Experimental Investigation on Preparation and Analysis of Al_2O_3/TiO_2-water Nanofluids

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Abstract. Nano fluids is defined as the dispersion of the nanoparticles in the conventional heat transfer such as water, ethylene glycol etc which enhances the heat transfer performance compared to conventional fluids. Heat recovery is the capture of energy contained in the fluid which would otherwise be lost to the surroundings. This heat recovery is generally obtained from heat exchanger in most of the engineering systems and has a wide variety of applications like in power plants, nuclear reactors, heat recovery systems, processing industries, refrigeration and air conditioning systems etc. In the present study, a twisted helical tube heat exchanger is used as a heat recovery system. The twisted helical tube heat exchanger, through which hot water flows, is enclosed in a shell through which nano fluid flows. The centrifugal force developed inside the twisted helical tube results in the development of a secondary flow which is the key factor for enhancing the rate of heat transfer. This present study focuses on the experimental study and analysis on $Al2O_3$-TiO_2 nanofluids in twisted helical tube heat exchanger by using two step method. The present study shows the overall heat transfer coefficient, Reynolds number, Nusselt number, Dean number, Helix number and effectiveness of $Al2O_3$-TiO_2 nanofluids.

Keywords— Twisted helical tube heat exchanger, $Al2O_3$-TiO_2 nano fluids, heat transfer enahancement, effectiveness.

1. Introduction

Thermal properties of coolants play an important role in heating and also in cooling applications. Conventional coolants such as water, engine oil, and ethylene glycol have inherently poor thermal conductivity which makes them inadequate for high cooling applications. Due to the low heat transfer properties of conventional coolants, the performance enhancement and the compactness of heat exchangers is affected. So, there is a need for the improvement of heat transfer properties of conventional coolants. The heat transfer properties of the conventional coolants can be improved by suspending the solid particles. The recent studies have proven that the suspension of the nano particles in the base fluid will alter the heat transfer properties of the coolants.

1.1 History of nanofluid

The twenty-first century is an era of technological development and has already seen many changes in almost every industry. The introduction of nano science and technology is based on the famous phrase "There's Plenty of Room at the Bottom" by the Nobel Prize-winning physicist Richard Feynman in 1959. Feynman proposed this concept using a set of conventional-sized robot arms to construct a replica of themselves but one-tenth the original size then using that new set of arms to manufacture a even smaller set until the molecular scale is reached.

1.2 Introduction to heat exchanger

Heat exchanger is nothing but a device which transfers the energy from a hot fluid medium to a cold fluid medium with maximum rate, minimum investment and low running costs.

1.3 History of heat exchanger

In the 1950s, aluminium heat exchangers made moderate inroad in the automobile industry with the invention of the vacuum brazing technique, large scale production of aluminium-based heat exchangers began to raise and grow resulting from advantages of the controlled atmosphere brazing process (Nocolok brazing process introduced by ALCAN). With increasing years introduction of “long life” (highly corrosion resistant) alloys further improved performance characteristics of aluminium heat exchangers. Extra demands for aluminium heat exchangers increased mainly due to the growth of automobile air-conditioning systems.

1.4 About heat exchanger

The heat transfer in a heat exchanger involves convection on each side of fluid and conduction taking place through the wall which is separating the two fluids. In a heat exchanger, the temperature of fluid keeps on changing as it passes through the tubes and also the temperature of the dividing wall located between the fluids varies along the length of heat exchanger.

Examples:

- Boilers, super heaters, reheaters, airpreheaters
- Radiators of an automobile.
- Oil coolers of heat engine
- Refrigeration of gas turbine power plant.
- In waste heat recovery system.

Types:

- Direct contact type of heat exchanger,
- Non contact type of heat exchanger.

Direction of motion of fluid:

- Parallel flow,
- Counter flow
- Mixed flow.

1.5 Material and Methods Nanofluids

Nanofluids are liquids that contains solid nanoparticles with size typically of 1 to 100 nm suspended in liquid. Nanofluids have become the point of interest due to the reports of improved heat transfer properties. When compared to the larger size particles, the resistance to the sedimentation shown by the nanoparticles is higher because of the Brownian motion. The nanofluidis with stable suspension for long durations can be achieved by reducing the density between solids and liquids or by increasing the viscosity of the liquid.

1.6 Properties of Nanofluid

Three properties that make nanofluids promising coolants are:

- Increased thermal conductivity,
- Increased single-phase heat transfer,
- Increased critical heat flux.

Therefore, exploiting the unique characteristics of nanoparticles, nanofluids are created with two features very important for heat transfer systems: (i) high stability, and (ii) high thermal conductivity.

1.7 Effect of Nanoparticles in Base Fluid

Compared to micrometer sized particles, nanoparticles possess high surface area to volume ratio due to the occupancy of large number of atoms on the boundaries, which make them highly stable in suspensions. Since the properties like the thermal conductivity of the nano sized materials are typically an order of magnitude higher than those of the base fluids, nanofluids show enhancement in their effective thermal properties. Due to the lower dimensions, the dispersed nanoparticles can behave like a base fluid molecule in a suspension, which helps us to reduce problems like particle clogging, sedimentation etc. found with micro particle suspensions. The combination of these two features; extra high stability and high conductivity of the nanofluids make them highly preferable for designing heat transfer fluids. The stable suspensions of small quantities of nanoparticles will possibly help us to design lighter, high performance thermal management systems.

1.8 Applications

Nanofluids can be used as coolants in various application such as electronic power circuits, car engines, HVAC, high power lasers, X-ray generators, boilers, nuclear reactor, power plants, microelectronics, manufacturing, metrology, defense etc. So the enhanced heat transfer characteristics of nanofluids may offer the development of high performance, compact, cost effective liquid cooling.

Table 1: Dimensions of Coil

D_i(m)	D_o(m)	P(m)	D_{mean} (m)	D_{shell}(m)
0.008	0.009	0.02	0.035	0.075

Table 2: Manufacturing of Shell

Component	Material
Helical coil	Copper
Shell	Poly vinyl chloride
Insulation	Asbestos
End caps	Poly vinyl chloride

Table 3: Quantity and Specifications

QUANTITY	SPECIFICATIONS
Shell	1 No.
Diameter of shell	0.075m
Length of shell	0.53m
End cap	2 No's
Diameter of end cap	0.08 m
Thickness of shell	0.002 m

Table 4: Thermo Physical Properties of Nano-particles & Base Fluids

Property	Water	Al_2O_3	TiO_2
Thermal Conductivity k (W/m^0C)	0.68	0.38	0.151
Viscosity μ (m^2/s)	0.62	0.0041	0.003
Density ρ (kg/m^3)	992	3970	4230
Heat Capacity Cp (J/kg^0C)	4182	765	611

2. Fabrication of Twisted Helical Tube Heat Exchanger

Initially copper tube of length 4m is filled with sand and ends of the tube is closed with caps. This is done to prevent crimpling of tube while bending the tube in making process of helical form. The tube with sand is now heated to make it soft and malleable to bend the tube.

Now the tube is twisted for each twist of 180^0 with an equal interval of over a tube length of 4m. The twisted tube is helically wound for a core diameter of 0.035m by maintaining a pitch of 0.02m for a total number of turns.

The twisted helical tube is concentrically inserted in PVC shell of 0.075m diameter and 0.53 m length by providing shell end caps. The twisted helical tube heat exchanger is provided with hot water and nanofluids entrance and exit at shell and tube. It is also arranged for measuring for inlet and outlet temperatures of hot and nanofluids by using digital probes. The hot water pump (0.5hp) is arranged for the supply of hot water through copper tube from hot water tank. The water tank is provided with immersion heaters for a total heat load of 3000watts.

2.1 Preparation Of Nano Fluid

Nano fluids are mainly made up of metals, oxides, carbides and carbon nano tubes that can easily be dispensed in heat transferring fluids, such as water, ethylene glycol, hydrocarbons and fluorocarbons by addition of stabilizing agents

Single-Step Direct Evaporation Method

In this method, the direct evaporation and condensation of the nanoparticles in the base liquid are obtained to produce stable nanofluids. Moreover, nanofluids made using this method showed higher conductivity enhancement than the ones made using 2-step method. But a disadvantage of the method is that only low vapor pressure fluids are compatible with the process .It limits the applications of the method.

Two-Step Method

In this method, nanoparticles are first prepared in a form of powders by physical or chemical methods, e.g. grinding, laser ablation, inert gas condensation, chemical vapor deposition, sol-gel processing, etc. and then suspended in base fluid. Nanopowders were mixed with water and stabilizers and then sonicated by ultrasonic mixer for a set period of time. This method of production is cheaper, because nanopowders are produced on large scale.

However, due to large and active surface area nanoparticles tend to agglomerate and settle down in the base fluid. Therefore, in order to prepare a stable nanosuspension sonication, stabilizers/surfactant are added. In this method a small amount of suitable etc. So the enhanced heat transfer characteristics of nanofluids may offer the development of high performance, compact, cost effective liquid cooling.

3. Experimental Setup and Working

Fig. 1 Experimental setup of twisted helical tube heat exchanger

3.1 Setup of the system

The experimental setup shown in figure1 represents the experimental setup layout. It is a twisted helical tube heat exchanger consisting of a test section, a constant temperature bath (nearly 180 litres capacity) for supplying hot water, heaters, pump, control systems, nanofluid tank & temperature indicators. The twisted helical tube is having dimensions of 4m length of copper tube, internal diameter of 0.008m and outer diameter of 0.009m. Shell pipe is having an internal diameter of 0.075m and outer diameter of 0.078m.

The outer surface of pipe is well insulated by using 0.015m diameter asbestos rope to reduce heat losses to the atmosphere. The flow rates are regulated by using measuring jar of 1 litre capacity and the time taken by using a stop watch

The immersion heaters are placed in lower tank filled with water. The outlet of twisted helical tube heat exchanger is directed to small tank so that the lower tank is maintained at constant temperature. The inlet of shell is connected to nanofluid tank and outlet is left to the same bath tub where the same nanofluid recirculated to the test rig.

4. Preparation of Al_2O_3 and TiO_2 nanofluid

In this paper, a new combination of Al2O3-TiO2 nanofluid with water as base fluid is synthesized by using Two step method withhelp of the stirring equipment. For 0.1% volume concentration (for 10 liters of water 2x 7.5=15.2 grams of Al2O3) hybrid nanofluid is produced and for same 0.1% of volume concentration (for 10 liters of water 42.3 grams TiO2) hybrid nanofluid is produced. Aluminium oxide (Al2O3) and Titanium oxide (TiO2) nanoparticles are taken in the 2:1 and 1:1 weight proportions based on the quantity of the nano powder and it is mixed in water (Base fluid). For mixing the nanoparticles in a base fluid (water), first of all the water is heated up to temperature of 70^0C with help of immersion heaters producing power of 3000Kw and the nano powder is mixed with a hot fluid and it is stirred continuously for 3-4 hours and then Uniform dispersion and stable suspension of nanofluids (Al2O3-TiO2) can be achieved by two step method.

Fig.2 weighing of Al2O3 Nanopowder

Fig.3 weighing of TiO2 Nanopowder

5. Experimental working

i)The tube side fluid is heated to a temperature of 50^0C and above, with the aid of immersion heaters and is stirred to maintain a uniform heat distribution.
ii)In this time the nano powder 15.2 grams of Al2O3- 43.6 grams of TiO2 is weighing by using electrical weighing balance machine.
iii)For mixing the nanoparticles in a base fluid (water) first of all the base fluid is heated up to temperature of 70^0C with help of immersion heaters producing power of 3000Kw and the nano powder is mixed with a hot fluid and it is stirred continuously for 3-4 hours and then Uniform dispersion and stable suspension of nanofluids (Al2O3-TiO2) can be achieved by two step method.
iv) In this heating time, the shell side (nanofluid) flow rate (litre/sec) is set to desired value.
v) Once the lower tank containing water reached required temperature, the hot water is pumped into the twisted helical tube and the flow rates (litre/sec) are adjusted to desired values.
vi) Once the system is reached to the steady state temperatures then the readings are noted by using digital temperature indicators.
vii) The readings of temperatures obtained for same flow rates are tabulated and required parameters such as Nusselt number, Reynolds number, Dean Number, effectiveness, overall heat transfer coefficient were calculated for $Al_2O_{3-}Tio_2$ Nanofluids .

6. Nomenclature

Table 4: Shows about the Symbols Representation And Units

Symbol	Representation	Units
C_p	Specific heat of fluid	J/kg ^{0}C
H	Heat transfer coefficient	W/m^2 ^{0}C
h_i(exp)	Experimental heat transfer coefficient	W/m^2 ^{0}C
P	Pitch of the coil	m
L	Heat exchanger length	m
LMTD	Log mean temperature difference	^{0}C
m	Mass flow rate	kg/s
Nu	Nusselt number	-
Q	Heat transfer rate	W
Re	Reynolds number	-
U_o	Overall heat transfer coefficient	W/m^2 ^{0}C
V	Velocity	m/s
g	Acceleration due to gravity	m/s^2
D_i	Inner diameter of inside tube	m
D_o	Outside diameter of inside tube	m
μ	Viscosity of the fluid	N s/m^2
ρ	Density of the fluid	kg/m^3
V_t	Volume flow rate for tube water	m^3/s
V_{nano}	Volume flow rate for nanofluid	m^3/s
T_{hi}	Tube water inlet temperature	^{0}C
T_{ho}	Tube water outlet temperature	^{0}C
T_{ni}	nanofluid inlet temperature	^{0}C
T_{no}	nanofluid outlet temp.	^{0}C
m_{nano}	Mass flow rate for nanofluid	kg/s
Q_h	Amount of heat transfer rate for tube side water	W
Q_{nano}	Amount of heat transfer rate for nanofluid	W
Q_{avg}	Average heat transfer rate	W
De	Dean number	-

He	Helix number	-
m_h	Mass flow rate for tube water	kg/s
R	Heat transfer ratio	-
γ	Pitch ratio	-
ε	Effectiveness	-
k	Thermal conductivity	W/m ^{0}C

7. Calculations

7.1 Al_2O_3 (Aluminum oxide)

T_{hi}= 56.8^{0}C

T_{ho}= 36.2^{0}C

T_{ni}= 22.1^{0}C

T_{no}= 32.7^{0}C

$m_h = \rho_h \times V_t = 996 \times 0.05 x 10^{-3} = 0.0498$kg /s

$m_n = \rho_n \times V_n = 3970 \times 0.04 x 10^{-3} = 0.1588$ kg /s

$Q_h = m_h c_h(T_{hi}-T_{ho})$ =0.0498x4183(56.8-36.2) = 4291.25 W

$Q_n = m_c\, c_n(T_{no}- T_{ni})$ = 0.1588x765(32.7-22.1) = 1263.41 W

$Q_{avg} = (Q_h + Q_n)/2$ = 2777.38 W

$$\text{LMTD} = \frac{\Delta T_I - \Delta T_O}{\ln\left(\frac{\Delta T_I}{\Delta T_O}\right)} = \frac{24.3-14.1}{\text{Ln}\left(\frac{24.3}{14.1}\right)} = 18.73^0\text{C}$$

Cross-sectional area of tube, $A_o = \pi dL = \pi \times 0.0083 \times 0.99 = 0.02581$ m^2

Overall heat transfer coefficient,

$$U_o = \frac{Q_{avg}}{A_0\,\text{LMTD}} = \frac{2777.38}{0.02581 x 18.73} = 9360.72\ \text{W/m}^2\,{}^0\text{C}$$

V_t = AxV

$$V = \frac{0.025}{0.02581} = 0.7748\ \text{m/s}$$

$$Re = \frac{vd}{\mu/\rho} = \frac{0.7748 X 0.0083}{1.05 \times 10^{-6}} = 11472.97$$

$$De = Re\left(\frac{D}{d}\right)^{0.5} = 11472.97\left(\frac{0.0083}{0.496}\right)^{0.5} = 1484.23$$

$$\gamma = \frac{P}{2\pi Rc} = 0.0205$$

$$Nu = 0.152\, De^{0.431} Pr^{1.06}\, \gamma^{-0.277} = 0.152(1484.23)^{0.431}\,(10.6)^{1.06}\,(0.0205)^{-0.277} = 89.38$$

We know that,

$$Nu = \frac{h_i D}{K}$$

$$h_i = \frac{Nu.k}{D} = \frac{89.38 \times 0.642}{0.0083} = 6913.48\text{W/m}^2\,{}^0\text{C}$$

$$He = \frac{De}{(1+\gamma^2)^{0.5}} = \frac{1484.23}{(1+0.0205^2)^{0.5}} = 1483.81$$

$$R = \frac{C_{min}}{C_{max}} = \frac{T_{no}-T_{ni}}{T_{hi}-T_{ho}} = 0.514$$

$$NTU = \frac{U_o A_o}{C_{min}} = \frac{9360.72 \times 0.07848}{10.6} = 69.30$$

$$\text{Effectiveness, } \varepsilon = \frac{1-\exp[-NTU(1-R)]}{1-R\exp[-NTU(1-R)]} = 0.99$$

7.2 TiO_2 (Titanium dioxide)

T_{hi}= 56.8^{0}C

T_{ho}= 39.7^{0}C

T_{ni}= 22.1^{0}C

T_{no}= 34.2^{0}C

$m_h = \rho_h \times V_t = 996 \times 0.05 x 10^{-3} = 0.0498$ kg /s

$m_n = \rho_n \times V_n = 4230 \times 0.04 x 10^{-3} = 0.1692$ kg /s

$Q_h = m_h c_h (T_{hi} - T_{ho}) = 0.0498 x 4183 (56.8-39.7) = 3562.15$W

$Q_n = m_n c_n (T_{no} - T_{ni}) = 0.1692 x 611 (34.2-22.1) = 1168.20$ W

$Q_{avg} = (Q_h + Q_c)/2 = 2365.17$ W

$LMTD = \frac{\Delta T_I - \Delta T_O}{\ln\left(\frac{\Delta T_I}{\Delta T_O}\right)} = \frac{22.8-17.8}{Ln\left(\frac{22.8}{17.8}\right)} = 20.362\ ^0C$

Cross-sectional area of tube, $A_o = \pi dL = \pi \times 0.0083 \times 0.99 = 0.02581\ m^2$

Overall heat transfer coefficient,

$U_o = \frac{Q_{avg}}{A_0\ LMTD} = \frac{2365.17}{0.02581 x 20.362} = 9993.42 W/m^2\ ^0C$

$V_t = AxV$

$V = \frac{0.025}{0.02581} = 0.7748$ m/s

$Re = \frac{vd}{\mu/\rho} = \frac{0.7748 X 0.0083}{0.003 \times 10^{-6}} = 2850.12$

$De = Re\left(\frac{D}{d}\right)^{0.5} = 2850.12\left(\frac{0.0083}{0.496}\right)^{0.5} = 1202.32$

$\gamma = \frac{P}{2\pi Rc} = 0.0205$

$Nu = 0.152\ De^{0.431} Pr^{1.06}\ \gamma^{-0.277} = 0.152(1202.32)^{0.431}\ (13.5)^{1.06}\ (0.0205)^{-0.277} = 72.8$

We know that,

$Nu = \frac{h_i D}{K}$

$h_i = \frac{Nu.k}{D} = \frac{72.8 \times 0.151}{0.0083} = 5499.469 W/m^2\ ^0C$

$He = \frac{De}{(1+\gamma^2)^{0.5}} = \frac{1202.12}{(1+0.0205^2)^{0.5}} = 1201.09$

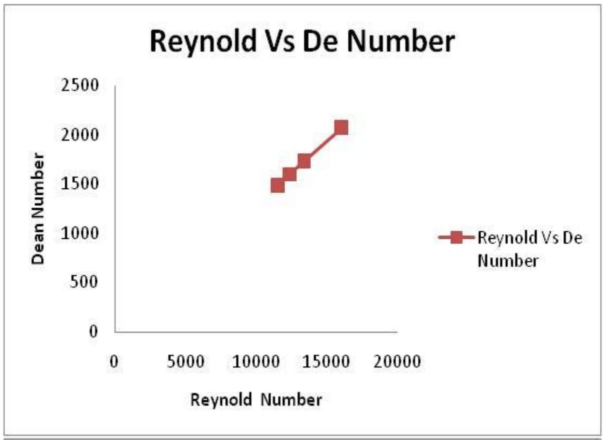
$R = \frac{C_{min}}{C_{max}} = \frac{T_{no} - T_{ni}}{T_{hi} - T_{ho}} = 0.707$

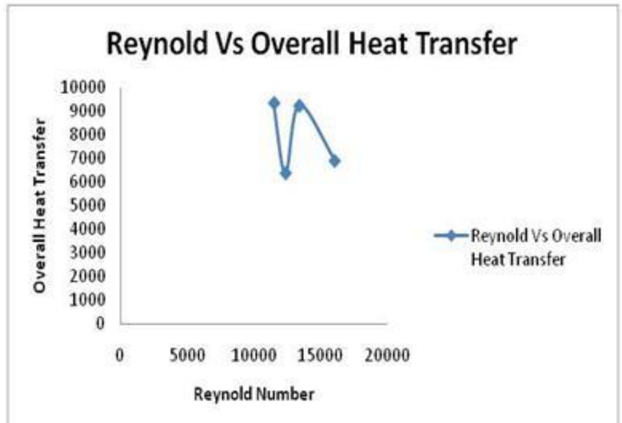
$NTU = \frac{U_o A_o}{C_{min}} = \frac{9993.42 \times 0.02581}{12.1} = 63.41$

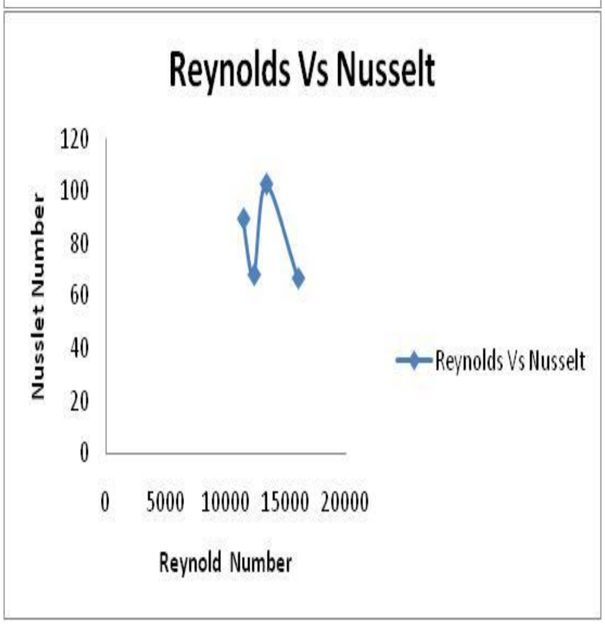
Effectiveness, $\varepsilon = \frac{1-\exp[-NTU(1-R)]}{1-R\exp[-NTU(1-R)]} = 0.79$

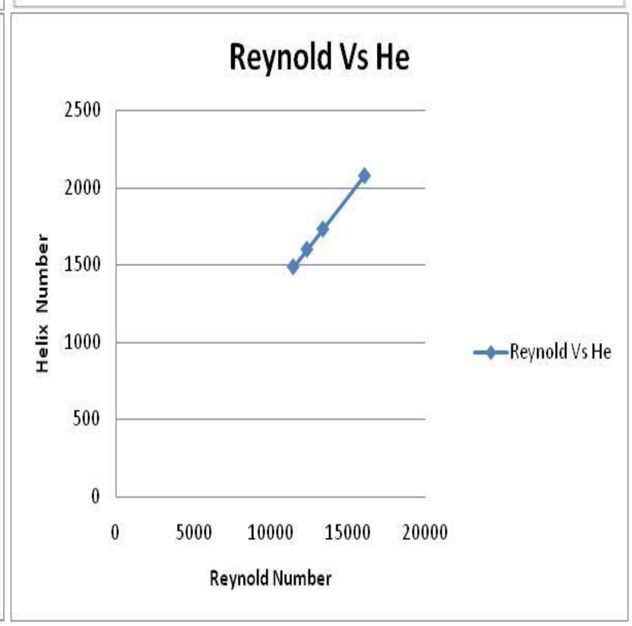
8. Result and Discussion

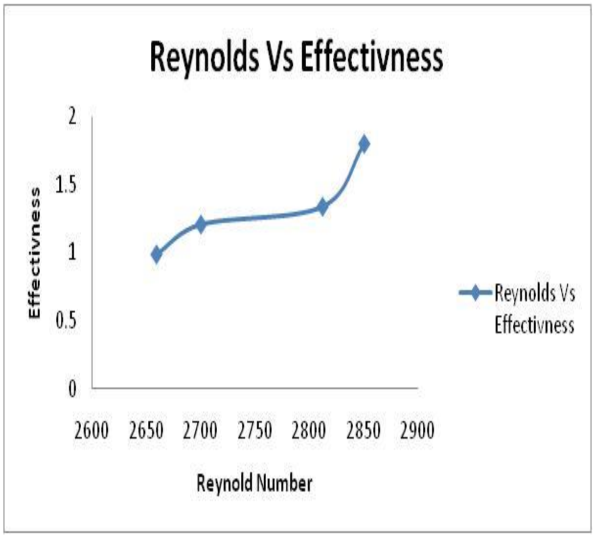
Graphs for Al_2O_3

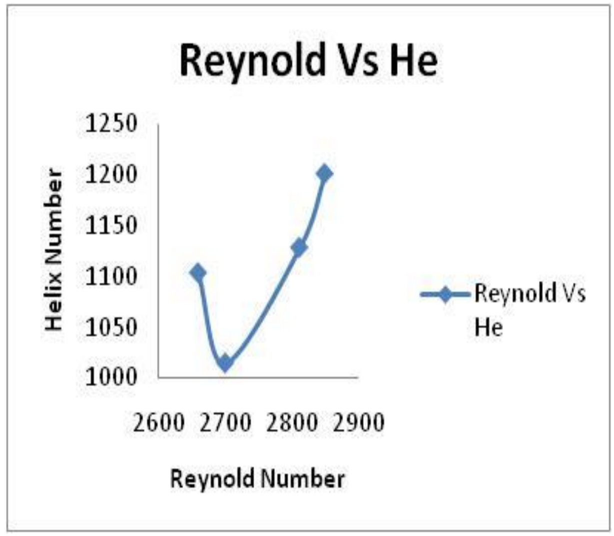




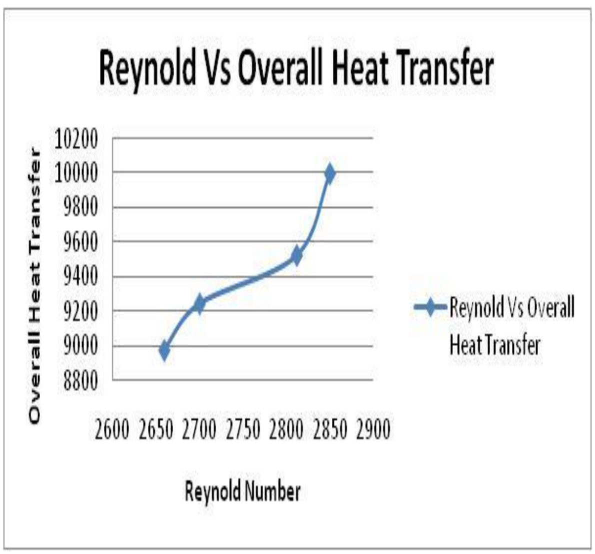


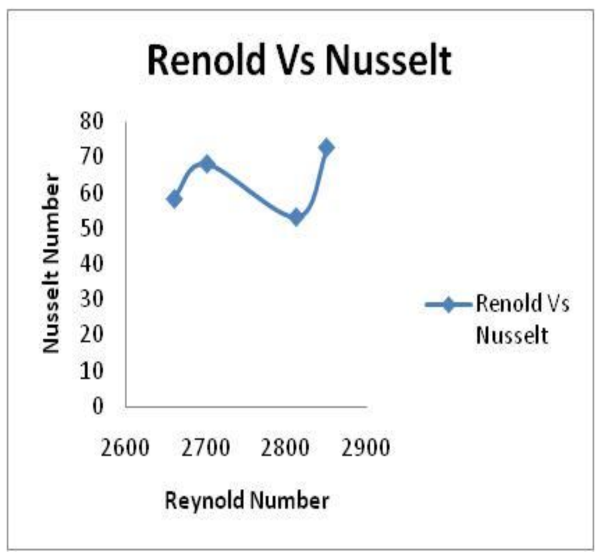


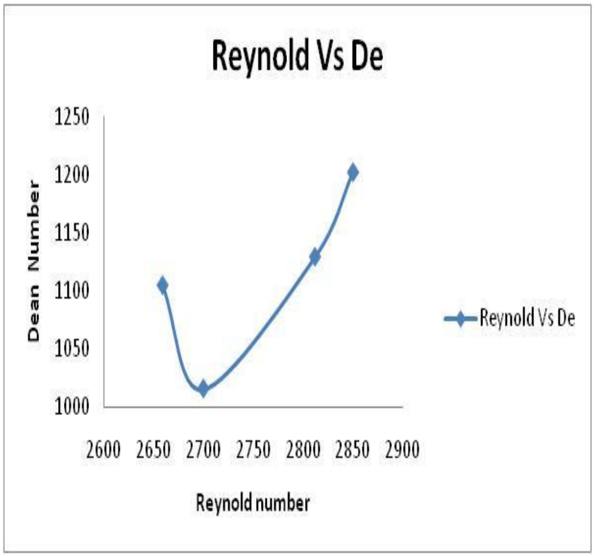


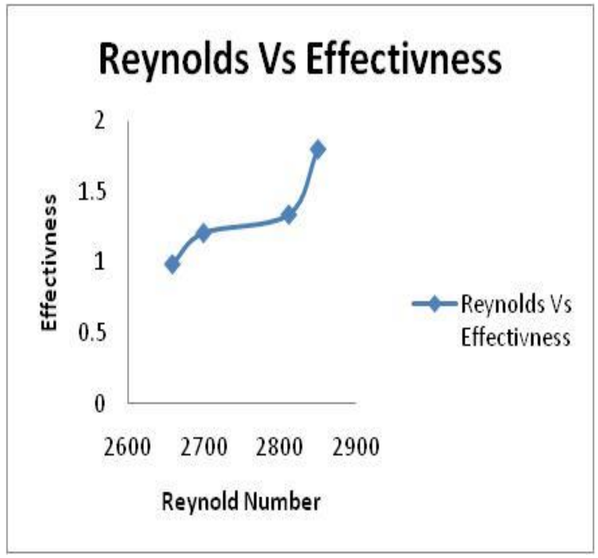


<u>Graphs for TiO_2</u>









9. Conclusion

i) From the experimental investigation, it is evident that for same flow rate there is a significant enhancement of Al_2O_3 is more than the TiO_2 nanofluid.
ii) It has also been observed for same volume of concentration (0.1%) the enhancement of overall heat transfer coefficient of Al_2O_3 is more than TiO_2.
iii) For different weight proportions of Al_2O_3 (2:1) and TiO_2 (1:1) the different dimensionless numbers (Reylonds Number, Nusselt Number,Dean Number, Helix Number), Overall heat transfer coefficient and effectiveness are observed.
iv) From experimental investigation it is observed that at same temperature the effectiveness of Al_2O_3 is more than TiO_2.
v) At same velocity, flow rate and for temperature the dimensionless numbers like Reylonds Number, Nusselt Number, prandtl number of Al_2O_3 increases and Dean Number, Helix Number are decreases when compared with TiO_2.

References

1. Effectiveness study on Al_2O_3 -TiO2 Nanofluid heat exchanger Senthilkumar A P. et al. / International Journal of Engineering and Robot Technology. 3(2), 2016, 73 – 81
2. Singh K."Thermal Conductivity of Nanofluids", *Defence Science Journal*, 58(5),2008, 600-607.
3. Michal Drzazga,Marcin Lemanowicz, GrzegorzDzido and Andrzej Gierczycki."Prosimycytowacjako: *Inz. Ap. Chem.*, 51(5), 2012, 213-215.
4. Gabriela Huminic, Angel Huminic. "Application of nanofluids in heat exchangers: A review", Renewable and Sustainable Energy Reviews, 16(8), 2012, 5625-5638.
5. Golakiya Satyamkumar, Sarvaiya Brijrajsinh. "Analysis of Radiator with Different Types of Nano Fluids", Journal of Engineering Research and Studies, 6(1), 2015, 01-02.
6. Sai Sasank P. "Experimental Studies on Automotive Radiator Performance using Water and Al2O3 Nanofluid", International Journal of Engineering Research and Technology, 3(9), 2014, 1347-1350.
7. Sayantan Mukherjee, Somjit Paria." Preparation and Stability of Nanofluids-A Review", IOSR Journal of Mechanical and Civil Engineering, 9(2), 2013, 63-69.
8. Dae-Hwang Yoo, Hong K S, Hong T E."Thermal Conductivity of Al2O3/Water
Suresh S, Venkitaraja K P, Selvakumara P, Chandrasekarb M. "Synthesis of Al 2O3– Cu/water hybrid nanofluids using two step method and its thermo physical properties", Colloids and Surfaces A : Physicochem. Eng. Aspects, 388(1-3), 2011, 41-48.