PERFORMANCE STUDY OF CONICAL STRIP INSERTS IN TUBE HEAT EXCHANGER USING WATER BASED TITANIUM OXIDE NANOFLUID

by

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Abstract

The objective of the study is to observe the Nusselt number and friction factor behavior in a tube heat exchanger fitted with staggered and non-staggered conical strip inserts using water based titanium oxide nanofluid under laminar flow conditions. Water based titanium oxide nanofluid was prepared using a two-step method with a volume concentration of 0.1% and 0.5%. The tube inserts used were staggered and non-staggered conical strips having three different twist ratios of 2, 3 and 5. The experimental results indicated that the Nusselt number increased in the presence of water based titanium oxide nanofluid compared to the base fluid. Nusselt number further increased enormously with the use of conical strip inserts than a tube with no inserts. It was observed that the strip geometry and the nanofluid had a major effect on the thermal performance of the circular tube heat exchanger. It was found that with the staggered conical strip having a twist ratio of Y=3 and 0.5% volume concentration of nanofluid provided the highest heat transfer. Correlations have been derived using regression analysis.

Keyword: Nusselt number, Friction factor, Titanium oxide nanofluid, conical strip.

1. Introduction

Improvisation of the performance of the heat exchanger has wide range of applications [1]. Heat exchangers plays a significant role in internal combustion engines, air conditioning, various power plant and all energy related areas [2]. In this, one of the technique is to produce a working fluid with increased properties by using modern technology [3]. Remarkable developments in the field of nanotechnology provide an opportunity to produce new working fluid called Nanofluid for thermal equipment. Initially, it was prepared by Choi et al [4] with different volume concentrations. Choi et al [5] measured the thermal property of nanofluids and compared it with the base fluid. The result shows a positive effect thermal conductivity over the negative effect of increase in viscosity. Advantages of nanofluids are high specific area, high dispersion stability, adjustable properties [6].

Recent review articles from Zoubia Hadded et al [7] and Azwadi che Sidik et al [8] illustrated the preparation methods of Nanofluids. Chio et al [9] initiated the heat transfer study with property measurements. Utomo et al [10] showed that thermal conductivity of titanium oxide is lower than Maxwell model and viscosity is higher than Einstein-Bachelor model. Chandrasekar and Suresh [11] studied the mechanisms of Heat transport in nanofluids.

The heat transfer rate increased due to the addition of nano particles without any flow passage [12]. Sajadi et al [13] reported that heat transfer coefficient increases by 11% and 18% with increasing volume fractions of zno/water nanofluid, respectively, to 1 vol.% and 2 vol.%. Shanthi et al [14] studied the heat transfer character of Nanofluids with improved thermal transport properties. The swirl flow devices are a passive method that has independent power property [15].

Some of the swirl flow devices are Helical screw tapes, wire coil inserts with geometrical considerations were used in tube exchangers. Karimi et al [16] proposed new empirical correlation to predict the viscosity of nanofluids as a function of volume concentration, temperature, and the viscosity of base fluid.

Sundar and Singh [17] reviewed the effect of different inserts. Chandrasekar et al [18] found that the heat transfer enhances 34% with the use Al_2O_3 Nanofluids and further increases was observed up to 20% with wire coil inserts along with Al_2O_3 Nanofluids. Selvaraj et al [19] analyzed different geometry of grooved tube like circular, square and trapezoidal using cfd. Selvam et al [20] reported twisted tape with pins are desirable in order to increase the heat transfer rate. Suresh et al [21] observed enhancement Observed 48% enhancement in Nusselt number using spiral rod insert. Chandrasekar et al [22] experimental result shows the Al_2O_3 Nanofluids increase the Nusselt number up to 12.24% due to the effect of wire coil inserts. Shahidi et al [23] investigated heat transfer and pressure drop behavior of MWCNT-water nanofluid turbulent flow inside vertical coiled wire inserted tubes and observed 102% increase in Nusselt number. This paper presents both the convective heat transfer and friction factor characteristics in the fully developed laminar flow using TiO_2/water nanofluid with 0.1%, and 0.5% volume concentration under constant heat flux with staggered and non- staggered conical strip inserts.

2. Preparation of nanofluids

Water-based TiO_2 nanofluids was prepared with concentrations of 0.1%, and 0.5% using two step method. Nanofluid with an essential volume concentration was prepared by dispersing measured quantities of TiO_2 nanoparticles in distilled water. After dispersion the fluid were sonicated in an ultrasonic bath continuously for 6 hours to develop a uniform dispersion and stable suspension which govern the final properties of Nanofluids [24]. Diameter of nanoparticles are verified using SEM analysis. Fig.1 shows the surface morphology of TiO_2 Nanoparticles.

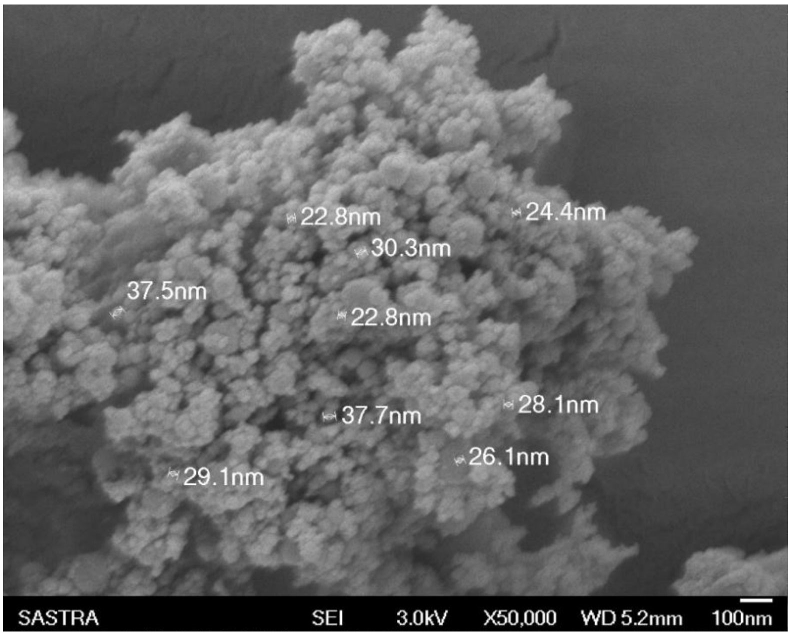


Fig. 1 SEM analysis of TiO_2 nanoparticles

3. Thermophysical properties of TiO_2/water Nanofluid

The thermal conductivity of TiO_2/water nanofluid was measured using a KD_2 Pro thermal analyser. The experimental value of thermal conductivity was compared with Maxwell's equation [25]. Maxwell proposed this model for spherical nanoparticles.

$$\frac{k_{nf}}{k} = \frac{k_s+2k+2\phi(k_s-k)}{k_s+2k-2\phi(k_s-k)}. \quad (1)$$

From the correlation proposed by Yu and Choi [26] is given by equation (2),

$$k_{nf} = \frac{1}{4}[(3\phi-1)k_s + (2-3\phi)k] + \frac{k}{4}\sqrt{\Delta}. \quad (2)$$

Where $$\Delta = \left[(3\phi-1)^2\left(\frac{k_s}{k}\right)^2 + (2-3\phi)^2 + 2(2+9\phi-9\phi^2)\left(\frac{k_s}{k}\right)\right]$$

k_{nf} -Thermal conductivity of nanofluid,
ks - Thermal conductivity of solid particle,
k - Thermal conductivity of bulk fluid, ϕ- volume fraction.

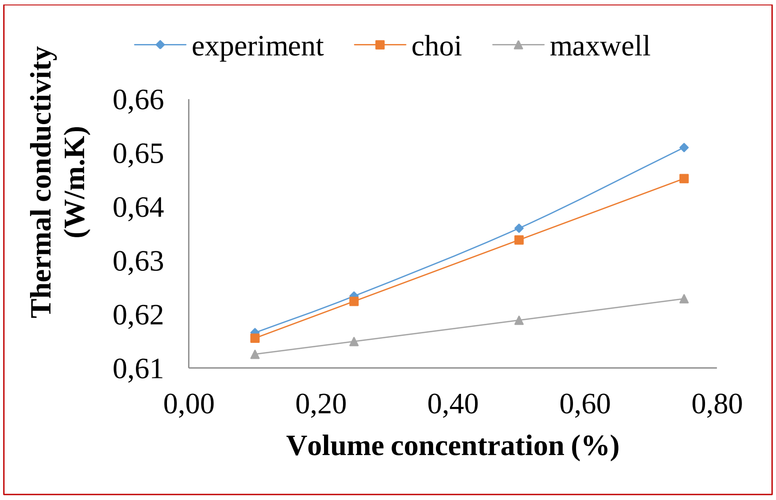


Fig.2 Experimental value of thermal conductivity of TiO_2/water Nanofluids compared to classical models

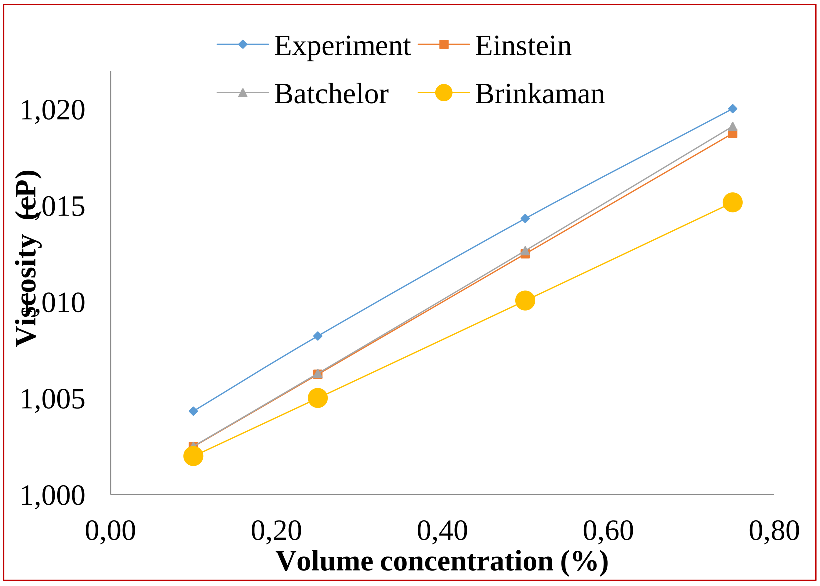


Fig.3 Comparison of viscosities of the experimental values with theoretical values.

Fig. 2 shows the comparison of experimental data with Maxwell and Choi classical models. The results show reasonably good agreement with the classical models at the lower concentration, however the experimental value were found to deviate from the classical models at higher concentrations.

The viscosity of nanofluid was measured by Brookfield cone and plate viscometer. The viscosities of TiO_2/water nanofluid were measured for different particle concentrations using Brookfield viscometer. Fig. 3 shows the comparison of viscosities of the experimental values with theoretical values based on models proposed by Einstein (3), Batchelor (4) and Brinkman (5) models as shown below [27].

Einstein model $\mu_{nf} = \mu(1 + k_1\phi)$. (3)

Batchelor model $\mu_{nf} = \mu(1 + k_1\phi + k_2\phi^2)$. (4)

Brinkaman model $\mu_{nf} = \frac{\mu}{(1-\phi)^{\frac{3}{2}}}$. (5)

Where, μ_{nf}- Viscosity of Nanofluid, μ - Viscosity of base fluid.

The stability of the nanofluid at different concentrations were measured by measuring the zeta potential. It was ensured that the nanoparticles were dispersed well and the nanofluid was stable due to very large repulsive forces between the nanoparticles as the pH is far from isoelectric point [28].

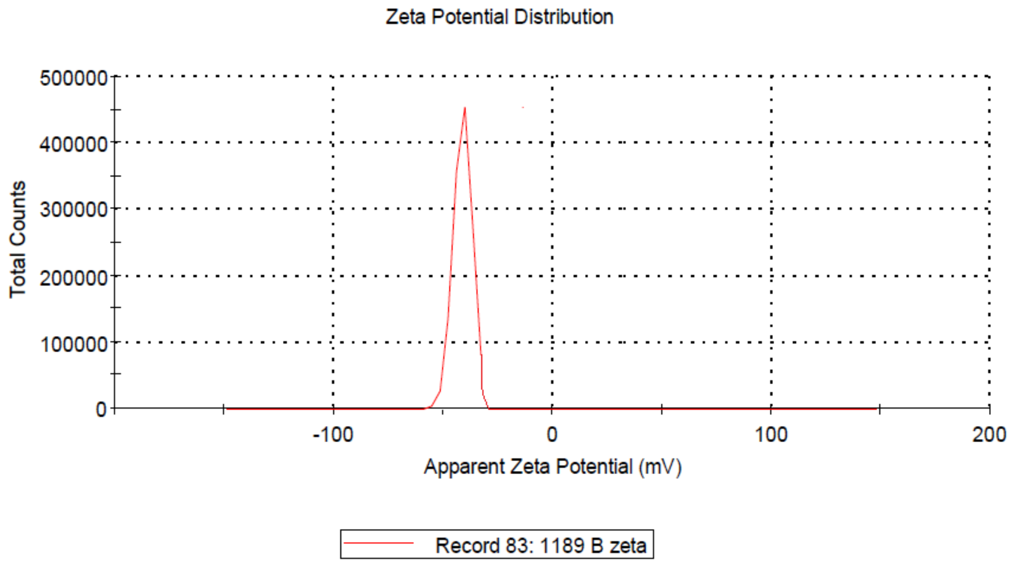


Fig.4 Zeta potential values for TiO_2/Water Nanofluids

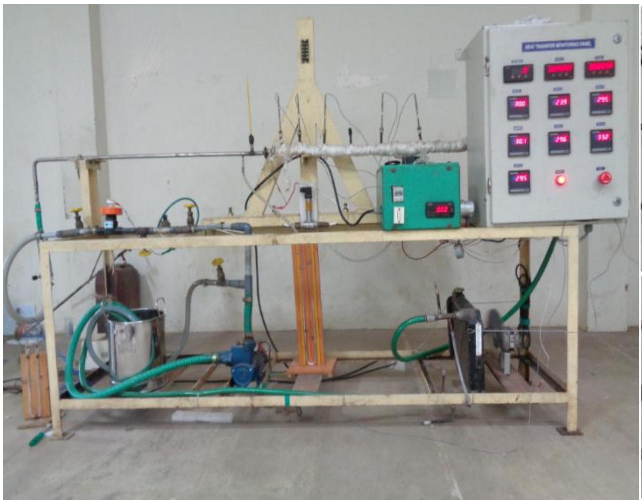
Table 1: stability of Nanofluids for different zeta potential values

Zeta potential [mV]	Stability behaviour of the colloid
0 to ±5	Rapid coagulation or flocculation
±10 to ±30	Incipient instability
±30 to ±40	Moderate stability
±40 to ±60	Good stability
more than ±61	Excellent stability

Table 1 shows the level of stability with respect to the zeta potential values. From the data obtained from the table 1, we can conclude from the fig. 4, that the TiO_2 nanofluid is stable.

4. Experimental set up and operating procedure

Fig. 5 shows the photographic view of the experimental setup. The setup consisted of a calming section, test section, riser section, reservoir and pumping. The nanofluid is stored in a reservoir and pumped from the reservoir by a circulating pump. The nanofluid enters the calming section, this section serves to smooth the flow prior to entry into test section. The test section is made of a copper tube of



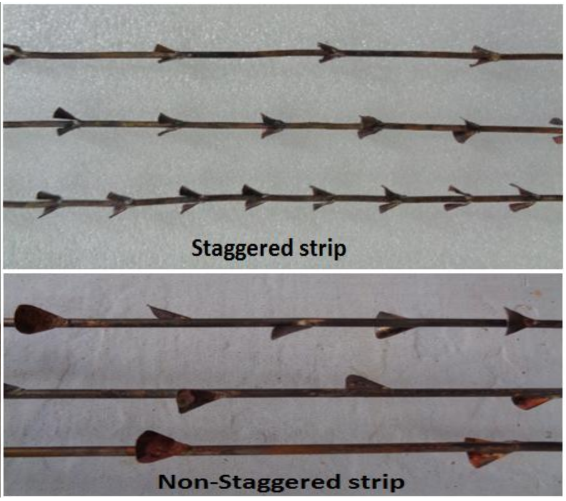


Fig.5 Photographic view of setup

Fig.6 Different types of strips

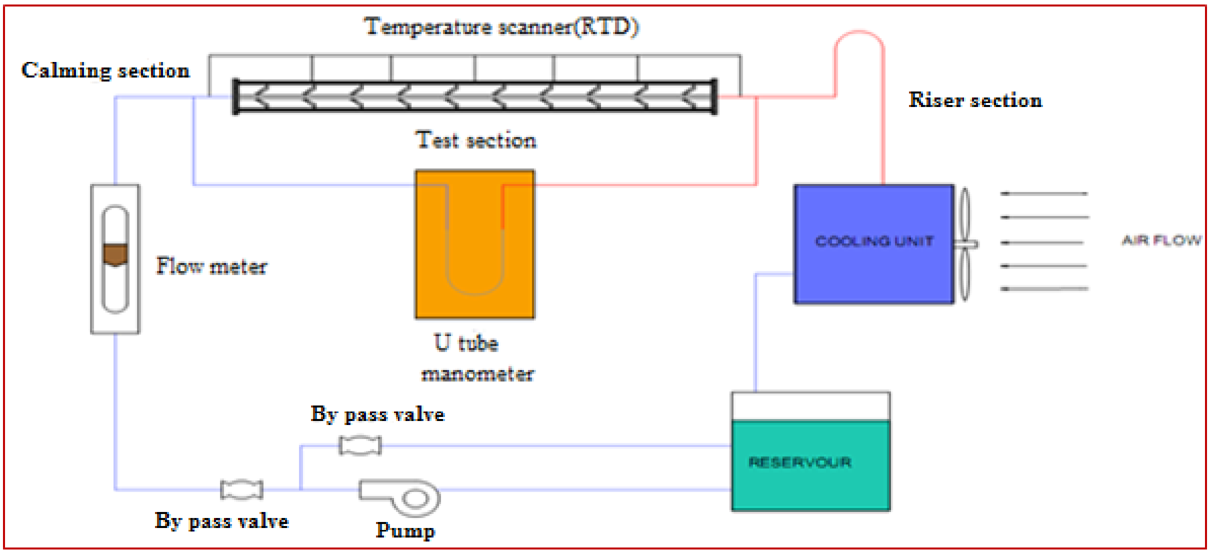


Fig.5a Schematic diagram of setup

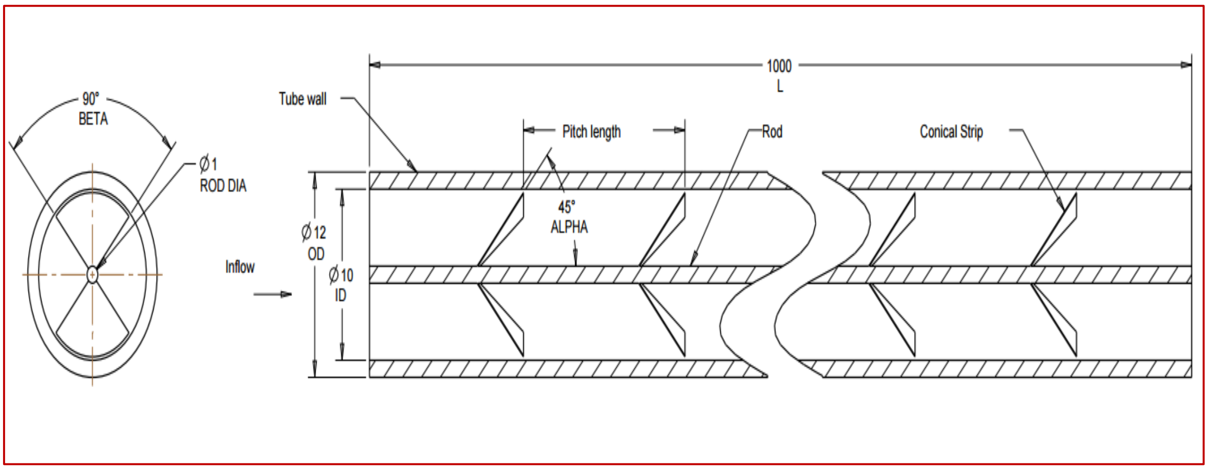


Fig.6a Geometry of the conical strip

1m length and having an internal diameter of 0.01 m. Fig 5a shows the Schematic diagram of setup The heat flux is applied to the test section by an insulated Nichrome heating wire having a capacity of 300 Watts. To reduce the heat loss to the atmosphere the heater wound test section is insulated by glass wool. Temperatures along the wall of the test section were measured by seven RTDs which have an accuracy of ±0.1 °C. Following the test section is the riser section. The riser section aids in maintaining a uniform flow in the test section and also to run full. The pressure drop along the test section is measured by a mercury U-Tube manometer. The fluid flow is measured by a rotameter. Fig. 6. shows the Staggered and non-staggered conical strip inserts. Staggered conical strips are those which are uniformly connected over the entire length of the rod. On the contrary, non-staggered conical strips are those which are randomly distributed over the entire length of the rod. The strips are made of copper sheet having 1 mm thickness. The geometry of the conical strip defined in fig 6a. The twist ratio equation and the different twist ratios used in the experiment are shown below

$$\mathrm{Y} = \frac{\text{Pitch length of the rod}}{\text{Diameter of the test section}}$$

Table 2: Twist ratios used in the experiment

S. No	**Pitch length in mm**	**Diameter in mm**	**Twist ratio Y**
1.	20	10	2:1
2.	30	10	3:1
3.	50	10	5:1

5. Data Reduction

The friction factor for fully developed flow was determined by Poiseuille equation

$$f = (\frac{D_i}{L})(\frac{2\Delta P}{\rho u_m^2}) \tag{6}$$

Change in pressure was calculated using U tube manometer where mercury is used as manometric fluid. The heat transfer rate was calculated by

$$Q = \frac{V^2}{R} = \dot{m}\, Cp\, (T_{out} - T_{in}) = hA(T_{wall} - T_{f\ avg}) \tag{7}$$

The Nusselt number was calculated using equation (8).

$$Nu = hD/k \tag{8}$$

6. Results and Discussion

Initially, the experiment was conducted on a tube with no inserts for validation. The experimental Nusselt number data was verified by comparing the results with Shah equation for laminar flow. Fig. 7 shows the comparison of Nusselt number for experimental and theoretical data.

Shah Equation for laminar flow

$$Nu = 1.953(RePr\frac{d}{L})^{1/2} \tag{9}$$

Poiseuille equation

$$f = \left(\frac{D_i}{L}\right)\left(\frac{2\Delta P}{\rho u_m^2}\right) \tag{10}$$

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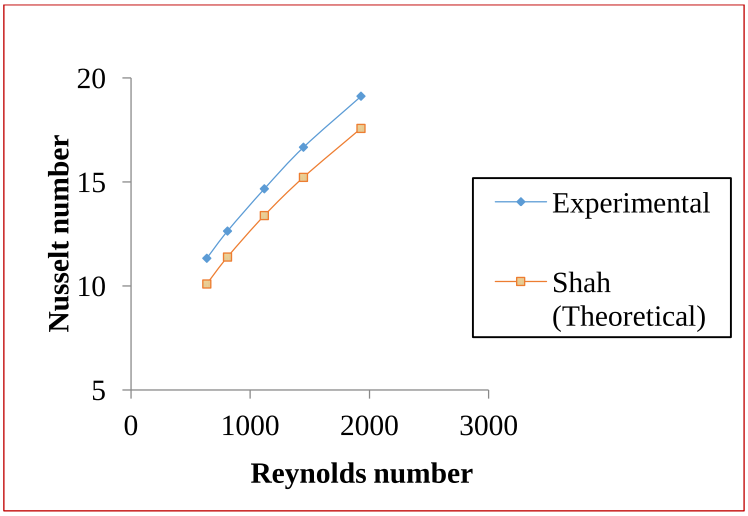

Fig.7 Nusselt Number vs Reynolds number for experimental and theoretical data

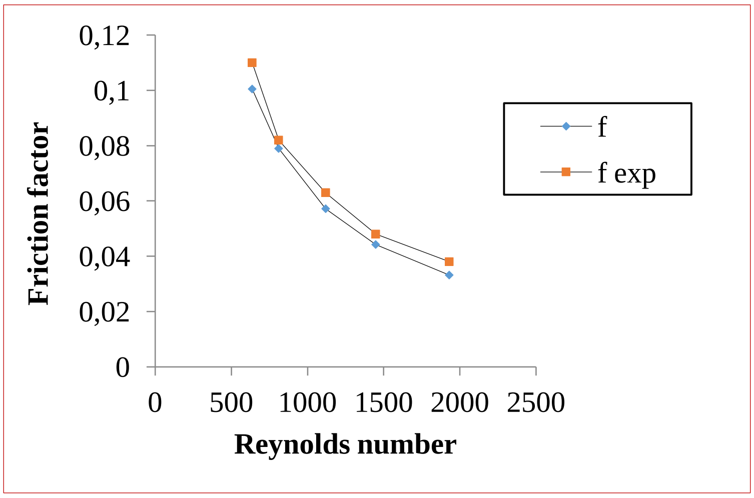

Fig.8 Friction factor verification

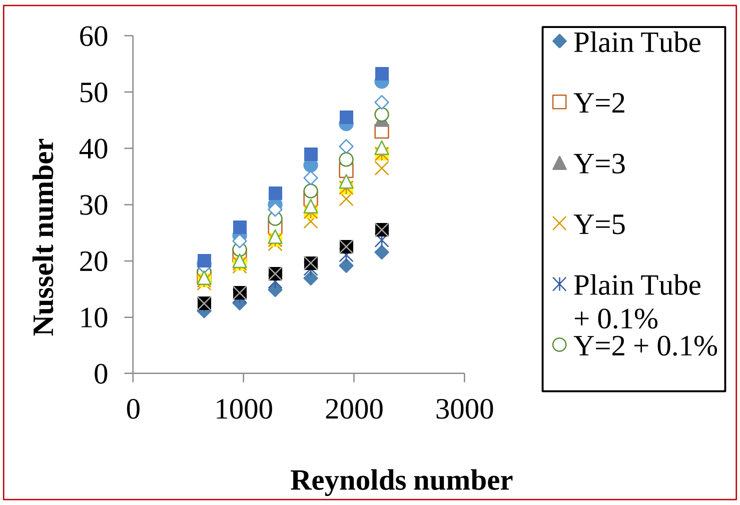

Fig.9 Nusselt number observation for staggered conical strip

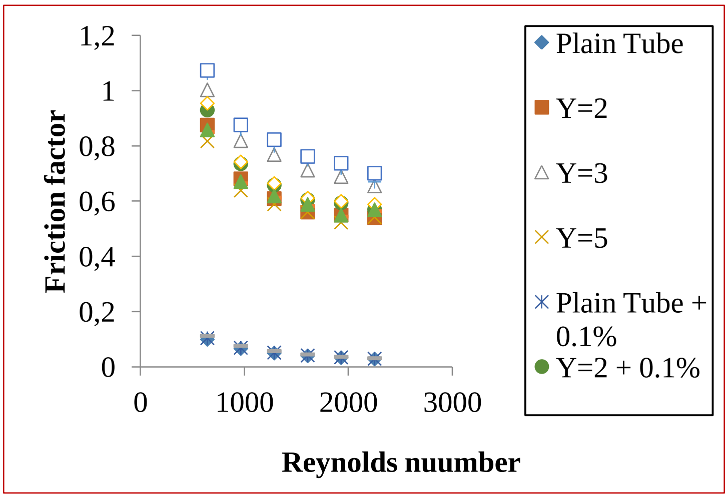

Fig.10 Friction factor observation for staggered conical strip

Similarly, the friction factor comparison was made with the Poiseuille equation (10). Fig. 8 shows the comparison of experimental friction factor with theoretical results. The figure shows that the experiment results are in good agreement with the theoretical results

Fig. 9 represents the Nusselt number vs Reynolds number under laminar flow conditions with staggered tape inserts. The maximum Nusselt number was achieved with the use of conical strip inserts as compared to plain tube. It can be seen that the maximum rate of Nusselt number was obtained for nanofluid with 0.5 % concentration and having a twist ratio of 3. These results indicate that for a given Reynolds number, the increase in Nusselt number with increase in volume concentration is not same always. Level of flow turbulence made by separation and reattachment mechanism using conical strips. The chaotic movement of the solid particles in the flow will disturb the thermal boundary layer formation at the surface of the tube wall. This disturbance would delay the development of thermal boundary layer. Due to this higher heat transfer coefficient of the fluid was observed. Fig.10 shows that the friction factors of nanofluids at various Reynolds numbers. There was a moderate increase with the increase in friction factor due to conical strip inserts.

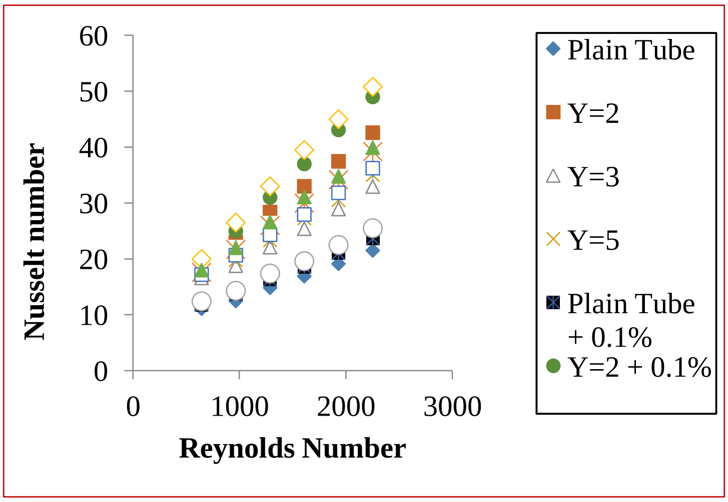

Fig.11 Nusselt number observation for Non-staggered conical strip

Fig. 11 represents the Nusselt number vs Reynolds number under laminar flow conditions with non- staggered tape inserts. It can be seen that the maximum rate of Nusselt number was obtained for nanofluid with 0.5 % concentration and having a twist ratio of 2. Fig.12 shows that the friction factors of nanofluids at various Reynolds numbers. There was a moderate increase with the increase in friction factor due to conical strip inserts.

Nanofluid enhances the heat transfer rate as compared to regular coolants. Moreover, the use of inserts further increases the tube enhancement capabilities. Conical strip insert allows a greater mixing of fluid inside the heat exchanger tube and increases the turbulence in the tube. It promotes higher shear stress on the wall, which in turn promoted the heat transfer from the tube wall to the core as reflected by temperature field.

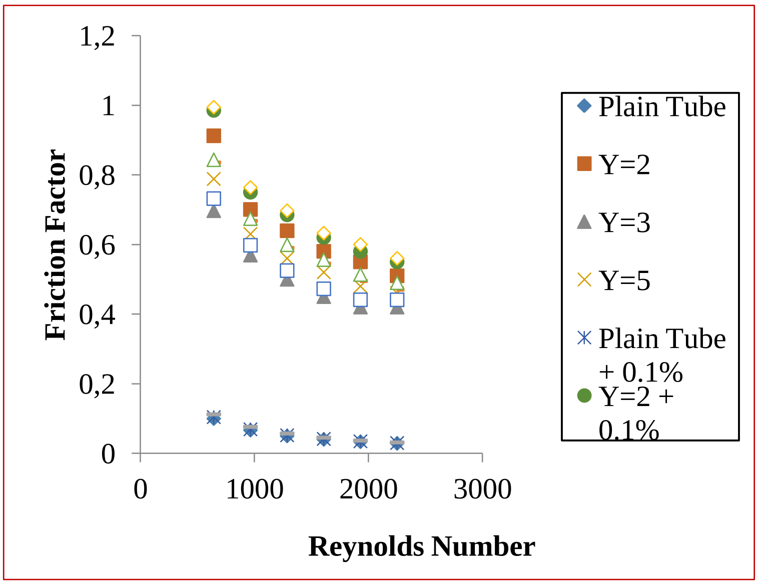

Fig.12 Friction factor observation for Non-staggered conical strip

The addition of inserts in the tube has led to the requirement of higher pumping power. A balance has to be made considering the economics with respect to the increased pumping power requirement and the heat transfer with the conical inserts.

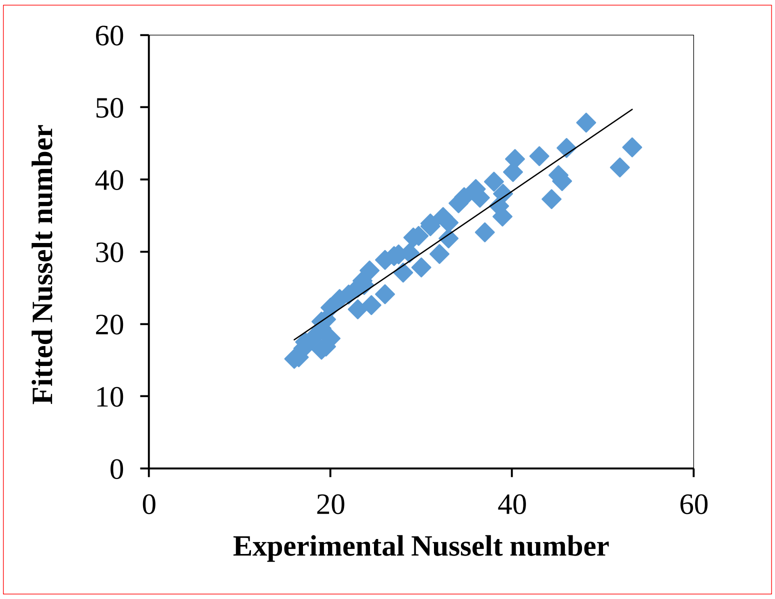

Fig. 13 Comparison of Experimental and Fitted Nusselt number

In this study, based on the experimental data, correlations were developed by using regression analysis for determining Nusselt number and friction factor with TiO_2/water Nanofluids. This correlation is developed for conical strip inserts.

$$Nu = 0.0169\, Re^{0.721} Pr^{1.637} Y^{-1.164} (1 + \emptyset)^{0.2328} \quad (11)$$

$$f = 0.7764\, Re^{-0.350} Pr^{1.686} Y^{-0.081} (1 + \emptyset)^{0.1384} \quad (12)$$

The above equations, the Nusselt number and friction factor is a function of Reynolds number, Prandtl number, twist ratio and nanofluid volume concentration. From Figure 14 and 15, it can be seen that the equations (11) and (12) are in agreement with the experimental values.

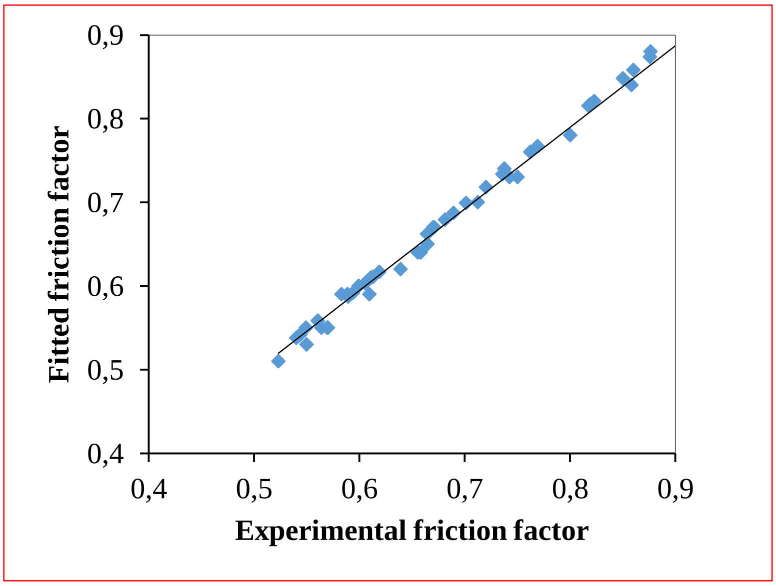

Fig.14 Comparison of Experimental and Fitted friction factor

7. Conclusion

In this study the Nusselt number and Friction Factor characteristics of water based TiO_2 nanofluids were analyzed. The experiment was carried out in a tube heat exchanger fitted with Staggered and non-staggered types of conical strips having three different twist ratios of 2, 3 and 5 under laminar flow conditions. The following observations were made.

- The nanofluid showed increased heat transfer on comparison with base fluid alone, thereby enhancing the heat transfer capabilities of regular fluid.
- The use of staggered and non-staggered conical inserts was found to further increase the Nusselt number.
- The maximum Nusselt number was achieved at Reynolds number of 2251 with 0.5% volume concentration when staggered conical strips were used with a twist ratio of 3.
- In case of Non Staggered conical strips, the maximum Nusselt number was observed for a lower twist ratio of 2 having the same concentration of 0.5% of nanofluid.
- The conical inserts increased the friction factor of the flow. This in turn increases the pumping power requirements. A balance has to be achieved considering the heat transfer improvement requirement and pumping power availability.

Nomenclature

A	Surface area of the tube, m^2	Pr	Prandtl number
C_p	Specific heat, J/kg K	Q	Heat transfer, W
D	Diameter of the tube, m	R	Resistance, Ohms
f	Friction factor	Re	Reynolds number
h	Heat transfer coefficient, W/m^2 K	T_f	Fluid Temperature, ℃
k_s	Thermal conductivity of solid , W/m K	T_w	Wall Temperature, ℃
K_{nf}	Thermal conductivity of Nanofluid, W/m K	Φ	Volume fraction
L	Length of the test section, m	U	Overall Heat Transfer coefficient, W/m^2 K
ṁ	Mass flow rate, kg/s	u	Mean Velocity, m/s
Nu	Nusselt number	V	Voltage, Volt
Δp	Pressure drop, N/m^2	Y	Twist ratio
ρ	Density, kg/m^3		

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