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ENHANCEMENT OF HEAT TRANSFER USING COMBINATION OF NANOFLUIDS (Al_2O_3/WATER) AND PERFORATED TWISTED TAPE INSERT

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Abstract*-The research was carried out with perforated twisted tape insert and different volume fraction (0.1% & 0.2%) of Al_2O_3/Water. A stainless steel perforated twisted tape insert was conducted into a plain tube. The test section consisted of a circular copper tube of 26.6 mm inner diameter, 900 mm length with five K-type thermocouples. Perforated twisted tape insert had a length of 812.8 mm, width of 20 mm, thickness of 1.5 mm, twist ratio of 5.8. Nusselt numbers for combination of perforated twisted tape insert and 0.2% volume fraction of Nano fluids (Al_2O_3/Water), combination of perforated twisted tape insert and 0.1% volume fraction of Nano fluids (Al_2O_3/Water), combination of perforated twisted tape insert and water increased 41%, 25% and 14% respectively than the plain tube. The combination of perforated twisted tape insert and 0.2% volume fraction of Al_2O_3 has been best for the enhancement of heat transfer rate compared to the others.*

Keywords: Nanofluids, Twist Ratio, Insert, Nusselt Number, Friction Factor

1. INTRODUCTION

The technique of increasing heat transfer is constantly improving. At the start of the 20th century, the experiment to improve heat transfer began [1]. Increasing energy demand resulted in high energy and material costs, resulting in increased effort to produce heat exchanger equipment with high performance. There are various techniques to increase the heat transfer. Among them using insert is the passive techniques to enhance the tube side heat transfer. Perforated twisted tape insert generates swirl flow that reduces thermal boundary layer thickness and increases convective heat transfer. It can be used in many engineering applications, such as heat recovery, air conditioning and cooling systems and chemical reactors [2]. When a fluid contains less than 100nm size particle is called nanofluids. Previous research has shown that the physical characteristics of nanofluids have improved in terms of base fluids like oil or water such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer [3]. It is clear that research has been popularized in recent years on the uses of nanofluids. A number of studies indicate that heat transfer with nanofluid has been increased [4]. Akbari and Behzadmehr [5] studied Al_2O_3/water nanofluid mixed convection heat transfer in a horizontal tube with constant heat flux. Their results show that using 2% and 4% volume Al_2O_3 particles, the convective heat transfer is increased from 9 to 15%. Duangthongsuk and Wongwises [6] investigated with 0.2% TiO_2 nanoparticles in water that enhance heat transfer coefficient 6 to 11%. Teng et al. [7] investigated the changes of different size nanoparticles in heat transfer of water based Al_2O_3 nanofluid. They concluded that for smaller size nanoparticles thermal conductivity is higher. Heris et al. [8] analyzed the heat transfer performance of Al_2O_3/water and CuO/water nanofluids. They found that water based Al_2O_3 nanofluid enhance more heat transfer than water based CuO nanofluids. Salam et *al.* [9] experimented with rectangular shaped twisted tape insert to increase the heat transfer. Range of Reynolds number was 10000-19000 and the variation of heat flux was 14 to 22 kW/m^2 for smooth tube and 23 to 40 kW/m^2 for insert in tube. Nusselt number increased 2.3 to 2.9 times and friction factor increased 1.4 to 1.8 times than the plain tube without insert. Sarada et *al.* [10] investigated with twisted tape inserts for varying width ranging from 10mm-26 mm. The Reynolds number range was 6000-13500. For 26mm width twisted tape insert heat transfer increased 36 to 48% than plain tube without insert and for 22mm width twisted tape insert heat transfer increased 33 to 39% than plain tube without insert. Hasan and Sumathy [11] obtained that helical tape inserts could increase the heat transfer rate 1.15-1.7 times than the plain tube when Reynolds number ranging from 8,050-13,600.

2. EXPERIMENTAL FACILITY

For the enhancement of heat transfer rate at first a plain tube without perforated twisted tape insert of stainless steel was used. Then a perforated twisted tape insert of stainless steel through the plain tube was used. At last the combination of perforated twisted tape insert and Nano fluids(Al_2O_3/Water) was used. The test section consists of a tube which is made of copper with 26.6mm and 30mm internal and external diameter respectively. Constant heat flux was maintained by nichrome wire which was surrounded over test section. By five K type thermocouple outer surface temperature of test section was measured. By two thermometers inlet and outlet fluid temperature was measured. At mixing box, the outlet thermometer was placed. By the manometer pressure drop was measured for the test section. Open loop system was used for fluid flow. Rotameter was used to determine the flow rate of fluid. Base fluid was flow with the help of centrifugal pump. Constant voltage was applied with the help of voltage regulator. When all the device was reached at steady state condition data were taken by changing the fluid flow rate [12].

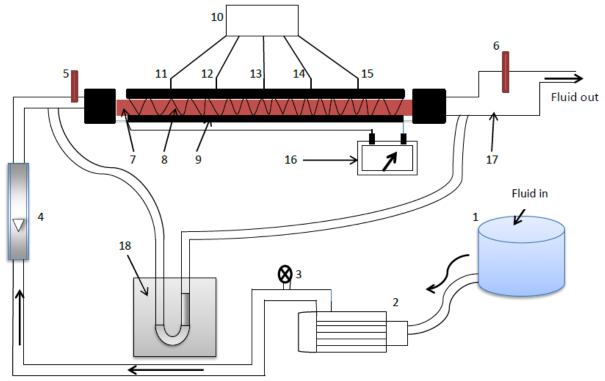

Figure 1: Diagram of research set up

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
11-15. Thermocouples (5)
16. Voltage regulator
17. Mixing chamber
18. U-tube manometer

Figure 2 shows the perforated twisted tape insert that has a length of 812.8 mm, width of 20 mm, thickness of 1.5 mm, twist ratio of 5.8 and perforation of 4mm.

Figure 2: Photographic view of insert

3. MATHMATICAL MODELING

Required equations are given below,

Volume concentration, $\varphi=\frac{\left(\frac{W}{\rho}\right)Al2O3}{\left[\left(\frac{W}{\rho}\right)Al2O3+\left(\frac{W}{\rho}\right)bf\right]}$ (1)

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

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

Bulk temperature, $T_b=\frac{To+Ti}{2}$ (4)

Outer surface temperature, $T_{wo}=(T_1+T_2+T_3+T_4+T_5)/5$ (5)

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

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

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

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

Reynolds number, $Re=\frac{\rho\ Um\ di}{\mu}$ (10)

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

Experimental Nusselt number, $Nu_{exp}=\frac{hdi}{k}$ (12)

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

where n=3/10 for cooling, 2/5 for heating

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, $fex=\frac{\Delta P}{(\frac{L}{di})(\frac{\rho U_m^2}{2})}$ (16)

Viscosity of nanofluid, $\mu_{nf}=(1+2.5\varphi)\ \mu_{bf}$ (17)

Density of nanofluid, $\rho_{nf}=\varphi\rho_{np}+(1-\varphi)\ \rho_{bf}$ (18)

Specific heat of nanofluid, $C_{Pnf}=\varphi C_{P,np}+(1-\varphi)\ C_{P,bf}$ (19)

Thermal conductivity of nanofluid,

$k_{nf}=[k_{np}+2k_{bf}+2\varphi\ (k_{np}-k_{bf})\ /\ [k_{np}+2k_{bf}-\varphi(k_{np}-k_{bf})]$ (20)

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4. RESULTS AND DISCUSSION

After checking the accuracy of the set up all data are collected for plain tube with water, insert with water, insert with different volume fraction of Al_2O_3. Heat transfer coefficient, Nusselt number, friction factor was calculated by eqn 8,12 and 16 respectively. Figure 3 shows the variation of heat transfer coefficient with Reynolds number. With the increase of Reynolds number convective heat transfer coefficient increases. In this research the range of Reynolds number was 4433 to 14340. For the plain tube without insert with water the range of heat transfer coefficient (h) was 531-1431 W/m^2k. With the use of insert with water the values of h were 612-1709 W/m^2k. But when 0.1% Al_2O_3 nanoparticle was mixed with base fluid water, the value of h increased significantly and the value ranging from 1404 to 3798 W/m^2k. With 0.2% Al_2O_3 volume fraction in base fluid the value of h was 1598-4298 W/m^2k.

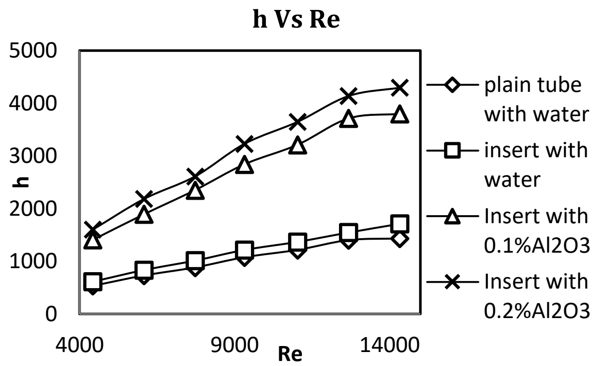

Figure 3: Variation of Heat transfer coefficient with Reynolds Number

Figure 4 shows the variation of Nusselt number with

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Reynolds number. For plain tube without insert the Nusselt number was 22.77-61.37. The value of Nusselt number was 26.23-73.32 for insert with water. For 0.1% and 0.2% Al_2O_3 in base fluid the Nusselt number was 28.51-77.12 and 32.45-87.28 respectively.

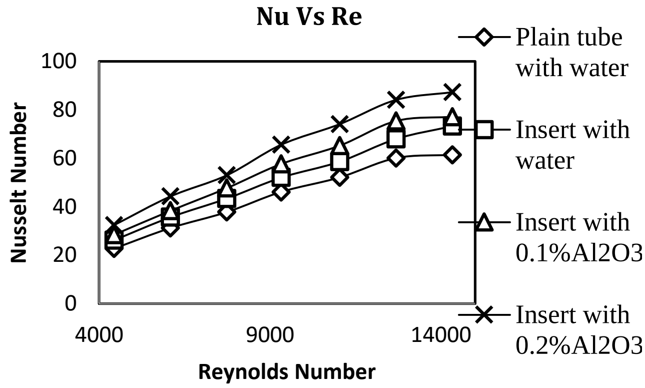

Figure 4: Variation of Nusselt Number with Reynolds Number

Figure 5 shows that how Nusselt number increases with respect to plain tube without insert. Nusselt number increases 1.12 to 1.19 times for insert with water than plain tube without insert. For 0.1% Al_2O_3 and insert Nusselt number increases 1.22 to 1.26 times than plain tube. For 0.2% Al_2O_3 and insert Nusselt number increases 1.4 to 1.42 times than plain tube without insert.

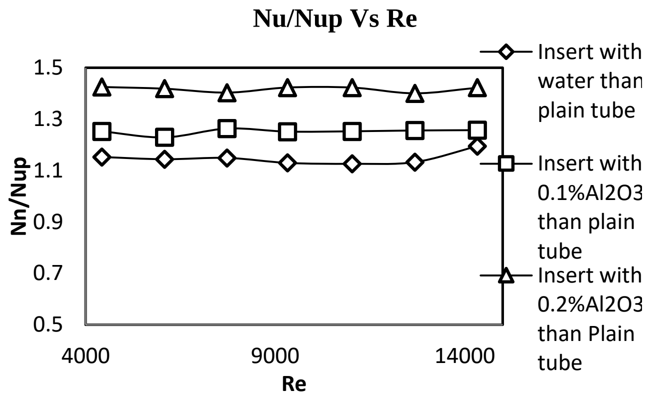

Figure 5: Variation of Nu/Nu_p with Reynolds Number

Figure 6 shows the friction factor variation with Reynolds number. For lower Reynolds number friction factor is higher. Friction factor decreases with the increase of Reynolds number. For Plain tube without insert, insert with water, insert with 0.1% Al_2O_3 in base fluid and insert with 0.2% Al_2O_3 in base fluid the value of friction factor was 0.09-0.20, 0.12-0.30, 0.16-0.35 and 0.20-0.40 respectively.

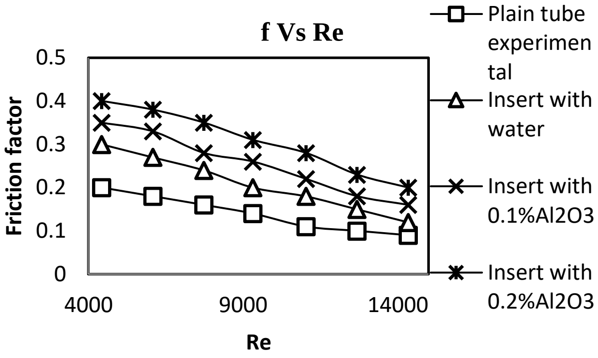

Figure 6: Variation of friction factor with Reynolds Number

Figure 7 shows the increase of friction factor compared to plain tube without insert. Friction factor increases 1.33 to 1.62 times for insert with water than plain tube without insert. For 0.1% Al_2O_3 in base fluid and insert friction factor increases 1.75 to 2 times than plain tube without insert. For 0.2% Al_2O_3 in base fluid and insert friction factor increases 2 to 2.54 times than plain tube without insert.

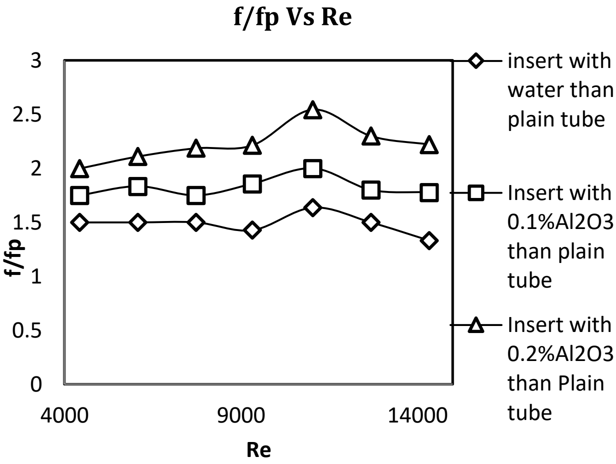

Figure 7: Variation of f/f_{plain} with Reynolds Number

5. CONCLUSION

It is necessary to determine the tube side heat transfer coefficient. Heat transfer coefficient, Nusselt number increases with Reynolds number but friction factor decreases with Reynolds number. Higher convective heat transfer coefficient is obtained for the combination of 0.2% Al_2O_3 and insert. For the combination of insert with 0.2% Al_2O_3, 0.1% Al_2O_3 and insert with water average increase of Nusselt number is 1.42, 1.25 and 1.14 times than the plain tube without insert. For the combination of insert with 0.2% Al_2O_3, 0.1% Al_2O_3 and insert with water average increase of friction factor is 2.22, 1.82 and 1.48 times respectively than the plain tube without insert.

6. ACKOWLEDGEMENT

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8. NOMENCLATURE

Symbol	Meaning	Unit
Φ	Volume fraction	Dimensionless
ρ_{A2O3}	Al_2O_3 Density	kg/m^3
W	Amount of Al_2O_3	gm
d_i	Inside diameter of tube	m
A_x	Area of cross sectional	(m^2)
A_s	Tube surface area	(m^2)
L	Test section length	(m)
T_b	Bulk temperature	(^0C)
T_o	Outer temperature of fluid	(^0C)
T_i	Inlet temperature of fluid	(^0C)
T_{1-5}	Termocouple reading	(^0C)
Q	Heat added	(W)
m	Mass flow rate of fluid	(kg/s)
C_p	Specific heat of water	(J/kg^0C)
T_{wi}	Test section inner surface temperature	(^0C)
T_{wo}	Test section outer surface temperature	(^0C)
U_m	Velosity	(m/s)
K_{Cu}	Thermal conductivity of copper tube	($W/m^2\,^0C$)
Re	Reynolds number	Dimensionless
Pr	Prandtl Number	Dimensionless
Nu_{th}	Theoretical Nusselt number for plain tube	Dimensionless
Nu_{exp}	Experimental Nusselt Number	Dimensionless
Δp	Pressure difference	(N/m^2)
Δh	Manometer difference	(m)
f_{th}	Theoretical Friction Factor for plain tube	Dimensionless
f_{exp}	Experimental friction factor	Dimensionless
μ_{bf}	Viscosity of base fluid	(kg/ms)
μ_{nf}	Viscosity of nanofluid	(kg/ms)
ρ_{nf}	Density of nanofluid	(kg/m^3)
ρ_{bf}	Density of base fluid	(kg/m^3)
C_{Pnf}	Specific heat of nanofluid	(J/kg^0C)
C_{Pbf}	Specific heat of basefluid	(J/kg^0C)
k_{nf}	Thermal conductivity of nanofluid	($W/m^2\,^0C$)
k_{bf}	Thermal conductivity of base fluid	($W/m^2\,^0C$)

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