping Power vs Reynolds number

The variation of friction factor with different Reynolds number is illustrated in Figure 6. The figure demonstrates that the friction factor decreases with the increase in Reynolds number. It is found that friction factor is higher for MgO nanofluid than that of plain tube. It is also found that friction factor increased 1.32 times for nanofluid than that of the plain tube.

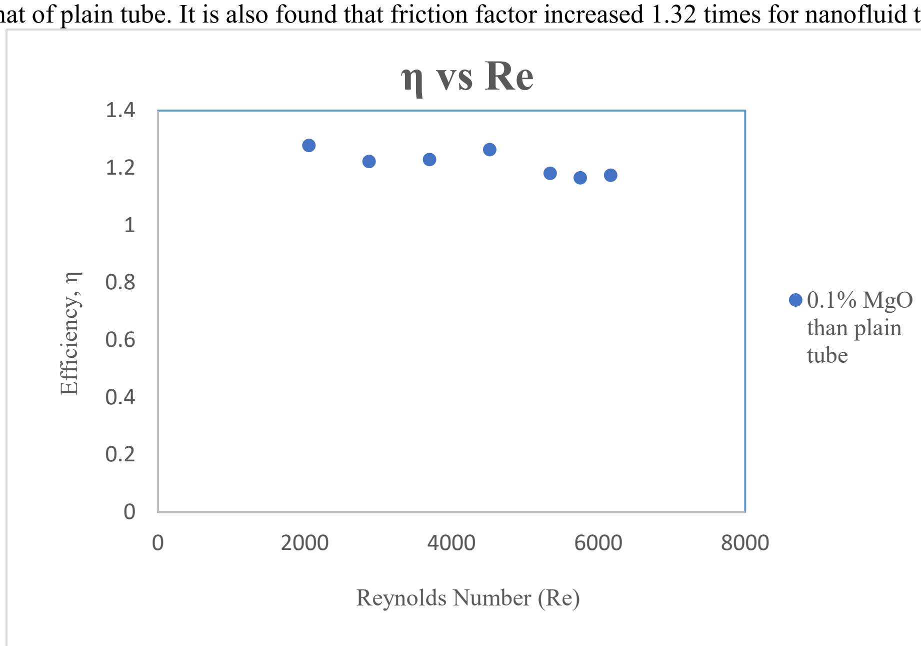


Figure 8. Efficiency vs Reynolds number

Figure 7 shows that pumping power increases with increase of Reynolds number. Whenever nanofluid is used instead of water more power need to flow the fluid inside the tube. It is shown from figure that pumping power is higher for 0.1% MgO than that of the plain tube. Figure 8 demonstrates that by using 0.1% volume fraction of MgO nanofluid the efficiency increases at an average of 1.21 times than that of plain tube with water.

## 6. Conclusion

Nanoparticles have low particle momentum and very mobility. The small size of the nanoparticle molecules allows for free movement and hence micro convection, which promotes heat transfer rate. The outcomes of these analysis which we found that:

- Nusselt number increases with the increase of Reynolds number. Nanofluid has better heat transfer characteristics than water and the percentage of increase in Nu is 21.60% than water. Friction factor is 1.32 times higher than that of plain tube.
- Pumping power also increases with the increase of Reynolds number. Pumping power is higher for 0.1% MgO than that of the plain tube.

## References

Kadhim, Z. K., Kassim, M. S. and Hassan, A. Y. A., Effect of (MgO) nanofluid on heat transfer characteristics for integral finned tube heat exchanger. *International Journal of Mechanical Engineering and Technology (IJEMT)*, 7, 11-24, 2016.

Kayhani, M. H., Soltanzadeh, H., Heyhat, M. M., Nazari, M. and Kowsary, F., Experimental study of convective heat transfers and pressure drop of $TiO_2$/water nanofluid. *International Communications in Heat and Mass Transfer,* 39(3), 456-462, 2012.

Moraveji, M. K. and Razvarz, S. Experimental investigation of aluminum oxide nanofluid on heat pipe thermal performance. *International Communications in Heat and Mass Transfer,* 39(9), 1444-1448, 2012.

Reddy, M. C. S. and Rao, V. V. Experimental investigation of heat transfer coefficient and friction factor of ethylene glycol water based $TiO_2$ nanofluid in double pipe heat exchanger with and without helical coil inserts. *International Communications in Heat and Mass Transfer,* 50, 68-76, 2014.

Vermahmoudi, Y., Peyghambarzadeh, S. M., Hashemabadi, S. H. and Naraki, M. Experimental investigation on heat transfer performance of $Fe_2O_3$/water nanofluid in an air-finned heat exchanger. *European Journal of Mechanics-B/Fluids*, 44, 32-41, 2014.

Sundar, L. S. and Sharma, K. V. Turbulent heat transfer and friction factor of $Al_2O_3$ nanofluid in circular tube with twisted tape inserts. *International Journal of Heat and Mass Transfer,* 53(7-8), 1409-1416, 2010.

Akhtari, M., Haghshenasfard, M. and Talaie, M. R. Numerical and experimental investigation of heat transfer of α-$Al_2O_3$/water nanofluid in double pipe and shell and tube heat exchangers. *Numerical Heat Transfer,* Part A: Applications, 63(12), 941-958, 2013.

Chavda, N. K., Patel, J. R., Patel, H. H. and Parmar, A. P. Effect of Nanofluid on Heat Transfer Characteristics of Double Pipe Heat Exchanger: Part-I: Effect of Aluminum Oxide Nanofluid. *International Journal of Research in Engineering and Technology*, 3(12), 42-52, 2014.

Hashemi, S. M. and Akhavan-Behabadi, M. A. An empirical study on heat transfer and pressure drop characteristics of CuO–base oil nanofluid flow in a horizontal helically coiled tube under constant heat flux. *International Communications in Heat and Mass Transfer*, 39(1), 144-151, 2012.

Kumar, P. M., Kumar, J. and Suresh, S. Experimental investigation on convective heat transfer and friction factor in a helically coiled tube with $Al_2O3$/water nanofluid. *Journal of Mechanical Science and Technology,* 27(1), 239-245, 2013.

Kahani, M., Heris, S. Z. and Mousavi, S. M., Experimental investigation of $TiO_2$/water nanofluid laminar forced convective heat transfer through helical coiled tube. *Heat and Mass Transfer,* 50(11), 1563-1573, 2014.

Wongcharee, K. and Eiamsa-Ard, S., Enhancement of heat transfer using CuO/water nanofluid and twisted tape with alternate axis. *International Communications in Heat and Mass Transfer,* 38(6), 742-748, 2011.

Arya, H., Sarafraz, M. M., Pourmehran, O. and Arjomandi, M. Heat transfer and pressure drop characteristics of MgO nanofluid in a double pipe heat exchanger. *Heat and Mass Transfer,* 55(6), 1769-1781, 2019.

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