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Experimental Investigations on Heat Transfer and Friction Factor of Silver Nanofliud in Absorber/Receiver of Parabolic Trough Collector with Twisted Tape Inserts

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Abstract

Heat Transfer and friction factor data at various volume concentrations for flow in absorber/Receiver and with and without twisted tape inserts is determined experimentally (with water and silver Nanofluid). The experiments are conducted in the Reynolds number range 500≤ Re<≤ 6000 with twisted tape inserts of different twist ratios in the range 0.577 ≤H/D/≤1.732. 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≤ Φ≤0.1 % volume *concentration of silver Nanofliud are higher compared to flow of water in absorber/receiver. The experiments show that Nussult Number, friction factor and enhancement efficiency are found to be 1.25 -2.10 times, 1.0 -1.75 times and 135%-205%, respectively, over, plain absorber/receiver of parabolic trough collector. Finally new generalized correlations function for predicting heat transfer and friction factor for turbulent flow of both water and Silver Nanofliud are proposed with tape inserts*

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Keywords: *Heat transfer enhancement, Friction factor, Twisted Tape inserts, Heat transfer performance, Nanofliud*

1.0 Introduction

In Industrial Applications, Heat transfer fluid such as water, mineral oil and Ethylene Glycol play an important role. The heat transfer Augmentation with flow of water and silver Nanofliud in Absorber of parabolic trough collector has been observed; the use of twisted tape inserts for further enhancement is the aim of this study. An extensive literature review of all types of enhancement technique with external inserts till the year 1985 has

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been discussed by Bergles [1]. Shaha and Dutta [2] were reported experimental data on twisted tape generated laminar swirl flow friction factor and Nussult number for a large Prandle number (205<Pr< 518) and observed that on the basis of constant pumping power short length twisted tape is good choice because in this case swirl generated by the twisted tape decays slowly down streams which increases the heat transfer coefficient with minimum pressure drop as compared to full length twisted tape. Manglik and Bergles [3] were considered twisted tape with twist ratio (3, 4.5 and 6.0) using water (3.5< Pr< 6.5) and proposed correlation for Nussult number and friction factor and reported physical description and enhancement mechanism. Loknath [4] was reported experimental data on water (240< Re< 2300, 2.6< Pr< 5.6) of laminar flow through horizontal tube under uniform heat flux condition and fitted with half length twisted tape. He found that on the basis of unit pumping power and unit pressure drop half length twisted tape was more efficient than full length tape. .Shaha and Chakraborty [5] were found that laminar flow of water (145<Re<1480, 4.5<Pr<5.5, tape ratio 1.92<y<5.0) and pressure drop characteristics in a circular tube fitted with regularly spaced, there was drastic reduction in pressure drop corresponding reduction in heat transfer. Thus it appears that on basis of constant pumping power a large number of turn may yield improved thermo hydraulic performance compared with single turn on twisted tape. In turbulent flow, the dominant thermal resistance is limited to thin viscous sub layer. Royds [6] was reported that a tube inserted with twisted tape performs better than plain tube and twisted tape with tight twist ratio provides better heat transfer at a cost of increase in pressure drop for low Prandle Number fluid. This was due to the small thickness of thermal boundary layer for low Prandle Number fluid and tighter twist ratio disturb entire thermal boundary layer thereby increasing heat transfer with increase in pressure drop. Date [7] was reported that friction and Nu for water flow in tube containing twisted tape deviate 30 percent than experiment with plain tube .Klaczak[8] found usefulness of short length twisted tape with water (1300< Re <8000) than full length twisted tape. Al-fahed et al [9] found that there was an optimum tape width depending upon twist ratio and Re for best thermodynamic characteristics for full length tape with water. Manglik and Bergles[10] were developed correlation for both laminar and turbulent flow (3.5< Pr <6.5) with tape but shows that correlation for laminar turbulent transition need to be developed with water. K.S.Reddy and K.Ravikumar[11] studied numerical simulation of energy efficient receiver for parabolic trough collector .Balbir Singh [12] had studied simulation of convective heat transfer coefficient in receiver tube of parabolic trough collector. K.S.Reddy and K.Ravikumar[13] studied thermal analysis of Solar Parabolic trough with Porous disc receiver.E.Belgen [14] had studied heat transfer in inclined rectangular receiver for concentrated solar radiations. L.Syam Sundar and K.V.Sharma[15] were studied turbulent heat transfer and friction factor of Al2o3 Nanofliud in circular tube with twisted tape inserts. Experimental data of heat transfer coefficient and friction factor for silver Nanofliud flow in absorber with twisted tape inserts is not available in the literature. The present study is undertaken to obtain experimental data with silver Nanofliud and to develop correlation function for Nussult Number and friction factor.

Nomenclature

c	Concentration ratio/constant
D	Diameter
η_i	Instantaneous efficiency /enhancement factor(%)
f	friction factor
h_{avg}	Average heat transfer coefficient (W/sq m)
q	Heat transferred (W)
Q	Energy
Re	Reynolds Number
Pr	Prandle Number
T_s	wall temperature (˚C)
T_b	Mean (bulk) temperature (˚C)
Nu	Nussult number
y	Twist ratio

Greek symbols

α	Absorbtivity/helix angle
Φ	constant /volume fraction
ρ_b	Density

Subscripts

avg	average
b	Bulk
exp	Experimental
emp	Emperical
nf	nanofliud
s	surface
sw	swirl

2.0 Experimental Analysis

2.1 Experimental Setup

In the present Research work the solar parabolic trough collector receiver tube with heat transfer fluids for various geometries (with and without inserts) is analyzed and compared with experimental results. Experimental set up consists of a test section, fluid circulation system, heating arrangement. The schematic diagram is as shown in fig 1.The plain absorber/receiver (test section) is made up of copper having inside diameter 20 mm and outside diameter 22 mm and 1500 mm in length. The tapes are made up of aluminium for different helix angle 30˚, 45˚and 60˚.These Twisted tape inserts are as shown in fig 1(a). The geometry dimension of tape inserts are as follows: length of each tap inserts is 1500 mm, width of each tape as 19 mm, thickness of tape: 1mm and 1.5mm.The twisted tape tapes are in turn inserted into the plain absorber/receiver. The plain absorber/receiver is insulated with asbestos tape to avoid heat loss to atmosphere. A band heater (of capacity 500 W each) is used as electrical heater which is wounded over plain absorber/receiver. The insulating material helps to reduce radial losses.

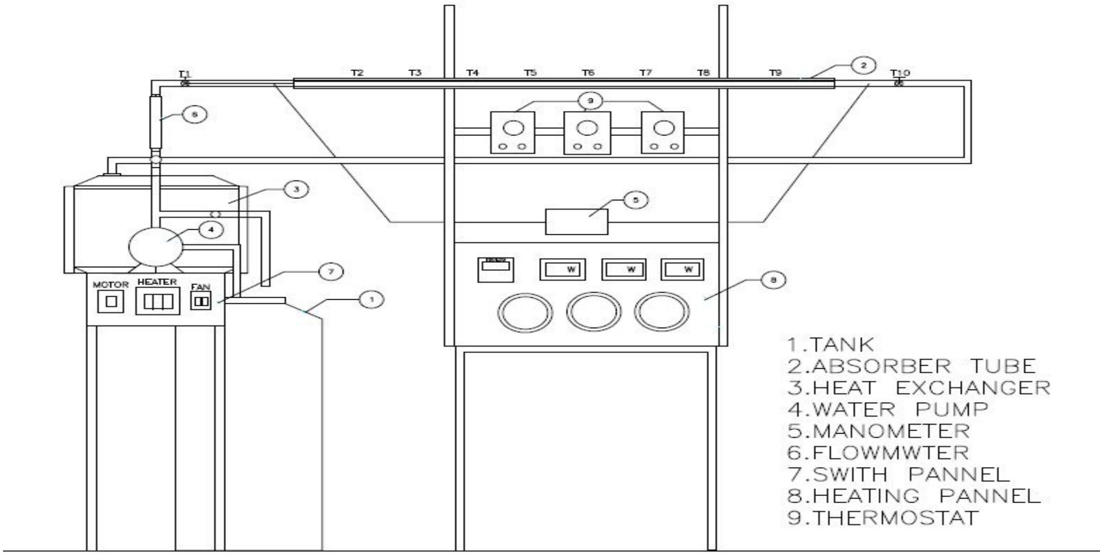

Fig. 1 Experimental Setup

2.2 Experimental Approach

The experimental set up consist of the testing receiver/absorber, Heat transfer fluid tank, pump, heater, temperature control system, Data acquisition systems, valves, pipes etc.The Heat transfer fluids(water and Nanofliud) is pumped through the flow meter into receiver /absorber and continued to be heated to the required experimental temperature. The receiver is heated by electrical heater (Solar radiation). The heat flux on testing receiver/absorber can be changed to the required value by changing the output of electrical heater. The Experimental setup is as shown in fig. 1. The analysis of Nu vs. Re, and other parameter for experimental data is carried out .As per experimental data a generalized correlation function for turbulent convective heat transfer and friction factor is investigated. The experimental procedure is as follows: At first the fluid pump is switched on and fluid is allowed to flow for few minutes. Then the electrical heater is switched on and allowed to heat for few minutes. The electrical power is adjusted with the help of Dimmer stat to the required value (uniform value). The flow rate of fluid through the test section is set to desired value and kept constant with the help of flow control valve. First the variations in wall temperature at all location are observed until constant value is attained at all eight locations. Then the outlet bulk temperature of fluid is monitored. The steady state condition is attained when outlet fluid temperature did not fluctuate over some duration of time. At the steady state condition thermocouple readings are monitored with help of selector switch/data logger and then recorded. The manometer reading are observed and taken from digital micro manometer. The fluid flow rate is changed with the help of flow control valve after each experimental run, hence changed the Reynolds number. Electrical power supply is kept constant/uniform for change of fluid flow rate. Different data are taken in similar way in each experimental run at steady state condition.

Fig. 1(a) Actual Photo of Twisted Tape

2.3 Uncertainty Analysis

A Detailed systematic Error analysis is made to estimate the error associated with experimentation by Beckwith .The uncertainties of Nussult number, Convective heat transfer coefficient and Heat rate are ± 8 %, ± 8 %, and ± 9 % respectively.

3.0 **Result Analysis**

3.1 Validation of the Experimental Results

First of all, the results obtained from experiments on heat transfer and friction factor characteristics in plain absorber are validated in terms of Nussult Number and friction factor with water. The Nussult Number and friction factor obtained from present plain absorber are compared with those from the proposed correlation of Dittus and Bolter for the Nussult number and proposed correlation by Moody for the friction factor respectively. The data obtained from the experiments for the plain absorber are reasonable agreement with the predicted results form the proposed correlation within the data range for the Nussult Number and friction factor respectively. The results revealed the accuracy of the experimental setup and used measurement technique. The correlation is obtained from the present plain absorber with tape inserts for Nussult number and friction factor with water and Silver Nanofliud.

3.2 Heat Transfer Performance with water and Silver Nanofliud

The effect of using twisted tape inserts in absorber /receiver on heat transfer characteristics is shown in fig. 2, fig 3 and fig. 4 .It shows that the Nussult Number obtained from absorber with inserts is higher than plain absorber. It is depicted that the effect of tape inserts increased at high Reynolds Number due to the intensive mixing of fluid which increased the heat transfer rate and high flow velocity. Thus the increase in Nussult number is low at smaller Reynolds Number while it became greater at the higher Reynolds Number. It could be attributed that the tape inserts caused swirl flow or secondary flow and pressure gradient being created along the radial direction. The heat transfer rate is also changed with the helix angle of the tape inserts. It is higher with minimum helix angle. The experimental data for comparison of Nussult Number and friction factor are not available in literature for Nanofliud with twisted tape inserts. Hence, the present data for flow of water and Nanofliud in absorber and with twisted tape inserts is subjected to regression and the correlation function is obtained valid for the range 500 ≤Re ≤6000, 0≤ Φ≤0.1 % and *0.577 ≤H/D/≤1.732* (Φ=0 for water, *H/D=0 for plain absorber)*

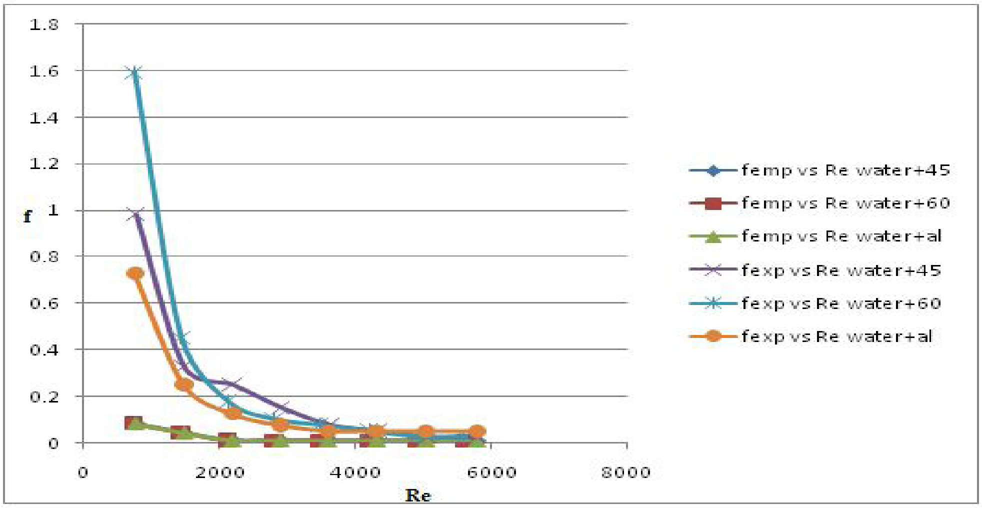

Fig. 2 Re Vs f (Water with Twisted Tape Inserts)

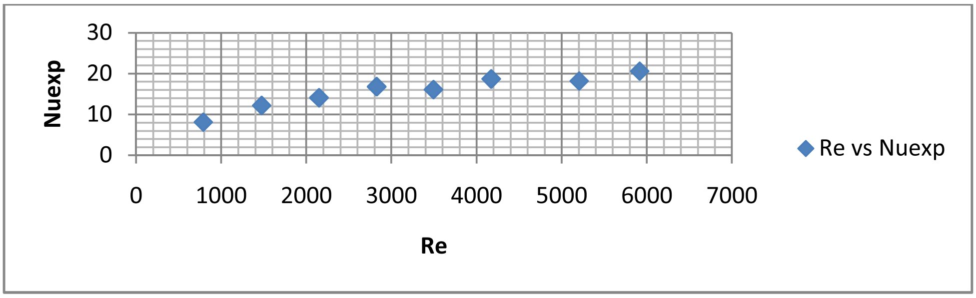

Fig. 3 Re Vs Nuexp (Water without Twisted Tape Inserts)

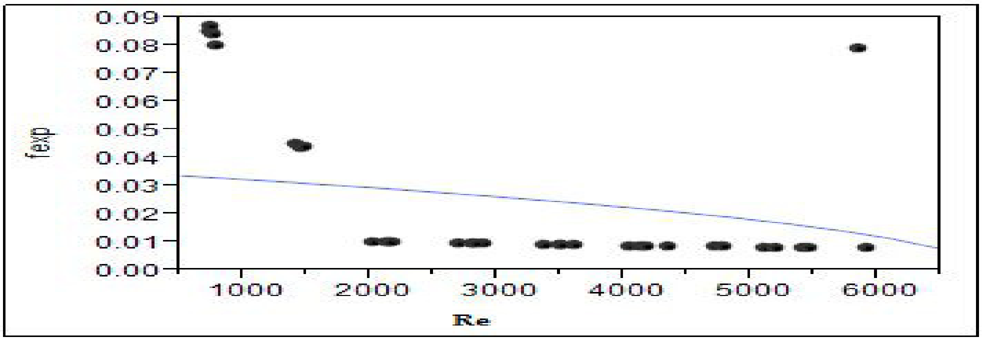

Fig. 3(a) Re Vs fexp (Water without Twisted Tape Inserts)

3.3 Flow Performance with water and Silver Nanofliud

The relationship between friction factor and Reynolds number for using twisted tape inserts are presented in fig 2 and fig. 5.It could be seen from fig 5 that the friction factor is in similar trend for both plain absorber and absorber with tape inserts. It could be clearly depicted from fig. 5 that friction factor continue decreased with increase in Reynolds number for plain absorber with different tape inserts. As expected from fig. 5, the friction factor obtained from the absorber with tape inserts is significantly higher than that of plain absorber. The friction factor for absorber with tape inserts is successfully higher than plain absorber because of larger contact surface areas and the dissipation of dynamic pressure of fluid at high viscosity loss near the absorber wall. Moreover, the pressure loss had a high possibility to occur by the interaction of pressure forces in the boundary layer. Also the flow velocity is larger since the motion is not in an axial direction. From experimental results, the friction factor is larger in absorber with tape inserts than plain absorber. The friction factor is also changed with helix angle of tape inserts. It could be shown from fig. 5 and fig. 6 that the friction factor is higher at lower helix angle than those of higher helix angle due to higher swirling flow or turbulence flow and long residence time in absorber. The higher friction factor is found with absorber with helix angle 30˚ than other tape inserts. From fig. 2, it could be noted that pumping power from tape inserts decreased at low Reynolds Number due to weak swirling flow but increased significantly at higher value of Reynolds Number. It is shown from fig. 5 that the required pumping power for the absorber with tape inserts is higher than that of plain absorber at the comparable Reynolds Number .The variation of efficiency with difference in temperature is as shown in fig 7. The relationship between friction factor and Reynolds number and Nussult Number with Reynolds Number using twisted tape inserts with Nanofliud are presented in fig 8 and fig 9 respectively.

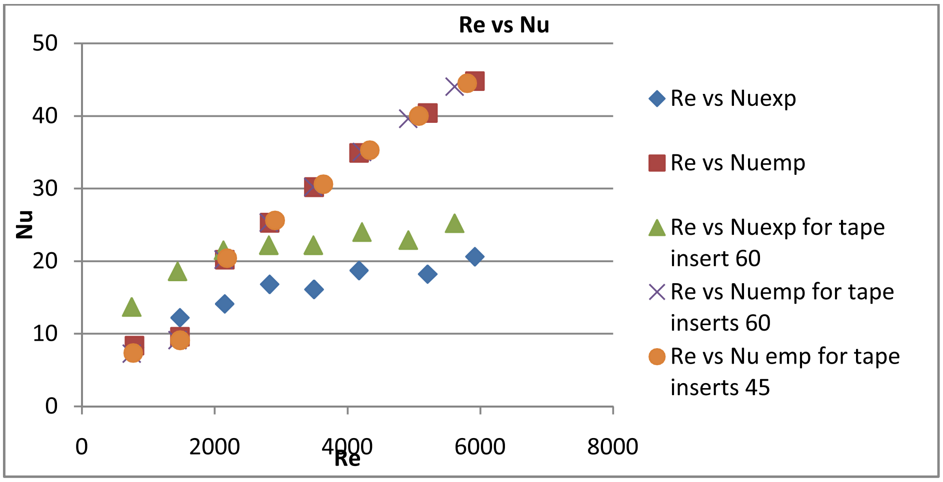

Fig. 4 Re Vs Nu (Water with Twisted Tape Inserts)

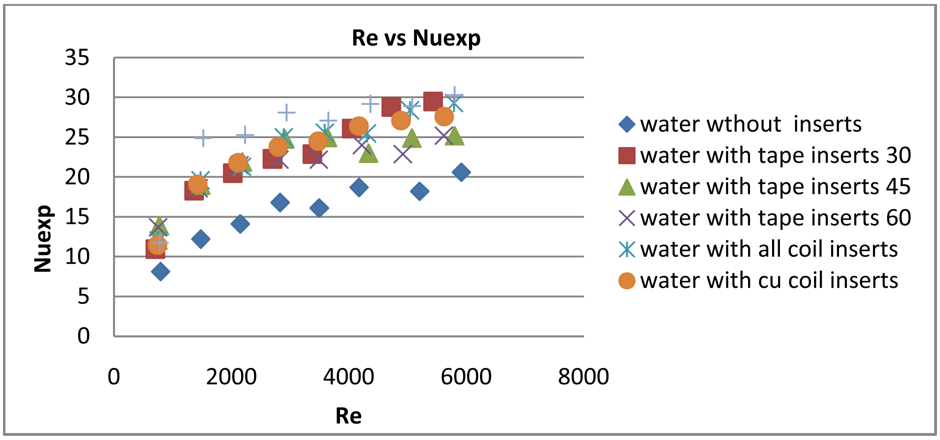

Fig. 5 Re Vs Nuexp (Water with Twisted Tape Inserts)

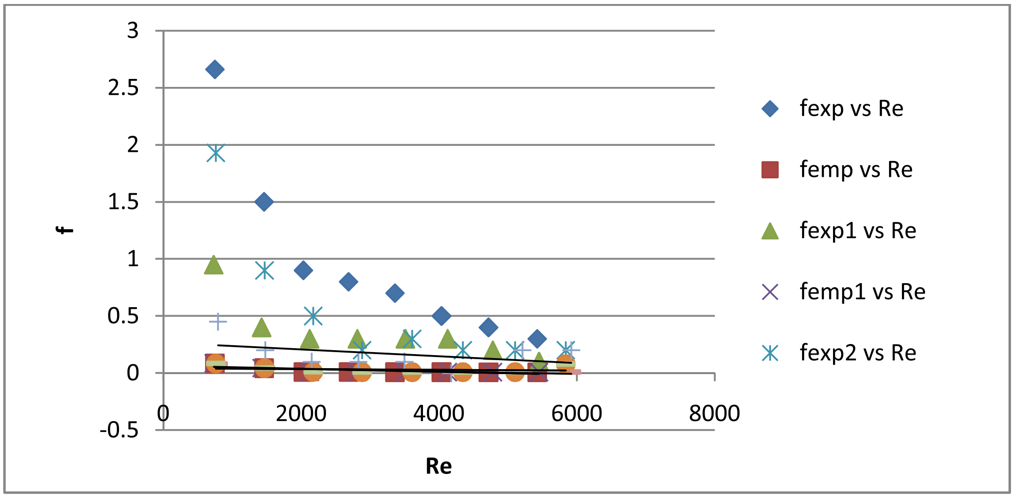

Fig. 6 Re Vs f (Water with Twisted Tape Inserts)

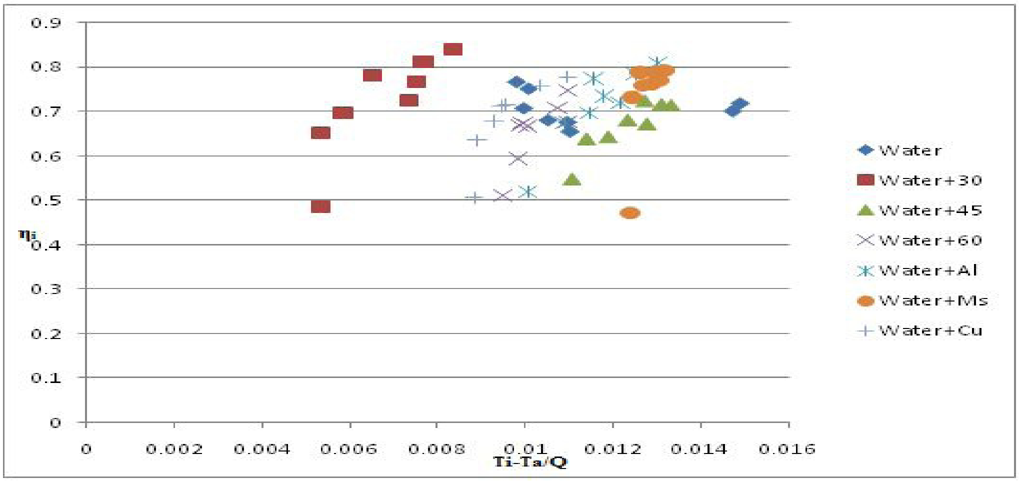

Fig. 7 Efficiency (η_i) Vs (Ti-Ta)/Q

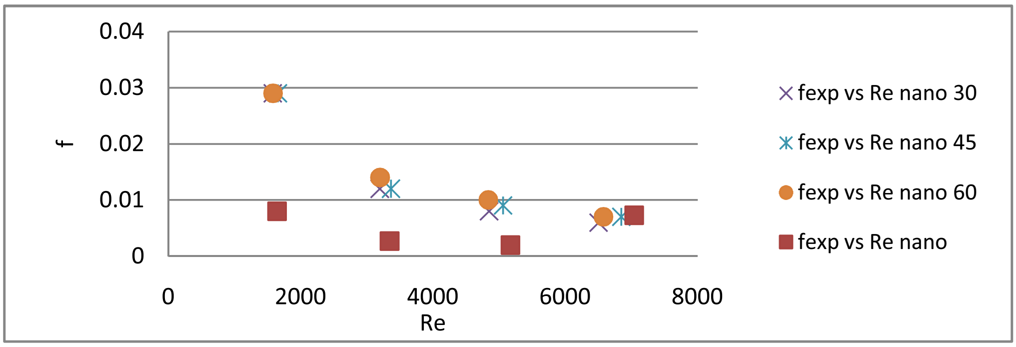

Fig. 8 Re Vs f (Silver Nanofliud with Twisted Tape Inserts)

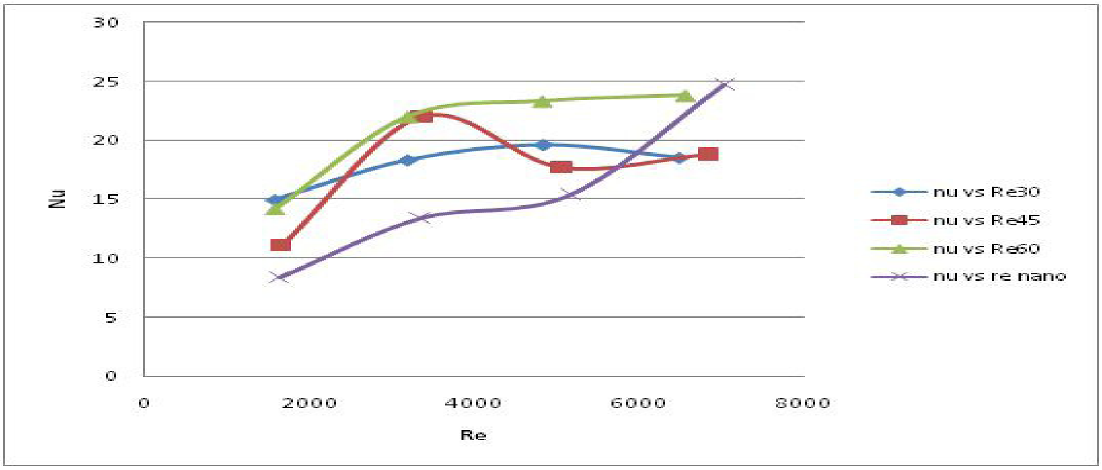

Fig. 9 Re Vs Nu (Silver Nanofliud with Twisted Tape Inserts)

3.4 Prediction of Turbulent Convective correlations function

In the present Research, three sets of data (3x8=24 runs) are generated carefully for each tape insert. From fig 4, fig 5, Fig 8 and fig 9, it is evidenced that the Nussult Number and friction factor are function of Reynolds Number. This might be correlated as:

$N_u = C\, Re^{m} P_r^{n}$ (1)

$f = C_1 Re^{m1}$ (2)

3 .5 Performance Estimation

Several performance criteria to estimate thermo hydraulic performance of the enhancement technique have been proposed by Bergle et al [3] ,the performance is evaluated at constant pumping power .The enhancement efficiency(η_i) at constant pumping power is the ratio convective heat transfer coefficient of absorber with tape inserts (h_a) to the plain absorber (h_p).

$\eta_i = h_a / h_p$ (3)

The heat transfer enhancement is provided with expense of increasing pressure drop caused by tape inserts.

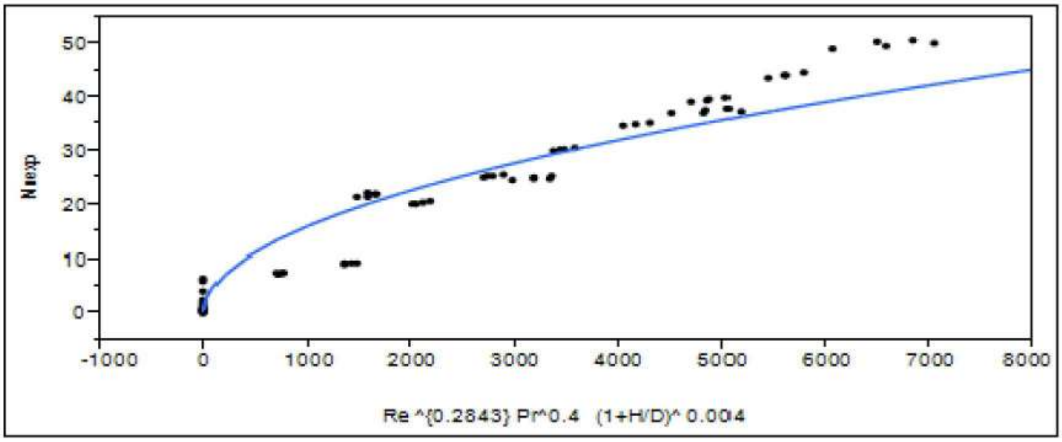

Fig. 10 Generalized functions (Water with Tape Inserts)

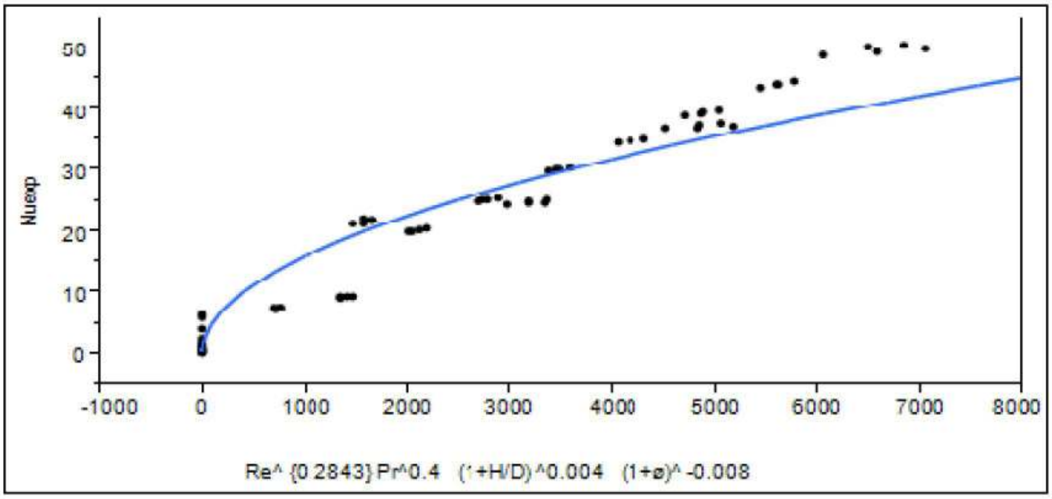

Fig. 11 Generalized functions (Nanofliud with Tape Inserts)

3.6 Experimental Analysis

We have investigated the influence of heat transfer fluid properties, receiver geometries (with and without inserts) and solar radiation (simulated heat flux) on overall heat collection. We have examined the influence of various geometrical parameters for heat flux condition with working fluids (water and Silver Nanofliud) and analyzed with experimental results. The balance between energy supplied by heating and energy absorbed by the flowing fluid is established using equation and for every set of data and experimental heat transfer coefficient is estimated. The experimental Nussult number of fully developed laminar flow and turbulent with water and Silver nanofliud are investigated. The experimental Nussult number of fully developed laminar and turbulent flow is shown in fig 4 .The reason for heat transfer enhancement is the effect of thermo physical properties comparatively are greater for Nanofliud . Experiments with twisted tape inserts are conducted with water and Silver nanofliud following the similar procedure for the flow in plain absorber without tape insets.The procedure is repeated with tapes of different ratio of 0.577, 1.0.and 1.732. The experimental Nussult number of water for flow in an absorber/receiver is presented in fig 4. However no literature is available for comparison with Silver nanofliud .From fig 4, it can be observed that higher heat transfer rate are obtained with twisted tape inserts than plain absorber/reciver.The experimental Nu of water in a plain absorber with different twist ratio of twisted tape inserts is plotted and accordingly regression equation is obtained. The experimental friction factor for water estimated from equation are compared and shown in fig 5 .A generalized regression equation is developed for estimation of Nussult number and friction factor of water and Nanofliud under fully developed turbulent flow condition. Fig. 10 and fig. 11 Shows Generalized correlation functions (for water and Silver nanofliud with twisted tape inserts)

4.0 Conclusion

An experimental study is conducted to investigate heat transfer enhancement in an absorber by means of twisted tape inserts (inserted in absorber/receiver of parabolic trough collector). The study reveals that tape inserts caused an increase of heat transfer at the cost of increase of pumping power. From the experimental results the following could be concluded:

i) The Nussult Number for absorber with tape inserts varied from 1.25 to 2.10 times in comparison that of plain absorber.

ii) The friction factor for the absorber with tape inserts varied from 1.0 to 1.75 0 times than plain absorber for the comparable Reynolds Number.

iii) The enhancement factor for the absorber with tape inserts varied from 135 %to 205 % at constant pumping power.

iv) There is no significant increase in pressure drop or friction factor for silver Nanofliud in comparison to water at the same twist ratio.

v) The following Generalized correlation function of Nussult number and friction factor are developed for prediction of heat transfer for identical cases based on results of present work. The proposed generalized correlation function for turbulent flow for water and Silver Nanofliud for flow in plain absorber and with twisted tape inserts are as follows:

For water with Twisted tape inserts:

$$N_u = 1.2546\, Re^{\{0.2843\}}\, P_r^{0.4}\, (1+H/D)^{0.004} \quad (4)$$

$$f = \{0.0841\}\, Re^{\{-0.2729\}}\, (1+H/D)^{-0.1701} \quad (5)$$

For Silver Nanofliud with Twisted tape inserts:

$$N_u = 1.3167\, Re^{\{0.2843\}}\, P_r^{0.4}\, (1+H/D)^{0.004}\, (1+\phi)^{-0.008} \quad (6)$$

$$f = 0.0841\, Re^{\{-0.2729\}}\, (1+H/D)^{-0.1701}\, (1+\phi)^{-0.5} \quad (7)$$

$$N_{usw} / N_u = 1.4058-(0.0280/\, y) \quad (8)$$

Valid For the range $500 \leq Re \leq 6000$, $0 \leq \Phi \leq 0.1$ % and *0.577 ≤H/D/≤1.732* (Φ=0 for water, *H/D=0 for plain absorber)*

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