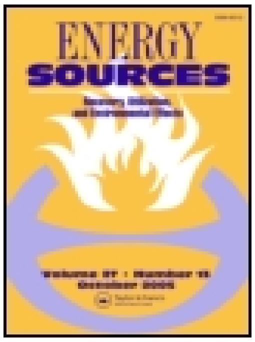

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ARTICLE



# Performance enhancement of solar collector using strip inserts and with water based $Al_2O_3$/DI water nanofluids

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**ABSTRACT**

The effectiveness of solar collector using conical strip inserts with $Al_2O_3$ /Deionized (DI) water nanofluids is presented in this paper. The experiments were conducted under various volume concentration levels from 0.15% to 0.35% with the interval of 0.05% of the nanofluids coupled with conical strip inserts in the Reynolds number ranging between 4000 and 15000. A higher heat transfer enhancement was observed for 0.35% volume concentration. The heat transfer rate increased by 7.82% at the lowest Reynolds number and 22.34% at the highest Reynolds number. The heat transfer increased further in the presence of conical inserts. It was observed that the heat transfer got enhanced by 28.59% at the lowest Reynolds number and 59.89% at the highest Reynolds number. The combination of nanofluids/Conical strip inserts performed better than nanofluids with no inserts.

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**KEYWORDS**
$Al_2O_3$; solar collector; strip inserts; nanofluid; friction factor; Nusselt number

## Introduction

The design of energy-efficient thermal system made up of low-cost materials is very important to fight against the current energy demand as well as the increasing cost of the material. Solar energy which is freely available renewable energy plays a significant role in meeting the current energy demand (Du et al. 2019). A solar collector is a device used to convert available solar heat into a useful form of energy. The working fluid in the Solar collector absorbs the solar heat and is transformed into the hot fluid which is used for water heating in the small-scale application. The conversion of radiation energy from the sun into useful heat is enhanced by changing the thermal conductivity of the working fluid and the turbulence promoters (Chaurasia and Sarviya 2019). Replacing working fluid with the nanofluids and using inserts as turbulence creator is an effective method to improve the efficiency of the solar collector (Logesh et al. 2018).

Choi (Choi and Eastman 2001) conducted an experiment at Argonne National Laboratory and observed a remarkable increase in the thermal conductivity when the base fluid was added with CNT. Xuan et al. (Xuan and Li 2003) experimentally verified that the heat transfer performance improved when the base fluid was replaced with Cu/water nanofluids. Ding et al. (Ding et al. 2006) reported that the maximum heat transfer enhancement was achieved by carbon nanotube under laminar flow conditions. Hwang et al. (Hwang, Jang, and Choi 2009) conducted experiment on $Al_2O_3$ nanofluids under various volume concentrations in plain tube. They observed that the heat transfer coefficient increased by 8% when the volume concentration was 0.3%. Wei Yu et al. (Yu et al. 2012) found that $Al_2O_3$/ethylene glycol mixture increased the heat transfer coefficient by about 57% and 106% when the volume concentration was 1% and 2%. The heat transfer increased when the volume concentration

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increased and it was limited to avoid the settlement of nanoparticle in the flow passage. The volume concentration of about 2% increased the performance up to 100% but the thermal cycle of the nanofluids decreased enormously. Based on the inference drawn from the literature survey, the increase in the volume percentage of nanoparticle has a significant effect on the stability of nanofluids (Arulprakasajothi et al. 2018a). The combined effect of inserts or turbulence promoters and nanofluids attracts more researchers to focus on compensating for the limitation of nanofluids (Arulprakasajothi et al. 2018b). Chandrasekar et al. (Chandrasekar, Suresh, and Chandra Bose 2012) conducted an experimental study to understand the combined effect of $Al_2O_3$/water with wire coil insert in a circular coil heat exchanger. The result showed that the nanofluids increased the Nusselt number by 12.24 with a volume concentration of 0.1% and the enchantment of Nusselt number was doubled when the same nanofluids were investigated with wire coil inserts. Jaffer et al. (Jafar et al. 2019) found the same kind of observation when $Al_2O_3$/water nanofluids was investigated with conical strip inserts. Arulprakasajothi et al. (Arulprakasajothi et al. 2019) reported on the effect of the conical strip in the tube heat exchanger. The same kind of related works are listed in Table 1 and the comparative results are shown in Figure 1.

Many researchers have conducted a separate experimental study with nanofluids and inserts to observe the individual role on the performance enhancement. But the combined study of nanofluids with inserts is very limited (Arulprakasajothi et al. 2018; Medhi et al. 2019; Zhu, Wu, and Yang 2011). The performance study of parabolic trough collector solar collector with different concentrations of Al2O3/water coupled with newly fabricated conical strip inserts has been focused on in the present work.

## Preparation of Nanofluids

$Al_2O_3$/water nanofluids were prepared by dispersing the $Al_2O_3$ nanoparticle into deionized water. The sonication process was used to get the uniform dispersion of nanoparticles. The sonication process was conducted for one day with a proper time interval to achieve good stability. The stability of nanoparticles was examined by observing the settlement of nanoparticles for certain time limits. There was no significant settlement after three months which meant that the nanofluids had good stability. The characterization of nanofluids was done by scanning electron microscope (SEM) and X-ray diffraction (XRD) they are shown in Figures 2a and 2b. The characterization result showed the surface morphology of the nanoparticle and the purchased $Al_2O_3$ nanoparticle were identified in a spherical shape.

**Table 1.** Relevant work.

| Reference | Nanofluid and base fluid | Tube insert | Outcome |
|---|---|---|---|
| (Sundar et al. 2018) | $Al_2O_3$ & Water | Twisted tape | Improved Nusselt no up to 30% |
| (Azmi et al. 2014) | $TiO_2$/Water-Ethylene | Twisted ape | Heat transfer increased by 13.85% |
| (Eiamsa-ard and Kiatkittipong 2014) | $TiO_2$-Water | Twisted ape | Heat transfer growth 40% and friction factor 23% |
| (Durga Prasad and Gupta 2016) | $Al_2O_3$-Water | Twisted ape | Growth in Nusselt number 34.24% as well as growth in pressure drop by 29% |
| (Mahmoudi et al. 2017) | $TiO_2$-Ethylene glycol water | Helical coil | Growth in heat transfer rate and pressure drop with nanoparticle and helical coil inserts 13.85% and 10.69%, respectively. |
| (Esmaeilzadeh et al. 2014) | $Al_2O_3$-Water | Twisted tape | Heat transfer coefficient enhancement upto 33.51% |
| (Nakhchi and Esfahani 2018) | Cu-Water | Twisted tape | Thermal performance increased up to 46.04% |

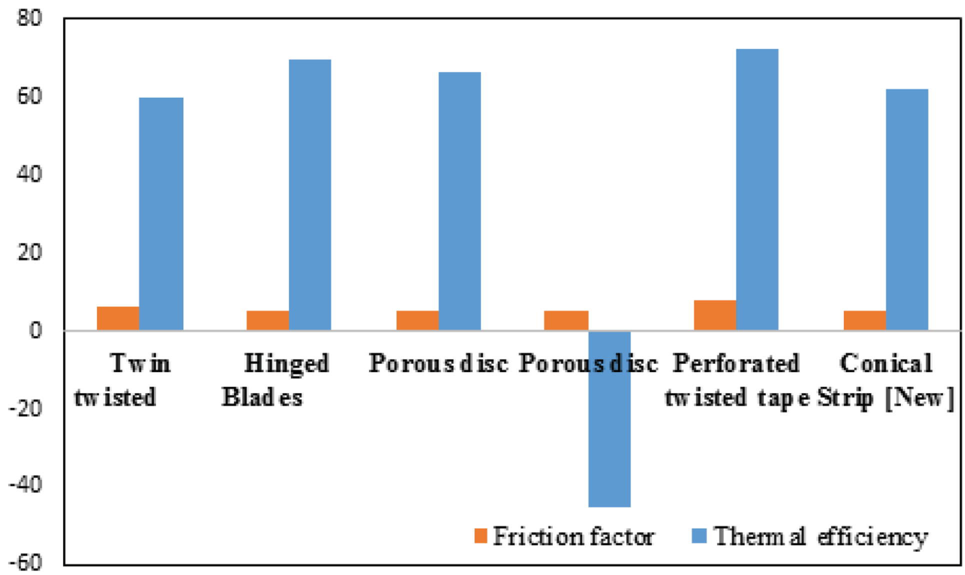



Figure 1. Comparison of results with other works.

## Experimental set-up

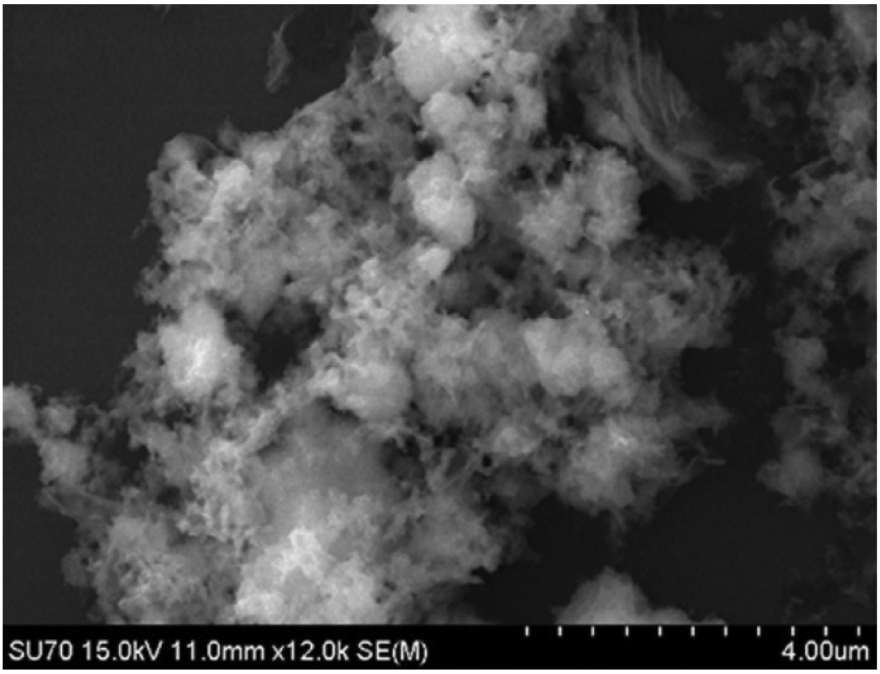
Figure 3 is the diagram of the experimental set-up of the parabolic trough collector. In a solar collector (forced convection type) the electric pump is used to maintain the flow. Two calibrated RTD PT 100 type temperature sensors have been used to measure various temperatures of fluid at the inlet and exit of the absorber with a digital temperature indicator of 0.1°C accuracy. A rotameter has been used to measure the fluid mass flow rate with an accuracy of 1%. Isothermal pressure drop was measured by using a U tube manometer between two ends of the tube section. An Eppley Pyrheliometer has been used to measure the solar radiation intensity and its precision can be controlled within 2%. The reflector surface was made of a highly solar reflective material of reflectance 0.974, a special black-painted copper tube of absorptance 0.97 was tested by a double beam. Table 2 lists the specifications of the solar collector. In the test section, we use a helically corrugated tube shown in Figure 4 and a copper plain tube having a length of 1000 mm, with inner and outer diameters being 15 mm and 17 mm, respectively. The tube geometric specifications are tabulated in Table 3.

Figure 5 shows the newly fabricated novel conical strip inserts. The strips are made up of copper sheets and distributed over the 1 mm diameter copper rod. The distribution of strips is made based on the aspect ratio. The number of strips attached to the rods varies with the aspect ratio.

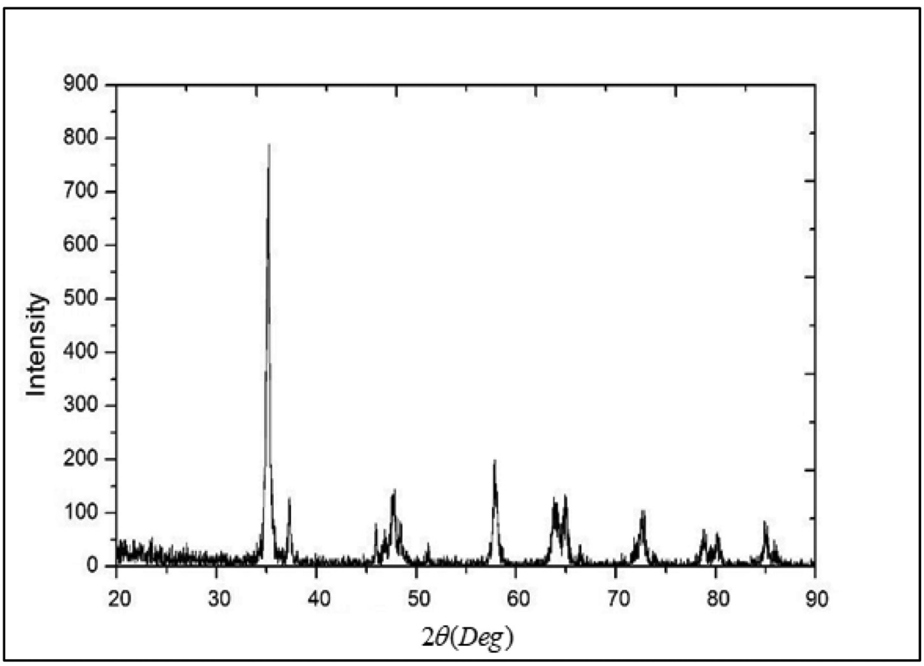
## Results and discussion

The experimental analysis initiated with deionized water has been performed to understand the effect of nanofluids and validation of experimental setup. The comparison of experimental values with well-shown Shah equation is shown in Figure 6 and the friction factor comparison is shown in Figure 7. There is a good agreement with equations 1(Shah 1975) and 2 for the Nusselt number and friction factor, respectively.

$$Nu = 1.953\left(\mathrm{Re}\ \mathrm{Pr}\frac{d}{x}\right)^{1/3} for\left(\mathrm{Re}\ \mathrm{Pr}\frac{d}{x}\right) \geq 33.33 \tag{1}$$




a) SEM image of Al2O3




b) XRD Analysis of Al2O3 nanoparticles

**Figure 2.** Characterization of nanofluids. (a) SEM image of $Al_2O_3$. (b) XRD Analysis of $Al_2O_3$ nanoparticles.

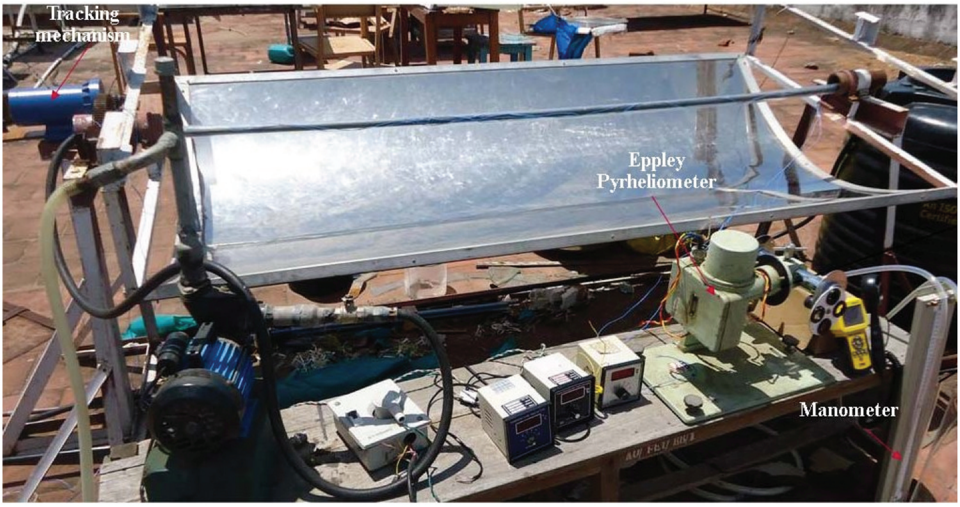



**Figure 3.** Experimental set-up.

**Table 2.** Specifications of solar collector.

| Length of Aperture (*L*) | 2 m |
|---|---|
| Width of aperture (*W*) | 1 m |
| Distance of focal point (*F*) | 0.25 m |
| Inner diameter of envelop cover ($D_{c,int}$) | 18 mm |
| Outer diameter of envelop cover ($D_{c,ext}$) | 22 mm |
| Concentration ratio (*C*) | 25.46 |
| Absorptance of the receiver tube ($\alpha$) | 0.97 |
| Transmittance of the receiver tube ($\tau$) | 0.8 |
| Tracking mechanism type | Electronic |

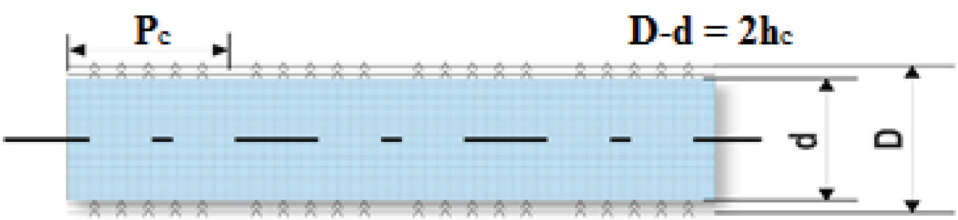



**Figure 4.** Schematic diagram of corrugated tube.

**Table 3.** Geometric specification.

| HCT no. | Corrugation height, hc (mm) | Corrugation pitch, Pc (mm) |
|---|---|---|
| 1 | 0.6 | 8 |
| 2 | 0.85 | 8 |
| 3 | 1 | 8 |
| 4 | 0.85 | 10 |
| 5 | 1 | 10 |
| 6 | 0.85 | 12 |
| 7 | 1 | 12 |

$$f = \frac{64}{\mathrm{Re}} \tag{2}$$

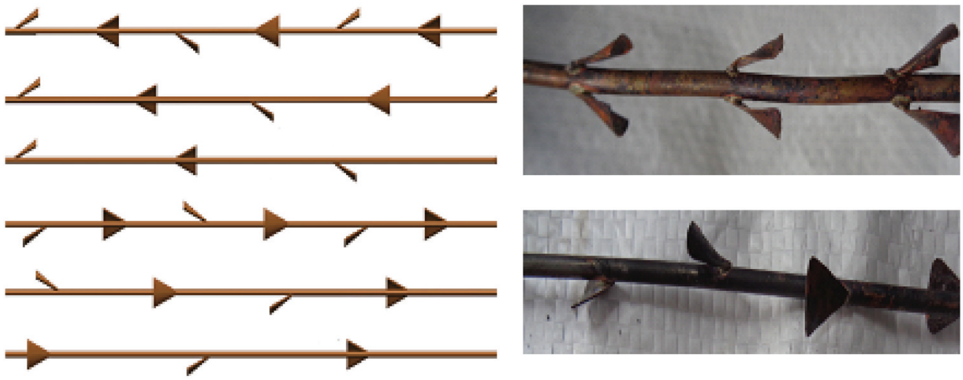


Figure 5. Schematic representation of conical rod inserts.

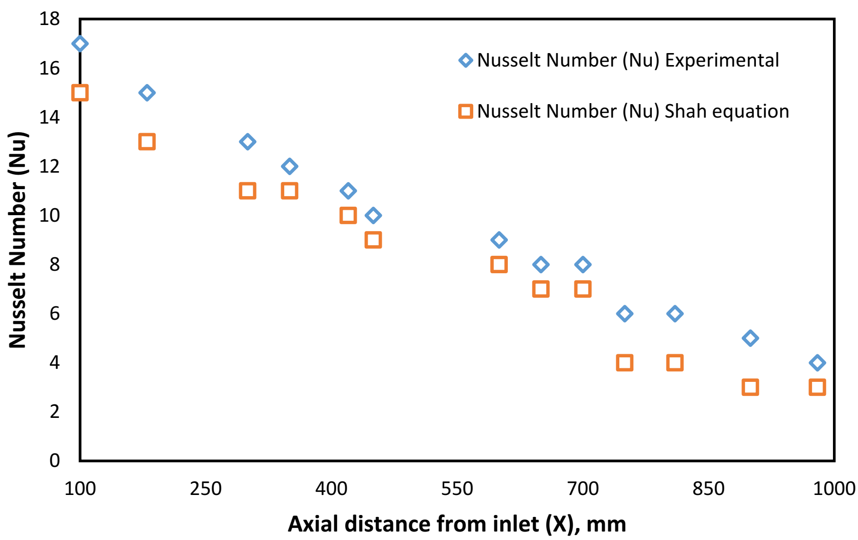



Figure 6. Variation of Nusselt number.

The experimental set-up was validated with the theoretical model before conducting the performance test. The Nusselt number and the friction factor variation with the theoretical equations are shown in Figures6 and 7. It shows a good agreement with equations 1 and 2 for the Nusselt number and friction factor, respectively. Figures 8 and 9 show the Nusselt number and friction factor study of the plain tube. The results show that the higher volume concentration of nanofluids gives better enhancement and further enhancement was achieved when it was coupled with conical strip inserts. The staggered-type conical strip inserts (CSI 1), the strips being evenly distributed on the rod, show the better result with higher Reynolds number and Non – staggered conical strip inserts (CSI 2) increase the Nusselt number compared with the other combination with lower Reynolds number. Nanofluids increase heat transfer performance due to its Brownian motion and increased thermal conductivity. The conical strip inserts create turbulence besides increasing the translational and rotational movement of the nanofluids at the molecular level which improves its thermal characteristics further. The friction factor effect is considered a negative effect and this effect increases with volume concentration. Figure 8 shows the significant effect of conical strip inserts on the nanofluids. The combination of insert and nanofluids decreases the friction factor when the Reynolds number increases. Aluminum dioxide

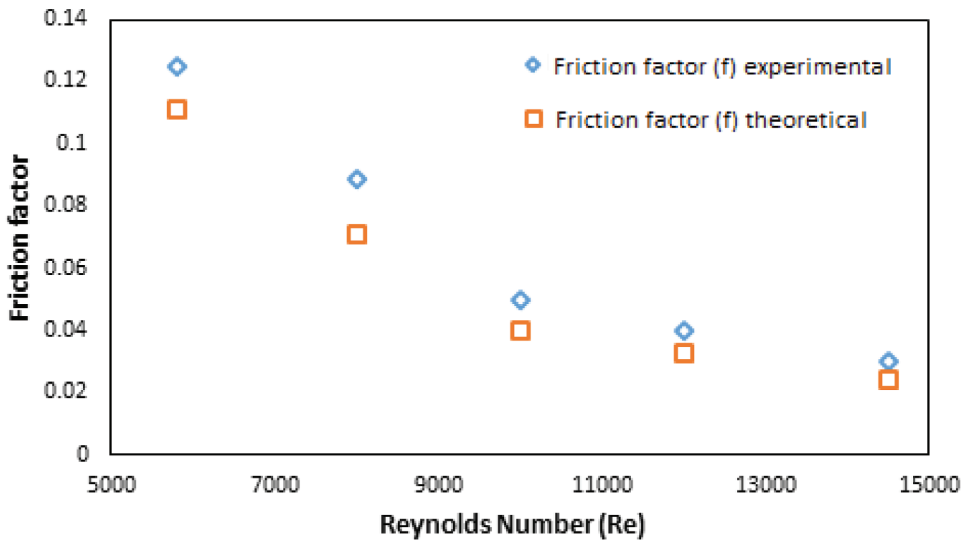



Figure 7. Friction factor comparison.

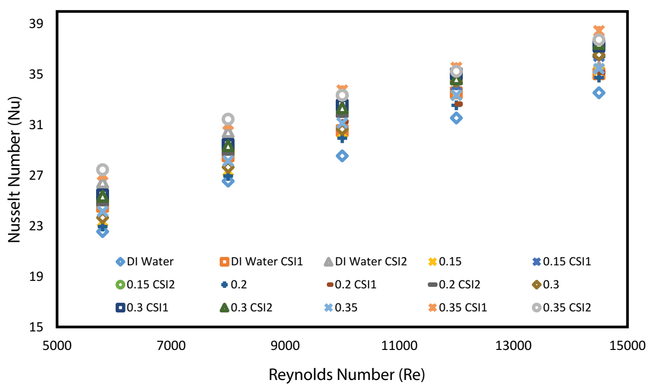



Figure 8. Nusselt Number study for plain tube.

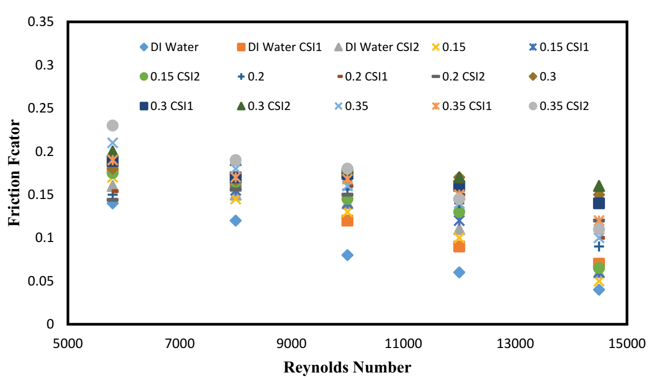



Figure 9. Friction factor study for plain tube.

nanoparticles restrict the development of boundary layer thickness and contain its growth which will facilitate performance enhancement (Balaji et al. 2018).

The insert promotes turbulence when it is coupled with nanofluids and boosts the boundary layer phenomena. The conical strip attached to the rod causes the secondary flow and the reduction of hydraulic diameter. The energy transfer between the particles increases due to irregular intermolecular agitation promoted by the inserts (Anbu, Venkatachalapathy, and Suresh 2017).The same experiment was conducted with a corrugated tube with different pitch and height. Figure 10(a-d) shows the Nusselt number for four different corrugated tubes. Figure 11(a-d) depicts the effect of the friction factor.

The self-cleaning behavior is the main advantage of using the corrugated tube. This behavior reduces the chance of fouling on the flow passage and increases the material life. The uneven flow passage increases uniform mixing between the nanoparticles with the base fluid and ensures maximum energy transfer. The corrugated tube with minimum height and pitch combination showed a higher Nusselt number with a higher Reynolds number. The higher volume concentration of nanofluids (0.35%) showed a better enhancement in the entire flow field independent of the Reynolds number variation. The staggered and non-staggered strips behaved the same manner when it was introduced in the corrugated tube. The friction loss was reduced in the higher Reynolds number region. Compared with the plain tube the loss is negligible with the corrugated tube. Figures 12 and 13 show the thermal performance factor for the plain tube and the corrugated tube with pitch 10 mm and height 1 mm, respectively. For the same flow conditions, the thermal performance rose with the insertion of conical strip inserts. Both staggered and non-staggered conical strips performed better. The thermal performance factor is the ratio between the changes in heat transfer rate to change in friction factor. The thermal performance factor was more than unity for all cases. Figure 13 shows the thermal performance factor for the corrugated tube. The maximum value was observed for higher volume concentration (0.35%) of nanofluids without any inserts. The experimental results showed that the addition inserts played a significant role in the plain tube rather than the corrugated tube.

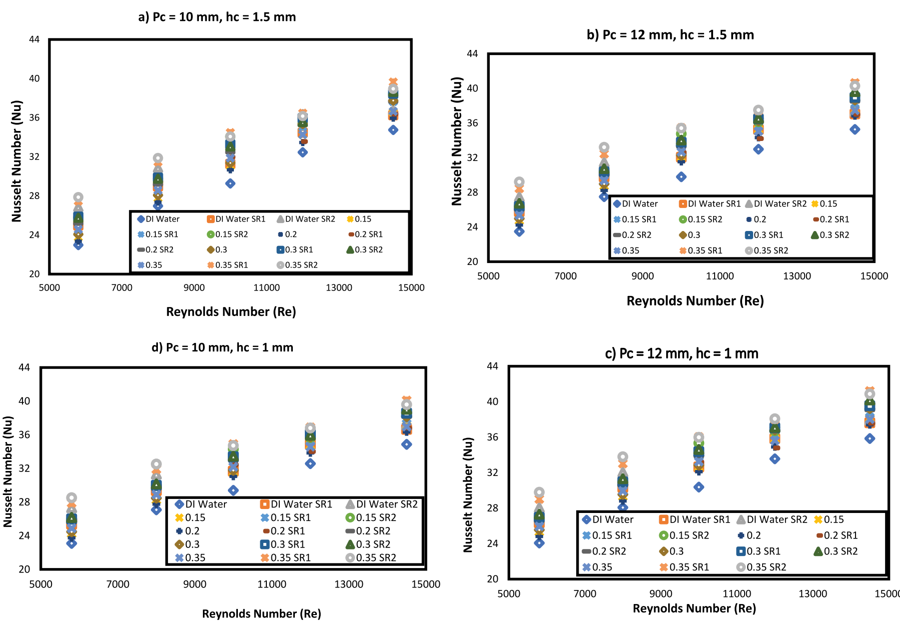



Figure 10. Nusselt Number study for corrugated tube.

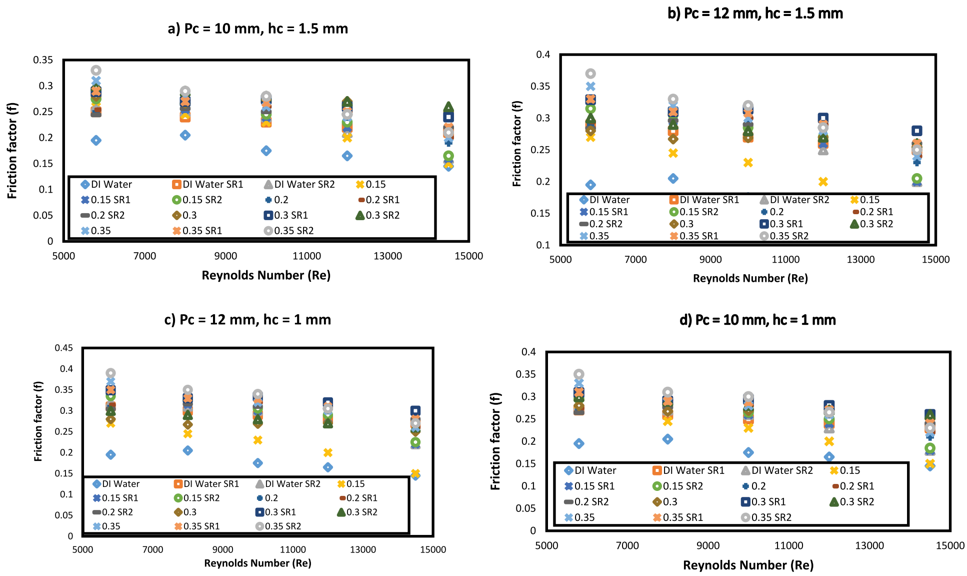



**Figure 11.** Friction factor study for corrugated tube.

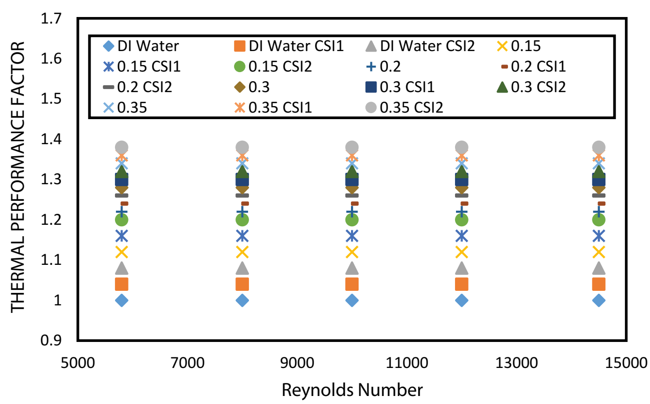



**Figure 12.** Thermal performance factor study for plain tube.

## Conclusion

The thermal performance on parabolic trough collector with water-based Aluminum dioxide nanofluids coupled with conical stir inserts was studied. The nanofluids were prepared with various volume concentrations and the inserts were newly fabricated. The thermal performance of the plain tube flow path was compared with the corrugated tube flow path. The experimental results led to the following conclusions:

The heat transfer improved with the increase in the volume concentration of the Aluminum dioxide nanoparticle with the base fluid. The enhancement was further improved with the addition of conical strip inserts. The maximum performance was achieved with a 0.35% volume concentration of nanofluids combined with a staggered conical strip at a higher Reynolds number and with a nonstaggered conical strip at a lower Reynolds number.

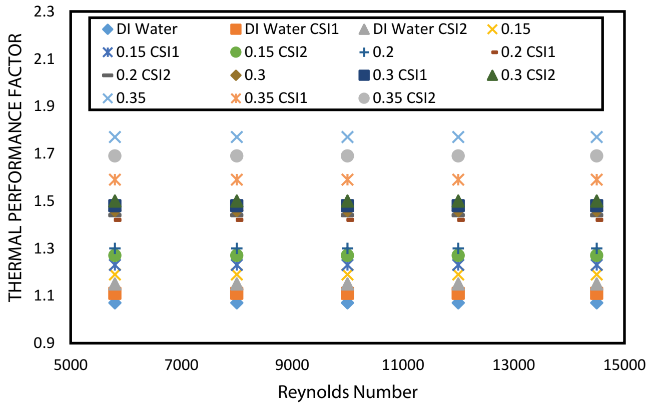



**Figure 13.** Thermal performance factor study for corrugated tube.

Water-based Aluminum dioxide nanofluids having 0.35% volume concentration improved the Nusselt number by 9.66% when it was coupled with a nonstaggered conical strip (CSI2) at the Reynolds number of the range 5000–9000. The same nanofluids having 0.35% volume concentration improved the Nusselt number by 11.42% when it was coupled with a staggered conical strip (CSI1) at the Reynolds number of the range 9000–15000.

The maximum value of Nusselt number (44) has been achieved with the corrugated tube of pitch 12 mm containing 0.35% volume concentration of nanofluids without any inserts. The experimental result showed that the addition of inserts played a substantial role in the plain tube rather than the corrugated tube.

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