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Investigation of Heat Transfer Enhancement in a Pipe using Zinc Oxide/Water Nanofluid and Twisted Tape Insert

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Abstract

An experimental work was conducted for determining the coefficient of heat transfer and enhancement of heat transfer of heat exchanger using water and Nanofluid flowing through circular duct inserted with rotating twisted tape. A stainless-steel pipe of outer diameter 34mm and internal diameter of 30mm and a test section length of 800mm was used. The tape which is made to rotate inside the tube. An invariable heat of the tube was produced by using heaters located on the external part of the circular duct. In this work, an advanced category of fluids, which can be produced by suspending Nanoparticles in establishing fluids. Due to suspension of Nanoparticles the thermo-physical attributes of Nanofluids are changed when compared with those of currently used fluids and this represents the best hope for the improved heat carrier in the heat exchanger.

In the present investigation, an experimental study has been carried to determine the results of Nanofluid in the place of currently used heat transfer fluids like water, etc. For this we are comparing the experimental results obtained from experiments done on water and water based Zinc Oxide Nanofluid. The experiment is conducted using rotating twisted tape with the speed varying from 0, 150, 250 and 350 RPM and flow rate of 4, 6 and 8 LPM.

The outcome of the experimental study and possible gains of Nanofluids with zinc oxide nanoparticles have been approximated. With the use of Nanoparticle assisted fluids its thermal conductivity is more than the formal fluids as we obtained in the present work. Also increasing the heat transfer rate.

Keywords- Heat transfer, Nanofluids, Zinc Oxide, twisted tape.

NOMENCLATURE-

T	Temperature, °C
P	Pressure, N/m²
V	Velocity, m/s
Q	Heat supplied, Watt
P	Density, kg/m³
$\dot{m}$	Mass flow rate, Kg/s
φ	% volume concentration
$\bar{Q}$	Flow rate, m³/s
$\check{T}_{w,i}$	Average inside pipe temperature, °C
$\check{T}_{w,o}$	Average outside pipe temperature, °C
Ac	Cross sectional area of pipe, m²
As	Surface area of pipe, m²
Cp	Specific heat, J/Kg K
Di	Inside diameter of pipe, m
Do	Outside diameter of pipe, m
L	Length of pipe, m
Kw	Thermal conductivity of pipe, W/m K
H	Heat transfer coefficient, W/m² K
H	Pitch length, m
S	Spacing length, m
LPM	Litre per minute
RPM	Revolution per minute
Nu	Nusselt number
Re	Reynolds number
Pr	Prandtl number

1. Introduction

A heat exchanger is a gadget used to exchange heat between a solid object and a liquid, or between at least two liquids. The liquids might be isolated by a solid wall to avoid blending or they might be in direct contact. They are generally utilized as a part of room heating, refrigeration, cooling, control stations, concoction plants, petrochemical plants, oil refineries, flammable gas handling, and sewage treatment. The great case of a heat exchanger is found in an internal combustion engine in which a circulating liquid known as motor coolant moves through radiator coils and air flows past the loops, which cools the coolant and heats the approaching air. Another illustration is the heat sink, which is an uninvolved heat exchanger that exchanges the heat produced by an electronic or a mechanical gadget to a liquid medium, regularly air or a fluid coolant.

Heat exchange improvement is the way toward expanding the viability of heat exchangers. This can be accomplished when the heat exchange energy of a given gadget is expanded or when the weight misfortunes created by the gadget are decreased. An assortment of methods can be connected to this impact, including creating secondary flow or expanding limit layer turbulence.

A nanofluid is a liquid containing nanometer-sized particles, called nanoparticles. These liquids are designed colloidal suspensions of nanoparticles in a base liquid. The nanoparticles utilized as a part of nanofluids are commonly made of metals, oxides, carbides, or carbon nanotubes. Basic base liquids incorporate water, ethylene glycol and oil.

2. Methodology and Materials

The following Fig.1 shows the present experimental setup schematically and Fig.4.8. is assembled actual setup. At a distance of 100mm from the both ends of the pipe two holes are tapped for water to flow in and out through the pipe. Collar type heater of maximum 1.5 kW capacities is wound around the pipe to heat the water. 3 washer type thermocouples (K-type) on the outer surface of pipe are situated at different locations to give the temperatures T1, T2, T3 and for measuring the inlet and outlet water temperatures T4, T5 2 stem type thermocouples (K-type) are placed at the tapped holes. DC motor of maximum 1500 RPM and RPM sensor is coupled with shaft. Water pump with control valve is situated near the storage tank to pump the water from storage tank. The storage tank capacity is max 50 liters. On the panel board for taking the readings all indicators, controllers are fixed.

Fig.1 Assembled actual setup

2.1 Fabrication of Twisted Tape

The stainless-steel tape of length 800 mm, thickness 1.4 mm, and width 21.4 mm was taken. Two holes are made using drilling machine at both the ends of the strip. One end was held by the tool post and other end was twisted by giving a slow rotary motion. At a same time, tape to prevent deformation the tool post side was held under tension. As shown in Fig.2.

Fig.2 Twisted used in present work

2.2 Zinc Oxide Nanoparticles Specification

Table 1: Zinc Oxide Nanoparticles Specification

Molecular formula	ZnO
Purity	99.9%
Average particle size	30-50nm
Colour	Milky white
Morphology	Nearly spherical
Specific surface area (SSA)	20-60 m^2/g
Bulk Density	0.28-0.48 g/cm^3
True Density	6 g/cm^3

2.3 Thermo-Physical properties of ZnO and water

Table 2: Thermo-Physical properties of ZnO and water

Properties	ZnO	Water
Density (kg/m^3/)	6000	997
Thermal conductivity (W/mk)	29	0.628
Specific heat (J/Kg K)	514	4178
Viscosity (pa-s)	0.000132	0.000778

2.4 Preparation of nanofluid

In this present work, the ZnO nanoparticles were purchased from Nano Research Lab, Jharkhand India. First for 0.2% volume concentration ZnO/water nanofluid the weight of the nanoparticles was calculated. The nanoparticles were poured into the water and stirred for couple of hours. Till the nanoparticles were dispersed evenly in water.

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Fig.3 ZnO Nanoparticles sample

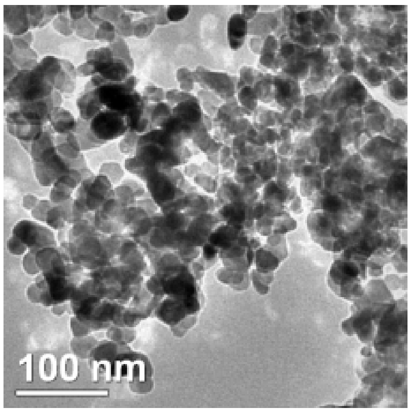

Fig.4 TEM analysis of ZnO nanoparticles

2.5 Volume Concentration of nanofluids

In this present work, 0.2% concentration of nanofluid is used. Using the law of mixture relation, the volume concentration of nanoparticles for preparing nanofluid is calculated. For 100 ml of water the weight of ZnO nanoparticles needed for preparation of as a base fluid is calculated using Eq.(1).

$$\varphi = \frac{\frac{W_{ZnO}}{\rho_{ZnO}}}{\left[\frac{W_{ZnO}}{\rho_{ZnO}} + \frac{W_{water}}{\rho_{water}}\right]} \qquad (1)$$

After finding the weight of zinc oxide nanoparticles for 0.2% of volume concentration for 100ml of water using the law of mixture relation. It is then poured into to the tank containing 15 liters of base fluid and stirred mechanically for 2 to 3 hours continuously. In this work surfactants or acid is used because acid may damage the test section and other parts by corrugating it.

2.6 Determination of thermo-physical properties of 0.2% ZnO nanofluid

The determine the convective heat transfer coefficient the significant properties of Nanofluids which are specific heat, density, thermal conductivity has to be determined. The thermo-physical properties of 0.2 concentration ZnO nanofluid are determined experimentally and the results are compared with the theoretical model.

a. Density of 0.2% concentration ZnO nanofluid-

Using Hydrometer, the density of the ZnO nanofluid is measured for 0.2% volume concentration. The experimental results are compared with theoretical data using the Eq.(2) as given below

$$\rho_{ZnO} = \varphi\,\rho_P + (1-\varphi)\rho_{water} \qquad (2)$$

b. Specific heat of 0.2% concentration ZnO nanofluid-

Specific heat capacity is the amount of heat energy required to raise the temperature of a substance per unit of mass. For 0.2% volume concentration, the specific heat can be measured and it is valid for a homogeneous mixture. It is given in the following Eq(3).

$$Cp_{nf} = \varphi\, Cp_{ZnO} + (1-\varphi)Cp_{bf} \qquad (3)$$

Where,

Cp_{nf} – Nanofluid specific heat

Cp – Nanoparticle specific heat

Cp_{bf} – Specific heat of base fluid

c. Thermal Conductivity of 0.2% concentration ZnO nanofluid-

In the present work, Maxwell model is used for finding the theoretical thermal conductivity for 0.2% volume concentration ZnO nanofluid. The equation is given by Eq.(4).

$$K_{nf} = \frac{K_p + 2K_{bf} + 2\varphi(K_p - K_{bf})}{K_p + 2K_{bf} + \varphi(K_p - K_{bf})} K_{bf} \qquad (4)$$

d. Viscosity of 0.2% concentration ZnO nanofluid-

Viscosity correlation was built by Einstein for Nanofluids when the volume concentration of Nanoparticles is lower than 5% concentration is given by Eq.(5) in terms of nanoparticle volume concentration in the base fluid.

$$\mu_{nf} = \mu_{bf}(1 + 2.5\varphi) \qquad (5)$$

3. Experimental Procedure

The experiment was done using the experimental setup as shown in Fig.5. Conduct the experiment using water as the working fluid. Start the test rig initially setting the switch ON the main console, then the power supply is adjusted using the dimmer to a constant heat rate. The experiment is carried with a different rotation speed of the twisted tape for 0, 150, 250 and 350 RPM and for different flow rates of 4, 6, and 8 LPM. The test fluid flows through the pipe and waited till the temperatures remains steady for 2 to 3 minutes. Then the readings are noted down. The

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flow rate is set by controlling the valve. The readings are taken at 15 minutes' interval, data are shown in the indicators. The readings are taken and tabulated then proceeded for further calculation. In this, we calculate the heat transfer coefficient, Nusselts number, Re number, and Prandtl number. And this is base results for our further validation purpose. The temperature of the test section is raised by adding heat on the outer surface of the test section using a variable dimmer stat of maximum capacity of 4 amps. After some time, the temperature reaches a steady state. The temperatures are displayed on a temperature measurement indicator. On the outer surface of the test section three thermocouple sensors are placed to determine the surface temperatures T1, T2, and T3 and at inlet and outlet hose two separate thermocouple sensors are placed for determining the water inlet and outlet temperature T4 and T5 respectively. The same procedure is again repeated for nanofluid which is 0.2% concentration ZnO in water. But first water is made to flow in the pipe and after steady state is reached, water is replaced by nanofluid and the temperature readings for the nanofluid is noted down.

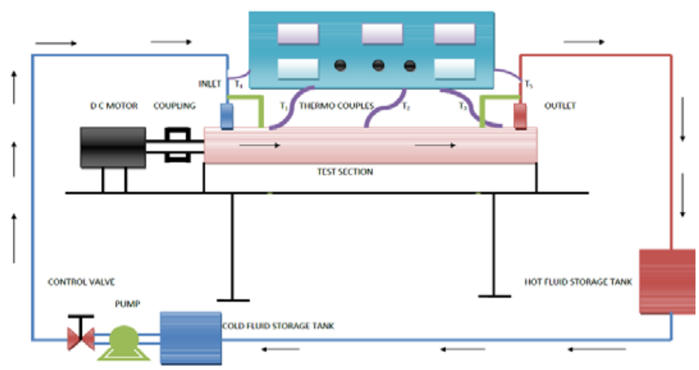

Fig.5 Experimental setup

3.1 Calculation Methodology-

Heat supplied by heater to working fluid is calculated by measuring heat added to the fluid. Heat added to working fluid is given by,

$$Q_{water} = \dot{m}\, C_p\, (T5\text{-}T4) \qquad (6)$$

Where,

$$\dot{m} = \rho\, A_C\, V \qquad (7)$$

$\bar{Q}$ → flow rate in m^3/s

$\dot{m}$ → Mass flow rate of working fluid in *Kg/s*

A_C → Cross sectional area of pipe in m^2

V → Velocity of flow in *m/s*

C_p→ Specific heat of fluid in *KJ/Kg K*

T5 & T4 → Outlet and Inlet temperature of fluid in *K*

The heat transfer rate is assumed to be steady state and is equal to the convective heat transfer which is given by,

$$Q_{water} = Q_{convected} \qquad (8)$$

The convective heat transfer is given by

$$Q_{convected} = h\, A_s\, (T_{w,i} - T_b) \qquad (9)$$

h→ Convective heat transfer coefficient in W/m2 K

A_s → Surface area of pipe in m2

$T_{w,i}$→ average inside tube temperature in K

T_b→ Bulk temperature in K

$$A_s = \pi\, D_i\, L \qquad (10)$$

A_s → Surface area of pipe, in m2

D_i→ Inside diameter of pipe in m

L → Length of pipe in m

$$T_{w,i} = \frac{T_{w,o} - (Q\, \ln\frac{D_o}{D_i})}{2\pi\, K\, L} \qquad (11)$$

$$T_b = \frac{(T5 + T4)}{2} \qquad (12)$$

$$T_{w,o} = \frac{(T1+T2+T3)}{3} \qquad (13)$$

$T_{w,o}$→ Average outside pipe temperature in K

D_o→ Outside diameter of pipe in m

K → Thermal conductivity of pipe in W/m K

T_b → Bulk mean temperature of the water

From above equations, convective heat transfer coefficient is given by

$$h = \frac{(m\, Cp\, (T5-T4))}{(As\, (Tw,i-Tb)} \qquad (14)$$

The Nusselt number with twisted tape insert is given by

$$Nu = \frac{(h\, Di)}{K_f} \qquad (15)$$

K_f → Thermal conductivity of fluid in W/m K

Re number at given flow rate is calculated by

$$Re = \frac{(\rho V\, Di)}{\mu} \qquad (16)$$

Prandtl number is determined by

$$Pr = \frac{(\mu\, C_P)}{K_f} \qquad (17)$$

For 2100<Re<10000, the theoretical Nusselt number is calculated using the Eq.5.12

$$Nu_{th} = 0.036\, (Re^{0.8})(\, Pr^{0.33})(D/L)^{0.055} \qquad (18)$$

$$h_{th} = (Nu_{th} k)/D_i \qquad (19)$$

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4. Results and Discussion

The variation of coefficient of heat transfer and Nusselt number with Reynolds number is discussed for both water and 0.2% concentration ZnO/water nanofluid. Its validated for different flow rates that is 4, 6, and 8 LPM and also for different rpm that is 0, 150, 250, and 350 rpm. In case of water the validation is done for with and without the use of twister tape.

Case (I): Variation of coefficient of heat transfer and Nusselt number with Reynolds number for water as working medium.

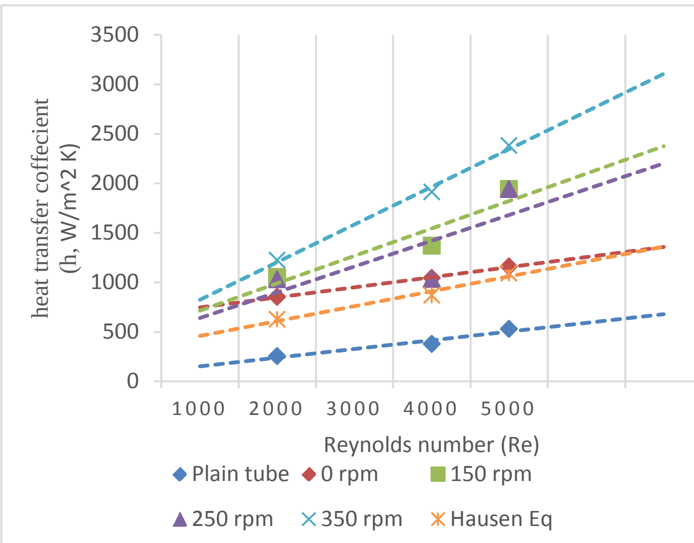

Fig.6 Variation of coefficient of heat transfer with Reynolds number for water as working medium.

The variation of the heat transfer coefficient with Reynolds number for plain tube and different RPM of twisted tape inserts for the experimental results and Hausen equation for flow rates of 4, 6 and 8 LPM is shown in Fig.6. The graphs clearly show that the convective heat transfer coefficient increases with increase in flow rate and also with increase in rotational speed of the twisted tape. It is found to be 88.14%, 83.14%, and 79.70% increment in heat transfer coefficient for the LPM of 4, 6, and 8 LPM respectively. The heat transfer rate is observed to higher when twisted tapes are used and lower when twister tape is not used. As the flow rate and RPM of the twisted tape increases heat transfer rate also increases.

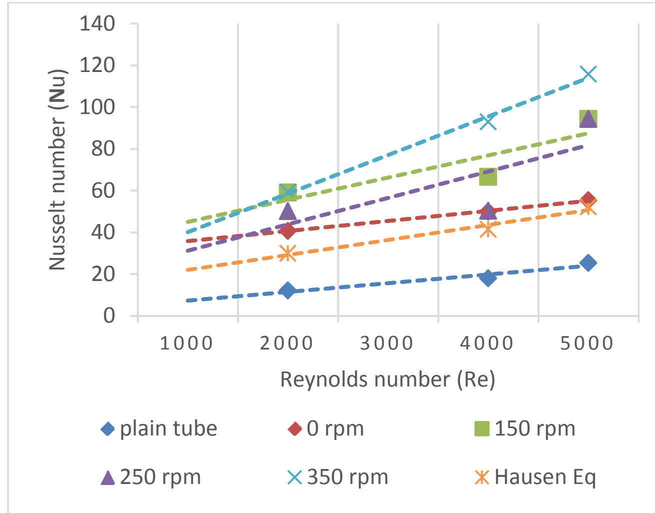

Fig.7 Variation of Nusselt number with Reynolds number for water as working medium

In Fig.7 we can observe that here is an enormous increase in Nusselt number and hence in heat transfer coefficient when twister tape is used at different rpm of 0, 150, 250, and 350 rpm and at different flow rate of 4, 6, and 8 LPM. It is found to be 86.55, 81.85%, and 76.99% increment in Nusselt number for the different LPM 4, 6, and 8 LPM respectively.

Case (II): Variation of coefficient of heat transfer and Nusselt number with Reynolds number for 0.2% concentration ZnO/water nanofluid using twister tape as working medium.

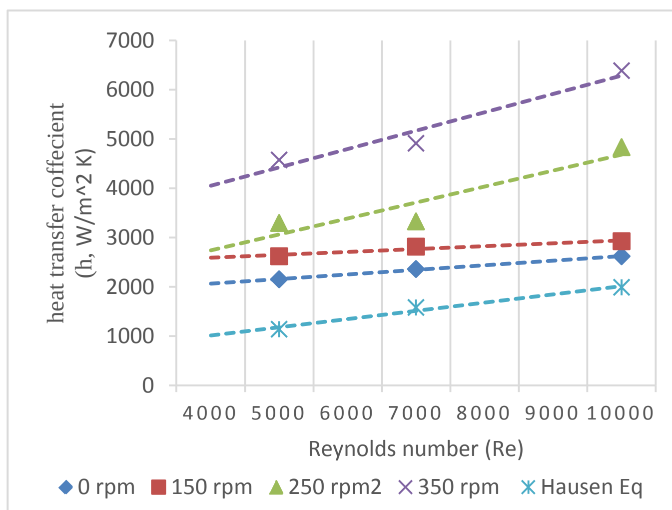

Fig.8 Variation of coefficient of heat transfer with Reynolds number for 0.2% concentration ZnO/water nanofluid using twister tape as working medium

The variation of the heat transfer coefficient with Reynolds number for different RPM of twisted tape inserts for the experimental results and Hausen equation for different flow rates of 4, 6 and 8 LPM is shown in Fig.8. The graphs clearly show that the convective heat transfer coefficient increases with increase in flow rate and also with increase in rotational speed of the twisted tape. It is found to be 68.32%, 61.03%, and 62.7% increment in heat transfer coefficient for LPM of 4, 6, and 8 LPM at 350 RPM respectively. As the RPM of the twisted tape increases heat transfer rate also increases.

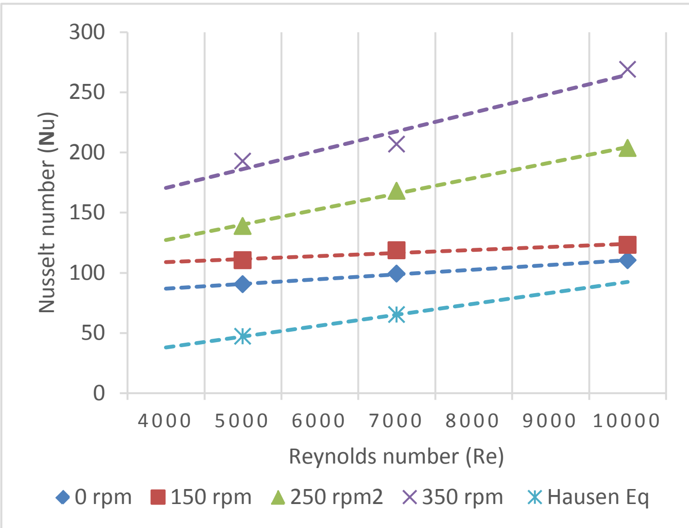

Fig.9 Variation of Nusselt number with Reynolds number for 0.2% concentration ZnO/water nanofluid using twister tape as working medium.

In Fig.9 we can observe that here is an increase in Nusselt number and hence in heat transfer coefficient when twister tape is used at different rpm of 0, 150, 250, and 350 rpm and at different flow rate of 4, 6, and 8 LPM. It is found to be 69.19%, 55.09%, and 56.97% increment in Nusselt number for LPM of 4, 6, and 8 LPM at 350 RPM respectively.

Case (III): Comparison of heat transfer coefficient and Nusselt no with Reynolds number for Water and 0.2% concentration ZnO/water nanofluid at 350 rpm.

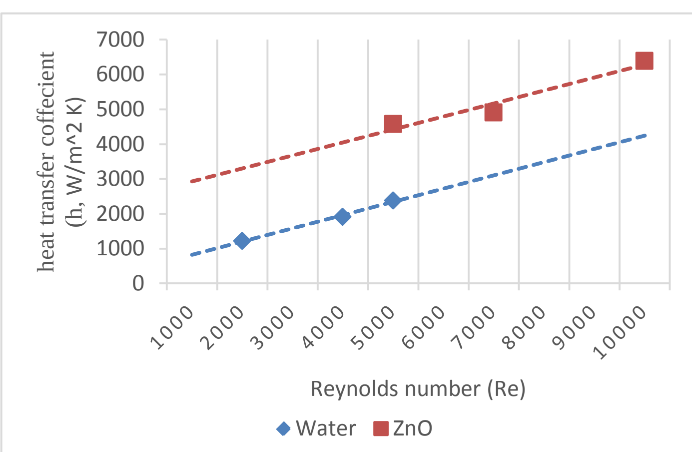

Fig.10 Variation of coefficient of heat transfer with Reynolds number for water and ZnO at350 RPM

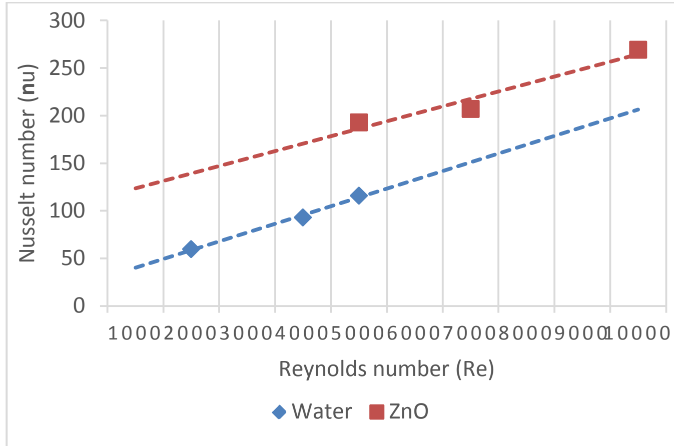

Fig.11 Variation of Nusselt no with Reynolds number for water and ZnO at 350 RPM

In Fig.10 and Fig.11 we can clearly see the variation of heat transfer coefficient and Nusselt number respectively for ZnO and water at 350 RPM. It is evident from the figure that the heat transfer coefficient for Zinc Oxide Nanofluid is 62.71% times and the Nusselt number for Zinc Oxide Nanofluid is 56.97% times more than the water at same operating conditions.

5. Conclusions

The flow rate of the fluid greatly influenced the heat transfer rate. At higher Reynolds number, higher heat transfer rate can be obtained. Using twisted tape insert cause a secondary swirling motion of the fluid inside the tube there by generating the new thermal boundary layer for fluid flow. The time of residence for the fluid in the tube increases with the insertion of twisted tape. Thereby increasing heat absorption capability of the working fluid. Turbulence motion of the fluid is created by twisted tape insert. And as the rpm of the twisted tape increases, more turbulence is created thereby increasing the heat transfer rate. In the nanoparticle, suspended fluid (0.2% concentration ZnO/water nanofluid) there is increase in heat transfer due to the enhanced thermal conductivity. The use of Nanofluids helps in increasing the heat transfer rate. And are better replacement fluids in the place of conventional heat transfer fluid.

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