CFD Analysis of Heat Transfer and Friction Factor Characteristics of ZNO/Water through Circular Tube with Rectangular Helix Inserts With Different Thicknesses

Amit Singh Bisht
PG Scholar, Department of Mechanical Engineering, BTKIT Dwarahat, India.

Vinod Kumar
Assistant professor, Department of Mechanical Engineering, BTKIT Dwarahat, India.

Aman Kumar Sukija
PG Scholar, Department of Mechanical Engineering, BTKIT Dwarahat, India.

Abstract- A CFD analysis was carried out to investigate heat transfer and friction factor characteristics of ZNO/water Nano fluid through circular tube with rectangular helix inserts with various thicknesses at constant heat flux. In this work ZNO/water Nano fluids with two volume concentrations of were used as the working fluid. The P/D ratio of rectangular helix inserts remained constant while the thicknesses were changed to different values. The CFD analyses were performed in laminar flow regime. Results indicated that rectangular helix insert inserts enhanced the average convective heat transfer coefficient, and also more the thickness of rectangular helix inserts is more the enhancement of convective heat transfer coefficient is. Also, the highest increment was achieved at maximum volume concentration. Results showed that Nano fluids have better heat transfer performance when used with thicker rectangular helix insert tapes. At the same time, the increase in rectangular helix inserts thickness leads to an increase in friction factor. In the end, the combined results of these two phenomena resulted in enhanced convective heat transfer coefficient and thermal performance.

Index Terms –Nano fluid, heat transfer, rectangular helix insert, friction factor, pressure drop, ZNO/water Nano fluid.

1. INTRODUCTION

Several heat transfer enhancement (HTE) techniques have been used in many engineering applications such as nuclear reactor, chemical reactor, chemical process, automotive cooling, refrigeration, and heat exchanger, etc. HTE techniques are powerful tools to increase heat transfer rate and thermal performance as well as to reduce of the size of heat transfer system in installing and operating costs. HTE techniques can be classified into 2 categories; (1) active method: by supplying external power source to the fluid or the equipment; (2) passive method: by turbulence promoter (such as special surface geometries, twisted tape, propeller, tangential inlet nozzle, snail entry, axial/radial guide vane, spiral fin) or fluid additives (such as Nano fluid), without using any direct external power source. Due to its easy installation/operation and cost saving, passive method has drawn great attention.

Heat transfer and pressure drop characteristics of laminar flow of a Nano fluid through a tube fitted with full length twisted inserts with fixed twist ratio and different thickness experimentally investigated by Esmaeilzadeh et al.[1] and results showed that Nano fluids have better heat transfer performance when utilized with thicker twisted tapes. Thermal performance characteristics in a heat exchanger tube studied by Eiamsa-ard et al. [2] with ZNO nanoparticles with different concentrations as the working fluid. And result showed that Nusselt number, friction factor and thermal performance factor increased as a number of tapes and ZNO nanoparticles concentration increased .Turbulent forced convection heat transfer and friction of ZNO–water Nano fluid flowing through a concentric tube U-bend heat exchanger with and without helical tape inserts in the inner tube were studied experimentally by Durga et al. [3] The experiments were conducted in the turbulent region. The results indicate that an increase in Reynolds number and Prandtl number yields to an increase in the average Nusselt number. The moment and heat transfers of a non-Newtonian fluid flowing in steady laminar regime by a circular tube with a twisted tape at fixed wall temperature is studied by Iribe et al. [4] using CFD. The effect of different twist ratios of the tape on the convective heat transfer and the pressure drop are investigated over the laminar region and result showed that a twisted tape induces a swirling flow, which consequently generates an enhancement in heat transfer. Numerical simulation for three dimensional laminar mixed convective heat transfers at different Nano fluids flow in an elliptic annulus with constant heat flux done by the Dawood et al.[5]The results revealed that SiO_2–Water nanofluid has the highest Nusselt number, followed by ZNO–Water, ZnO–Water, CuO–Water, and lastly pure water. Heat transfer for turbulent fluid flow through a tube by using double helical tape inserts was investigated experimentally by.Bhuiya et al.[6].The effects of insertion of the helical tape turbulators with different helix angles on heat transfer and pressure drop in the tube for turbulent region were examined. Experimental results showed that the heat transfer and thermal performance of the inserted tube were significantly increased compared to those of the plain tube.

2. MATHEMATICAL FORMULATIONS AND SOLID MODELING

2.1 *Physical modal*

The physical model of the test section mainly consists of horizontal cylinder inside a cylinder rectangular helix inert is placed The cylinder was made from cooper of 9.00 mm outer diameter, 7.00 mm inside diameter 2 mm thickness, and 1000 mm length. Rectangular helix insert is modeled in solid works having dimensional parameter of 1000 mm length, P/D ratio 3.21 width 7 mm, thickness 2 mm, and helix angle 21° Nanoparticles and various base fluids are selected as the working fluid and the thermo physical properties assumed to be temperature independent. The thermo-physical properties of water and nanoparticle materials which used for simulation

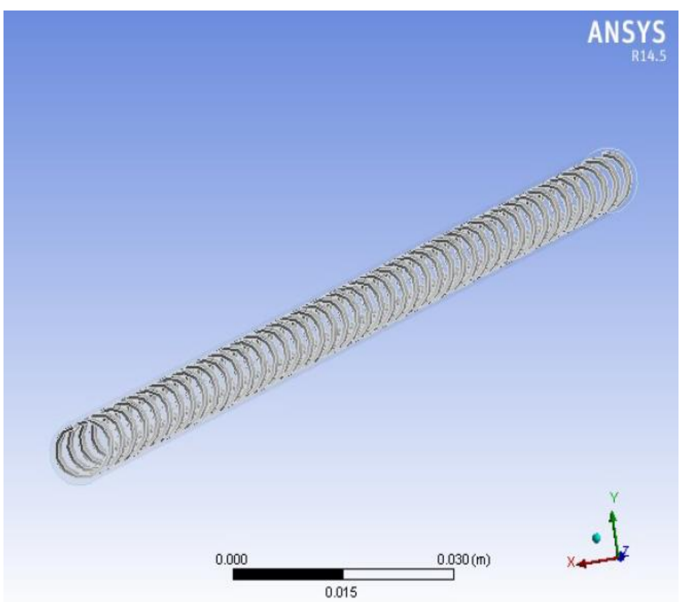

Fig. 1 Design of Rectangular Helix Insert

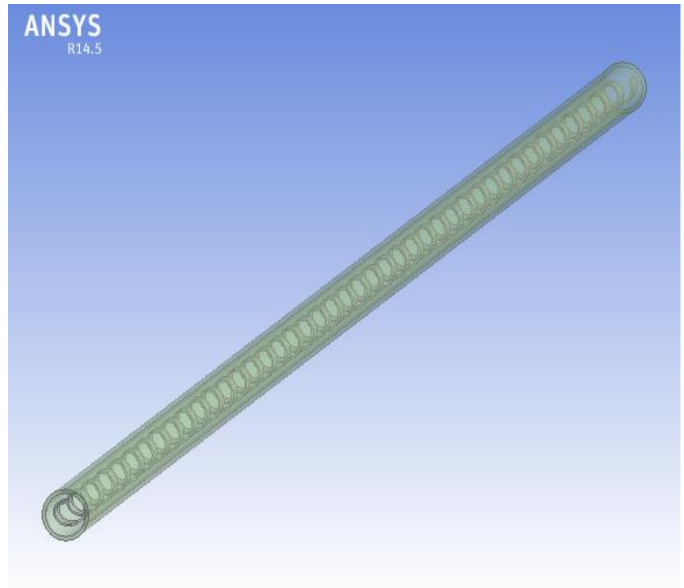

Fig. 2 Geometry of rectangular helix insert inside a plain tube

2.1 *Governing equations*

The three-dimensional Navier–Stokes and energy equations were used to describe the flow and heat transfer in the cylindrical pipe. Heat is to the fluids through the wall. Numerous assumptions were made on the operating conditions of the annulus: (i) the annulus operates under steady state conditions and three-dimensional; (ii) the Nano fluid is Newtonian and incompressible; (iii) fluid is in single phase and the flow is laminar; (iv) the external heat transfer effects are ignored; (v) the outer walls of the cylinder are adiabatic; and (vi) constant thermophysical properties are considered for the Nano fluid. The governing equations for flow and heat transfer in the annulus are as follows

Continuity equation

$$\frac{\partial \rho}{\partial t} + \nabla \times (\rho \mathbf{v}) = 0 \qquad (1)$$

Momentum equation

$$\rho \frac{DV}{Dt} = \nabla \times \tau_{ij} - \nabla \rho + \rho F \qquad (2)$$

2.2 *Boundary conditions*

At the inlet, different velocities depending on the values of Reynolds number were used, and the inlet temperature was taken as Tin=292 K. The constant heat flux used was 5000 W/m^2 to heat up the walls. At the domain outlet the flow and heat transfer are assumed to be fully developed. The boundary condition can be expressed as follows:

(1) At the inlet of the channel

$$u = u_{in}, v = 0$$

(2) At the walls:

$$u = v = 0$$

(3) At the exit:

$$P = P_{atm}$$

2.3 *Nano fluids thermophysical properties*

The thermo physical properties of ZNO nanoparticles which are density, heat capacity, effective dynamic viscosity, effective thermal conductivity given in Table 1. Meanwhile the Nano fluids thermophysical properties for 20 nm particle size and volume fraction of 0.5% and 1% for nanoparticles ZNO are given in Tables 2 and 3. These properties are calculated using the following equations:

The density and specific heat of Nano fluid were evaluated from Equation (1) and (2) respectively.

$$Pnf = (1 - \emptyset)\ \rho_{w+}\ \emptyset\rho_{np} \quad (3)$$

$$C_P, nf = \frac{\emptyset\ \rho_{np}\ C_{p,np} + (1-\emptyset)\ \rho_w\ C_{p,w}}{P_{nf}} \quad (4)$$

Thermal conductivity is given by Equation 3

$$\frac{k_{nf}}{k_w} = \frac{k_{np} + 2k_w + 2\emptyset(k_{np} - k_w)}{k_{np} + 2k_w - \emptyset(k_{np} - k_w)} \quad (5)$$

Viscosity of Nano fluid was calculated via the general Einstein's formula.

$$\mu_{nf} = \mu_w(1 + \eta\emptyset) \quad (6)$$

Where $\eta = 2.5$, as recommended for hard particles

2.4 *Heat transfer and friction factor measurements*

The steady state convective heat transfer rate was assumed to be equal to the heat transfer to the working fluid in the test tube as expressed below.

$$Q_f = Q_{conv} \quad (7)$$

Where

$$Q_f = \dot{m}C_{P,f}(T_0 - T_i) \quad (8)$$

The heat absorbed by water at thermal equilibrium was found to be 3-7% lower than that supplied by electrical heater plates. This is due to convection and radiation heat losses from the test tube to surroundings. Thus, only the heat transfer rate absorbed by fluid was taken for internal convective heat transfer coefficient calculation. The convection heat transfer from the test tube can be written by

$$Q_{conv} = hA(\check{T}_w - T_b) \quad (9)$$

Where

$$T_b = \frac{T_0 + T_i}{2} \quad (10)$$

And

$$\check{T}_w = \sum T_w / 15 \quad (11)$$

Where the average wall temperature $\check{T}_w$ was calculated from 15 data of the local wall temperatures (T_w) lined between the inlet and the exit of the test tube. The average heat transfer coefficient (h) and the average Nusselt number (N_u) were then estimated as follows:

$$h = \dot{m}C_{P,f}(T_0 - T_i)/A(\check{T}_w - T_b) \quad (12)$$

The Nusselt number is given by

$$Nu = hD/k \quad (13)$$

The Reynolds number is given by

$$Re = UD/v \quad (14)$$

Friction factor was evaluated pressure drop within the system as

$$f = \frac{\Delta P}{\left(\frac{L}{D}\right)\rho U^2/2} \quad (15)$$

Where U is mean water velocity in the tube. All of thermo-physical properties of a fluid were determined based on the overall bulk water temperature achieved from Eq. (10). [2]

1. RESULTS AND DISCUSSION

The thermo-physical properties (density, specific heat, viscosity and thermal conductivity) of ZNO/water Nano fluid were evaluated based on the properties of the base fluid and nanoparticles. It was assumed that nanoparticles were well dispersed in the base fluid (water). Although this assumption may be not true in real systems because of some physical phenomena such as particle migration, it is acceptable for evaluating the approximate physical properties of Nano fluids. Properties of Nano particle of ZNO and properties of Nano fluid at 0.5% and 1% concentration are given in table 2 and table 3

Table 1 Physical Properties of Nano particle [2]

Chemical formula	Y-ZNO
Morphology	Spherical
Crystal phase	Gamma
Thermal conductivity	13(W/m K)
True density	5600 (kg/m^3)
Specific heat	495.2(kJ/kg K)

Table 2 For 0.5 % concentration of ZNO Nano fluid [4]

Density	1023.5(kg/m^3)
Specific heat	4085.29 (kJ/kg K)

Viscosity	$1.012x10^{-3}$(kg/m − s)
Thermal conductivity	0.606 (W/m K)

Table 3 For 1% concentration of ZNO Nano fluid [4]

Density	1046 (kg/m^3)
Specific heat	4078.3 (kJ/kg K)
Viscosity	$1.025x10^{-3}$(kg/m − s)
Thermal conductivity	0.617 (W/m K)

3.1 *CFD Simulation*

In the current simulation, the 3D laminar model is applied to describe the Nano fluid flow through circular tube with a plain pipe and rectangular helix insert used with plain pipe under steady conditions. The governing equations and constitutive relations are discretized and solved by using the commercial software "ANSYS 14.5". Meshing is done in ANSYS 14.5 software.

Inlet is designated as velocity inlet .wall is having constant heat flux. Atmospheric pressure is imposed at the outlet of the tube (i.e., it is designated as pressure-outlet in FLUENT™). At the outlet gauge pressure is zero. All the cell walls are static, the velocity tangent to the walls is assumed to be zero, and the pipe wall temperature is set as 300K. The fluid flow is thermally coupled to the rectangular helix wall.: Standard for pressure and second Order Upwind for momentum and energy. A convergence criterion of 10^{-4} was used for the pressure and the z-velocity component, 10^{-6} for the x-velocity component and the y-velocity component, and 10^{-5} for the energy. The grid independence was ensured by meshing the geometry with different spacing between the cells with max skewness of 0.795 for plain tube with rectangular helix insert is adopted and for 0.753 for plain pipe without using insert Uniform heat flux condition is applied at wall of tube with a value of 5000 w/m^2 and tube is made up of material cooper.

3.2 *Validation*

CFD Nusselt number and friction factor results of the fully developed laminar flow in plain tube were confirmed by existing correlations for Nusselt number and friction factor, respectively. Results obtained for Nusselt number are compared with those predicted by Shah Equation at Re = 750 and constant heat flux of q= 5000 w/m^2 as it is evident; the deviation of experimental data and Shah Equation is in the range of 0.1% to 14.1%. Our work's results for water have good agreement with shah equation. And also, based on Shah Equation, the rate of enhancement of Nano fluid in the current study seems a reasonable enhancement.

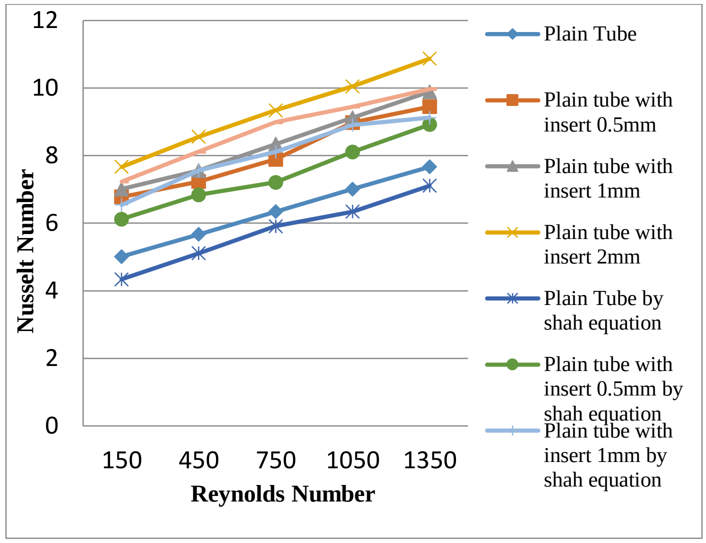

Fig. 3 Validation of Nusselt number for plain tube using ZNO (1%) with different insert thickness by shah equation

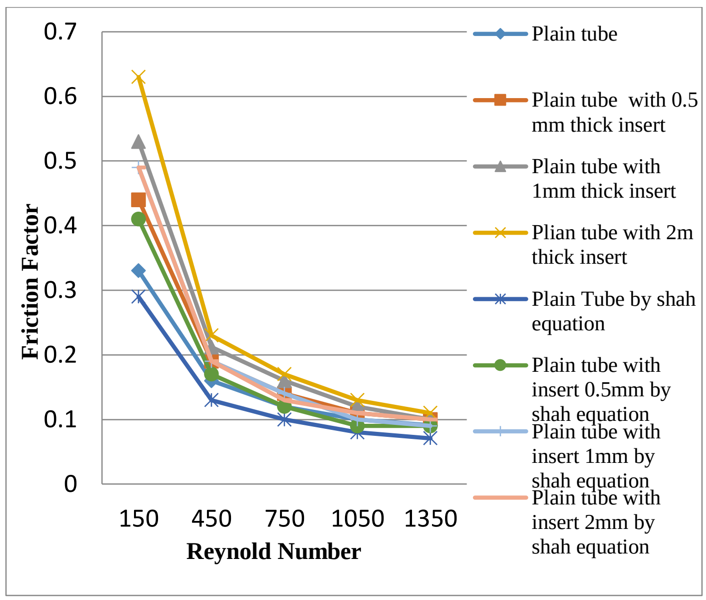

Fig. 4 .Validation of friction factor for plain tube using ZNO (1%) with different insert thickness by shah equation

3.3 *Convective heat transfer coefficient*

We investigated the heat transfer enhancement for two Nano fluid concentrations of 0.5% and 1% compared to water, and found that convective heat transfer coefficient is highest when 1% volume concentration is utilized as working fluid. Therefore, in the present work, in order to fully appreciate the highest enhancements caused by rectangular helix thickness augmentation and Nano fluid, together, results for 1% and 0.5% concentration are shown in the presented in table 5 and table 6. Figure6 shows the enhancement for convective heat transfer coefficient versus Reynolds number for 1% volume concentration and 0.5% volume concentration with rectangular helix insert of varying thickness (0.5 mm, 1 mm, and 2 mm). As it is shown, convective heat transfer coefficient enhances with increasing insert thickness. This enhancement is greatest when the Insert with 2 mm thickness is utilized with 1% volume concentration. This shows that insert thickness is a contributing factor in heat transfer enhancement because increase of insert thickness leads to better cross mixing near the tube wall and increasing the tape thickness further portions the tube which causes an increase in flow velocity, therefore enhancing the heat transfer coefficient.

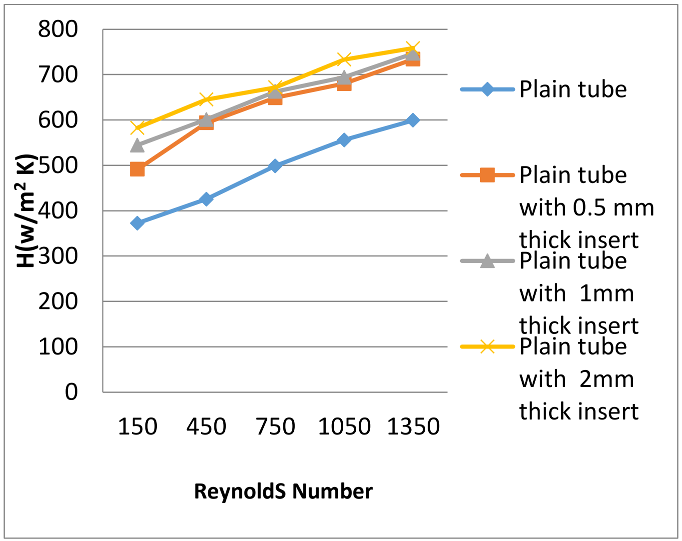

Fig. 5 Variation of heat transfer Coefficient along with increase in Reynolds number for plain pipe using ZNO (1%) with different insert thickness.

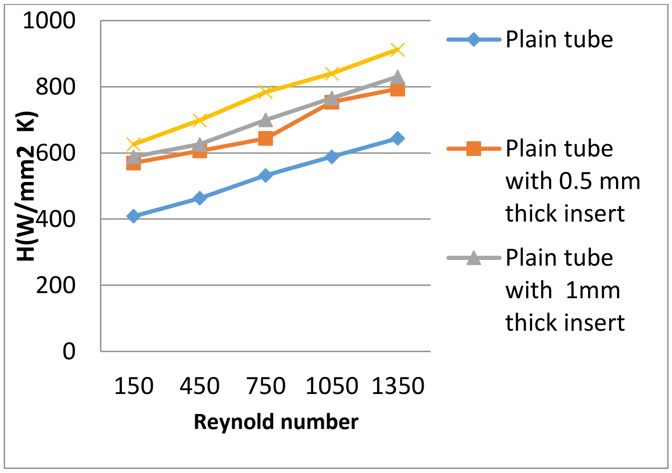

Fig. 6 Variation of heat transfer coefficient along with increase in Reynolds number for plain pipe using ZNO(1%) with different insert thickness.

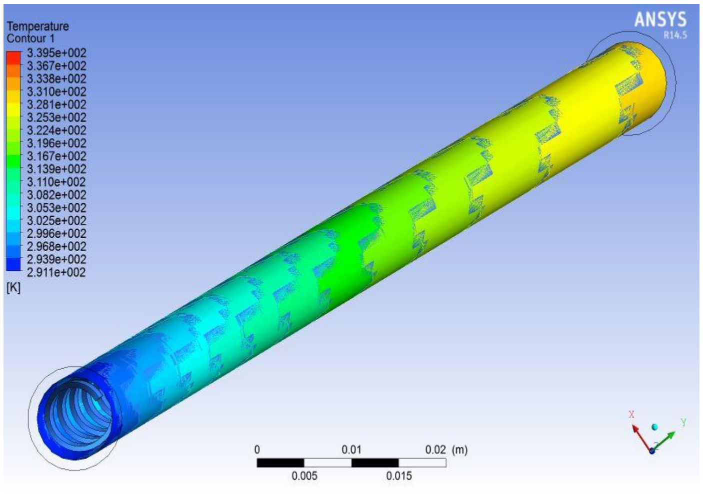

Fig. 7 Temperature variation in plain tube having ZNO(1%) with insert of 2 mm

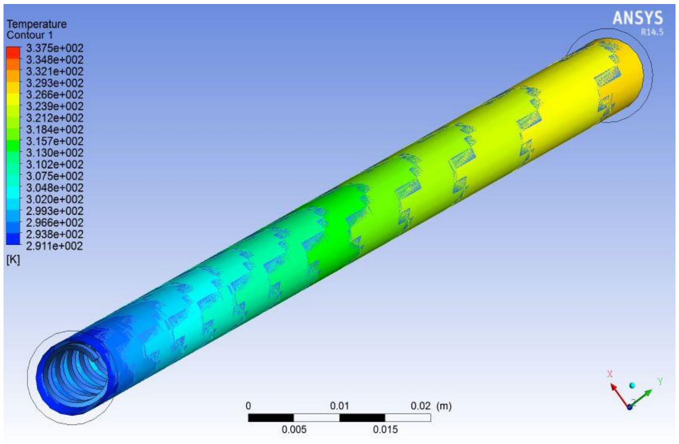

Fig. 8 Temperature variation in plain tube having ZNO(0.5%) with insert of 2 mm

Table 5 Comparison of heat transfer coefficient for plain pipe using water and plain pipe using ZNO(0.5%) with 2 mm insert thickness.

Reynolds number (Re)	Heat transfer coefficient for plain tube using water	Heat transfer coefficient for plain tube using ZNO (0.5%) with 2 mm thick insert	% Increment
150	356.24	482.7	26.864
450	372.24	545.08	31.296
750	400.01	590.83	32.460

1050	429.7	650.06	33.383
1350	453.06	703.13	35.240

Table 6 Comparison of heat transfer coefficient for plain pipe using water and plain pipe using ZNO (1%) with 2 mm insert thickness

Reynolds number (Re)	**Heat transfer coefficient for plain tube using water**	**Heat transfer coefficient for plain tube using ZNO (1%) with 2 mm thick insert**	**% Increment**
150	356.24	596.12	40.104
450	372.24	612.77	41.729
750	400.01	678.05	43.982
1050	429.7	712.55	44.818
1350	453.06	811.48	45.349

3.4 *Pressure drop and friction factor*

The pressure drop of distilled water for different thickness of rectangular helix insert tape and plain tube without using insert were measured with the help of ANSYS 14.5 The friction factor measurements are depicted in. The use of rectangular helix insert increase friction factor due to larger contact surface and reduction of fluid free flow area which causes a high speed swirl flow. Also, from the results, more the thickness of insert is more the increase of friction factor is. But as the velocity increase friction factor decreases for both plain tube and plain tube with rectangular helix insert and pressure drop increases.

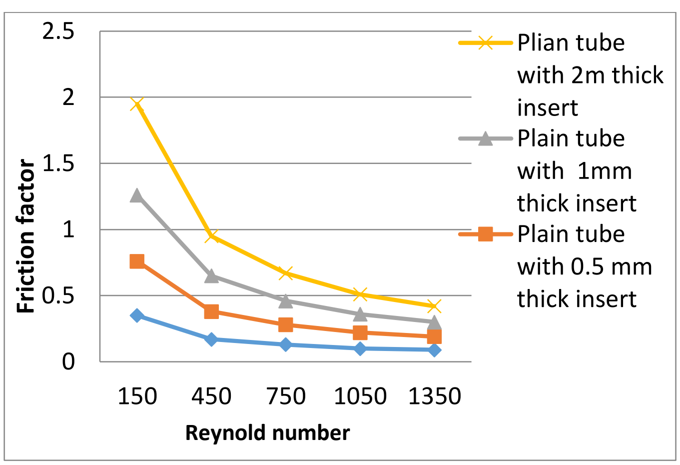

Fig. 9 Variation of friction factor along with increase in Reynolds number for plain pipe using ZNO (0.5%)

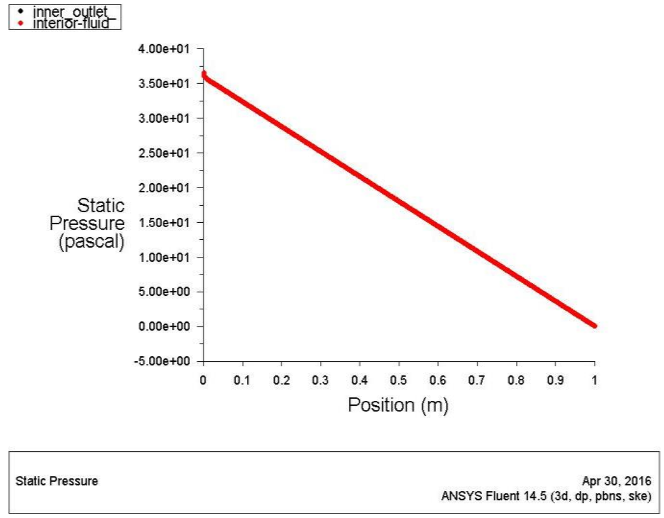

Fig. 10 Decrement in pressure from inlet to outlet when plain tube is using ZNO(0.5%) under constant heat flux at Re 450

3.5 *Nusselt Number*

The variation of the Nusselt number as a function of the Reynolds number for all the case studies is presented in which it is possible to observe that the increase of the Reynolds number results in an increase of the Nusselt number as well. The increase of the Nusselt number indicates an enhancement in the heat transfer coefficient due to the convection increases. The overall results show that in all the case studies, where the tube is equipped with any insert, the Nusselt numbers are higher than those obtained for the plain tube. And Nusselt number increase as the thickness of insert increases and as the volume concentration increase but decrease in outlet temperature when Reynolds number increases because less time of contact between heated wall and flowing fluid

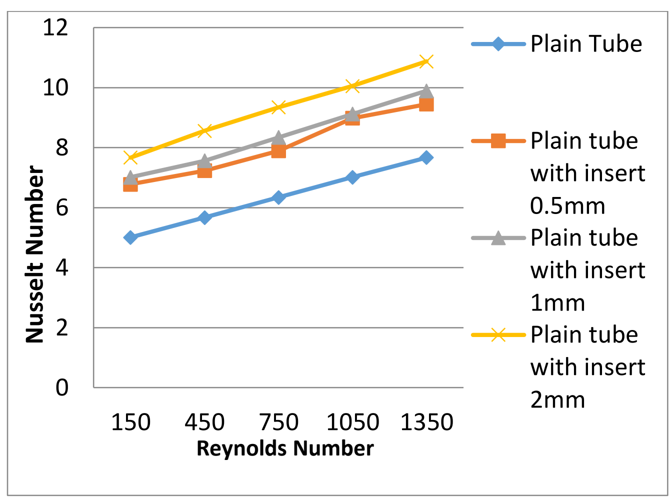

Fig. 11 Variation of Nusselt number along with increase in Reynolds number for the plain pipe using ZNO (1%)

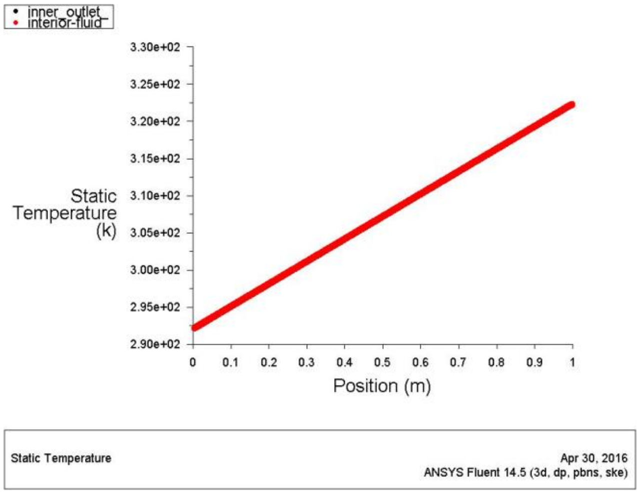

Fig. 12 Increment in temperature when plain tube is using ZNO (0.5%) under constant heat flux at Re 750

4. CONCLUSIONS

Convective heat transfer performance and pressure drop of ZNO/water Nano fluid in laminar flow through a circular tube fitted with rectangular helix insert with different thicknesses were studied with the help of software ANSYS 14.5 Under constant heat flux 1000 w/m^2 Results showed that:

- Rectangular helix insert enhance the average convective heat transfer coefficient, and also more the thickness of Rectangular helix insert is more the enhancement of convective heat transfer coefficient is.
- The highest enhancement is achieved at maximum thickness and volume concentration.
- Nano fluids have better heat transfer performance when utilized with thicker rectangular helix inserts it increases the heat transfer up to 50.34 % when utilized under ZNO(1%) with insert of 2 mm.
- The of rectangular helix insert increase friction factor due to larger contact surface and reduction of fluid free flow area which causes high speed swirl flow. More the thickness of rectangular helix insert is more the increase of friction factor is. Ultimately, the convective heat transfer enhancement outweighs the effect of friction factor increase, leading enhanced thermal performance.

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