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CFD Analysis for Heat Transfer Enhancement Using Nano-Fluids in Double Pipe Heat Exchanger

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ABSTRACT
This work includes the effect of different working fluid on the performance of heat exchanger. For analysing the effect of different working fluid, it considered air, water and different nanofluids and measure the Nusselt number and friction factor for each case. It also analysed the effect of change in Reynolds number on the performance of heat exchanger for different working fluids. For analysing the effect of change in Reynolds number, it considered four different Reynolds numbers that is 10000, 12000, 14000 and 16000. For performing the numerical analysis ANSYS fluent was used. Through numerical analysis it is found that for air as a working fluid heat transfer is less, whereas in case of water it is marginally higher than the air. But for all nano-fluids, heat transfer is much higher than the air and water. For analysing the effect of different nano-fluid, this work includes three nano-fluids that are Al_2O_3, $TiO_2$and ZrO_2. Through analysis it is concluded that heat transfer is more in case of TiO_2 as compared to other nanofluids, air and water. With increase in Re number heat transfer gets increase whereas as friction factor get decrease.

KEYWORDS: *Heat transfer, Nusselt number, friction factor, heat exchanger, nano-fluids*

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1. INTRODUCTION

A Heat exchanger may be stated as a device which transfers energy from a hot fluid to a cold fluid, either maximum or minimum rate within least investment as well as operating cost. In this process never two fluids mixed with each other. Heat exchanger is the main unit in action that gives the efficiency as well as security to numerous of the processes. In such type of job we have to estimate the enactment of the heat exchangers of different types that is tubular, plate and shell & tube. All these heat exchangers may be functioned in both parallel as well as counter flow arrangements. The heat exchanger is accomplished amongst hot and cold water. This device offers a thermal energy flow among two or more fluids at some temperatures. Shell and tube heat exchangers are most useful type of heat exchanger likewise utilized in an extensive range of industrial uses like power generation, heat recovery in wastage system, engineering firms, cooling and refrigeration, space applications, petrochemical activities and many different areas. The foremost attentions regarding the effectiveness of shell tube heat exchanger are comes in a region of turbulence, drop in pressure, coefficient of heat exchanger, fouling, as well as percentage or aggregate of stream rates on tube to shell side, length of heat exchanger as well as baffle types.

Heat exchangers are used to transfer heat in between two medium or body through active or passive mode of heat transfer. Heat exchanger is design to have high specific heat transfer rate, in order to that many researchers have optimized the different process parameters. In the same manner for increasing the heat transfer rate effect of different working fluid was analyzed in this work. For analyzing the effect of different working fluid air, water and different nano-fluid was considered during the analysis. Effect of different Re number with change in working fluid was also analyzed. For making nano-fluids it considered 0.4 weight percentage of nano particles and different mathematical relation was used to find the properties of nano-fluid. CFD analysis was performed using Ansys Fluent and find the temperature, pressure, Nusselt number and friction factor for different case.

2. Development of solid model of heat exchanger for validation

For validation of the numerical analysis of heat exchanger, first it considered tube in tube heat exchanger having circular turbulator with circulator perforation as considered in base paper. The solid model of heat exchanger is developed on the basis of geometry parameters considered by Sheikholeslami et.al [1] during its experimental analysis. The geometric specification of solid model of heat exchanger is given in the below table

Table.1 Value of geometric specification

Geometric specification	Values	
Inner pipe diameter (mm)	Inner diameter	28
	Outer diameter	30
Outer pipe diameter (mm)	Inner diameter	50
	Outer diameter	60
Turbulator Thickness (mm)	6	
Turbulator Width (mm)	7	
Length of pipe (m)	2	

During the development of solid model of heat exchanger here it considered 5.83 pitch ratio in between the two turbulators. The solid model of the heat exchanger is shown in the below fig.

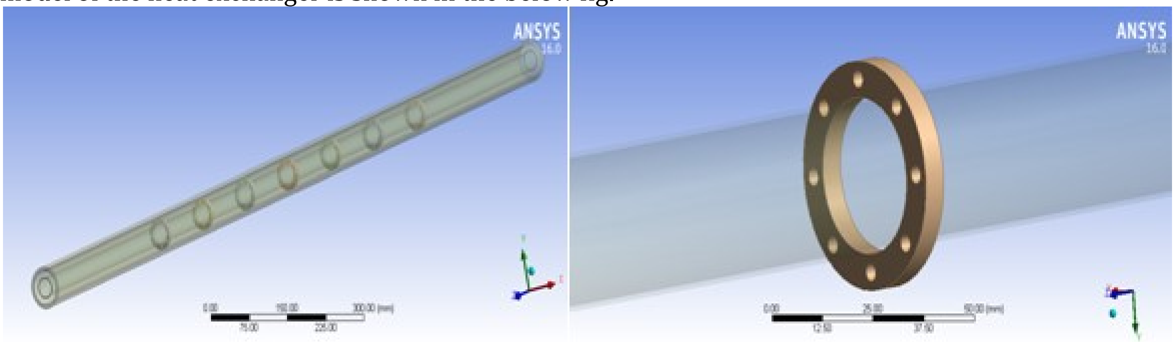

Fig.1 solid model of tube in tube heat exchanger

2.1. Meshing

To perform the numerical analysis here, it has to discretize the solid model in to number of elements and nodes. To perform proper mesh different meshing tool where use for the refinement of mesh. Mesh of the circular turbulators heat exchanger is shown in the below fig. number of elements- 457587, number of nodes-457865

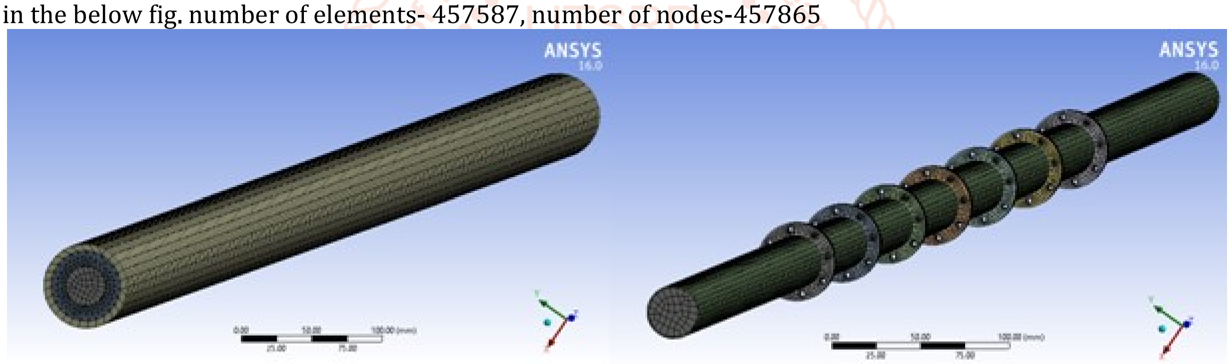

Fig.2 Shows the mesh of the circular turbulator heat exchanger

2.2. Material Selection

Here in this work warm fluid water is flowing in the inner tube whereas cold fluid that is air is flowing in the outer pipe. The inner pipe of heat exchanger is made of copper material whereas outer tube is made of Plexiglas which acts as a thermal insulating material.

2.2.1. For Hot Fluid

Water is used as a hot fluid which is flowing in the inner tube. Here properties of water at the inlet of heat exchanger is shown in the below table.

Table.2 Properties of water at the inlet of heat exchanger

Density (kg/m^3)	970.84
Specific heat (J/kg-k)	4185.105
Dynamic viscosity (kg/m-s)	1.765×10^{-4}
Thermal conductivity (W/m-k)	0.6556

2.2.2. For cold fluid

Air is used as a cold fluid which is flowing in the outer tube of heat exchanger. The properties of air at the inlet of heat exchanger.

Table.3 Properties of air at the inlet of heat exchanger

Density (kg/m^3)	1.1472
Specific heat (J/kg-k)	1001.225
Dynamic viscosity (kg/m-s)	1.1956×10^{-5}
Thermal conductivity (W/m-k)	0.025

2.2.3. For inner tube
Here in this work copper is used for inner tube manufacturing, the properties of copper material is shown in the below table.

Table.4 Properties of copper material

Property	Value
Density (kg/m^3)	8978
Specific heat (J/kg-k)	381
Thermal conductivity (W/m-k)	387.6

2.2.4. For outer tube
For outer tube it used Plexiglas as a manufacturing material which act as thermal insulator. It prevents heat to go inside the tube.

Table.5 Properties of plexiglas material

Property	Value
Density (kg/m^3)	1180
Specific heat (J/kg-k)	1466
Thermal conductivity (W/m-k)	0.000581

2.3. Properties of Nano-fluid used
For calculating the effect of different cooling medium on the performance of tube in tube heat exchanger with turbulator, here in this word different cooling medium was considered. It considered air, water and three different nano fluids that is aluminium oxide (Al2O3), titanium oxide (TiO2) and Zirconium oxide (ZrO2). For making nano fluids here in this work, it considered 0.4 weight percentage of nano particles in water medium. For calculating the properties of nano fluid at 0.4 weight percentage of nano particles different mathematical relations was used. The relations used for calculating the properties of nano fluid are mention here.

2.3.1. For calculating density of nano fluid
$$\rho_{nf} = v\rho_s + (1 - v)$$

ρ_{nf} is the density of nano fluid, v is the volume fraction of nano fluid, ρ_s is the density of base material of nano particles and, ρ_w is the density of water.

2.3.2. For calculating the Viscosity of nano fluid
$$\mu_{nf} = \mu_w(1 + 2.5v)$$

Where, μ_{nf} is the dynamic viscosity of nano fluid, μ_w dynamic viscosity of water and, v is the volume fraction of nanoparticles.

2.3.3. For calculating the specific heat of nanofluid
$$C_{p,nf} = [v(\rho_s C_{p,s}) + (1 - v)(\rho_w - C_{p,w})]/\rho_{nf}$$

Where, $C_{p,nf}$ is the specific heat of nano fluid, $C_{p,s}$ specific heat of nano particles base material, $C_{p,w}$ specific heat of water and, v is the volume fraction of nanoparticles.

2.3.4. Thermal conductivity of nanofluids
$$\frac{k_{nf}}{k_{bf}} = [\frac{k_p + 2k_{bf} + 2v(k_p - k_{bf})}{k_p + 2k_{bf} - v(k_p - k_{bf})}]$$

Where, k_{bf} thermal conductivity of base fluid, k_{nf} is the thermal conductivity of nano fluid. Based on the above mention mathematical relations the properties of different nano fluids at 0.4% volume fraction is mention in the below tables

➢ **For Al_2O_3**

Properties	Value
Density (kg/m3)	1009.88
Thermal conductivity (W/mK)	0.605
Specific heat (kJ/kgK)	4130.077
Dynamic Viscosity (Pa-s)	0.00101

➢ **For TiO_2**

Properties	Value
Density (kg/m3)	1010.636
Thermal conductivity (W/mK)	0.608
Specific heat (kJ/kgK)	4124.87
Dynamic Viscosity (Pa-s)	0.00101

- **For ZrO_2**

Properties	Value
Density (kg/m3)	1016.408
Thermal conductivity (W/mK)	0.602
Specific heat (kJ/kgK)	4090.45
Dynamic Viscosity (Pa-s)	0.00101

2.4. Boundary condition and Validation of CFD model

The temperature of warm fluid at inlet is 346.11 K and flowing at a velocity of 0.063 m/s. whereas cold fluid is flowing at a velocity of 0.9669 m/s and temperature of cold fluid at inlet 301.16 K as considered during the experimental analysis performed by Sheikholeslami et.al[1].For validating the CFD model of heat exchanger having discontinuous perforated circular turbulator, here it examines the heat exchanger having circular discontinuous turbulator with circular perforation as consider during the experimental analysis performed by Sheikholeslami et.al[6].The inlet and outlet conditions of hot fluid and cold fluid were same as considered during the experimental analysis and calculating the value of Nusselt number, Darcy friction factor. The contour of temperature and velocity for different Re numbers are shown in the below section

- **For Re 6000**

The temperature contours for 6000 Re number is shown below

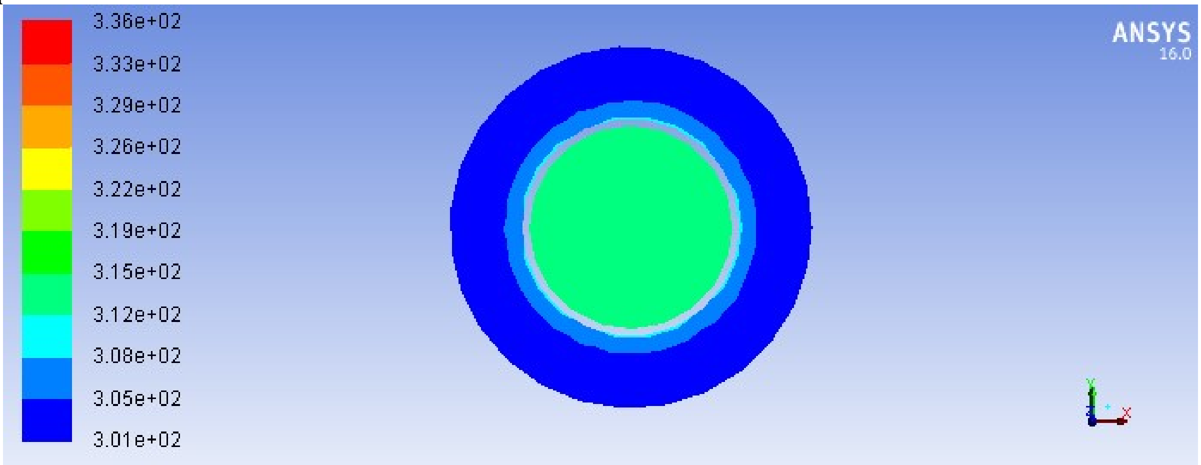

Fig.3 Temperature contour of hot fluid outlet for Re 6000

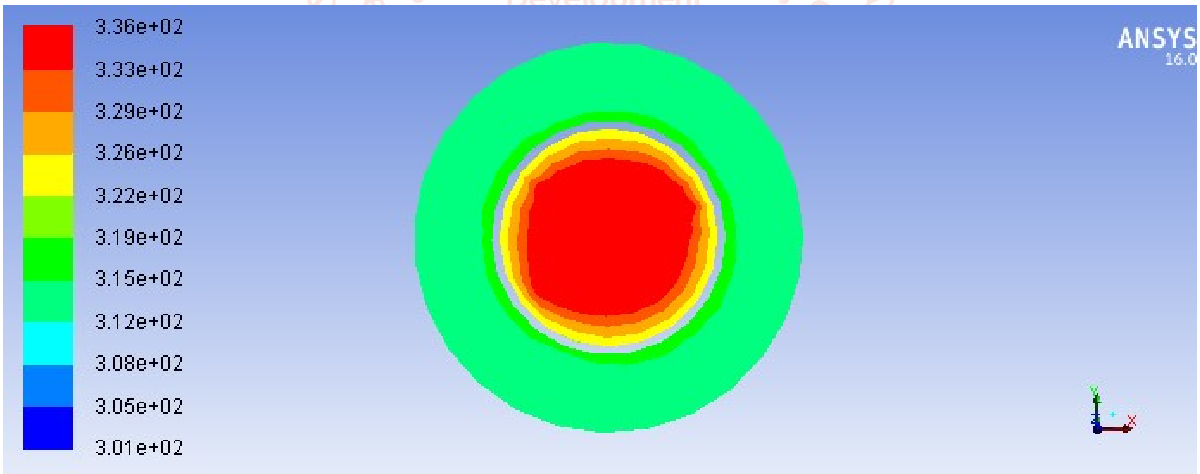

Fig.4 Temperature contours of hot fluid inlet for Re 6000

Through numerical analysis it is found that, temperature of air flowing in the outer tube get increase as move toward the outlet, which shows the heat transfer from inner pipe to air. Through numerical investigation we have calculated the value of Nusselt number for different Re number and through calculation we have calculated the value of Darcy friction factor and Thermal performance.

For examine the value of Darcy friction factor (f) following mathematical calculation where used. The mathematical equation used for calculating friction factor

$$f = \frac{2\,\Delta P\, D_H}{L\, \rho\, u^2}$$

Where ΔP is the pressure difference at the inlet and outlet, D_h is the hydraulic mean diameter, L is the length of heat exchanger, ρ density of air and u is the velocity of air at inlet. With the support of eq. 1 we can calculate the value of friction factor for different Re numbers.

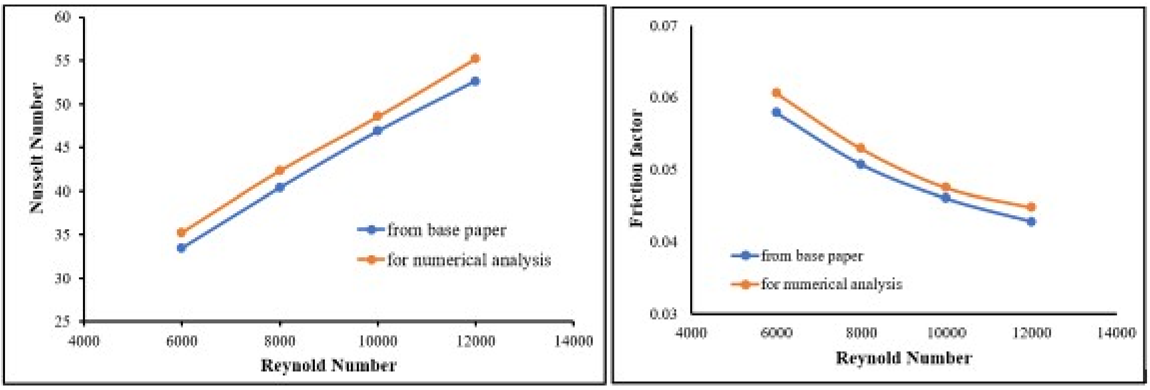

Fig.5 comparison of value of Nusselt number and friction factor at different Re numbers

From the above fig. it is found that the value of friction factor decreases as the Re number increases. The value of friction factor calculated from numerical analysis is near to the value of friction factor give in the base paper, so the numerical model develop for circular turbulator is correct.

3. Effect of different working fluid

For analyzing the effect of different working fluid new design of tube in tube heat exchanger was considered. The geometric parameters that are considered during the preparation of solid model was mention in the below table.

Table.6 Shows the geometric parameters of heat exchanger that are considered for the numerical analysis

Geometric specification	Values	
Inner pipe diameter (mm)	Inner diameter	28
	Outer diameter	30
Outer pipe diameter (mm)	Inner diameter	50
	Outer diameter	60
Turbulator Thickness (mm)	6	
Turbulator Width (mm)	7	
Length of pipe (m)	2	

Base on the above mention geometric parameters solid model of tube in tube heat exchanger was made. The solid model of heat exchanger considered for the analysis of effect of different working fluid is shown in the below fig.

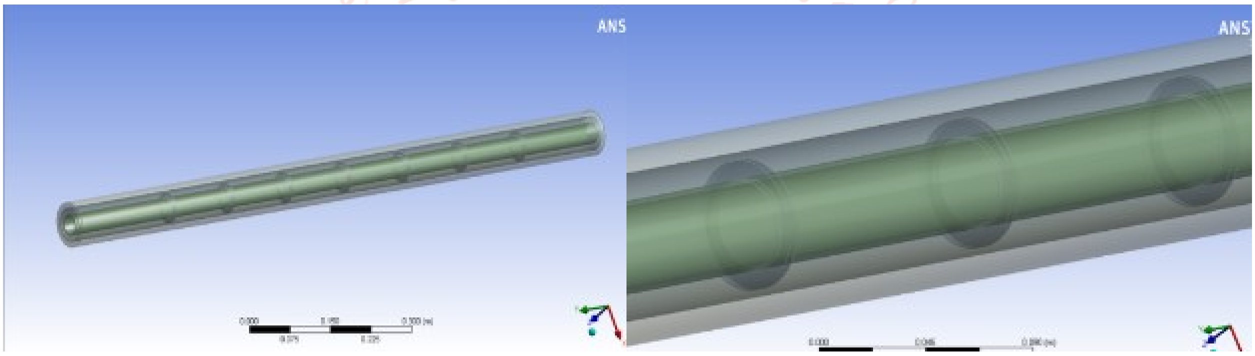

Fig.6 solid model of tube in tube heat exchanger

For evaluating the effect of different cooling fluid on heat transfer, different cooling mediums were considered. Each cooling fluid was analyzed with different Re numbers that is 10000, 12000, 14000 and 16000. For each case value of Nusselt number, friction factor and thermal performance was calculated.

3.1. Boundary conditions

For analyzing the effect of different cooling fluids on heat transfer through heat exchanger, following mention boundary condition was considered. During analysis hot fluid that is water which is flowing inside the inner tube has 0.063 m/s velocity, and 116685.89 Pa pressure at the inlet of heat exchanger. Whereas cold fluid which is flowing in the outer tube and entering from the opposite side of heat exchanger has different Re numbers with pressure 200000 Pa. The temperature of cold fluid at the inlet of heat exchanger is 300 K, whereas the temperature of hot fluid at the inlet of heat exchanger is 375 K. For performing the numerical analysis, in this work it uses K-epsilon model with standard wall function solution algorithms. It also used the couple base solver to solve the numerical analysis.

3.2. Comparison of different Working fluid

After numerically analyzing different working fluid at different Re number comparison was done. The value of nusselt number for different working fluid is compare in the below table.

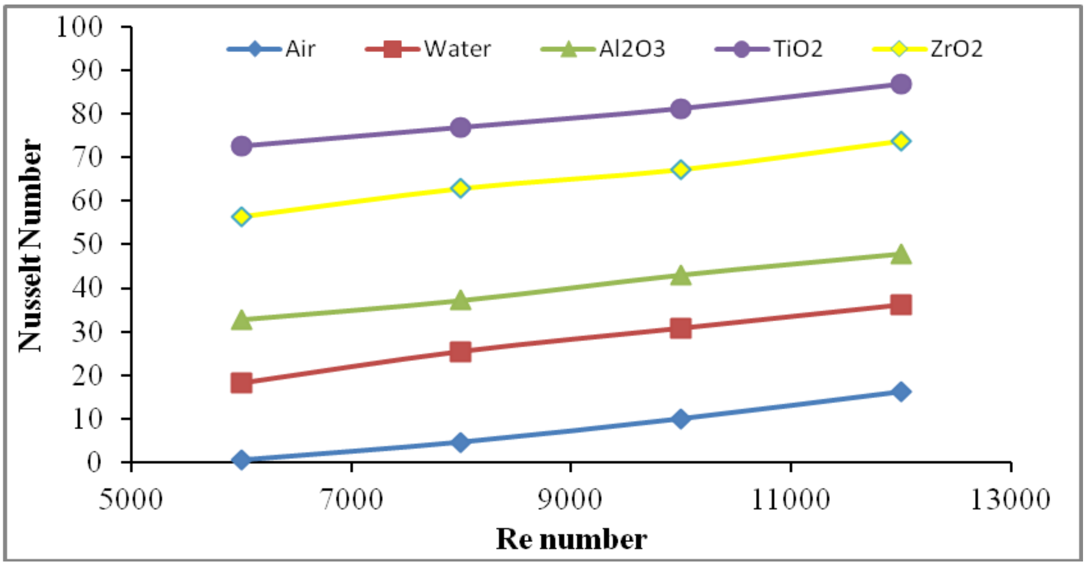

Fig.7 comparison of value of Nusselt number for different working fluid

From above fig. it is found that value of Nusselt number for air is very low as compared to other working fluid. As the Reynolds number increases the value of Nusselt number increases for each working fluid which shows the increase of heat transfer rate from the heat exchanger. When water is used as a working fluid, the value of Nusselt number is more as compared to air at each Reynolds number with the use of nano fluids, the value of Nusselt number more as compared to air and water used as a working fluid. Through graph it is found that value of Nusselt number for TiO2 is much higher as compared other fluid, whereas the value of friction factor for TiO2 is also high.

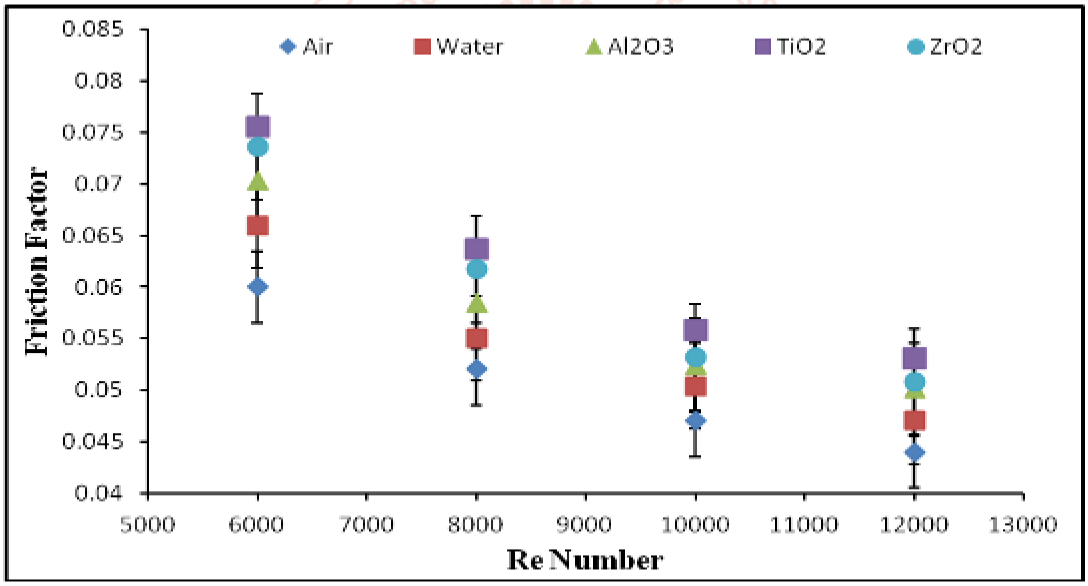

Fig.8 Comparison of value of friction factor for different Re number

4. Conclusion

Through analysis it is found that working fluid play an important role in heat transfer from heat exchanger. It is found that as the Re number increases the value of Nusselt number increase, whereas the value of friction factor gets decreases. Through CFD analysis it is found that the value of Nusselt number for TiO2 is significantly higher as compared to the other working fluid. After TiO_2, ZrO_2 shows the significant higher heat transfer rate as compared to water, air and Al_2O_3 and same trend is follow in case of friction factor value for each case of Re number. Through CFD analysis, it can say that heat transfer from heat exchanger is mainly depends on the working fluid. Though the friction factor is more in case of TiO_2 as working fluid, heat transfer is much higher as compared to other working fluid which compensates the increase in friction factor. Overall it is found that as per our requirements it can use different working fluid to fulfill our requirements.

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