ANALYSIS OF VARIOUS NANO FLUIDS IN CONCENTRIC TUBE HEAT EXCHANGER WITH TURBULATOR USING CFD

[1]Abhishek Emmanuel Masih, [2]Arvind Singh

[1]Research scholar, [2]Assistant Professor
[1,2]Department of Mechanical Engineering
[1, 2]Corporate Institute of Sci. & Tech., Bhopal

***Abstract*: Nanofluids are basically nano sized solid particles which can be either metallic or nonmetallic, suspended in a base fluid such as water, ethylene glycol etc. The nanofluids are generally sought to be much better working fluids as compared to the base fluids because of their enhanced thermal properties. In this research, nanofluids such as Al_2O_3-H_2O, TiO_2-H_2O and ZrO_2-H_2O were analyzed and compared on the basis of thermal parameters such as overall heat transfer coefficient and Nusselt number. The basis of comparison was suspending these nanoparticles at various concentrations of 0.4 %, 0.8 % and 1.2 % volume by weight and at various Reynolds number ranging from 4000 to 20000. For investigation an experimental setup was modeled with the help of CFD which involved a tube in tube heat exchanger. A helical wire coil turbulator of 39 mm pitch was used to promote the turbulence in flow in the inner tube. The results were drawn and compared with that of pure water which involved the case of with and without turbulator. The investigation showed the overall heat transfer coefficient and the average Nusselt number increased with the increase in the Reynolds number as well as the particle concentrations. Moreover out of the three nanofluids, the TiO_2-H_2O nanofluid exhibited better heat transfer capabilities. Also the use of turbulators caused the swirl motion in the flow which enhanced the heat transfer coefficient.**

***Keywords*: Heat exchanger, turbulators, Nano fluids, Heat transfer coefficient, Nusselt number**

1. Introduction

Nanotechnology is a branch of science and technology which makes use of the particles in the nano scale order, namely in the molecular and atomic order respectively. In this field, the particles considered are analyzed individually from their bulk specifications. The properties of the bulk materials on the whole are expected to remain unchanged, whereas at the nano scale order these properties alter. When these solid particles (of nano scale order) are dispersed in any fluid medium (known as the base fluids) collectively they are known as “nanofluids”, a term coined by Choi et al. [1] in 1995 at Argonne National Laboratory, USA.

In this study the behavior of these nanofluids are analyzed when they are used in the heat exchangers. We will discuss the synthesis of nanofluids later, but first let us understand what heat exchangers are and what its various types are. A heat exchanger is a device that exchanges the heat between two or more flowing fluids. In simper words one flowing fluid is at the lower temperature, called the cold fluid, and the other fluid is at the higher temperature, called the hot fluid, from which heat has to be extracted. The fluid with the lower temperature flows inside the geometry of the heat exchanger to extract heat from the hot fluid flowing with the higher temperature, and thus the cold fluid takes up the heat of the hot fluid, making the hot fluid losing its heat to the cold fluid and thus lowering its temperature. The cold fluid after extracting heat from the hot fluid has a temperature rise, thus fulfilling the function of the heat exchanger. This is the basic function of any heat exchanger.

Here in this work we have performed the numerical analysis of tube in tube heat exchanger having turbulator inside the inner tube. Here in this work a turbulator having 39 mm pitch was introduced inside the inner tube and the value of heat transfer was measured. In order to measure the effectiveness of turbulator we have performed numerical analysis on both kind of geometries i.e. heat exchanger with and without turbulator.

Here in this work first water is used as the working fluid, and then nanofluids with different nano particles. The heat exchanger used by Akyürek et.al [23] for the experimental analysis was considered to perform numerical analysis. For calculating the effect of different nano metallic particles here we have considered three different metallic oxides in nano particle size to make nanofluid. In order to calculate the effect of change in Nusselt number on heat transfer hear we have considered five different Reynolds numbers that is 4000, 8000, 12000, 16000 and 20000.

2. Development of Solid model

The geometrical parameters used to develop solid model of heat exchanger is shown in the below table.

Table.1 Value of different geometric parameters of heat exchanger

Parameters	Values
Tube length	1.3 m
Inner tube diameter	12 mm
Tube wall thickness	2 mm
Outer tube diameter	33 mm
Pitch of turbulator	39 mm

Based on the above geometric parameters it developed the solid model of nano fluid heat exchanger. The solid model of heat exchanger is shown in the below fig.

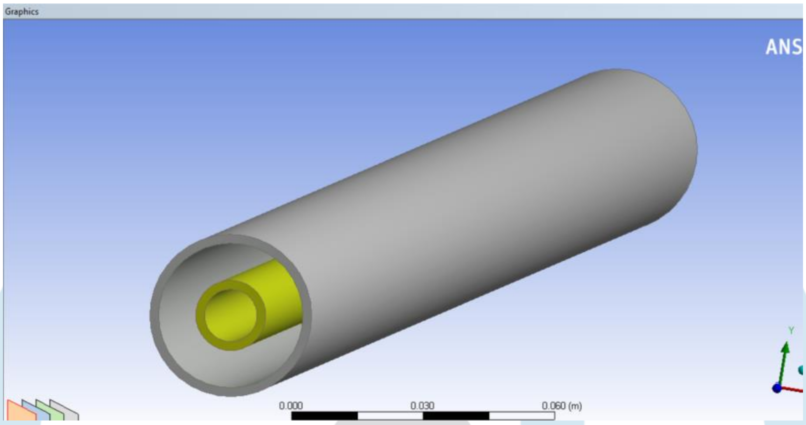

Fig.1 Solid model of heat exchanger without helical turbulator

After analyzing the heat exchanger without turbulators, we analyzed the effect of use of turbulator in the inner tube of heat exchanger to increase the heat transfer rate. The solid model of heat exchanger having helical turbulator inside the inner tube is shown in the below fig.

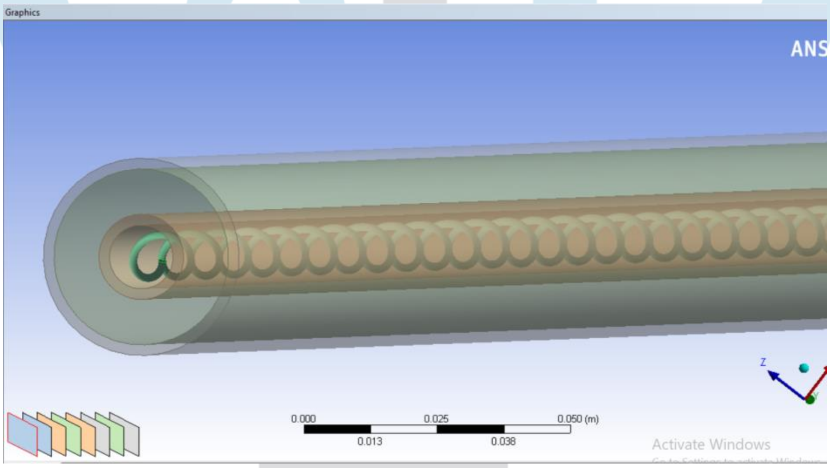

Fig.2 Solid model of heat exchanger with helical turbulator

3. Meshing

To perform the numerical analysis of heat exchanger with or without turbulator it is necessary to discretize heat exchanger in to number of body and element. During numerical analysis, it calculates the result on element and nodes. In order to test the independency of number of nodes and elements, here we have discretized the body with different number of nodes and element and found that, result does not depends on number of elements and nodes.

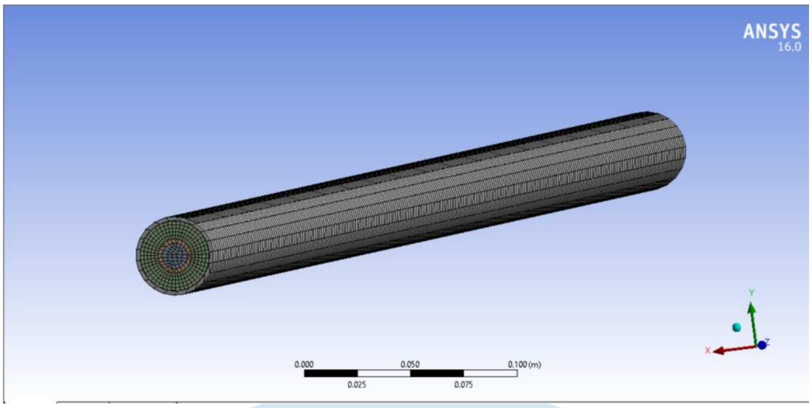

Fig.3 Mesh of heat exchanger without helical turbulator

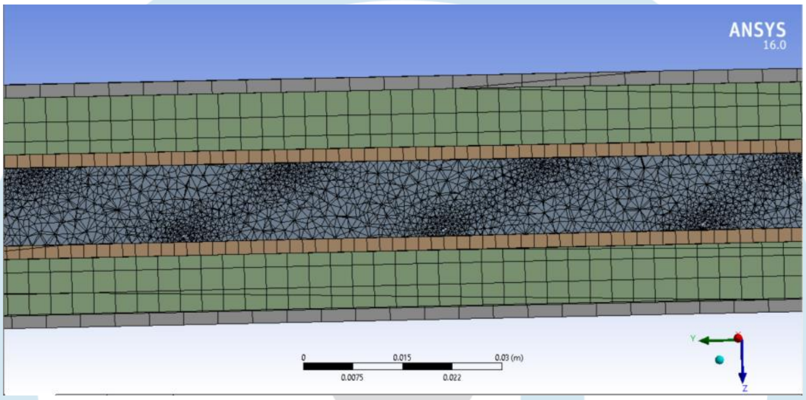

Fig.4 Cross sectional view of heat exchanger mesh

4. Mathematical model

In order to calculate the performance of heat exchanger Nusselt number and overall heat transfer coefficient is needed. With the help of CFD analysis temperature of hot and cold fluid at outlet were measured (the inlet temperatures were taken from the base paper). After measuring the temperature of hot and cold fluid, value of Nusselt number and Overall heat transfer coefficient were calculated with the help of following mathematical model.

4.1 Heat transfer from hot water fluid

$$Q_w = C_{p,w} \times m_w(T_{out,w} - T_{in,w}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where, Q_w is the heat transfer from water, C_{pw} is the specific heat of water, m_w mass flow rate of water, T_{outw} is the temperature of water at exit and T_{inw} is the temperature of water at inlet.

4.2 Heat transfer to nanofluid

$$Q_{nf} = C_{p,nf} \times m_{nf}(T_{out,nf} - T_{in,nf}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where, Q_{nf} is the heat transfer to nanofluid, C_{pnf} is the specific heat of nano fluid, m_{nf} mass flow rate of nano fluid, T_{outnf} is the temperature of nano fluid at exit and T_{innf} is the temperature of nano fluid at inlet.

In order to calculate the properties of nano fluid following mathematical model formulas were used

$$\rho_{nf} = v\rho_s + (1 - v)\rho_w \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where, 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.

For calculating the Viscosity of nano fluid

$$\mu_{nf} = \mu_w(1 + 2.5v) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

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

4.3 For calculating the specific heat of nanofluid

$$C_{p,nf} = [v(\rho_s C_{p,s}) + (1 - v)(\rho_w - C_{p,w})]/\rho_{nf} \quad \text{.....................(5)}$$

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.

4.4 The average heat transfer rate

$$Q_{avg} = \frac{Q_{nf}+Q_w}{2} \quad \text{......................................(6)}$$

4.5 The overall heat transfer coefficient

$$Q_{avg} = UA_i\Delta T_{lm} \quad \text{...(7)}$$

Where, U is the overall heat transfer coefficient, A_i is the surface are of inner pipe, ΔT_{lm} is the logarithmic mean temperature difference.

$$\Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln(\Delta T_2/\Delta T_1)} \quad \text{...........................(8)}$$

Where,

$$\Delta T_1 = T_{hi} - T_{co} \quad \text{..............................(9)}$$

$$\Delta T_2 = T_{ho} - T_{ci} \quad \text{...........................(10)}$$

4.6 Calculation of Nusselt number for nano fluid

From Gnielinski [23], we have

$$Nu = \frac{(\frac{f}{2})(Re-1000)Pr}{1+12.7(\frac{f}{2})^{0.5}(Pr^{(\frac{2}{3})}-1)} \text{............................ (11)}$$

Where,

$$f = [1.58\ln(Re) - 3.82]^{-2} \quad \text{..........................(12)}$$

$$h_o = \frac{Nuk}{D_h} \quad \text{...............................(13)}$$

$$h_i = \{\frac{1}{U} + \frac{1}{h_o}\}^{-1} \quad \text{...(14)}$$

Hence Nu for nanofluid is calculated as;

$$Nu_{nf} = \frac{h_i D_h}{k} \quad \text{................................(15)}$$

Thermal conductivity of nanofluids is given by;

$$\frac{k_{nf}}{k_{bf}} = [\frac{k_p+2k_{bf}+2v(k_p-k_{bf})}{k_p+2k_{bf}-v(k_p-k_{bf})}] \text{.........................(16)}$$

Where, k_{bf} is thermal conductivity of base fluid k_{nf} is thermal conductivity of nano fluid

5. Properties of nanofluids

For Al_2O_3-H_2O nanofluid

Concentration (% by weight)	Density (ρ) kg/m^3	Specific heat (C_p) J/kg-K	Thermal Conductivity (K) W/m-K	Dynamic viscosity (μ) Pa-s
0.4	1009.888	4130.077	0.605	0.00101
0.8	1021.776	4079.363	0.613	0.00102
1.6	1033.664	4029.81	0.620	0.00103

For TiO_2-H_2O nanofluid

Concentration (% by weight)	Density (ρ) kg/m^3	Specific heat (C_p) J/kg-K	Thermal Conductivity (K) W/m-K	Dynamic viscosity (μ)
0.4	1010.636	4124.87	0.608	0.00101
0.8	1023.272	4169.16	0.613	0.00102
1.2	1035.908	4014.80	0.677	0.00103

For ZrO_2-H_2O nanofluid

Concentration (% by weight)	Density (ρ) kg/m^3	Specific heat (C_p) J/kg-K	Thermal Conductivity (K) W/m-K	Dynamic viscosity (μ)
0.4	1016.408	4090.45	0.602	0.00101
0.8	1034.816	4019.04	0.6079	0.00102
1.2	1053.224	3941.84	0.611	0.00103

6. Boundary condition

Here in this work hot water is flowing in the outer tube, whereas the cold fluid is flowing in inner tube. The inlet temperature of hot water is 343 K whereas the inlet temperature of cold fluid is 293 K. The velocity of hot fluid is considered as 0.0084 m/s as considered in base paper, calculated at Re=4000, at 343K. The velocity of cold fluid changes as the Reynolds number of cold fluid changes.

7. Validation of Numerical analysis

In order to numerically validate the CFD model of heat exchanger for initial case we considered water as a working fluid. Here cold water flows as different Reynolds number inside the heat exchanger with or without helical turbulators.

7.1 For Re = 4000

Here in this section cold fluid is flowing at a Re 4000. Whereas the hot fluid is flowing at a speed of 0.0084 m/s. the temperature contour of heat exchanger for this Re number is shown in the below fig.

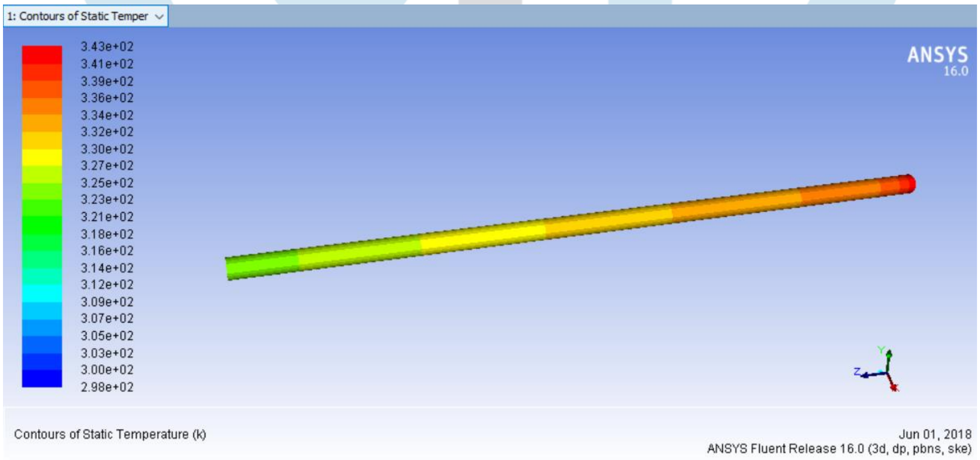

Fig.5 shows the temperature contours of heat exchanger tubes for Re = 4000

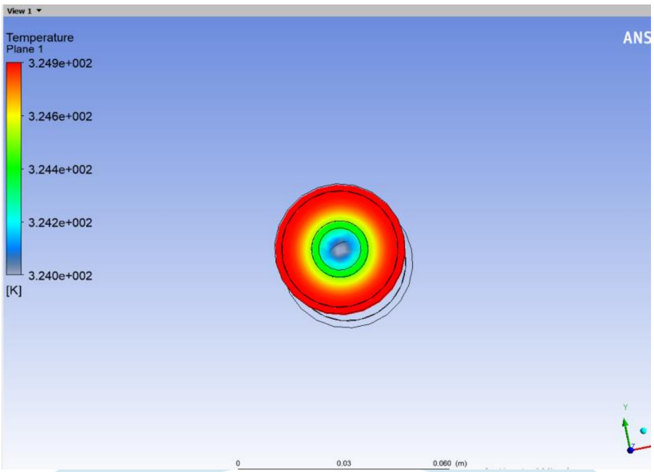

Fig.6 shows the temperature at the exit of hot fluid

Through CFD analysis we have calculated the value of temperatures of hot and cold fluid at inlet and outlet at Re = 4000. The temperature of hot and cold fluid at inlet and exit are mentioned in the below section. On the basis of temperatures at the exit and inlet, here we have calculate the value of Nusselt number (Nu) and Overall heat transfer coefficient (U) using eq. as mention in the above section.

The values of overall heat transfer coefficient calculated from the mathematical modeling were compared with the values obtained from the experimental analysis performed by Akyürek et.al [23].

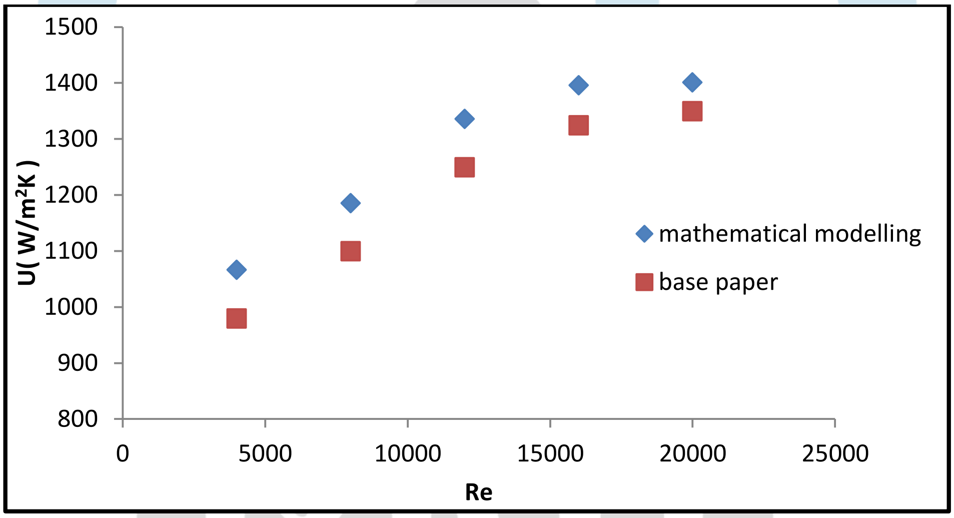

Fig.7 Comparison of Overall Heat transfer Coefficient for different Reynolds number

8. For Heat exchanger having helical turbulator

After validating the CFD model of heat exchanger, we then used the heat exchanger having helical turbulator inside the inner tube. The helical turbulator is made on the basis of geometrical pitch that is 39 mm, as given in the base paper. Turbulator is mainly used to increase the turbulence inside the heat exchanger. The use of helical turbulator is shown in the below fig.

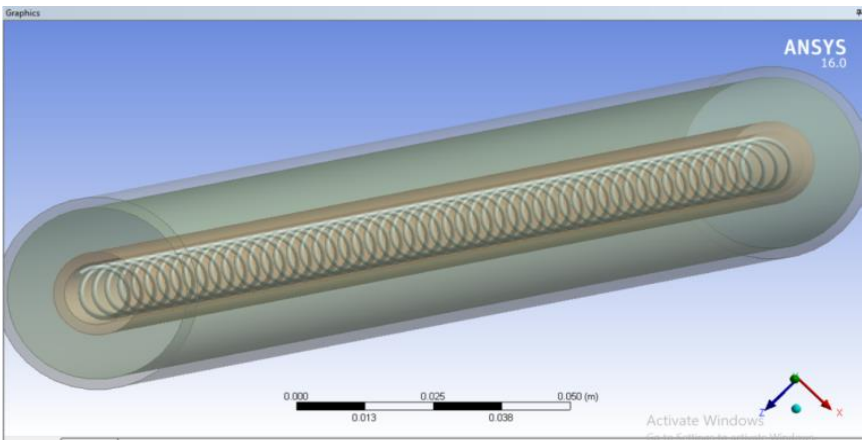

Fig.8 Heat exchanger having helical turbulator inside the inner tube

After performing the analysis on heat exchanger having helical turbulator, it is then comparing with the heat exchanger without turbulator. Through analysis it is found that the value of Nusselt number and overall heat transfer coefficient is more in case of heat exchanger with helical turbulator whereas the heat exchanger without helical turbulator shows less. This means that the heat transfer is more in case of heat exchanger with helical turbulator as compared to heat exchanger without turbulators. The comparison graph of Nusselt number and overall heat transfer coefficient where shown below section.

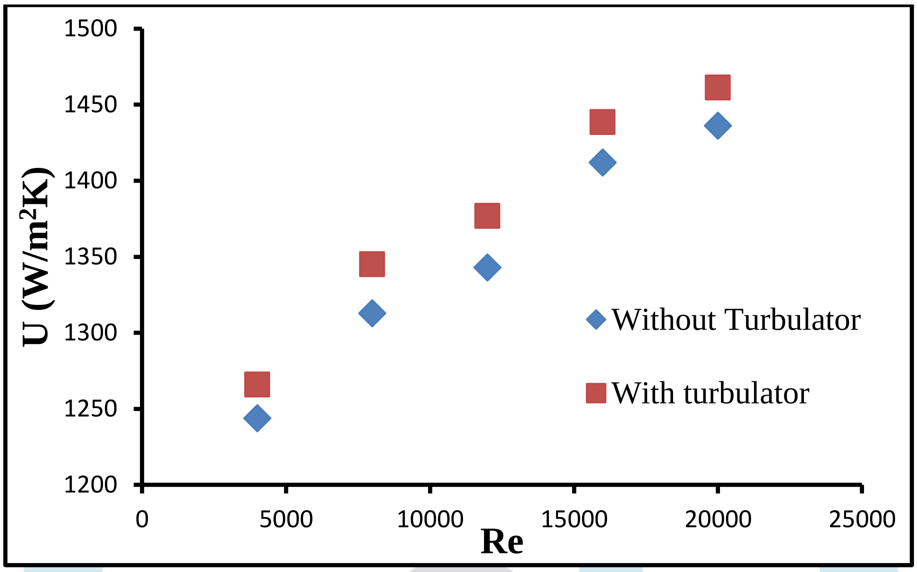

Fig.9 comparison of overall heat transfer coefficient

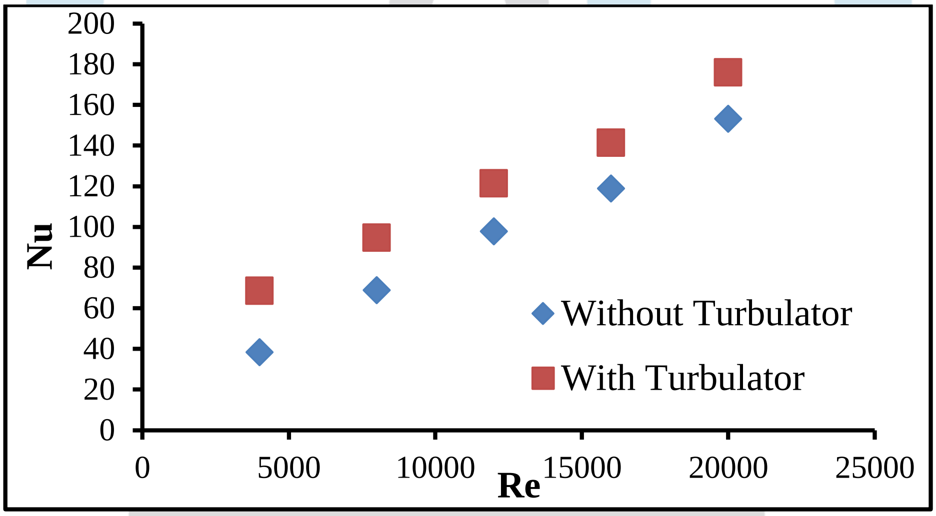

Fig.10 comparison of Nu number

After comparing the value of Nu and overall heat transfer coefficient, it is found that the heat transfer increases with the use of helical turbulator inside the heat exchanger. Due to the turbulator inside the inner tube turbulence inside the tube increases due to which contact time increases which results in increase of heat transfer rate.

8.1 Aluminum oxide (Al_2O_3) and Water

8.1.1 At 0.4% volume fraction

Here we have considered aluminum oxide (Al_2O_3) as a nanoparticle; it is mixed with water at volume fraction of 0.4% and used as a nano fluid inside the heat exchanger. The temperature contours of alumina nano fluid at different Re number.

8.2 Titanium oxide (TiO_2) and Water

Here in this section titanium oxide is used as a nano particles, the size of the nano particle were same as considered during the Al_2O_3 that is 40 nm. During analysis boundary conditions were same as considered in aluminum oxide section.

8.3 Zirconium Oxide (ZrO_2) and Water

Here in this section zirconium oxide is used as a nano particles, the size of the nano particle were same as considered during the Al_2O_3 that is 40 nm. During analysis boundary conditions were also remain same as considered in aluminum oxide analysis.

9. Comparison of different Nano fluids

To analyze the effect of different nano fluid on heat transfer, here we have compared the value of Nusselt number and overall heat transfer coefficient for different nano fluid for different volume fraction at different Reynolds number.

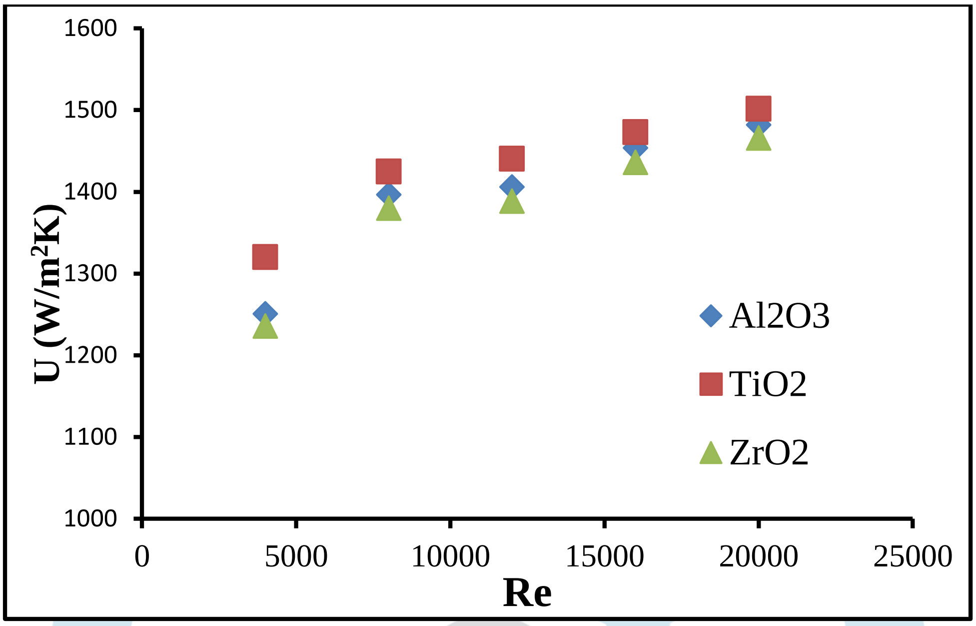

Fig.11 comparison of overall heat transfer coefficient for different nano fluids at 0.4%

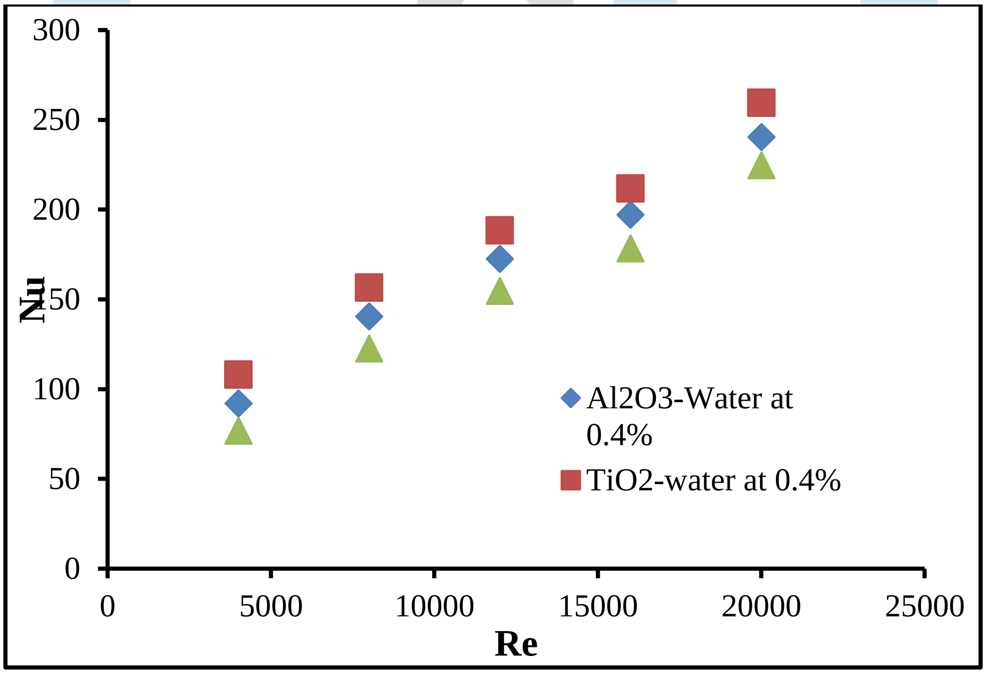

Fig.12 comparison of Nusselt Number for different nano fluids at 0.4%

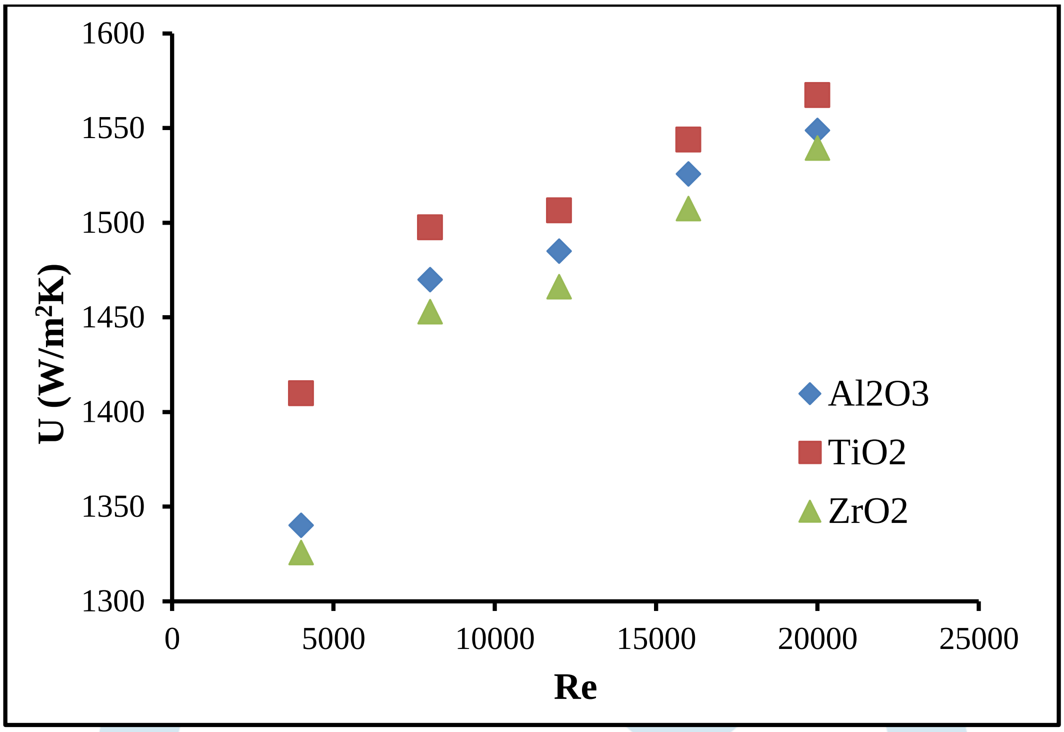

Fig.13 comparison of overall heat transfer coefficient for different nano fluids at 0.8%

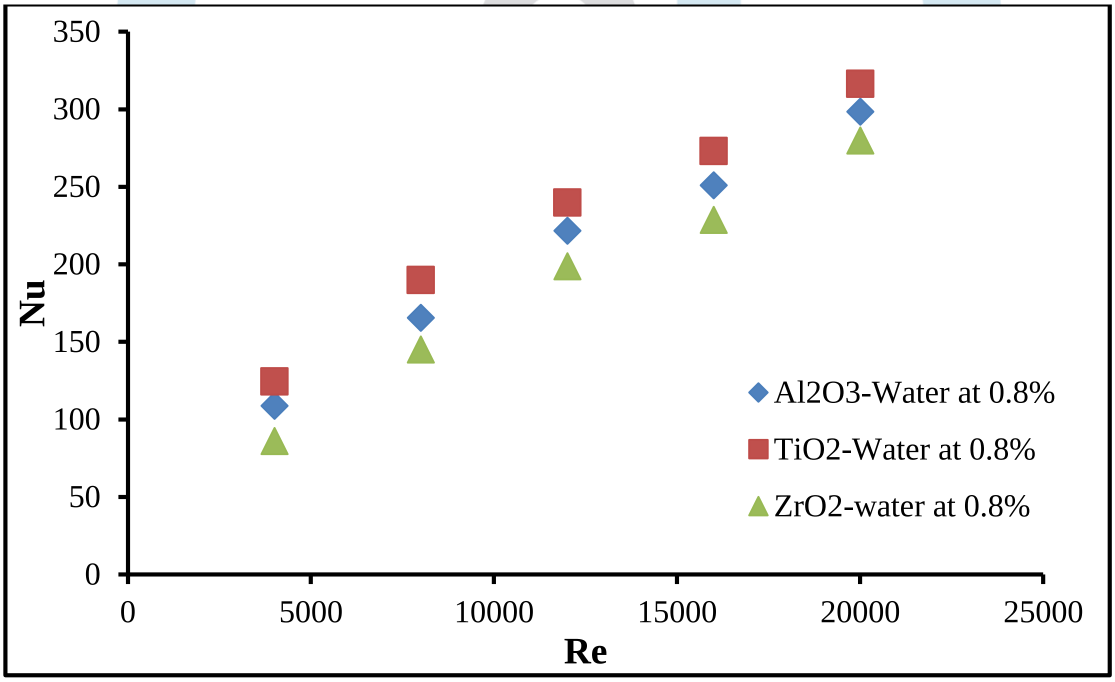

Fig.14 comparison of Nusselt Number for different nano fluids at 0.8%

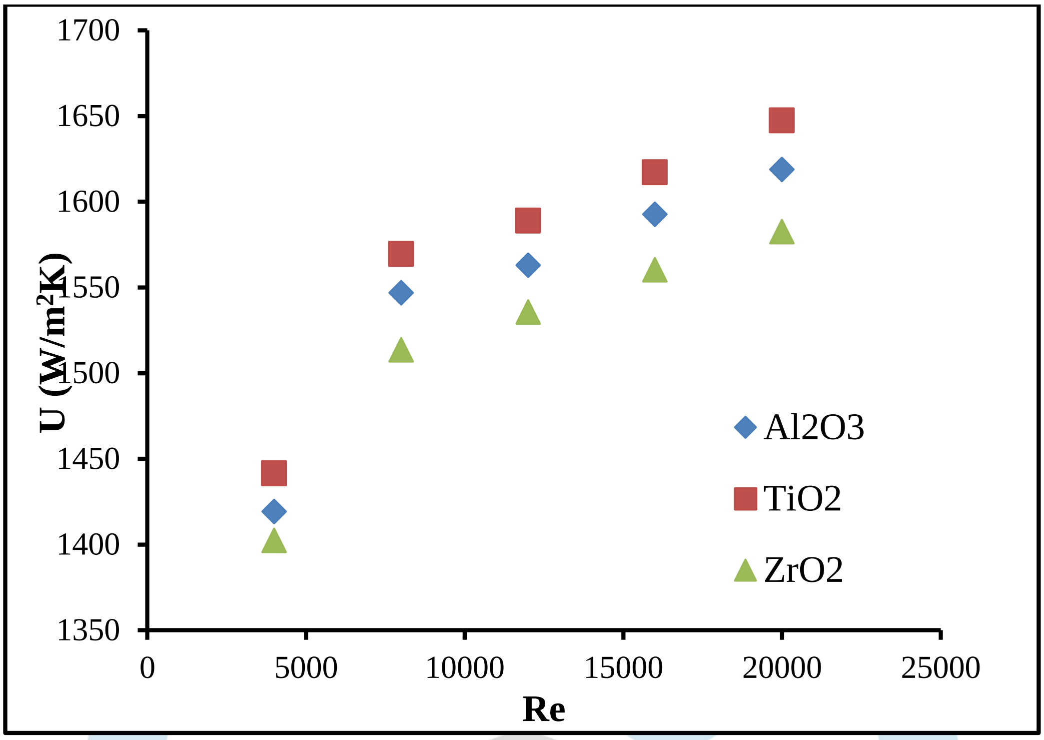

Fig.15 comparison of overall heat transfer coefficient for different nano fluids at 1.2%

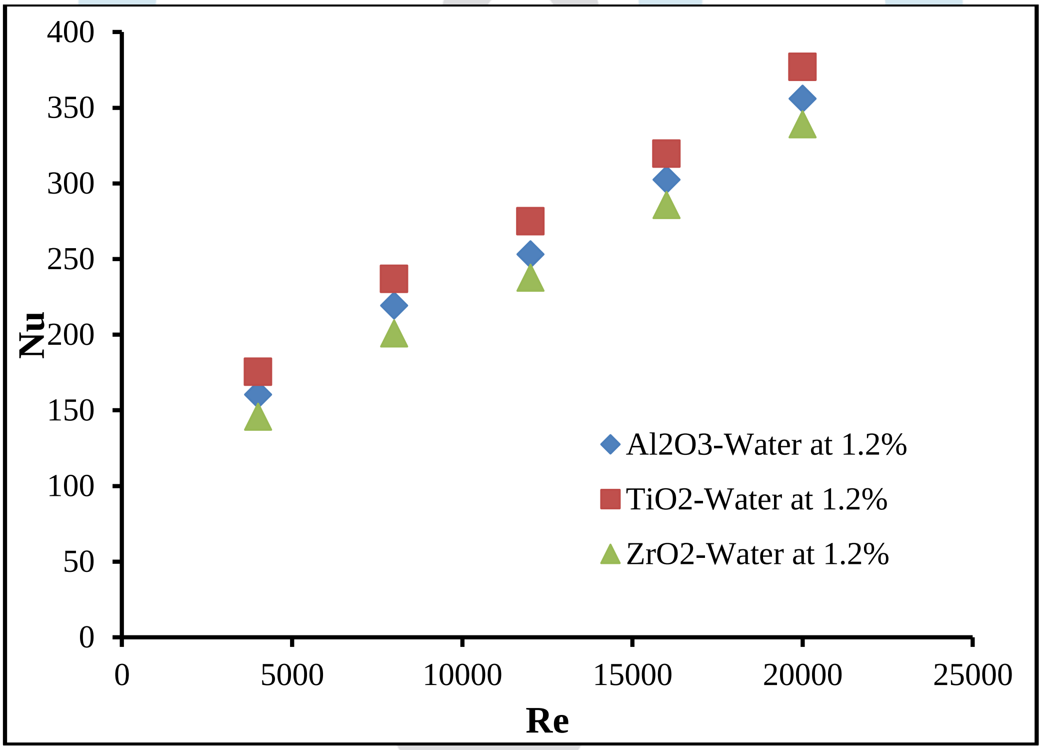

Fig.16 comparison of Nusselt Number for different nano fluids at 1.2%

After analysis it is found that the value of Nusselt number and Overall heat transfer coefficient are maximum for Titanium oxide (TiO_2) at all Reynolds number as compared to Aluminum oxide (Al_2O_3) and Zirconium oxide (ZrO_2). Through analysis it is found that the value of Nu number increases as the Re number of cold fluid increases. After going through the analysis of heat exchanger with and without helical turbulator it is found that the value of Nu and overall heat transfer coefficient is more in case of heat exchanger having helical turbulator. Due to the use of turbulator in inner tube turbulence in cold fluid increases which improves proper mixing of fluid inside the tube, due to this more cold fluid particles come in contact with the wall of inner pipe and carry heat which increases heat transfer rate.

10. Conclusions

- Developing CFD model of heat exchanger for analysis is a better and cost effect method for analysis, it also save the time.
- As the Re number increases the value of Nu number and over all heat transfer increases.

- Through analysis it is found that all nano fluid follows same behavior at all Re number of cold fluid.
- Using turbulator inside heat exchanger increases the turbulence inside the pipe which leads to increase heat transfer rate.
- From analysis it is found that the value of Nu number and overall heat transfer coefficient is higher in case of Titanium oxide (TiO_2) as compared to Aluminum oxide (Al_2O_3) and Zirconium oxide (ZrO_2).
- It is also found that as the volume fraction of nano particles increases the heat transfer rate of heat exchanger also increases.
- So in this work we can say that heat exchanger having helical turbulator at different Re number shows maximum heat transfer in case of Titanium oxide (TiO_2).

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