IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 8 Issue 4, April 2021
ISSN (Online) 2348 – 7968 | Impact Factor (2020) – 6.72
www.ijiset.com

Experimental Investigations On Heat Transfer And Friction Factor Of Hybrid Nanofliud Equiped With Angular Twisted Strip Inserts In A Parabolic Trough Solar Collector Under Turbulent Flow

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ABSTRACT

High temperature and higher-thermal efficiency are main goals to improve trough collector's technologies. For a parabolic trough collector the major factor for optimum heat transfer from sun to the heat transfer fluid passing in the absorber tube is to have high convection heat transfer coefficient. Literature shows that absorber tubes with various tape inserts are used and recommended to produce high convection coefficient. Typical twisted-tape (TT) enhances heat exchange between tube surface and working fluid by generating turbulent swirling flow. In this study, enhancement of convection coefficient in the absorber tube of a solar parabolic trough concentrator is equipped with a new angular Twisted strip inserts in a circular pipe, two different twist ratios (TR), TR=y/W= 4, 5.22 (y is the length required for one twist and W is the width of the tape) are used in an experimental laboratory trough collector. Heat Transfer and friction factor data at various volume concentrations for flow in absorber tube with and without twisted tape inserts is determined experimentally (with DI-H_2O and Hybrid Nanofluid (GO (30%) + TiO_2 (70%)(ϕ=0.5%)). The experiments were conducted in the Reynolds number range $500 \leq Re <\leq 6000$ with twisted tape inserts of different twist ratios in the range 4, 5.22. This study shows that twisted tape inserts when used shows great promise for enhancing heat transfer rate in absorber .The heat transfer coefficient and friction factor of $0 \leq \phi \leq 0.5$ % volume concentration of Hybrid nanofliud are higher compared to flow of DI-H_2O in absorber tube. The experiments show that Nusselt Number, friction factor and enhancement efficiency are found to be 1.45 -3.10 times, 1.0 -1.25 times and 145%-215%, respectively, over, plain absorber tube of parabolic trough collector. Finally new generalized correlations function for predicting heat transfer and

friction factor for turbulent flow of both DI-H_2O and Hybrid nanofluid are proposed with tape inserts.

Key words: *solar parabolic trough collector, Angular twisted strip insert, Twist ratio, Turbulent flow, Hybrid nanofluid, Heat transfer coefficient.*

1. Introduction

Solar energy utilization is one of the most effective ways for facing the recent problems in the energy domain which are associated with the global warming, the fossil fuel depletion and the increasing rate of electricity price (Casati et al., 2015[1]; Reddy et al., 2015[2]). Solar energy is abundant energy source (Tripathi and Tiwari, 2016[3]) which can either to be converted into useful heat and to electricity, the fact that makes it a suitable energy source for numerous applications from domestic hot water production to solar dryers and to electricity production in concentrating solar power plants (Qiu et al., 2017[4]; Tiwari and Tiwari, 2016[5]; Tzivanidis et al., 2016[6]). Concentrating solar collectors are the most suitable technology for operation in medium and high-temperature levels (over 150 °C) with high thermal efficiency (Fernández-García et al., 2010[7]). Among the developed technologies, parabolic trough collector (PTC) is one among the most mature solar collector types which are used in many applications (Wang et al., 2016[8]; Rovira et al., 2016[9]). For solar systems heat transfer augmentation techniques refer to different methods used to increase the rate of heat transfer without affecting much the overall operation of the system. Nithiyesh [10] classified existing heat transfer enhancement techniques into three groups: active techniques, passive techniques and compound techniques. In active techniques, heat transfer enhancements occur because of the external power existence. Passive techniques use geometrical modifications without needing external power input. Finally in compound techniques, any two or more of those techniques are used with each other. Using the modified twisted-tape that is investigated in this study is one of the effective passive techniques for such enhances of heat transfer rate and pressure drop by generating a turbulent swirling flow. The design of inserts plays a major role in heat transfer augmentation and have resulted in its own categories. There are varieties of inserts that are as simple as a straight rod with fins to twisted wires or twisted tapes to create flow turbulence. Inserts play an important role in changing the pressure within the tubes. The reduction of pressure has the ability to affect the heat transfer rate that is justified by many works of literature. Rod inserts having helical grove were observed to give more benefits than twisted tape inserts. The friction factor was found to be higher in helical inserts compared to its counterparts. Every insert is described using twist ratio, which is the ratio between the distance between the pitch of the spiral or helix to its smaller radius Strip inserts are found to enhance flow mixing and disturbance in the boundary layer and thus rise Nusselt number and friction factor unlike the plain tube (Kumar and Prasad. 2000[11]). Angular Twisted strip inserts in a circular tube gained interest among researchers interested to improve the heat transfer rate and overall thermohydraulic performance without affecting flow resistance and pressure drop. Unfortunately, most results revealed that widened slant angle and smaller pitch can improve the heat transfer rate, at the same time may lead to an increase in flow resistance (Jaisankar, Radhakrishnan, and Sheeba 2009[12]; Murugesan, Mayilsamy, and Suresh 2010[13]). Multiple longitudinal swirling flows downstream are observed in systems of bidirectional conical strip insert. Rapid exchange of cold and hot fluid in the central and boundary region may be the reason behind such behavior (Devarajan, Munuswamy, and Mahalingam 2017[14]). The slant angle, decreasing pitch and twist angle for turbulent flow (Mahalingam et al. 2017[15]). The laminar flow has a negative impact on flow resistance enhancement (Yuvarajan et al. 2017[16]). Improved thermal properties, constant temperature, and velocity distributions, more intense nanoparticle migration were results of higher intensity disturbances to the boundary layer in nonstaggered alignment (Devarajan et al. 2017[17]). Thus, for thermal hydraulics performance enhancement in laminar flow was observed (Arulprakasajothi et al. 2018b[19]). For silver/water nanofluid it is reported that the nanoparticle dispersion intensified by an increase of the distance from the tube inlet (Arulprakasajothi et al. 2018a[18]). In comparison to water, the nanodiamond-nickel hybrid nanofluids help in improving the Nusselt number by 35.43% (Arulprakasajothi et al. 2018b[19]). For all solar thermal applications, the efficiency of the devices can be improved designing of the systems (Mahalingam et al. 2018[20]), to design more efficient products (Arulprakasajothi, Chandrasekhar, and Yuvarajan 2018[21]). Passive heat transfer enhancement techniques are effective in improving the thermal efficiency of solar water heaters. The presence of twisted tape and employing nanofluids instead of water is found to enhance thermal performance without much pressure loss. (Arulprakasajothi et al. 2018a[18]; Devarajan et al. 2018[17]; Iqbal et al. 2018[18]; Santhana Krishnan et al. 2018[22]). In the present world, the demand for energy consumption has been increasing exponentially with the current trends in various sectors. In recent years, environmental issues are frequent problems of utilizing fossil energy sources. The performance of the receiver's absorber tube used in PTC solar collectors is efficient in improving collector efficiency when compared to flat plate collector in high-temperature applications. So, the absorber tube is considered to be an important component in PTC system for various applications like power generation, cooling, and heating. Hejazi et al. [23] carried out an experimental study on heat transfer enhancement and pressure drop changes for a tube with twisted-tape insert. Twisted-tapes with a twist ratio of 6, 9, 12 and 15 are investigated and the results are compared with a plain tube. For all twist ratios heat transfer and pressure drop enhancement are observed. The best heat transfer enhancement and thermal performance occurred for twist ratio of 6 and 9, respectively. Eiamsa-ard et al. [24] carried out numerical investigation on heat transfer in a tube with loose-fit twisted-tape insert. The results showed that the tube with twisted-tape insert without clearance between the edge of the tape and tube wall (tight-fit) had maximum heat transfer enhancement rather than the loose-fit twisted-tape insert and this enhancement increased with decreasing the clearance between the edge of the tape and tube wall. Eiasma-ard et al. [25] studied convective heat transfer in turbulent flow with short-length twisted-tape insert under uniform wall heat flux boundary conditions. The experiments are done at several tape length ratios of 0.29, 0.43, 0.57 and1.0 (full-length twisted-tape). It was found that heat transfer and pressure drop of the tube with full-length twisted-tape has higher convection coefficient than short-length twisted-tape. Jaisankar et al. [26] carried out an experimental study on heat transfer and friction factor for a solar water heater with spacer and rod at the ending edge of the twisted-tape for several lengths and twist ratios. Reduction of heat transfer coefficient enhancement for twisted-tape with rod and spacer was 17% and 29%, respectively as compared with full-length twisted-tape. It is also observed that use of twisted-tape with rod instead of full-length twisted-tape had low friction factor with less reduction on heat transfer enhancement. Ferroni et al. [27] carried out experimental investigation for isothermal condition for tubes with separated, multiple, short-length twisted-tape inserts in turbulent regime. Results showed that pressure drop with multiple short-length twisted-tapes were at least 50% lower than full-length twisted-tapes. Eiasma-ard et al. [28] investigated heat transfer enhancement and pressure drop in a single, full-length and regularly-spaced dual twisted-tape under uniform wall heat flux conditions. Result showed that the tube with dual twisted-tapes had higher heat transfer than the plain tube and tube with typical twisted-tape inserts. Their results also showed that the heat transfer of the regularly-spaced twisted-tape decreased with increasing space ratio. Eiasma-ard [29] investigated experimentally the influences of multiple twisted-tapes on heat transfer and friction factor in a rectangular channel. Results showed that the channel with the smaller twist ratio and more free space between tapes provided higher heat transfer rate and pressure drop than those with the larger twist ratio and less free space between tapes. Seemawute and Eiasma-ard [30] studied numerically flow in a tube with alternative axis twisted-tape insert. Their numerical results showed that the fluid in the tube with alternative axis twisted-tape insert has more uniform and temperature distribution than the typical twisted-tape. The eccentric pipe inserts showed better performance compared to the concentric tube inserts (Balaji et al. 2018[31]; Logesh et al. 2018[32]). Inserts not only led to reduced velocity magnitude but also made the temperature field more uniform (Rupesh et al. 2018[33]). On the basis of three-dimensional numerical model of a solar cavity receiver tube, the effects of inserts configurations, non-uniform heat flux boundary condition, thickness and positions of twisted-tape were studied and results showed that the twisted tapes with more thickness has the highest Nusselt number. The usage of helical twisted tape and additional reflecting surfaces creates a swirl flow inside the riser tube and boosts the solar concentration, respectively, which enhances the thermal performance and pressure drop in a V-trough thermosyphon solar water heater (Mahalingam 2018[20]). From the literature survey, we were able to conclude that there is a gap in data with the performance of angular flat strip twisted shaped insert in parabolic trough collector. Here we report the contribution of the angular flat strip twisted shaped insert with varying twist ratio in the parabolic trough collector. The experimental results reveal that the heat transfer improved with inserts. The geometry of the parabolic reflector section used solar flux of high reflectivity applied over the 2 m long stainless steel in the reflector rigid surface, 1m aperture width and 90° of rim angle, this focused all incident solar radiation into focal line and a heat collection element (copper tube) through which heat transfer fluid flows. The tube is placed on the focal line of the collector which is also parallel to its axis of rotation.

2. Experimental setup and observations

The photographic view of the solar parabolic trough collector experimental setup is shown in Figure 1 and the schematic diagram in Figure 2. It comprises a solar parabolic trough collector, flow meter, circulating pump and a storage tank. The specifications of the parabolic trough solar collector are given in Table 1. The north-south oriented solar parabolic trough collector consists of a copper tube absorber.

Table: 1 Specifications of the PTC set up

S.No	Components	Specifications
1	Heat generating unit with tracking system	
	Parabolic reflector • Length • Arc length (perimeter) • Depth • Focal length • Material	 4ft 6ft 0.68 ft 1.99ft SS with mirror film
	Sun tracker	Single axis
	Absorber tube • Length • Diameter • Absorber material • Piping material	 4ft 1 inch Copper, SS GI and Copper
2	Storage unit	
	Supply tanks • Capacity • Material Storage tanks • Capacity • Material • Insulation used • Working fluid	 46 ltrs SS 28 ltrs SS Glass wool with rexene Water
3	Control unit • Pump power rating • Head	 0.1 HP 6m

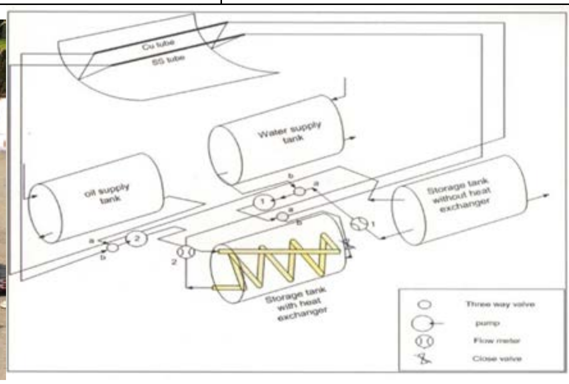

Figure 1: photographic view of the solar parabolic trough collector experimental setup

Figure 2 : schematic diagram of the solar parabolic trough collector experimental setup

According to the experimental study, throughout the experiment there is an exposure to direct solar radiation on the parabolic trough collector with the help of an electromechanical sun tracking system. The absorbed heat is transferred into the working fluid by forced convection using a pump through the copper tube. The working fluid inlet and outlet temperatures (Tfi) and (Tfo) are measured using RTD PT-100 temperature sensors. The absorber outer surface temperatures are measured using seven K-type thermocouples. The thermocouples are placed axially at a distance of 25, 50, 75, 100, 125, and 150cm respectively, from the inlet. A rotameter is used to measure the flow rate of the working fluid. The manometer readings help in calculating isothermal pressure drop. The intensity of solar radiation is recorded using an Pyrheliometer as shown in Figure 3. The wind speed in the location is measured using an anemometer as shown in Figure 4. The storage tank is connected to the main water supply and filled up to half of the storage tank. The water flow rate, the intensity of solar radiation, the inlet water temperature and the outlet water temperature of the absorber tube are periodically measured and recorded. Angular flat strip twisted shaped insert is attached with 2 mm diameter copper rod. Uniform and identical equispaced inserts employed with a height of 12 mm equalizing tape width and hence no reductions in radial heat transfer. The angular flat strip twisted shaped insert with the twist ratios of 4, 5.22 are designated as S1 & S2

Fig 3: Pyrheliometer

Fig 4: Anemometer

Fig 5. Angular Twisted Strips with Twist ratio 4

Fig 6. Angular Twisted strips of twist ratio 5.22 with opposite direction

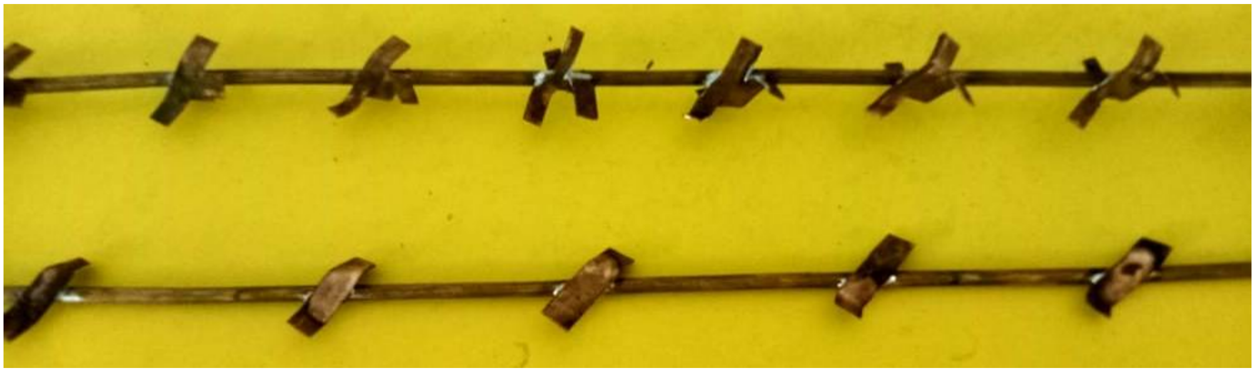

Fig 7: Angular Twisted strips of twist ratio 4, 5.22

S1 as shown in Figure 5 and S2 as shown in Figure 6 for forward and backward, respectively. Figures 5 and 6 show the photographic view of the angular twisted strips insert used in the present experiment.

2.1 Data reduction

In the absorber system, the convective heat transfer can be estimated using the relation given below

$$Q = m^{\cdot} C_p (T_o - T_i) = U_o A_o (T_{wo} - T_m) \qquad (1)$$

Under steady state, the coefficient of overall heat transfer is estimated using the relationship

$$\frac{1}{(U_o A_o)} = \frac{1}{(h_i A_i)} + ln \frac{\left(\frac{D_o}{D_i}\right)}{(2\pi k_w L)} \qquad (2)$$

The heat transfer can be quantified by using the Nusselt number (*Nu*) and coefficient of convective heat transfer (h_i) as indicated below

$$Nu = \frac{h_i D_i}{k} \qquad (3)$$

In the present work, the isothermal flow condition has been assumed and the pressure drop along the absorber tube has been measured to find out the friction factor using the following correlation:

$$f = \frac{\Delta p}{1/2 \rho V^2} \frac{D_i}{L} \qquad (4)$$

2.2 Validation of the experiment with a plain tube

Using Dittus-Boelter (1930) equation and Petukhov(1970) equation, the heat transfer (Nusselt number) and friction (friction factor), the experimental results are validated.

$$Nu_D = 0.023 Re_D^{0.8} Pr^n \qquad (5)$$

The estimated and experimental value of Nusselt number gives a maximum variation of ± 12% as shown in Figure 7. The plot implies that the Nusselt number is directly proportional to the Reynolds number and it is due to the higher fluid flow and high solar intensity. The friction factor deviation is found to be ± 10% as shown in Figure 8. The figure shows that the friction factor decreases with the increase in the Reynolds number.

The friction factor correlation from Hagen–Poiseuille is of the form

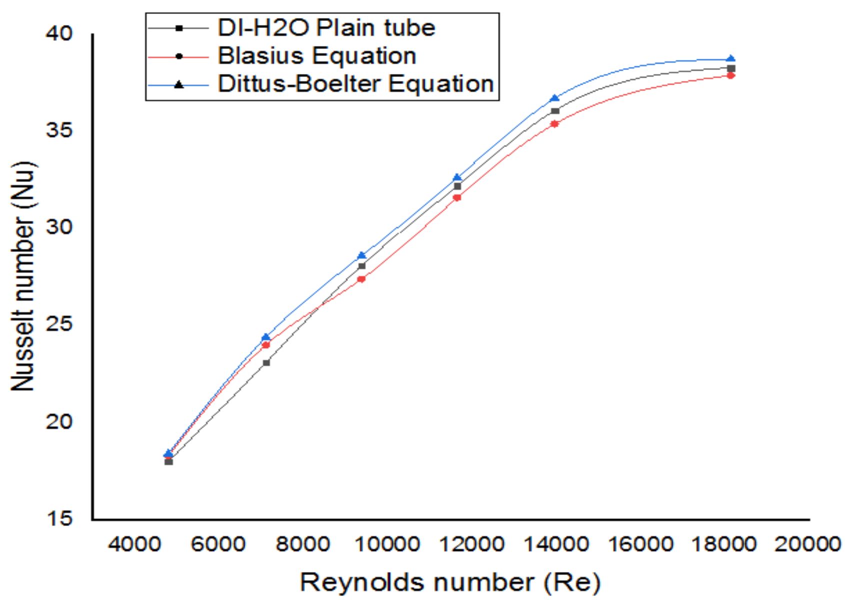

Figure 7: Heat transfer correlation of the plain tube Nusselt number.

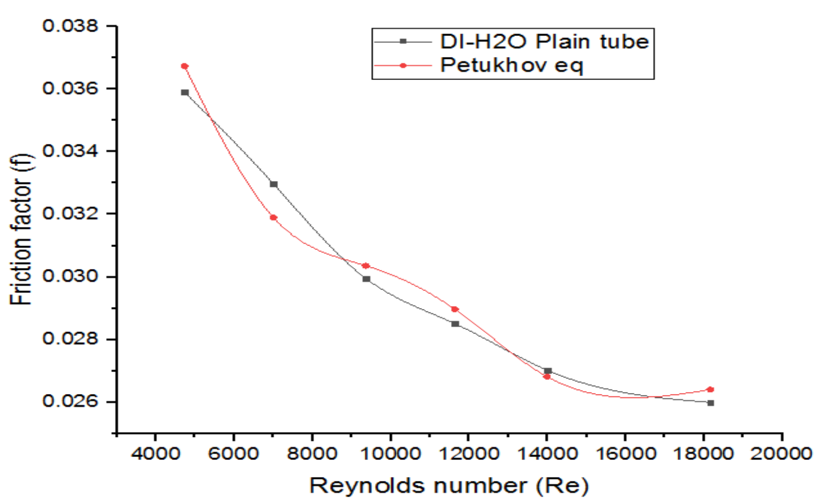

Figure 8: Friction factor verification for the plain tube

$$\lambda = \frac{1}{(0.79 \ln Re_D - 1.64)^2} \qquad (6)$$

3. Results and discussion

The effect of angular flat strip twisted shaped insert on heat transfer in the turbulent flow region, with various twist ratios and hybrid nanofluid (GO 30% + TiO_2 70%(Hybrid nanofluid ϕ = 0.5%))as the working fluid has been presented in this section. The friction characteristic of fluid flow in solar parabolic trough collector system is analyzed. Many researchers are interested with passive heat transfer enhancement technique due to the exclusion of the energy transfer. Different kinds of inserts and the modification of tube surfaces are the significant passive heat transfer enhancement methods. Twisted tape inserts with various geometrical variation attracted by many researchers. Experimental study of twisted tape inserts in parabolic trough collector is very less comparative to heat exchangers. The recent experimental works with the different inserts are listed in Table 2. Eiamsa-ard et al. studied the effect of twisted tape in PTC and observed increment in heat transfer up to 187%. Suri et al. reported that the Nusselt increases up to 5.92 times when perforated twisted tape used in PTC system. Jamal abad et al. reported 45% loss of heat transfer coefficient with porous media as passive insert which is inversely proportional to the study conducted by the Reddy et al.

Table 2: Comparision with other reported works

S.No	Author	Type of insert	Type of study	Findings
1	Eiamsa-ard etal.2010	Twin twisted tapes	Experimental	Re = 3700-21000 Heat transfer rates around 59.4 – 187 % , Friction factor = 6.37
2	Reddy et al. 2015	Porous disc	Experimental	Collector efficiencies 63.9% - 66.66%
3	Kalidasana et al 2016	Hinged blades	Experimental	Thermal efficiency of 69.33%
4	Jamal - Abad etal 2017	Porous media	Experimental	Overall loss coefficient decreases by 45%
5	Suri et al	Perforated Twisted tape	Experimental	Re = 5000-27000 Nu increased upto 5.92 times Friction factor increases 7.89 times

Concluded with 66.66% increases in collector efficiency with porous media as insert in the parabolic trough collector. Kalidasan et al. registered 69.33% increment in thermal efficiency with hinged blades as insert to parabolic trough collector (Table 3). Figure 9 shows the friction factor and Nusselt number development based on the Reynolds number for the plain tube. Our objective is to improve Nusselt number with the negligible effect of friction factor. Figure 10 shows the influence of inserts with the surface temperature with respect to the thermocouple position. The K type thermocouples are inserted in five different positions. The positions are evenly distributed to minimize the calculation error. The graphs clearly exhibit the effect of inserts in the surface temperature. All the inserts shows better result when compared to plain tube invariable with the twist ratio. The effect at the entrance region is more compared to the exit. The turbulence created by the inserts affects the surface temperature. Figure 11 shows the turbulence intensity developed by the inserts compared to plain tube and inserts. The graph clearly indicates

Table: 3: Probable errors involved in the measurements.

S.No	Measured Quantity (x)	Probable error (Δx)
1	Pressure drop (Δh)	Δ(Δh) = ± 0.0034m
2	Pipe diameter (d)	Δd = ± 0.00002 m
3	Mass flow rate (m)	Δm = ± 7.01 X 10^{-5} kg/s
4	Inlet temperature (T_{in})	ΔT_{in} = ± 0.1°C
5	Outlet temperature (T_{out})	ΔT_{out} = ± 0.1°C
6	Wall temperature (T_w)	ΔT_w = ± 0.1°C
7	Pyrheliometer	± 2%
8	Anemometer	±0.1 m/sec
9	Thermocouple (Type K)	± 1°C

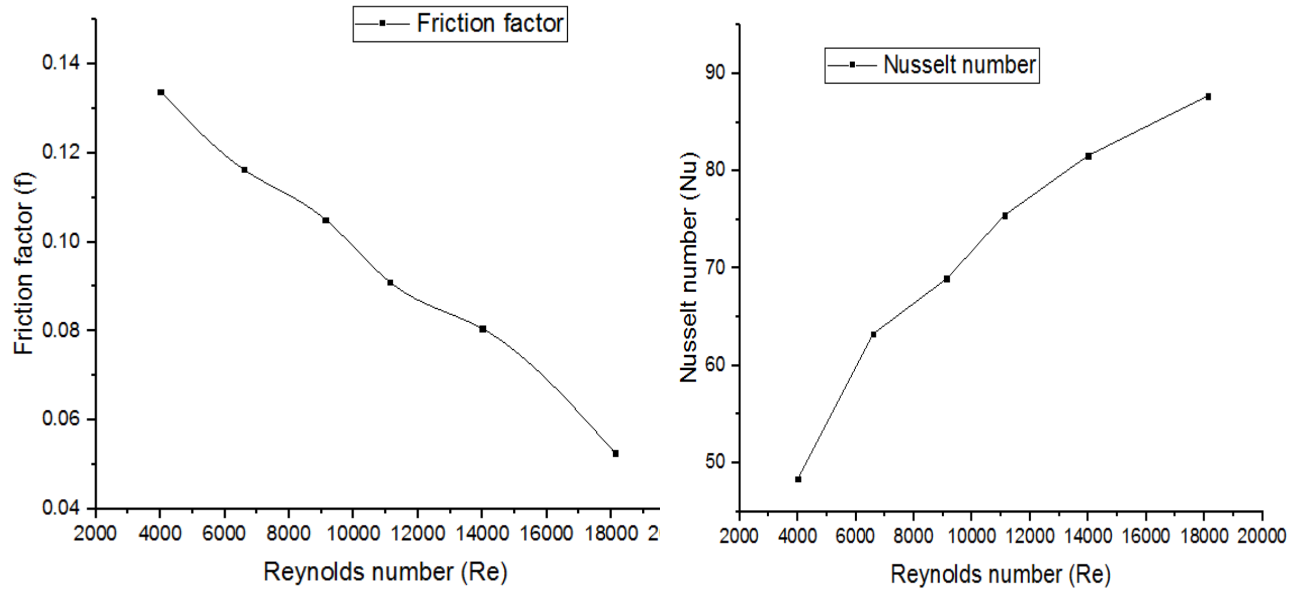

Figure 9: Effect of Reynolds number on friction factor and Nusselt number

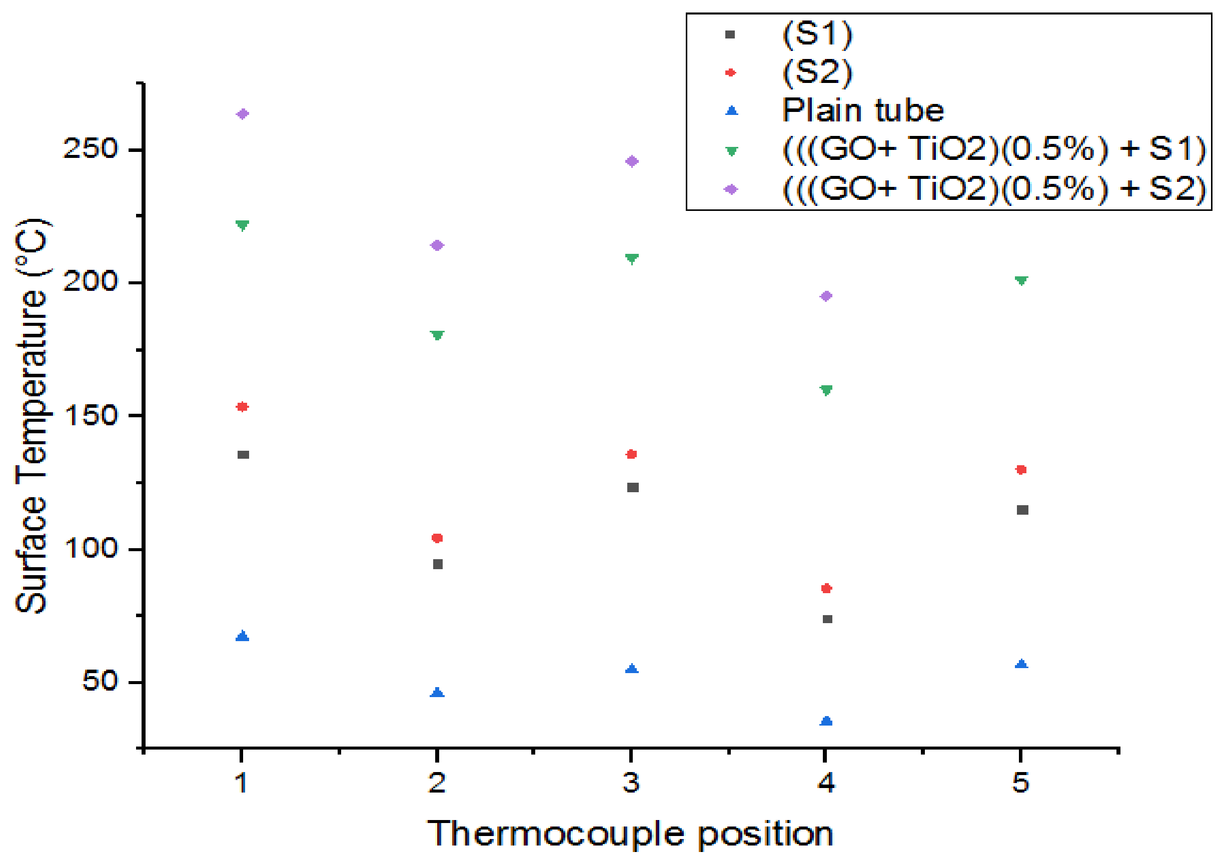

Figure 10: Surface temperature vs Thermocouple position

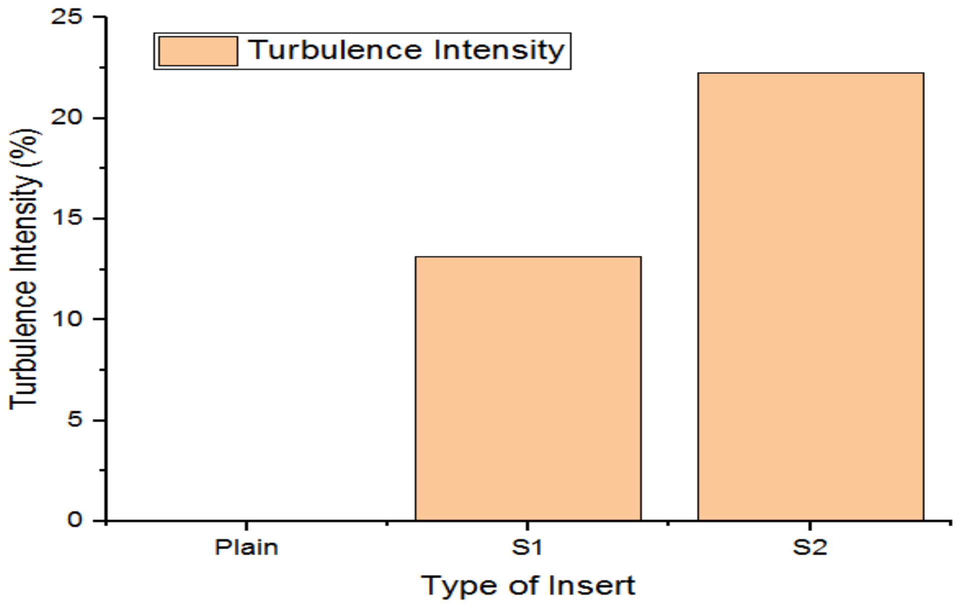

Figure 11: Turbulence intensity vs type of insert

The growth of turbulence intensity confirms the presence of inserts and the turbulence Intensity was observed in all cases. Figure 12 indicates the influence of Reynolds number on Nusselt number for plain tube absorber, angular strips inserts of various twist ratios 4 and 5.22 in the turbulent region. It clearly shows that for all combinations of the absorber with insert, the Reynolds number is directly proportional to the Nusselt number. Moreover, the increase in Reynolds number induces turbulence in addition to the swirl effect created by the twist magnifying the degree of heat transfer with DI-H_2O & Hybrid nanofluid (GO 30% + TiO_2 70%(ϕ = 0.5%)). Figure 13 shows that by increasing the twist ratio, the swirl effect weakens in the fluid flow, thus minimizing the heat transfer rate. The heat enhancement is higher with smaller twist ratio angular strip insert, because of the periodic change in flow which strengthens the intensity of swirl generation. The friction factor of the absorber tube of any combination decreases with increasing Reynolds number. According to Figure 13, it clearly shows that the friction factor is more in angular strip insert fitted absorber tube than in the plain absorber tube due to the change in the wetted surface area.

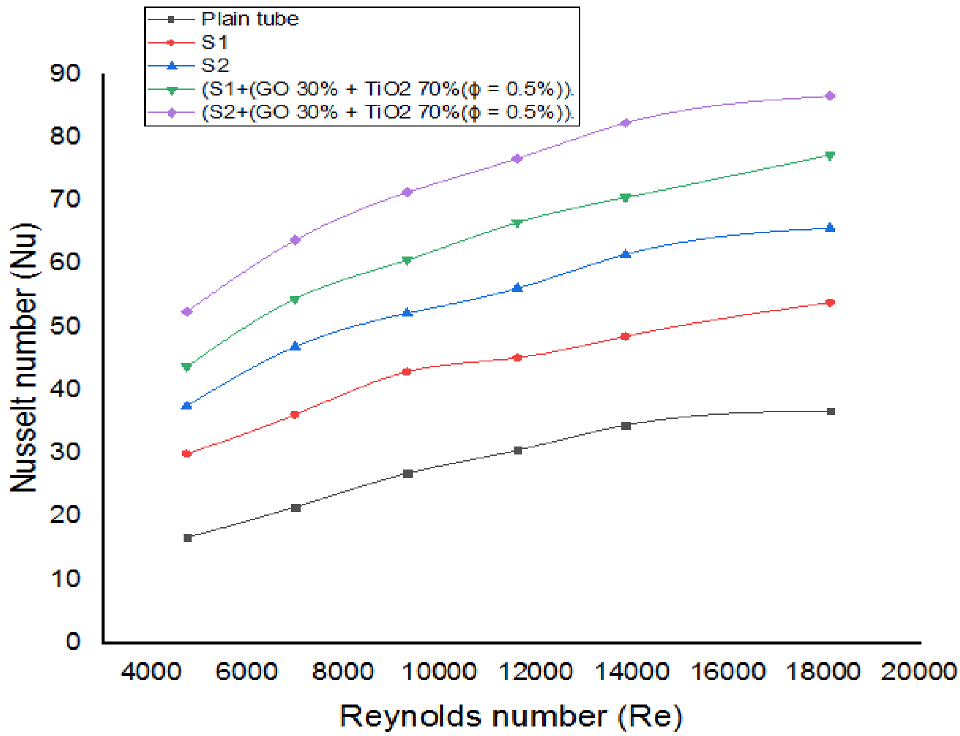

Figure 12. Comparison of heat transfer enhancement of various twist ratios of plain and angular twisted strips with plain tube absorber.

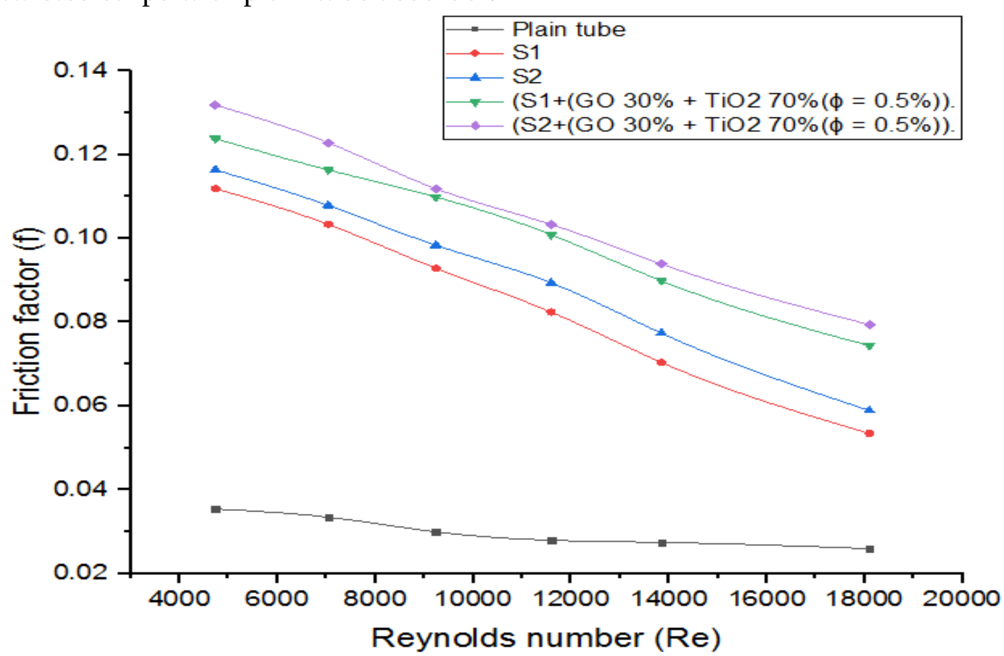

Figure 13: Comparison of friction factor of various twisted ratios plain and angular twisted strips of absorber

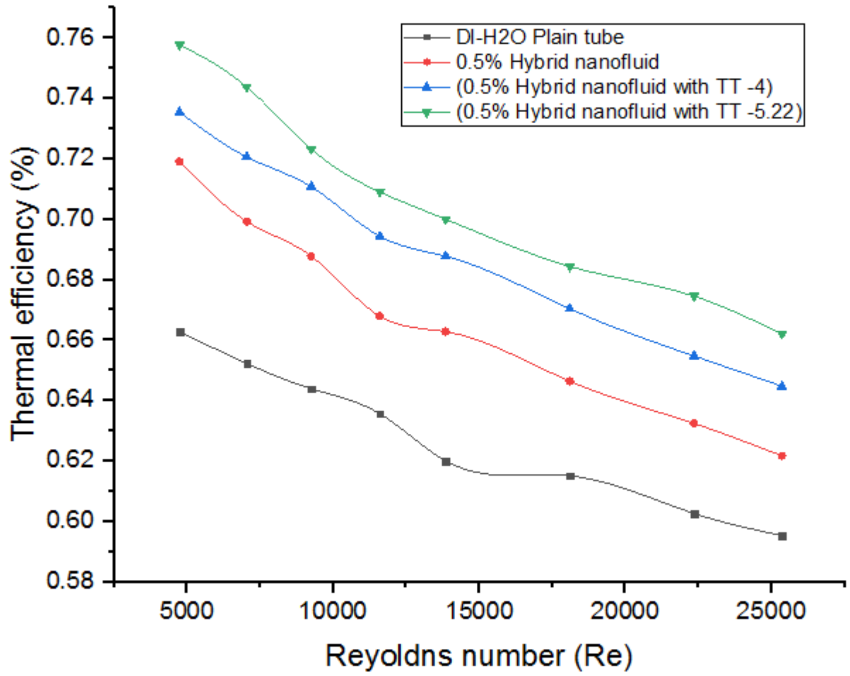

Figure 14: Variations of thermal efficiency with hybrid nanofluid of different twisted strips

Friction factor is high in angular strip insert with small twist ratio, due to the vortex flow generated by wet surface area and the periodic change in the flow direction. In this work, the angular strip insert with twist ratio 4 & 5.22 is designed and fabricated. The experimental results examined the heat transfer and pressure drop characteristics of this innovative inserts. Based on the recent review conducted by Manikandan et al. (Manikandan, Iniyanb, and Goic 2019) angular strip insert is not found in the literature. Among other inserts, the numerical study is reported more than the experimental study in the case of passive insert for heat transfer enhancement. Figure 13 shows the performance comparison with the negative effect of increase in friction factor. Newly fabricated angular twisted strip inserts shows the lower value of friction factor compare to others. Figure 14 shows the effect of Reynolds number on the thermal efficiency of the hybrid nanofluid of volume ϕ=0.5% with different angular twisted tape inserts. In a sense, thermal efficiency is a measure of how much solar radiation benefits the system. It is observed that thermal efficiency decreases due to the increment in Reynolds number. The reason for this can be interpreted as the increment of pumping power with the growth of the Reynolds number. The uncertainty analysis of the friction factor, pressure drop, Reynolds number and Nusselt number are calculated by the following equations.

$$\frac{\Delta f}{f} = \left[\left(\frac{\Delta(\Delta P)}{\Delta P}\right)^2 + \left(\frac{\Delta L}{L}\right)^2 + \left(\frac{3\Delta d}{d}\right)^2 + \left(\frac{2\Delta Re}{Re}\right)^2\right]^{0.5} \quad (7)$$

$$\frac{\Delta(\Delta P)}{\Delta P} = \frac{\Delta(\Delta h)}{h} \quad (8)$$

$$\frac{\Delta Re}{Re} = \left[\left(\frac{\Delta m}{m}\right)^2 + \left(\frac{\Delta d}{d}\right)^2\right]^{0.5} \quad (9)$$

$$\frac{\Delta Nu}{Nu} = \left[\left(\frac{\Delta V}{V}\right)^2 + \left(\frac{\Delta I}{I}\right)^2 + \left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta T_w}{T_w}\right)^2 + \left(\frac{\Delta T_f}{T_f}\right)^2\right]^{0.5} \quad (10)$$

The measured experimental values are used to find the above-mentioned parameters and the equation from 6 to 10 is used for uncertainty analysis. These parameters plays an important role to find the heat transfer characteristic. The maximum uncertainty values are the friction factor; pressure drop, Reynolds number and Nusselt number are 0.98%, 1.8%, 1.2% and 3.83%, respectively. All essential safety measures were considered during experiment to ovoid the instrumental error. The temperature and pressure measurement devices are calibrated carefully based on the manufacturers specification before conducting the test. The error values are based on the least counts and the sensitivity of the measuring instruments.

4. Conclusion

In the present study, flat angular strips have been taken with various twist ratios of 4 and 5.22 and found the Nusselt number and friction factor of a parabolic trough solar collector. Experimental results are well aligned with the theoretically predicted values of Nusselt number and friction factor. The observed increase in Nusselt number is due to the generation of swirl flow induced by the inserts. When compared to other inserts it has been found that the staggered flat angular strips inserts with a twist ratio of y/W = 5.22, namely S2, is more efficient. The study included a thorough experimental analysis of the consequences of flow in different angular twisted strip inserts for various configurations of absorber tube and their heat transfer properties and friction factor of fluid flow. When the rate of mass flow and solar intensity increases, there is enhanced heat transfer but there is reduction in fluid flow friction factor. Thus, from results we conclude that the friction factor and Nusselt number reached the higher limit for twist ratio of

5.22. The Nusselt number and friction factor declined when the twist ratio was increased due to the vigorous mixing of the fluid and swirl development in both axial and radial flow conditions. Thus large wetted surface area is due to improved swirl effect. The hybrid nanofluid has provided a great advantage in terms of convective heat transfer inside the PTC. It is noticed that thermal efficiency is enhanced by approximately 145% - 215% when using 0.5 vol% GO–TiO_2 hybrid nanofluid with angular twisted strip insert types instead of base fluid in plain tube. The thermal efficiency, which shows how much the system benefits from solar radiation, has increased significantly with the use of hybrid nanofluids. It is determined that the effect of 0.5 vol% GO–TiO_2 hybrid nanofluid has the highest thermal efficiency. Thermal efficiency tends to decrease with increasing pumping power at higher Reynolds numbers.

Nomenclature

Symbol	Description	Unit
A_o	Outer surface area	m^2
A_i	Inner surface area	m^2
C_p	Specific heat	J/kg-K
D_i	Inner diameter of tube	m
D_o	Outer diameter of tube	m
f	Friction factor	
k	Thermal conductivity	W/m-K
L	Length of test section	m
m	mass flow rate	kg/s
Nu	Nusselt number	
ΔP	Pressure drop	Nm^{-2}
ρ	Density	Kgm^{-3}
Y	Twist ratio	
Pr	Prandtl number	
Q	Heat transfer	W
Re	Reynolds number	
h	Heat transfer coefficient	W/m^2K
T_f	Fluid temperature	K
T_w	Wall Temperature	K
T_{in}	Inlet temperature	K
T_{out}	Outlet temperature	K
V	Velocity	m/s
U	Overall heat transfer coefficient	W/m^2K

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