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EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER ENHANCEMENT OF MINERAL OIL-WATER BASED TiO_2 NANOFLUID WITH DIAMOND-CUT SINGLE AND SEPARATED TAPE INSERTS

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Abstract- *The friction factor and coefficient of heat transfer of MO/Water/TiO_2 nanofluid flowing through a single tube were experimentally analyzed with and without diamond-cut tape inserts. A copper tube having 26.6 mm internal diameter, 30 mm outer diameter and 900 mm test length was used. The tests were carried out in the Reynolds number ranging from 1353 to 4293 for 0.01% volume concentration. The base fluid is prepared by taking into account 10% mineral oil and 90% distilled water. The coefficient of heat transfer and the friction factor were improved by 0.31 and 1.76 times for nanofluid (volume concentration 0.01%) relative to the base fluid flowing in a tube with single insert. In comparison to the base fluid flowing in a tube with separated inserts the coefficient of heat transfer and the friction factor are further increased by 0.61 and 2.14 times respectively for 0.01% nanofluid. The calculated values as stated above are compared with the literature values that were previously published.*

Keywords: Diamond-Cut Tape Inserts, MO/Water/TiO_2 Nanofluid, Heat Transfer Coefficient, Friction Factor, Heat Transfer Enhancement.

1. INTRODUCTION

A heat exchanger is a device which transfers heat between two or more fluids. Heat exchangers are used in both cooling and heating processes. In automobile, heat exchangers are used to dissipate heat from internal combustion engine through an appropriate liquid called coolant into the sink. Many conventional fluids are available in desired operating temperature range that are appropriate for holding the sink. Over the last few years, liquid water and ethylene glycol along with steam have been used as cooling system. A variety of changes are available in the automotive engineering field due to the introduction of new technologies, including advancements in heat dissipation abilities, size reduction and improved power generation. Even the features of heat transfer liquid, which are in need of heat dissipation from the vehicle to the atmosphere (surroundings) when going through the exchanger (radiator), there is a significant enhancement. The heat exchanger's efficacy depends on the heat transfer fluid's qualities and attributes. A stage has now arrived, which furthermore restricts the efficacy of heat exchangers by limiting heat transfer fluids. Currently nanofluids are substituting conventional liquids in order to overcome this limitations. Nanofluid is a nanometer-sized particle-containing fluid known as nanoparticles. These liquids are mainly nanoparticles in a base fluid designed colloidal suspensions. Typically, the nanoparticles used in nanofluids consist of metals, oxides, carbides, or nanotubes of carbon. Water, ethylene glycol, and oil are common base liquids. Nanofluids have novel characteristics that make them possibly beneficial in many heat transfer applications, including microelectronics, fuel cells, pharmaceutical procedures and motors with hybrid power, domestic refrigerator, chiller, engine cooling / vehicle thermal management, nuclear reactor coolant, heat exchanger, in grinding, machining, in defense and ships, in space technology. Compared to the base fluid, they display improved thermal conductivity and convective heat transfer coefficient. Engineers and scientists have performed several experimental studies to transform traditional fluids in to other nanofluids. In their previous efforts, High thermal conductivity micro-metallic particles were applied to heat transfer liquids in the hope of enhancing their thermal properties. Nonetheless, there were some issues during transit due to micron particle size, such as sedimentation and corrosion of pumps and tubes. The development of nano products in the recent years has renewed interest in nanofluid implementation. The suitability and efficiency of these traditional fluids can be improved through the application of nanoparticles such as Al_2O_3, TiO_2 and CuO in nanofluids [1]. Masuda et al. [2], Lee et al. [3], Wang et al. [4], Eastman et al. [5, 6], and Das et al. [7] focused primarily on evaluating the effective nanofluid thermal conductivity. Inserts improve the coefficient of heat transfer capability and limit the loss of friction factor. It characterizes the performance of inserts. Tube inserts are utilized to enhance the rate of heat transfer and fouling mitigation in various types of industries such as petroleum refineries, other chemical plant for several years. Mostafizur et al. [8] studies improvement of heat transfer for V-shaped twisted tape inserts of copper and stainless material and found increment of heat transfer of copper insert is as 2.52 times and of stainless steel insert as 2.5 times more than plain tube without insert. Jamal et al. [9] conducted experimental work to evaluate the heat transfer rate by using U-shaped twisted tape inserts at different spacing and heat transfer rate for inserts 25 mm, 40 mm and 80 mm spacing in U-shape was enhanced by 4, 3, 2 times. Bhuiya et al. [10] assessed the influence of twisted wire brush inserts on the heat transfer enhancement and pressure drop characteristics of turbulent flow for four different twisted wire densities (100,150, 200, 250) and found to have a significant impact on the improvement of heat transfer as well as an increase in friction factor over the plain tube data. Wazed et al. [11] showed the influence of perforated twisted tape inserts on the enhancement of heat transfer in turbulent flow through tube. A broad range of Reynolds number (1.3×10^4 to 5.2×10^4) are found in the study. In turbulent flow through a pipe with the inserts, the heat transfer coefficient was increased (up to 5.5 times) in the cost of increasing pumping power (1.8 times). In a tube with a perforated twisted tape insert, the effectiveness of heat transfer has been noticed to improve up to 4.0 times in comparison to the value of the plain tube. B. Salam [12] researched the improvement of heat transfer in the pipe using a rectangular cut twisted tape insert. He found Reynolds number in the range of 10000-19000 with heat flux variations of 14 to 22 kW/m^2 for a smooth tube and 23 to 40 kW/m^2 for insert tube. The Nusselt numbers with insert were improved by 2.3 to 2.9 times compared to the smooth tube by 1.4 to 1.8 times at the expense of a rise in friction variables. The experiment's efficiencies were discovered to range from 1.9 to 2.3, which increased as the amount of Reynolds increased. Cho [13] observed improvements in transfer of heat in a tube under the condition of turbulent flow with Al_2O_3 and TiO_2 nanofluids and suggested correlation of the Nusselt number. For their experiments on heat transfer in a pipe with inserts, most investigators have found water-based nanofluids. Namburu et al. [14] developed 60:40% of the EG / W solution based on CuO nanofluid for the first time and conducted viscosity tests. Naik and Sundar [15] regarded the 70:30 ratio of propylene glycol and water combination as the base fluid for CuO nanofluid formulation and observed far better thermal conductivity and viscosity relative to the base fluid. Namburu et al. [16] achieved numerical improvements in heat transfer with nanofluids of Al_2O_3, SiO_2 and CuO relative to the base fluid under the conditions of turbulent flow. Above all the studies observed no appropriate project or thesis on investigating the improvement of heat transfer inside a copper tube using diamond-cut tape insert at a uniform spacing. In this research work, diamond-cut single tape insert and diamond-cut separated tape inserts were used to find the tube side heat transfer coefficient, friction factor and Nusselt number and compare them to that of the plain tube.

2. METHODOLOGY

A good experimental setup is required to improve heat transfer so that better and appropriate results are achieved. In this existing project, two types of diamond cut tape inserts have been used which were designed in SolidWorks 2016. The single aluminum insert was 850 mm in length, 24 mm in width, 4 mm thickness and had

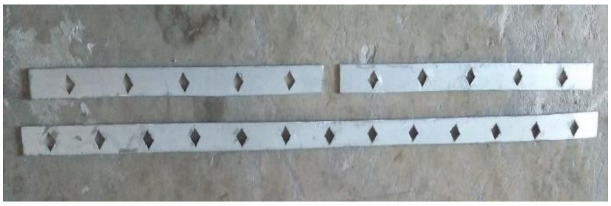


Figure 1: Diamond-cut single and separated inserts

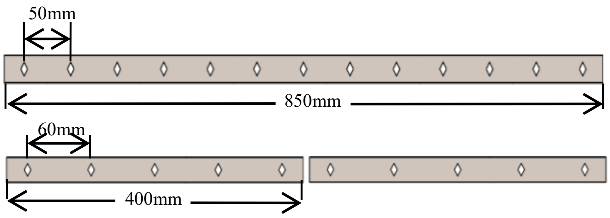


Figure 2: Dimensions of the inserts

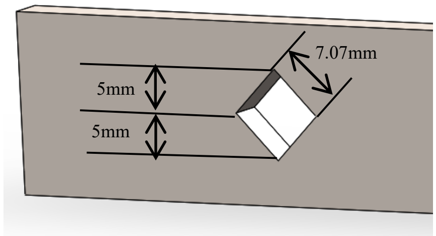
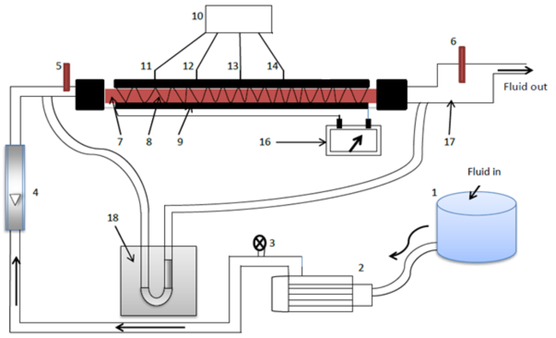


Figure 3: Dimensions of diamond-cut slots

13 diamond shaped slots cut at a distance of 50 mm from each other, whereas separated aluminum insert consists of two separate inserts, each of which was 400mm in length, 24mm in width, 4 mm thickness and each had 5 diamond shaped slots cut at a distance of 60 mm from each other.

Figure 4 displays a schematic diagram of the experimental system. A long tube made from copper with an inner diameter of 26.6 mm and an outer diameter of 30 mm, the partial length of which was used as the test segment. In a periodic length, a nichrome wire around the experimental test section was wrapped to heat the entire section uniformly. Constant heat flux state has therefore been established. Using mica sheet which was wrapped over the wire, sufficient quantity of fiber glass insulation has been used to avoid heat loss. Four k-thermocouples were used to calculate the outer surface temperature. The experiments conducted with mineral oil-water-based TiO_2 Nano-fluids, with 0.01% volume concentration.



1. Tank
2. Pump
3. Gate Valve
4. Rotameter
5. Inlet Thermometer
6. Outlet Thermometer
7. Test Section
8. Nichrome wire
9. Insulator
10. Temperature reading device
11-14. Thermocouples (4)
16. Voltage Regulator
17. Mixing Chamber
18. U-tube Manometer

Figure 4: Schematic diagram of experimental setup

After the experimental setup was assembled, the storage tank was filled with the working fluid. At the inlet and outlet of the test section, pressure drop was evaluated using a manometer. The rate of flow was evaluated by using a rotameter. Inlet and outlet temperature of the fluids was measured by a thermometer. Adding all the four thermocouples reading divided by four to calculate the outside surface temperature. Precaution was taken to keep the co-swirl twisted tape insert an accurate place. Precaution was taken that not take a touch on the nichrome-wire test section when it was heated.

3. MATHEMATICAL FORMULATION

The heat transfer efficiency of inserts in water and nanofluid was measured using the following formulas in the circular copper tube.

External surface area, $A_o = \pi\, d_o\, L$, where d_0 outer diameter, L is the effective length (1)

Internal surface area, $A_i = \pi\, d_i\, L$, where d_i is inner diameter (2)

Heat transfer rate, $Q = m\, C_p\, (T_o - T_i)$, c_p is specific heat, T_o is outlet temperature, T_i is inlet temperature (3)

Cross-sectional area, $A_x = \dfrac{\pi . d_i^{\,2}}{4}$ (4)

Velocity, $U_m = \dfrac{q}{A_x}$, where q is the flow rate (5)

Reynolds Number, $\mathrm{Re} = \dfrac{\rho . U_m . d_i}{\mu}$, μ is the dynamic viscosity, ρ is the density of the fluid (6)

Nusselt number, $Nu = \dfrac{h.d_i}{k}$, where h is convective heat transfer coefficient, k is thermal conductivity (7)

Prandtl number, $\Pr = \dfrac{\mu . C_p}{k}$, μ, and k at the bulk temperature (8)

Convective heat transfer coefficient, $h = \dfrac{Q}{A_x (T_{innersurface} - T_b)}$, T_b bulk temperature (9)

$Nu_d = 0.023\, \mathrm{Re}_d^{0.8}\, \mathrm{Pr}^{0.4}$ (By Dittus and Boelter) (10)

$Nu = 0.332\, \mathrm{Re}^{0.5} \mathrm{Pr}^{0.33}$ (11)

$$Nu = \frac{\left(\frac{f}{8}\right)(Re-1000).Pr}{1+12.7\left(\frac{f}{8}\right)^{0.5}(Pr^{2/3}-1)} \quad (12)$$

Pressure difference, $\Delta P = \Delta h \times \rho \times g$ (13)

$$Q = \frac{2\pi L k (T_{outer\ surface} - T_{inner\ surface})}{ln\left(\frac{d_o}{d_i}\right)} \quad (14)$$

Bulk temperature, $T_b = \dfrac{T_o + T_i}{2}$ (15)

Heat transfer coefficient, $h = \dfrac{Nu.k}{d_i}$ (16)

RMS value = $\{ (n_{1error}^{2} + n_{2error}^{2} + \ldots\ldots\ldots)/n \}^{1/2}$ (17)

Outer surface temp, $T_{wo} = \dfrac{\text{Thermocouple1 reading} + \cdots \ldots\ldots\ldots\ldots + \text{Thermocouple4 readin}}{4}$ (18)

Inner surface temp = $Outer\ Surface\ Temperature - Wall\ Temperature\ Difference$ (19)

Heat flux, $q = \dfrac{Q}{A_i}$, Q is heat transfer rate (20)

Experimental friction co-efficient, $f_{exp} = \dfrac{\Delta P}{\left(\frac{L}{d_i}\right)\left(\frac{\rho\, U_m^{\,2}}{2}\right)}$ (21)

Theoretical Friction Factor, $f_{th} = (0.79\, lnRe - 1.64)^{-2}$ (22)

Efficiency, $\eta = \dfrac{\frac{Nu}{Nu_s}}{\left(\frac{f}{f_s}\right)^{1/3}}$ (23)

Viscosity of Nano-fluid, $\mu = (1 + 2.5\varphi)\mu_b$ (24)

Density of Nano-fluid, $\rho_{nf} = \varphi \rho_p + (1-\varphi)\rho_{bf}$ (25)

Specific heat of nanofluid, $C_{p,nf} = \dfrac{\varphi(\rho . C_p)_p + (1-\varphi)(\rho . C_p)_{bf}}{(1-\varphi)\rho_{bf} + \varphi . \rho_p}$ (26)

$$\text{Pumping Power, } P_m = \frac{\Delta P \times \dot{m}}{\rho_b} \quad (27)$$

4. RESULTS AND DISCUSSION

At first, for the comparison of the calculated values with the Dittus and Boelter values found from Eq. (10), Nusselt numbers were calculated and RMS error was found around 29.13%. For plain tube Reynolds number was found in the range of 2056.031~6525.664. The rate of heat transfer between 461.362W and 1474.322W was found. In the range of 565.67 W / m^2.K to 1617.59 W / m^2.K, convective heat transfer coefficient was spotted. Evaluation of Nusselt number was done from Eq. (7) and the outcome was between 24.17 and 69.40. Friction factor increased in range of 0.31 to 0.065.

Afterward, using diamond-cut single tape insert with water, the rate of heat transfer was observed in the range of 504.61 to 1052.48 W. Reynolds number remained the same. Convective heat transfer coefficient was achieved in 674.68 to 2230.15 W/m^2.K ranges, Nusselt number in between 28.95 to 95.68 ranges, friction factor was decreased from 0.37 to 0.081 found from Eq. (21), where pressure drop was calculated by applying Eq. (13), and average enhancement efficiency of heat transfer was 1.28%.

When diamond-cut single tape insert with nanofluid (TiO_2/MO/water) was used, Reynolds number was found between 1353.797 to 4293.66, the other outcomes were obtained shows that that rate of heat transfer was found in 668.76 to 1429.501 W ranges, convective heat transfer coefficient varied from 652.61 to 2332.403 W/m^2.K ranges, Nusselt number was found in the range of 30.45 to 108.85, friction factor values were decreased from 0.937 to 0.169 ranges, and average heat transfer enhancement efficiency was found 1.31%.

When diamond-cut separated insert with water was applied, Results showed in 576.7 to 1144 W heat transfer rates, The coefficient of convective heat transfer ranged from 771.37 to 2369.47 W / m^2.K., The number of Nusselt between 33.09 and 101.66 ranges, the number of Reynolds remained the same as the plain tube, the friction factor values lies between 0.452 and 0.087 ranges and the average efficiency of heat transfer improved to 1.45%.

After that, when diamond-cut separated insert with nanofluid (TiO_2/MO/water) was used, The number of Reynolds was found between 1353.797 and 4293.66, while the other results showed that the heat transfer rate found in the ranges 477.68 to 909.68 W, the coefficient of convective heat transfer differed from 897.21 to 2695.420 W / m2.K, The number of Nusselt were found between 41.87 and 125.77, the values of friction factor were reduced from 1.082 to 0.185 and the average enhancement efficiency of heat transfer was increased to 1.61%.

The Nusselt number variation with respect to the Reynolds number is shown in Figure 5. For diamond-cut single insert Nu increases 0.29 times than plain tube whereas for separated insert Nu increases 0.45 times than plain tube. In case of nanofluid with 0.01% TiO_2 in base fluid, for diamond-cut single insert Nu increases 0.43 times than plain tube whereas for separated insert Nu increases 0.74 times than plain tube. It was also found that increasing Reynolds number increases heat transfer rate. In all the cases, heat transfer rate increased gradually for inserts and nanofluid compared to plain tube.

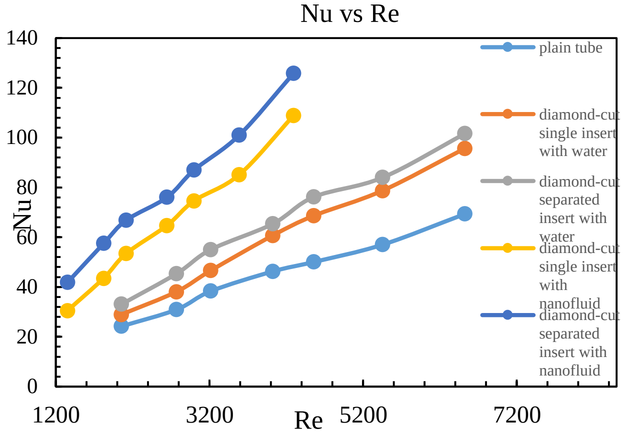


Figure 5: Variation of Nusselt number with Reynolds number

Friction factor variation with Reynolds number is shown in figure 6. Friction factor improved by 0.31 times and 1.76 times for water and for nanofluid with 0.01% volume concentration respectively compared to base fluid flowing through a tube with single insert. Again friction factor further improved by 0.61 times and 2.14 times for water and 0.01% nanofluid respectively compared to the base fluid flowing through a tube with separated inserts.

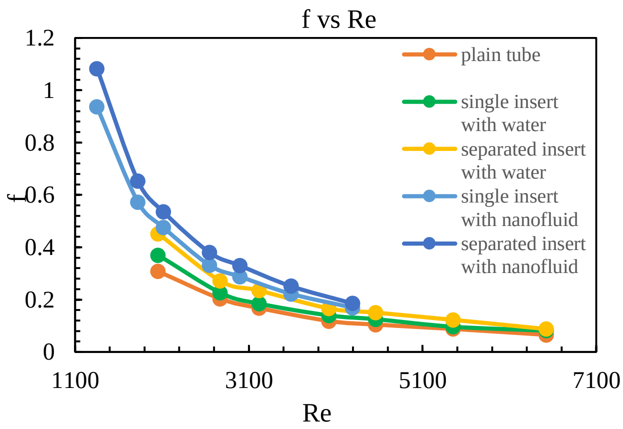


Figure 6: Variation of friction factor with Reynolds number

Figure 7 shows the variation of convective heat transfer coefficient with respect to Reynolds number. Average heat transfer coefficient increases for both the single and separated inserts with increasing Reynolds number. In case of diamond-cut single insert, with water the heat transfer coefficient increased 0.19~0.28 times than plain tube and with nanofluid it increased 0.15~0.44 times than plain tube. Whereas in case of diamond cut separated insert, with water coefficient of heat transfer increased 0.36~0.44 times than plain tube and with nanofluid it increased 0.58~0.61 times than the plain tube.

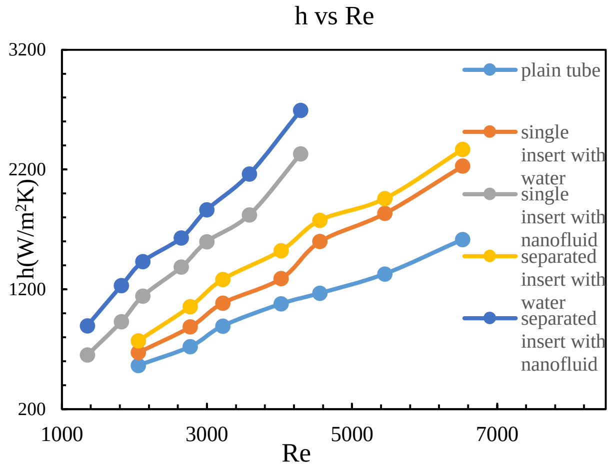


Figure 7: Variation of heat transfer coefficient with Reynolds number

From figure 8, it was observed that heat transfer efficiency was improved in terms of increasing the Reynolds number. The efficiency was found in the range of 1.19~1.37 compared to the plain tube for single insert with water, 1.15~1.44 for single insert with nanofluid, 1.36~1.46 for separated insert with water and 1.58~1.67 for separated insert with nanofluid. This variation of heat transfer efficiency is shown in figure 8.

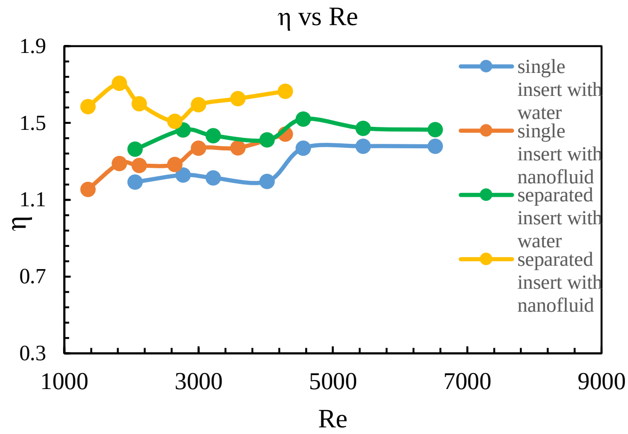


Figure 8: Variation of heat transfer enhancement efficiency with Reynolds number

Therefore, efficiency was improved when inserts were used and from above discussion it is clear that, among the used inserts the diamond-cut separated insert was efficient and better for both water and nanofluid.

5. CONCLUSIONS

Experimental exploration of heat transfer, heat transfer enhancement efficiency and friction factor of a circular tube with diamond-cut single and separated inserts with and without nanofluids are briefly described in current narration. The results are as follows:

i. The values of Nusselt number and friction factor for the copper tube with diamond-cut single and separated inserts were significantly higher than that of plain tube and largest value achieved for diamond-cut separated inserts along with nanofluid. The values were observed 0.74 times better in Nusselt Number and 2.14 times improved in friction factor relative to the plain tube.

ii. Coefficient of heat transfer was enhanced by 0.28 and 0.44 times than the smooth tube for single and separated inserts respectively with water. It was increased by 0.31 and 0.61 times than the smooth tube for single and separated inserts respectively with nanofluid. And clearly, the separated insert was better than the rest.

iii. The average heat transfer efficiency for single and separated insert along with water was found 1.28% and 1.45%. For nanfluid, efficiency was found 1.31% and 1.61% for single and separated inserts respectively. So, overall the separated insert is more efficient than the single insert for both the case with and without nanofluid.

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8. NOMENCLATURE

Symbol	Meaning	Unit
d	Tube diameter	(mm)
r	Radius	(mm)
L	Tube length	(mm)
A	Surface area	(m^2)
u_m	Mean velocity	(m/s)
V	Velocity	(m/s)
m	Mass flow rate	(kg/s)
ρ	Density	(kg/m^3)
μ	Dynamic viscosity	(kg/m-s)
C_p	Specific heat	(J/kg.K)
Q	Heat transfer rate	(W)
q	Heat flux	(W/m^2)
h	Heat transfer coefficient	($W/m^2.K$)
k	Thermal conductivity	(W/m.K)
T_o	Hot water temperature	(°C)
T_i	Cold water temperature	(°C)
$T1$	Thermocouple1 reading	(°C)
$T2$	Thermocouple2 reading	(°C)
$T3$	Thermocouple3 reading	(°C)
$T4$	Thermocouple4 reading	(°C)
T_b	Bulk Temperature	(°C)
T_{wo}	Outer surface temp.	(°C)
T_{wi}	Inner surface temp.	(°C)
Nu	Nusselt number	Dimensionless
ΔP	Pressure drop	Dimensionless
f	Friction factor	Dimensionless
Pr	Prandtl number	Dimensionless
Re	Reynolds number	Dimensionless
η	Thermal enhancement factor	Dimensionless