# Enhancement of Heat Transfer using Combination of Perforated Co-Swirl Twisted Tape Insert and Nanofluids

**Arif Ahmed, Asma Ul Hosna, Syed Masrur Ahmed**

***Abstract:** This analysis was carried out for enhancing tube side heat transfer performance by co-swirl twisted tape insert with ethylene glycol-water base $TiO_2$ Nano-fluids. The test section consists of a long copper tube of 26.6 mm internal diameter and 30mm outer diameter and 900 mm effective length. Each stainless steel insert was 850 mm in length, 10 mm in width, 1.5 mm thickness and the twisted ratio was 4.25. For measuring the bulk temperature two thermometers were used at the inlet and outlet section of the circular tube. Four K-thermocouples were used in the experiment section to determine the temperature of the outer surface. From rotameter, a definite amount of mass flow rate was measured for the calculation of flow velocity. As well as from manometer reading, pressure head was measured for determining pressure difference of the flow section. A nichrome wire was surrounded around the pipe for uniform heat flux. Nusselt numbers for i) combination of perforated co-swirl twisted tape insert and 0.03% volume fraction of Nanofluids ($TiO_2$/Ethylene Glycol/Water), ii) combination of perforated co-swirl twisted tape insert and 0.01% volume fraction of Nanofluids ($TiO_2$/EG/Water), and iii) combination of perforated co-swirl twisted tape insert and water were increased by 56.72%, 61.52%, 77.98% respectively than the plain tube.*

***Keywords** : Co-swirl twisted tape, nanofluids, Nusselt number, twist ratio.*

## I. INTRODUCTION

Numerous research studies on heat exchangers were carried out to achieve higher effectiveness [1]. Heat transfer enhancement methodology is common in many engineering applications including thermal recovery procedures, air conditioning, and cooling systems, nuclear energy, chemical reactors, high-performance laser system, chemical process plants and others [2]. An exciting subject for scientists and researchers in the latest decades has been the use of passive methods to improve heat transfer features in heat exchangers. In order to enhance heat transferred by these methods, numerical and experimental studies were performed.

**Revised Manuscript Received on November 30, 2019.**
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Passive heat transfer improvement methods are mostly preferred because of their simplicity and applicability in many applications. Furthermore, no external energy input is needed in passive methods except to move the fluid [3]. Several studies were conducted to explore the impact of fluctuation generators (turbulent promoters) with distinct geometries on heat exchanger thermal behaviors, such as winglets or fins, dimpled or grooved pipes, wire coils, twisted tapes. Due to the low price of the tape and ease of use in the current scheme, the method of producing fluid flow by inserting a twisted tape is considered as one of the most advantageous passive methods. Using a twisted tape insert reduces thermal boundary layer thickness, which results in enhanced convective heat transfer [4]. In many heat transport applications, heat transfer liquids such as water, ethylene glycol (EG) and mineral oil play a major role. To improve the low thermal features of conventional heat transfer fluids, solid nanoparticles are introduced into base fluids [5]. Nanofluids are thought to be the next-generation heat transfer fluids owing to their increased heat transfer efficiency and better stability compared to others [6]. Water's thermal conductivity is greater than Ethylene Glycol. However, in comparison with water, EG has reduced freezing and greater boiling point. Compared to water-based nanofluids, greater heat conductivity improvements are achieved with EG [7].

## II. EXPERIMENTAL FACILITY

The total section length of perforated co-swirl twisted tape insert (as shown in Fig. 1) was 900 mm and the twisted length was 850 mm and the insert width was 10 mm, the thickness was 1.5 mm. The porous diameter was 4 mm and twist ratio was 4.25.

**Fig. 1: Photographic view of perforated co-swirl twisted tape**

The experimental set up is displayed in Fig. 2. Long copper tube of internal 26.6 mm diameter and outer 30 mm diameter and length of 900 mm was used as the experiment section. In order to provide heating energy in the entire section, a spiral nichrome wire was wound around the outer surface of the test section on a regular basis. By this constant flow of heat was maintained. To prevent heat loss, a mica sheet was used. M-seal was used at the joining of pipe. The outer surface temperature was measured by four k-thermocouples which were placed in equal distance. The outside surface temperature was taken as the average of the four thermocouple readings. Pressure drop was evaluated with a U-tube manometer at the inlet and outlet of the experiment section. By this pressure difference, the friction factor was measured. With the help of rotameter (capacity 26 L/min), the flow rate was measured. The fluid flow rate for different data was varied and maintained constant during the experiment. The inlet and outlet temperature of the fluids were measured by a thermometer. The experiments were conducted with ethylene glycol-water-based $TiO_2$ nanofluids with 0.01% and 0.03% volume concentration. After the experimental set up was assembled, the storage tank was filled with the working fluid. The fluid flow control valve was placed between the reservoir and the test section. Once the heating unit was switched on, sufficient time had been provided to attain a stable state. In every run of fluid into the experimental section, fluid flow rate by rotameter, inlet and outlet temperature by the thermometer, outer surface temperature by thermocouple, pressure difference by U-tube manometer reading were noted down. The precaution was taken to keep the perforated co-swirl twisted tape insert in an accurate place. The precaution was taken about untouching on the nichrome-wire test section when it was heated.

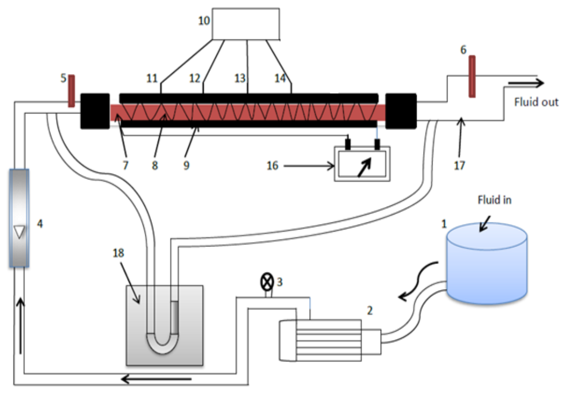


**Fig. 2: Schematic diagram of the experimental apparatus**

| | |
|---|---|
| 1. Tank | 8. Nichrome wire |
| 2. Pump | 9. Insulator |
| 3. Gate Valve | 10.Temperature reading device |
| 4. Rotameter | 11-14. Thermocouples |
| 5. Inlet thermometer | 16. Voltage regulator |
| 6. Outlet thermometer | 17. Mixing chamber |
| 7. Test section | 18. U-tube manometer |

$TiO_2$ nanoparticles, ethylene glycol, and deionized water were used for the preparation of Nano-fluids. The amount of $TiO_2$ nanoparticles necessary for various volume fraction was calculated using the formula in equation (1) [8],

Volume concentration, $\varphi=(W/\rho)_{TiO2}/[(W/\rho)_{TiO2}+(W/\rho)_{bf}]$ (1)

## III. MATHMATICAL MODELING

For developing the mathematical model the following equations are needed:

Cross sectional area, $A_x=\pi d_i^2/2$ (2)

Inner surface area, $A_s= \pi d_i L$ (3)

Bulk temperature, $T_b=(To+Ti)/2$ (4)

Outer surface temperature, $T_{wo}=(T_1+T_2+T_3+T_4)/4$ (5)

Heat added to the fluid, $Q=mC_p(T_o-T_i)$ (6)

Inner surface temperature,$T_{wi}=T_{wo}-Q\ln(d_o/d_i)/(2\pi K_{Cu}L)$ (7)

Convective heat transfer coefficient, $h=Q/[A_s(T_{wi}-T_b)]$ (8)

Velosity, $U_m=q/A_x$ (9)

Reynolds number, $Re=\rho U_m d_i/\mu$ (10)

Prandtl number, $P_r= \mu C_p/K$ (11)

Experimental Nusselt number, $Nu_{exp}=hd_i/K$ (12)

Theoretical Nusselt number for plain tube, $Nu_{th}=0.023Re^{0.8}Pr^n$ (by Dittus Boelter) (13)

where n=0.4 for heating, 0.3 for cooling

Pressure difference, $\Delta p=\Delta h\rho g$ (14)

Theoretical friction factor for plain tube, $f_{th}=(0.79\ln Re-1.64)^{-2}$ (15)

Experimental friction factor, fex= $\Delta p/[(L/di)(\rho U_m^2/2)]$ (16)

Viscosity of base fluid, $\mu_{bf}=(1-\varphi_{EG})\,\mu_{water}+ \varphi_{EG}\,\mu_{EG}$ (17)

Viscosity of nanofluid, $\mu_{nf}=(1+2.5\varphi)\,\mu_{bf}$ (18)

Density of nanofluid, $\rho_{nf}= \varphi\rho_{np}+(1-\varphi)\,\rho_{bf}$ (19)

Specific heat of nanofluid, $C_{Pnf}= \varphi C_{P,np}+(1 - \varphi)\,C_{P,bf}$ (20)

Thermal conductivity of nanofluid,

$k_{nf}=[k_{np}+2k_{bf}+2\varphi\,(k_{np} - k_{bf}) / [k_{np}+2k_{bf} - \varphi(k_{np} - k_{bf})]$ (21)

## IV. RESULTS AND DISCUSSION

Before using insert and nanofluids, all the data were taken for the water and plain tube without the insert to check the accuracy of the setup. With the increase of Reynolds number Nusselt number increases. From equation (8), (10), (12) convective heat transfer coefficient, Reynolds number, and experimental Nusselt number were calculated respectively. Experimental Nusselt for the plain tube without insert was 24.27 for the Reynolds number 2056. For the higher Reynolds number experimental Nusselt number was 69.4. The convective heat transfer was ranging from 565-1617 $W/m^2k$ for the plain tube without insert. The experimental friction factor was 0.032-0.20.

But with the perforated co-swirl twisted tape and water experimental Nusselt number was ranging from 38.20-105.77 and the range of convective heat transfer coefficient was 890.5-2465 $W/m^2k$. For the insert, the experimental friction factor slightly increased and the value was 0.04-0.3.

With 0.01% $TiO_2$ in the base fluid of 10% EG,90% water, and the selected perforated co-swirl twisted tape insert for Reynolds number 1665, experimental Nusselt number was 39.63 and for Reynolds number 5284, $Nu_{exp}$ was 109.57. The range of the experimental friction factor was 0.06-0.41. Due to the effect of ethylene glycol the range for convective heat transfer coefficient was 865-2381 $W/m^2k$.

The range of experimental friction factor was 0.06-0.41 With 0.03% $TiO_2$ in the base fluid and perforated co-swirl twisted tape insert, the experimental Nusselt number was 43.17-118.6. For this combination, convective heat transfer coefficient was 953-2586 W/m$^2$k. The range of experimental friction factor was 0.07-0.49.

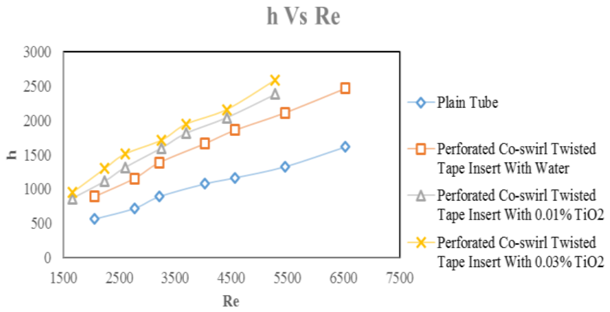


**Fig. 3: Variation of convective heat transfer coefficient with Reynolds number**

The variation of heat transfer coefficient(h, W/m$^2$k) with Reynolds is shown in Fig. 3. The highest convective heat transfer coefficient was found when 0.03% $TiO_2$ was dispersed in base fluid and with a combination of perforated co-swirl twisted tape insert. Average increase of heat transfer coefficient for 0.03% $TiO_2$ with insert, for 0.01% $TiO_2$ with insert, water with insert was 1.56, 1.52, 1.66 times than plain tube.

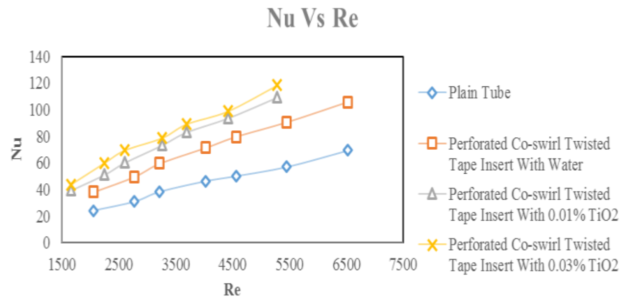


**Fig. 4: Variation of Nussselt number with Reynolds number**

Nusselt number increases with the flow rate as well as the Reynolds number as shown in Fig. 4. With insert and water, the Nusselt number increases gradually than the plain tube without an insert. Then Nusselt number increases with the increase of volume fraction of $TiO_2$ in the base fluid.

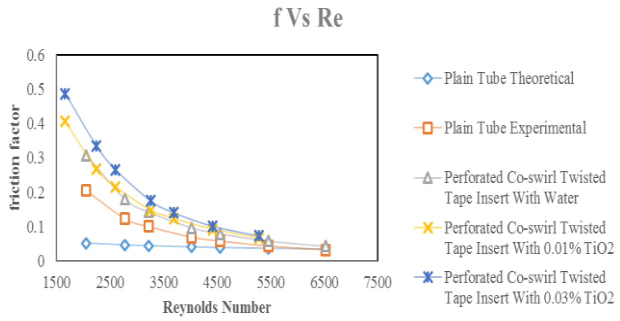


**Fig. 5: Variation of friction factor with Reynolds number**

The experimental friction factor decreases with the increase of the Reynolds number presents in Fig. 5. The friction factor average increases 2.45, 2.1, 1.40 times for 0.03% $TiO_2$ with insert , 0.01% $TiO_2$ with insert and water with insert respectively than the plain tube without an insert. The maximum friction factor was found for 0.03% $TiO_2$ in base fluid with the combination of perforated co-swirl twisted tape.

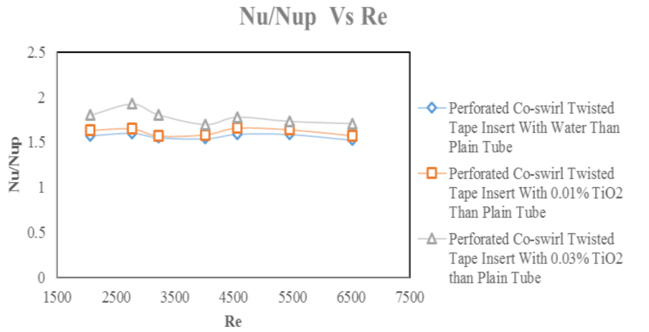


**Fig. 6: Variation of Nu/Nu$_p$ with Reynolds number**

Figure 6 shows that for perforated co-swirl twisted tape insert with water Nusselt number increases 1.52-1.6 times than plain tube and the average 1.57 times. For the combination of 0.01% $TiO_2$ in the base fluid and perforated co-swirl twisted tape Nusselt number increases 1.57-1.67 times than plain tube and the average 1.62 times. Similarly for the combination of 0.03% $TiO_2$ in the base fluid and perforated co-swirl twisted tape Nusselt number increases 1.70-1.93 times than plain tube and the average 1.78 times.

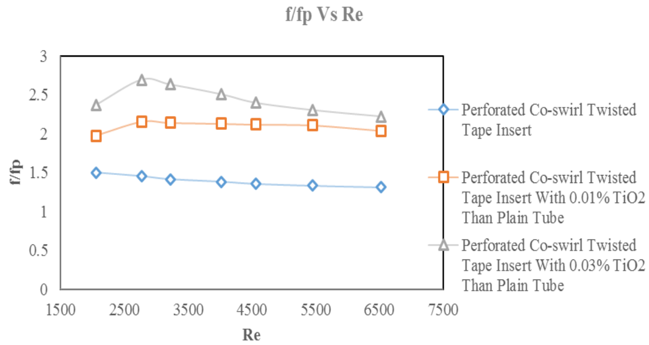


**Fig. 7: Variation of f/f$_p$ with Reynolds number**

Figure 7 shows that for perforated co-swirl twisted tape insert with water experimental friction factor increases 1.31-1.5 times with respect to plain tube and the average value is 1.40 times. For the combination of 0.01% $TiO_2$ in the base fluid and perforated co-swirl twisted tape friction factor increases 1.97-2.15 times with respect to plain tube and the average value is 2.01 times. Similarly for the combination of 0.03% $TiO_2$ in the base fluid and perforated co-swirl twisted tape friction factor increases 2.20-2.70 times with respect to the plain tube and the average value is 2.45 times.

## V. CONCLUSION

The aim of the research is to increase heat transfer. This research primarily focuses on Reynolds number, Nusselt number, friction factor as well as particularly the coefficient of convective heat transfer.

For 0.03% $TiO_2$ with insert, the convective heat transfer coefficient is higher and that is 1.66 times than the smooth tube with water. Similarly, this combination shows a 1.78 times increase of Nusselt number than the smooth tube and 2.45 times increase of friction factor. This experimental setup has some limitations. The pipe may be subjected to a high-pressure drop with the use of perforated co-swirl twisted tape and nanofluids. This results in high cost. Another issue is that higher pressure may cause the tube to fail. The thermocouple display could not able to show the fractional value. Therefore, our research inherits some errors. Additional studies can be conducted to examine the effectiveness of the heat transfer for perforated co-swirl twisted tape and for various volume fraction of $TiO_2$ in base fluid. This research will hopefully assist distinct people with an interest in a region associated with heat transfer.

## APPENDIX

| | |
|---|---|
| $\Phi$ | Volume concentration |
| $\rho_{TiO2}$ | The density of $TiO_2$ ($kg/m^3$) |
| W | Amount of TiO2 (gm) |
| $d_i$ | The inner diameter of the tube(m) |
| $A_x$ | Cross-sectional area($m^2$) |
| $A_s$ | Tube surface area($m^2$) |
| L | Length of test section (m) |
| $T_b$ | Bulk temperature ($^0C$) |
| $T_o$ | The outer temperature of the fluid ($^0C$) |
| $T_i$ | The inlet temperature of the fluid ($^0C$) |
| $T_1, T_2, T_3, T_4$ | Thermocouple reading ($^0C$) |
| Q | Heat added (W) |
| m | The mass flow rate of fluid (kg/s) |
| $C_p$ | Specific heat of water ($J/kg^0C$) |
| $T_{wi}$ | The inner surface temperature of the test section($^0C$) |
| $T_{wo}$ | The outer surface temperature of the test section($^0C$) |
| $U_m$ | Velocity (m/s) |
| $K_{Cu}$ | Thermal conductivity of copper tube ($W/m^2\,^0C$) |
| Re | Reynolds number |
| Pr | Prandtl Number |
| $Nu_{th}$ | Theoretical Nusselt number for plain tube |
| $Nu_{exp}$ | Experimental Nusselt Number |
| $\Delta p$ | The pressure difference ($N/m^2$) |
| $\Delta h$ | Manometer difference (m) |
| $f_{th}$ | Theoretical Friction Factor for plain tube |
| $f_{exp}$ | Experimental friction factor |
| $\mu_{bf}$ | The viscosity of the base fluid (kg/ms) |
| $\mu_{nf}$ | The viscosity of nanofluid (kg/ms) |
| $\rho_{nf}$ | The density of nanofluid ($kg/m^3$) |
| $\rho_{bf}$ | The density of the base fluid ($kg/m^3$) |
| $C_{Pnf}$ | Specific heat of nanofluid ($J/kg^0C$) |
| $C_{Pbf}$ | Specific heat of base fluid ($J/kg^0C$) |
| $k_{nf}$ | Thermal conductivity of nanofluid ($W/m^2\,^0C$) |
| $k_{bf}$ | Thermal conductivity of the base fluid ($W/m^2\,^0C$) |

## ACKNOWLEDGMENT

The authors wish to express thanks to the Department of Mechanical Engineering of Chittagong University of Engineering and Technology for the continuous assistance and support they have shown for this research. The authors also want to thank the heat transfer laboratory for their support.

## REFERENCES

1. M. A. Agung Tri Wijayanta, Pranowo, Mirmanto, Budi Kristiawan, “Internal Flow in an Enhanced Tube Having,” *Energies 2019, 12, 306*, pp. 1–12
2. S. Xie, J. Feng, and G. Zhang, “Study on simulation traction load with regenerative braking,” *Energy Procedia*, vol. 14, pp. 1299–1304, 2012
3. S. Tabatabaeikia, H. A. Mohammed, N. Nik-Ghazali, and B. Shahizare, “Heat Transfer Enhancement by Using Different Types of Inserts,” *Adv. Mech. Eng.*, vol. 2014, 2014.
4. M. K. Abdolbaqi, W. H. Azmi, R. Mamat, N. M. Z. N. Mohamed, and G. Naja, “Experimental investigation of turbulent heat transfer by counter and co-swirling flow in a flat tube fitted with twin twisted tapes ☆,” vol. 75, pp. 295–302, 2016.
5. Y. Zeng, X. Zhong, Z. Liu, S. Chen, and N. Li, “Preparation and Enhancement of Thermal Conductivity of Heat Transfer Oil-Based $MoS_2$ Nano-fluids,” 2013.
6. W. Yu, H. Xie, Y. Li, L. Chen, and Q. Wang, “Experimental investigation on the heat transfer properties of $Al_2O_3$ nanofluids using the mixture of ethylene glycol and water as base fluid,” *Powder Technol.*, vol. 230, pp. 14–19, 2012
7. K. V Sharma, S. K. Vandrangi, K. Habib, and S. Kamal, “Influence of Ethylene Glycol and Water Mixture Ratio on $Al_2O_3$ Nanofluid Turbulent Forced Convection Heat Transfer,” vol. 7, no. 6, pp. 123–128, 2016
8. M. C. S. Reddy and V. V. Rao, “Experimental studies on thermal conductivity of blends of ethylene glycol-water-based $TiO_2$ nanofluids ☆,” *Int. Commun. Heat Mass Transf.*, vol. 46, pp. 31–36, 2013.

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