IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 20, Issue 5 Ser. I (Sept. – October. 2023), PP 16-22
www.iosrjournals.org

Exploring Heat Transfer Enhancement In Double Pipe Heat Exchangers Using Circulating Twisted Tape Inserts And Nano-Fluids

Merugu Ajay Babu [1] Mohd. Mohinoddin[2] Narsimhulusanke[3]
[1]*Research Scholar University College Of Engineering Osmania University, Hyderabad.*
[2]*Professor Mechanical Engineering Department Muffakham Jah College Of Engineering & Technology,Hyderabad.*
[3]*Professor Mechanical Engineering Departmentuniversity College Of Engineering Osmania University, Hyderabad.*

Abstract
In today's era of industrialization, heat exchangers play a crucial role in energy consumption and are extensively used in mechanical and chemical industries. To minimize energy consumption and enhance thermal conductivity, industries are recognizing the benefits of using Nanofluids and nanoparticles in heat exchangers instead of conventional fluids.The double-pipe heat exchanger is a common type, where one fluid flows inside a pipe, and another fluid flows between that pipe and another surrounding pipe. The flow in a double-pipe heat exchanger can be either co-current or counter-current, and various factors such as inlet temperatures, flow rates, fluid properties, and composition can affect the amount of heat transferred.Current research is primarily focused on investigating of the heat flow rate and over all heat transfer coefficient of double-pipe heat exchangers using twisted tape inserts under different flow conditions. Twisted tape inserts are used to promote heat transfer, and Al_2O_3 and TiO_2 Nanofluids are recommended as the working fluids instead of conventional water-based liquids. In particular, nanoparticles with twisted tapes inserts are studied using experimental approaches under different flow conditions.

Keywords: *Al_2O_3, TiO_2, Heat exchanger, Nanofluid.*

Date of Submission: 01-09-2023 Date of Acceptance: 11-09-2023

I. Introduction

Heat exchangers are vital in industries like air conditioning, power generation, and petrochemicals. Researchers have explored three heat transfer methods: active, passive, and hybrid. Passive techniques [8], requiring no external power, include rough surfaces, extended surfaces, swirl flow devices, coiled tubes, additives for liquids, and surface tension devices. Twisted tapes [7], a type of turbulator, are notable among these methods. They enhance heat transfer by inducing secondary flow, increasing fluid velocity, and altering the boundary layer near tube surfaces. Twisted tapes [11] have proven cost-effective in various industrial applications.

In recent years, Nanofluids, combining traditional heat transfer fluids with solid nanoparticles measuring 1 to 50 nanometers, have emerged. They offer advantages like high heat transfer rates, low flow resistance, and improved thermal uniformity. Numerous studies show that higher nanoparticle concentrations increase thermal conductivity and heat transfer rates. For example, Al_2O_3 nanoparticles in a turbulent double pipe heat exchanger [9], observing improved heat transfer coefficients at higher concentrations. Wongwises et al. [1] pioneered adding nanoscale solid particles to base fluids, enhancing thermal conductivity. Eiamsa-Ardet al. [2] investigated CuO/water Nanofluids and corrugated tubes with twisted tapes, noting the impact of tape configuration on thermal performance. In another study, T. Mohankumar et al. [3] used Al_2O_3 water-based Nanofluids with a twisted tape in a corrugated tube, achieving a 2.89% increase in heat flow compared to plain water. These findings suggest that Nanofluids have potential in enhancing heat exchanger performance and other heat transfer systems.

II. Mathematical Formulation.

The heat transfer rate from the hot fluid, which includes nanoparticles like Al2O3 and TiO_2 ,was determined [12] using the following equation:

$$Q_h = m_{hf} * C_{phf} \, (T_{ho} - T_{hi})$$

The heat transfer rate in the cooling water was computed using the subsequent equation:

$Q_c = m_{cf} * C_{pcf} \ (T_{co}\text{-}T_{ci})$

In the course of this investigation, it became evident that the heat supplied by the hot Nanofluid exceeded the heat received by roughly 3%. This variation in heat transfer can be attributed to the impact of convection and radiation heat losses along the experimental section. Consequently, these factors significantly influenced the overall average heat transfer rate.

$Q_{avg} = \frac{Q_h + Q_c}{2}$

The flow pattern of a fluid can be described by the Reynolds number, which is calculated using the flow rate at the test tube's entrance. In situations involving purely viscous non-Newtonian fluids, the Reynolds number (Re) is defined as follows:

$\mathrm{Re} = \frac{\rho \cdot \vartheta d}{\mu}$

Friction factor of nano fluids is calculated by fallowing equation

$f_h = \frac{\Delta P_h}{(l/d) \rho_h (\frac{\vartheta_h^2}{2})}$

Over all heat transfer rate

Q_{ovr}=UAΔT

$$\Delta T = \frac{(T_{h\,out} - T_{c\,in}) - (T_{h\,in} - T_{c\,out})}{\ln \frac{(T_{h\,out} - T_{c\,in})}{(T_{h\,in} - T_{c\,out})}}$$

III. Experimentation.

The study aimed to experimentally explore the heat transfer properties of Nanofluids using a dedicated setup, as depicted in Fig 3.1. This setup consisted of various components, including a test section, storage containers for the working fluids, a heating and cooling system, and thermometers, flow measurement devices like a rotameter, a pressure measurement device, and a data acquisition system. The test section was designed as a horizontal double pipe heat exchanger with a counter flow configuration. In this setup, hot fluid flowed through the inner copper tube, while a cooling Nanofluid consisting of water circulated in the annular space between the inner and outer pipes. The inner copper pipe had dimensions of 16 mm inner diameter, 19 mm outer diameter, and a 1.5 mm thickness. Similarly, the outer steel pipe had dimensions of 50 mm inner diameter, 54 mm outer diameter, and a 2 mm thickness. To enhance heat transfer and modify fluid flow, twisted tapes made of aluminium sheet with dimensions of 2 mm thickness, 15 mm width, and a length of 900 mm were introduced into the test section. These tapes were tailored in terms of twist ratio and geometrical progression ratio to achieve the desired flow modifications.

Temperature measurements of the 5% Nanofluid concentration and cooling water were carried out at both the inlet and outlet of the test section using four type K thermocouples, which were calibrated before use. These thermocouples were connected to data loggers for data recording. The temperature of the Nanofluid was controlled using an electric heater and thermostat. Key parameters such as mass flow rates, inlet, and outlet temperatures of both the Nanofluid and cooling water were accurately recorded throughout the experiments. Pressure drop across the test section was measured using a differential pressure transmitter at both the entrance and exit. To precisely measure the Nanofluid flow rate, a magnetic flow meter was placed at the inlet of the test section. To ensure stable conditions for each test run, a pre-test duration of 10 to 30 minutes was observed, depending on factors like Reynolds number and the configuration of the twisted tape. The experiments covered a range of Reynolds numbers from 3000 to 15000, the experimental setup and data collection procedure were meticulously designed to investigate the heat transfer performance of Nanofluids under various flow conditions, employing 3.5mm twisted tape configurations. This methodology allowed to gather valuable data for subsequent analysis and assessment of Nanofluid heat transfer characteristics.

Fig.1 Experimental setup

IV. Results and Discussion

Analysis of Plain Twisted Tape TiO_2

The previous segment discussed on the investigation of the plain twisted tape [10] insert fitted heat exchanger by means of plain water was used for conducting the experimental record. The heat transfer and friction factor characteristics of the heat exchanger of plain twisted tape insert was observed. Now in this sector, it was analyzed that heat transfer, Nusselt number [5], heat transfer coefficient and friction factor [6] characteristics of heat exchanger by Titanium oxide Nanofluid and base water through plain twisted tape insert.

Variation of Nusselt Number

The domain with PTT Figure 2 shows difference of Reynolds number and Nusselt number with TiO_2 Nanofluid and water mixing. From the results observed, the Nusselt number increases while Reynolds number also increases. Because, this happen as result of viscous force created near the wall side of fluid as the Reynolds number increases. It is evident that the Nusselt number of PTT with TiO_2 is higher than the PTT with base fluid of water as indicated in Figure 2.

As a result of the Nusselt number of PTT with Titanium oxide gives up to 2% higher than the PTT with water at different Reynolds. The reason behind this is that, Titanate nanotubes were synthesized which involve generating the particles in a solution first, drop casting the wet particles onto a substrate, by removing the solvent, surfactants and other materials from the particles, characterized and dispersed in water to form stable Nanofluids. The Titanium Nanofluid shows a small thermal conduction enhancement 2 percentage.

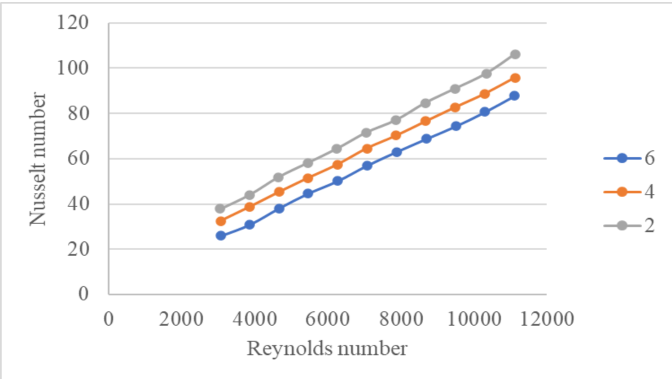

Fig. 2 Comparison on Reynolds number vs. Nusselt number for PTT with Plain water and TiO_2

Variation of Heat Transfer coefficient

The variation of Reynolds number and heat transfer coefficient of PTT with TiO_2 as shown in Figure 3. It indicates that the Reynolds number increases and the heat transfer coefficient also increases. The lower Reynolds number gives the minimum heat transfer coefficient as indicated in Fig 5.4. The heat transfer coefficient of the PTT with TiO_2 gives 1.98 percentage enhanced than that the PTT of the base fluid water

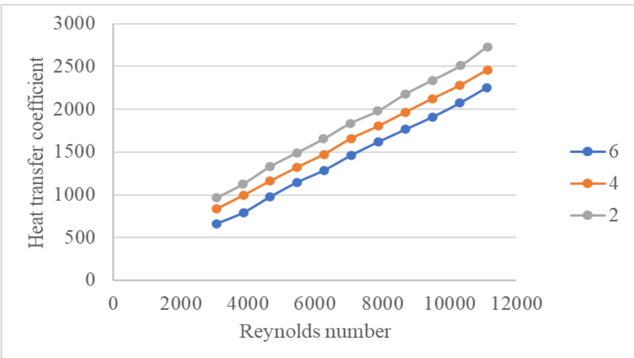

Fig. 3 Titanium oxide analysis of Reynolds number and Heat transfer Coefficient

Variation of Heat Transfer

Figure 4 shows the heat transfer enhancement with Reynolds number. The heat transfer rate increased with an increase in the Reynolds number. The tube induced with the PTT with Nanofluids gives the higher flow velocity in near tube wall side and twisted tape makes the tangential flow. In addition to that, turbulence is generated by the alternate pitch of the twisted tape. The observation of the heat transfer rate of PTT with Titanium oxide departs 1.96 times enhanced than the heat transfer of the PTT with plain water, the heat transfer coefficient of Nanofluids gives higher value than that of the common base fluid and gives little or no penalty in pressure drop.

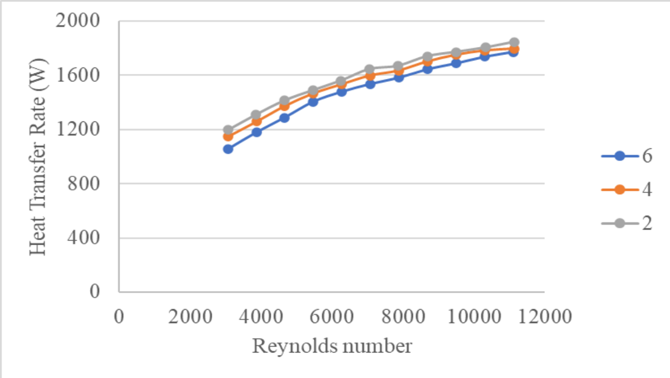

Fig. 5 Comparison on the Reynolds number with Heat transfer rate for PTT with Plain water and TiO2

Variation if Friction factor

The Reynolds number and friction factor of PTT by means of Nanofluids as shown in Fig 5.6 and the results revealed that the Reynolds number increases, friction factor decreased gradually as shown in Fig 6. The lower Reynolds number gives higher friction factor characteristics and higher Reynolds number gives the lower friction factor. Because of increase in Reynolds number, fluid flow rate decreased and suffers higher resistance flow. The detailed analysis of PTT of TiO_2 and base fluid were discussed, the results concluded that the PTT with Titanium oxide Nanofluids enhance more performance than the PTT with plain water and validated these results with experimental values. Because, the Nanofluids having more thermal conductivity as compared with the plain water and also copper made twisted tape inserts were used to extract more heat transfer.

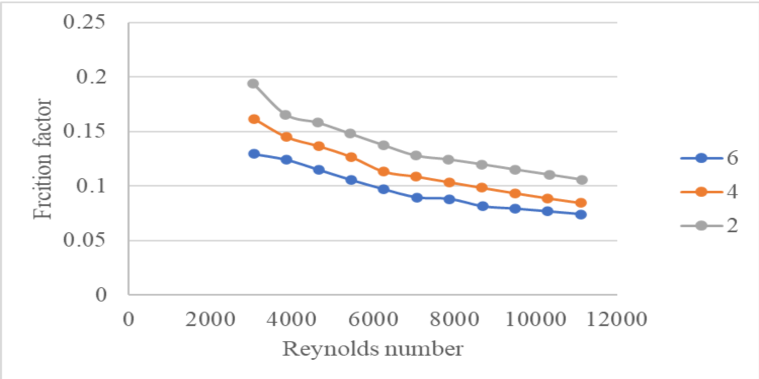

Fig. 6 Effect of Friction factor vs. Reynolds number

Analysis of Plain Twisted Tape Al_2O_3

Variation of Nusselt Number

In the previous chapter, it was examined that the Nusselt number and friction factor characteristics of the double pipe heat exchanger through plain twisted tape insert with different twisted ratio were compared. In the presence of twisted tape insert flow occurred with vortex motion or swirl flow in tube. The Nusselt number of the Nanofluid enhanced up to10% has compared with plain water circulation of fluid, because the thermal conductivity of Nanofluid was very higher as compared with the plain water. Because this arises as an outcome of viscous force creates near the wall side of fluid as Reynolds number increased. It is evidence of Nusseltnumber of Nanofluids, which is superior to plain water with PTT as indicated in Fig 7. As a result of the Nusselt number of Nanofluid with PTT with different twisted ratio gives 10% higher than the plain water at different Reynolds number variation.

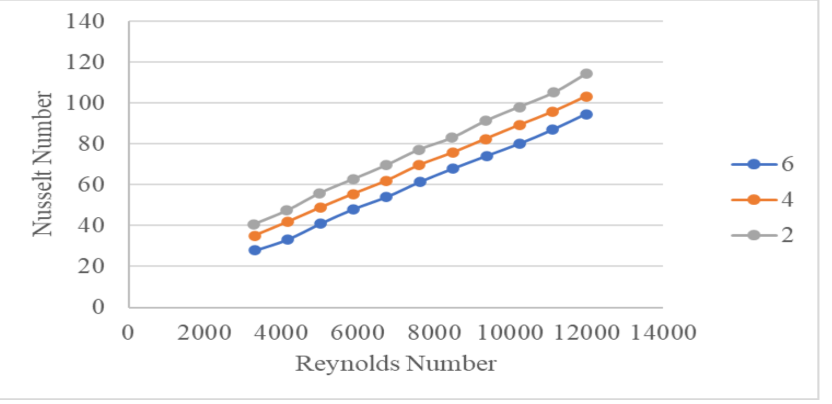

Fig. 7 Comparison on Reynolds Number vs Nusselt number for PTT with Al_2O_3

It is known that the increase in the concentration of surfactant improves the stability of Nanofluid, but shows lower augmentation of thermal conductivity Nanofluid. The stability of Nanofluid is the important parameter the heat transfer. The explanation behind this is that, higher thermal conductivity produces the additional heat extraction of the fluid flow and the tangential motion is produced on the twisted tape surface.

Variation of Heat Transfer coefficient

Now in this section, there was a discussion about the characteristics of the Nusselt number and heat transfer rate of plain twisted tape through plain water and Nanofluids (Al_2O_3). The nature of fluid flows at different section of tube length was measured and streamline in the flow track of the path followed by the flow of the field in the heat exchanger.In the PTT, the concentration of streamlines across the wall is weak as a result of the absence of twisted tape inserts. The streamlines are distributed evenly with addition of simple twisted tape. Because swirls arise from the twisted tape insert. Inside the cut, the streamlines have a greater concentration. This arises as a result of additional disturbance and mixing created by the cut.

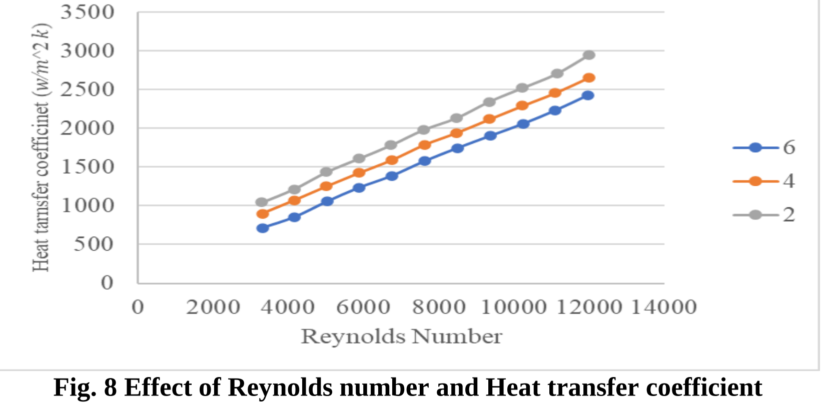

Fig. 8 Effect of Reynolds number and Heat transfer coefficient

Figs 8 & 9 showed the effect of Nusselt number and heat transfer coefficient of the heat exchanger with plain twisted tape insert being examined through plain water and Nanofluid. It was induced by means of twisted tape inserts and its maximum velocity take place at centre of the tube flow at these locations was fully formed. The velocity is shown to be almost equal on every location. The higher Reynolds number gives the maximum heat transfer coefficient is observed as shown in Fig 8. The Al_2O_3 heat transfer coefficient increases up to 11 % compared to the plain water in heat exchanger.

Variation of Heat Transfer

This chapter discusses on the effect of Reynolds flow number and the concentration of nanoparticles on enhancing convective heat transfer coefficient. The augmentation of convective heat transfer coefficient and Nusselt number for the influence of Reynolds number in laminar and turbulent regimes and the concentration of nanoparticle are explained. The result of the experimental value of Nanofluids gives higher value compared with plain water was shown in Fig 9. This is due to the decrease in the cross-sectional area of flow and increase in tube flow rate, which causes the fluid to swirl inside the tube with higher mass flow rate. The results increase the Nanofluids heat transfer coefficient with plain twisted tape inserts.

This is the evidence of heat transfer rate by means of Reynolds number of PTT with plain water and Nanofluids that are exposed in Fig 9. The heat transfer rate was increased through increase in Reynolds number and this happens with velocity of fluid which increased inside a tube. It has been observed that Reynolds number increases, so does Nusselt number also increases. According to the heat transfer rate enhancement, the Reynolds number increases.

As shown in Figure 9, the heat transfer rate of induced Nanofluid tubes is higher than that of plain tube causing the fluid within swirl at higher velocity. Thus, it allows the heat transfer coefficient of induced Nanofluid tubes to be higher than plain water. Reynolds number characterizes the relative importance of stresses due to inertial accelerations in the flow to stresses due to viscous effects. The graph shows linear as flow rate is proportional to velocity

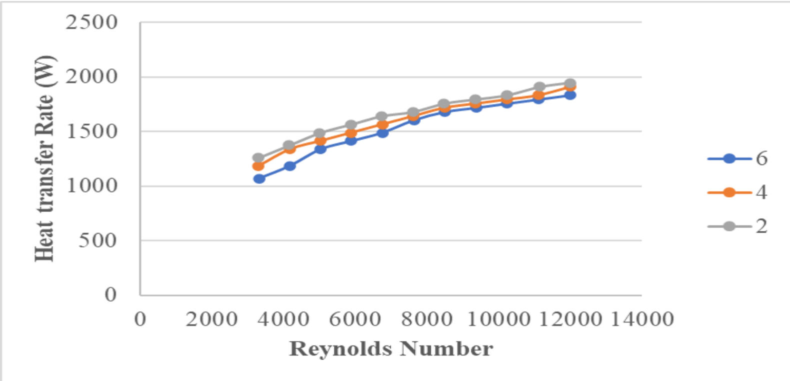

Fig. 9 Comparison of Reynolds number with Heat transfer rate

The heat transfer rate in the $Al_2O_3$is 10% times enhances compared with the plain water of the PTT. The experiments were conducted at different Reynolds number of the flow by varying the flow rates of water and Reynolds number is also varying from 3000 to 12000. The reason behind this states that, the twisted tape is giving the swirl flow motion and more contact surface in addition to the Nanofluids passing through the tube.

Variation of Friction factor

The Fig 10 shows variation of the Reynolds number and friction factor and it has indicated the friction factor continuously that decreased with increases of the Reynolds number. The lower Reynolds gives the maximum friction factor value as indicated in Fig 10. Because of lower Reynolds number and lower fluid flow rate, it suffers higher resistance flow.

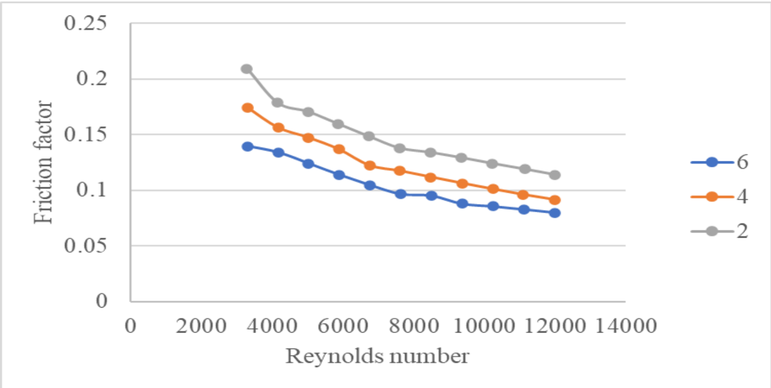

Fig. 10 Effect of Friction factor vs. Reynolds number

V. Conclusions

- The evaluation of different twisted tape configurations has demonstrated that using a shorter length of plain twisted tape (PTT) with a twist ratio of 2 yields the most favourable heat transfer performance compared to other tape arrangements. Specifically, the shortened PTT configuration with a twist ratio of 2 significantly improves heat flow and thermal characteristics when compared to a plain tube (PT) configuration. This improvement is attributed to the combined effects of turbulence generation, enhanced fluid mixing, and efficient use of space, all of which contribute to the observed enhancement in heat transfer properties.

- ❖ Additionally, the validation of using plain twisted tape with Titanium oxide Nanofluids shows an enhancement in the Nusselt number by 2% when compared to using helical coil twisted tape inserts with Titanium oxide. This improvement can be attributed to the swirl flow motion generated by the PTT and the higher thermal conductivity of Nanofluids.
- ❖ Furthermore, when analyzing the use of Aluminium oxide with Plain Twisted Tape Nanofluids, it is observed that the Nusselt number and heat transfer rate increase by 10% compared to plain water. This enhancement is attributed to the generation of swirl flow motion and turbulence vortex flow, which are facilitated by the superior mixing capabilities offered by Aluminium oxide in combination with Plain Twisted Tape Nanofluids.

References

[1]. Weerapun Duangthong Suk& Somchai Wongwises, "Heat Transfer Enhancement And Pressure Drop Characteristics Of Tio2 Water Nanofluid In A Double-Tube Counter Flow Heat Exchanger", International Journal Of Heat And Mass Transfer, Vol. 52, Pp. 2059 2067 (2009).

[2]. Eiamsa-Ard, S. And Kiatkittipong, K., 2014. Heat Transfer Enhancement By Multiple Twisted Tape Inserts And Tio2/Water Nanofluid. Applied Thermal Engineering, 70(1), Pp.896-924.

[3]. T. Mohankumar, K. Rajan, K. Sivakumar And V. Gopal "Experimental Analysis Of Heat Transfer Characteristics Of Heat Exchanger Using Nano Fluids" IOP Conference Series: Materials Science And Engineering. IOP Conference Series: Materials Science And Engineering, Volume 574, International Conference On Materials Engineering And Characterization 8–10 (2019).

[4]. Arulprakasajothi, M., 2015. Experimental Investigation On Heat Transfer Effect Of Conical Strip Inserts In A Circular Tube Under Laminar Flow. Front Energy.

[5]. Avinashsavekar, Dhiraj Jangid, Madhura Gurjar, Vikrant Patil And Sewatkar. C.M, "Analysis Of Heat Transfer In Pipe With Twist Tape Inserts", Proceedings Of The 2nd International Conference On Fluid Flow, Heat And Mass Transfer, Canada, April 30 To May 1, Pp 143, 1-8. (2015).

[6]. Chinaruk, Thianpong, Petpices, Eiamsa-Ard "Compound Heat Transfer Enhancement Of A Dimpled Tube With A Twisted Tape Swirl Generator", International Communication In Heat And Mass Transfer, Vol. 37, Pp. 39-46. (2009).

[7]. Dhamane N B, Nalawade D B, And Dange M M, "Experimental Study Of Heat Transfer For Wavy Twisted Tape Insert Of Various Pitches Placed In A Circular Tube", International Journal Of Innovative Research And Development, Vol.3, Issue 2, Pp.141-146. (2014).

[8]. Smith Eiamsa-Ard, And Kunlanankiathttipong, "Heat Transfer Enhancement By Multiple Twisted Tape Inserts And Tio2 /Water Nanofluid", Applied Thermal Engineering, Vol. 70, Pp. 896- 924. (2014)

[9]. Moya-Rico, J.D., Molina, A.E., Belmonte, J.F., Tendero, J.C. And Almendrosibáñez, J.A., 2020. Experimental Characterization Of A Double Tube Heat Exchanger With Inserted Twisted Tape Elements. Applied Thermal Engineering, 174, P.115234.

[10]. Kumar, C.N. And Murugesan, P., 2012. Review On Twisted Tapes Heat Transfer Enhancement. International Journal Of Scientific & Engineering Research, 3(4).

[11]. Kumar, C.N. And Murugesan, P., 2012. Review On Twisted Tapes Heat Transfer Enhancement. International Journal Of Scientific & Engineering Research, 3(4).

[12]. R.A. Hossain, M.A.K. Chowdhuri, And C.M. Feroz, "Design Fabrication And Experimental Study Of Heat Transfer Characteristics Of A Micro Heat Pipe", Jordan Journal Of Mechanical And Industrial Engineering, 4, 531 -542. (2010)

[13]. X. Guowei, Z. Junjie, M. Rui, And L. Yepang, "Novel Heat Pipe Radiator For Vertical CPU Cooling And Its Experimental Study", International Journal Of Heat And Mass Transfer, 130, 912 - 922. (2019).