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FABRICATING EXPERIMENTAL SET-UP TO STUDY THE EFFECT OF TITANIUM/WATER NANOFLUID CONCENTRATION ON HEAT TRANSFER AND FLUID FLOW CHARACTERISTICS IN A SINGLE PASS CROSS-FLOW COMPACT HEAT EXCHANGER

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ABSTRACT

Miniaturization of thermal system along with the high performance is one of the essential needs for the modern era of industries, industries and automobile cooling system. In heat transfer thermal conductivity plays a special role in the development of energy efficient fluids. Water, ethylene glycol, and oils falls in the categories of conventional fluids having poor thermal conductivity and put constrains on the development of energy efficient devices. Nanofluids, finds as panacea for thermal devices, which are produce by suspended the nanosized particles (1-100 nm) into the base fluids with the guidelines offered by the nanotechnology . Now days, nanofluids mostly gained attraction due to the superior properties over the base fluids. Nanofluids have ultra pro features which are significantly different from the base fluids as well as the conventional fluids. A lot of study has been done on the metal based nanofluids, however a very less work has been conducted on metal oxide based nanofluids. In the present work, effect of Ti/water nanofluids on the thermo hydraulic performance of single pass cross flow compact heat exchanger has been investigated. Nanofluids was fabricated by two step methods i.e. dispersing of metal oxide bases nanoparticles of size 15-25 nm in double distilled water. Second, sonicate the fluids for high stability of nanofluids & to avoid any agglomeration of nanoparticles in base fluid. With the variation of temperature, various thermo physical properties such as density, viscosity and thermal conductivity are measured. Experiments were conducted on single pass cross flow compact heat exchanger by varying the various parameters such as inlet temperature, flow rate through the heat exchanger, concentration of nanoparticles and velocity of air employed for cooling purpose. Performance of heat exchanger was investigated by studying the effect of these parameters on the hot and cold side Nusselt number and friction factors. Colburn factors were also studies along with the Nusselt number and friction factor on the cold side.

Keywords: Base Fluid, Cross-Flow Compact Heat Exchanger, Titanium Nanofluid, Two-Step Method, Thermo-Physical Properties.

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I. INTRODUCTION

Devices that are used for transferring the thermal energy between fluid and solid surface or between two fluids or more than two fluids in thermal contact when they are at different temperature are called heat exchangers. Heat exchangers involves only heating or cooling, evaporation or condensation of single and multi component of fluid and no externally heat and work interaction. Objective of heat exchanger is to recover or reject heat from a system. Flow of heat is function of heat transfer area, temperature difference and conductive or convective properties of fluid. Convective heat transfer between fluid and surface is given by Newton's law of cooling which is given by equation

$$Q_C = h*A* (T_S-T_f)$$

Where 'h' is 'convective heat transfer coefficient in (W/m^2K)', A is heat transfer surface area in (m^2), T_S is surface temperature in (K) and T_f is fluids temperature in (K).

1.1 Compact Cross-Flow Heat Exchanger

For any heat exchanger main requirement is its heat load and how fast and effectively heat exchanger does heat transfer. To increase the heat transfer rate we have to increase the (h*A) value and this can be done by either increase surface area or increase heat transfer coefficient or increase both, but heat transfer coefficient of fluid cannot be change and for constant heat transfer coefficient we can increase either area or temperature. Temperature difference increment has various limits, for example to supply hot fluid at high temperature and cold fluid at lower temperature extra work has to be done. Further increase in temperature lead to thermal stress in material of heat exchanger which leads to deformation of material and decrease the lifecycle of heat exchanger. To avoid this problem surface area of exchanger is increased and this need gives rise to birth of compact heat exchanger.

Compact heat exchanger are distinguished from other class of heat exchanger because of large surface area per unit volume which results in reduce in weight, energy requirement, space and cost. Surface area is $\geq$ 700 $m^2/m^3$for liquid to gas, and $\geq$ 400 $m^2/m^3$for liquid to liquid heat exchanges respectively with hydraulic diameter is $\leq$ 6mm. It consist of core matrix for distribution of fluid and provide large heat transfer surface area. Flow distribution part consists of header, manifolds tank, pipes, outlet and inlet nozzle seals etc.

1.2 Important Operating And Design Consideration

Important operating and design consideration for compact heat exchanger are listed below.

(1) High compactness led to large frontal area and having short flow length.
(2) Temperature and pressure is limited as compare to shell tube heat exchanger.
(3) At least one fluid having low convective heat transfer coefficient i.e. gas.
(4) Pressure drop and pumping power is very important for heat transfer.
(5) The hydraulic diameter of tubes is very small so fluid is free from dust and debris.
(6) Compact heat exchangers are not operating in high fouling application.

1.3 Tube Fin Compact Heat Exchanger

These are conventional type of heat exchanger means heat is transferred between two fluids first by conduction between fluid and tube surface and, by convection from tube surface to other fluid passed over extended surface

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by forced draft fan or by induced draft fan. In liquid to gas heat exchangers convective heat transfer coefficient on liquid side is much greater than the gas side and surface area on gas side is much greater than liquid side to balance the thermal conductance (h*A). For lager surface area fins are used at gas side attached to tube. Tubes are of different types having different cross section area like flat rectangular, elliptical, circular, and round rectangular. Tube fin heat exchanger can withstand high operating pressure on tube side but for high temperature it has certain limitations like type of bonding, material used, material thickness, conductivity of material etc.

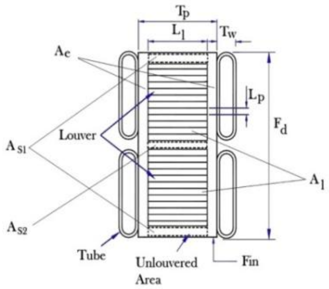

Fig.1 shows tube arrangement

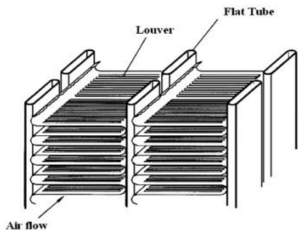

Fig. 2 shows Louvered fin arrangement

1.3.1 Applications of Tube Fin Heat Exchanger

Tube fin heat exchangers are used in many industrial applications like evaporator and condenser in refrigeration and air conditioning units. Tube fin are also used in internal combustion engines for water and oil cooling through radiators, pre-heaters, and after-coolers. Automotive condenser and evaporator are also used in automotive industry.

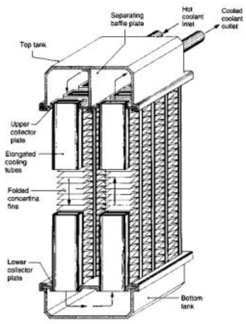

Fig.3 shows an automotive radiator of cross- flow compact heat exchanger

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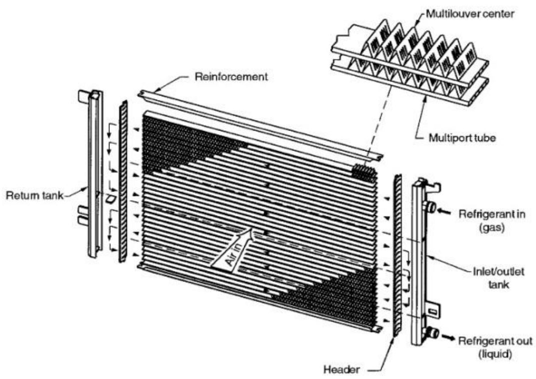

Fig.4 shows refrigerator of cross-flow compact heat exchanger

1.4 Nanofluids

New technique is recently in trend i.e. use of solid particle in suspension with liquid to enhance the thermo-physical properties of fluid flowing in heat exchanger. It increases the thermal performance and effectiveness of exchanger. These particles are of 1-100 nano meter in size dispersed in liquid to form meta-stable Fluid called Nanofluid. Nanofluids are panacea for thermal equipments. Recently it has been recognized as an opportunity to widen the next-generation's smart coolants for mechanically advanced devices that have shifted the paradigm to miniaturization but without compromising in working efficiency, power but these device results in more heat generation. Designing energy efficient and enhancement methods in heat transfer rate are one of the most important and challenging area in various industrial applications. To maintain the desired performance cooling is essential and for safe operation of wide variety of equipments and devices such as higher power engines, fuel cell, microelectronic devices (operated at high speed), super conducting magnets, ultrahigh-heat flux optical devices, x-rays machines, high-powered lasers, etc. Sometimes heat load exceeds 2000 W/cm2 [1] caused by compact size and high heat production rate. But the working fluids such as water, ethylene glycol, and oil etc. have poor heat transfer properties. Therefore there is a strong demand to develop the advanced heat transfer fluids with higher heat transfer properties. Development of high energy efficient heat transfer devices thermo fluid properties play very important role. To obtain higher heat transfer properties, various theoretical and experimental studies have been done. Maxwell (1873) did great effort by dispersing millimeter or micrometer size particles in liquids. However the major problem was settling down of large particles in suspension [2]. The key idea was that the very high thermal conductivity of solid particles which can be hundreds and even thousand times greater than that of the conventional heat-transfer fluids such as ethylene glycol and water. Keeping in mind Maxwell's concept, a new innovative concept of Nanofluids has come in to existence.

The term Nanofluid is coined by "Choi" in 1995 at the Argonne national Laboratory (ANL) [3]. Nanofluids are solid liquid composite materials consisting of solid nanoparticles typically of size (1-100) nm suspended in liquid. Suspended nanoparticles in conventional fluid are called Nanofluids. Nanofluids greatly enhance thermal properties hence thermal engineers take great interest in this new concept. Modern nanotechnology can produce metallic or non-metallic particles and carbon Nanotube of nanometer dimensions suspended in base fluid in small amount extensively increase thermal conductivity [4-6].

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Nanomaterials have unique mechanical, optical, electrical, magnetic, and thermal properties. Nanofluids are engineered by suspending nanoparticles with average sizes below 100 nm in traditional heat transfer fluids such as water, oil, and ethylene glycol. The purpose of nanofluids is to achieve the highest possible thermal properties at the smallest possible concentrations [1]. Therefore the thermal conductivity of fluids that contain suspended solid metallic particles is significantly higher than those of conventional heat transfer fluids [7]. Various enhancement mechanisms of thermal conductivity are studied that contribute in thermal conductivity [8-9]

(1) Brownian motion of nanoparticles, (2) Layering liquid molecules at liquid/particle interface. (3) Ballistic nature of heat transport. (4) Nanoparticle clustering.

1.4.1 Importance Of Nanofluids In Thermal Science Engineering

Nanofluids enhance heat transfer as we know that the size of heat transfer devices is getting scaled down gradually, so it necessitates the better cooling processes. Due to scaling down and high operating speed of devices such as micro-electro mechanical systems [MEMS], temperature increases to high limits which become a constriction for devices to operate at high power. Fluids used for cooling (water, oil, etc.) have poor thermal conductivity which leads to equipment limitation, reduced thermal and processing efficiency. Nanofluids recently have made its place in this advanced cooling mechanism and enhanced thermal conductivity of fluids. Enhancement in thermal properties depends on volume fraction of nanoparticles. With small particles concentration of nanoparticles we can increase heat transfer rate in thermal systems and can meet the cooling needs of thermal systems. Nanoparticle size play a very important role in enhancement of thermal conductivity as particle size below 50 nm the enhancement in thermal conductivity increased by 40% when 3% (v/v) CuO particles are used in ethylene glycol [10]. Therefore Nanoparticles enhanced the thermal conductivity and this enhancement makes lighter size heat exchanger with slow flow velocity, leading in reduced pump work attributable to less erosion in pipes and other components. Enhance heat transfer rate because nanoparticles have large surface area to volume ratio. A continues heat exchange between nanoparticles and base fluid through convection mechanism depending base fluid temperature and velocity of nanoparticle relative to base fluid [11] increase the heat transfer rate. Role of Brownian movement in heat transfer is very important in case of nanofluids. Heat transfer takes place when collision between particles occurs due to Brownian motion which depends on temperature and viscosity of base fluid, nanoparticle size. As temperature of base fluid increases its viscosity decreases and Brownian motion increases hence conductivity increases. The random motion of particles in base fluid is depend on particle size. Decrease in particle size leads to large motion and convection heat transfer phenomenon become dominant. [12].

1.4.2 Preparation of Nanofluids [1]

Nanoparticles are Metastable in fluids for long time. Nanoparticles preparation is done by two methods:

a). The two-step method: This is common and widely used method for preparation of nanofluid. Dry powder of Nanofibers, nanoparticles, is made by different methods (Physical method include Inert-gas condensation (IGC), mechanical grinding. Chemical method includes chemical vapour deposition (CVD), chemical

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emulsion, thermal spray pyrolysis) and then disperse into base fluid with the help of ultra- Sonication, intensive magnetic force agitation, surfactants.

b).The single-step method: In this process nanoparticles simultaneously make and disperse directly into base fluid. This is the advance method from two-step preparation. To minimise the problem of agglomerate one step method is used in which physical vapour condensation of metal and metal oxide. One-step physical method cannot produce nanoparticles at large scale and cost is also high. One-step Chemical method is developing rapidly.

1.4.3 Advantage of Nanofluids

[1] Better stability as compared to micro size, mili-sized particles.

[2] High heat conducting capability.

[3] High surface to volume ratio which provide large area for heat interaction between nanoparticles and base fluid.

[4] Negligible or small amount of pressure drop required less pump work because of small particle size and low volume fraction.

[5] No erosion and clogging in device channels hence miniaturization is possible.

[6] Adjustable thermal conductivity by different volume fraction in base fluid.

[7] Adjustable density with different particles volume concentration.

1.4.4 Application of nanofluids [1]

a).Cooling applications

"High intensity x-ray generate tremendous amount of heat (2000-3000W/cm2) as it bounce off minor which should be feasible by nanofluid technology".

b).Vehicles cooling

Nanofluids not only used as engine oil and coolant but also in lubricant, gear oil, and, transmission fluid.

c).Transformer cooling

"The power generation industry is interested in transformer cooling application of nanofluids for reducing transformer size and weight. The increased thermal transport of transformer oils translates into either reduction in the size of new transformers at the same level of power transmitted or an increase in the performance of existing transformers".

d).Defence applications

"Heat transfer fluids. Nanofluids also provide advanced cooling technology for military vehicles, submarines, and high-power laser diodes. A number of military devices and systems, such as high powered military electronics, military vehicle components, radars, and lasers, require high-heat-flux cooling, to the level of thousands of W/cm^2".

e).Other applications

Other possible areas for the application of nanofluids technology include cooling a new class of super powerful and small computers and other electronic devices for use in military systems, airplanes, or space craft as well as for large-scale cooling.

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1.4.5 Challenges of nanofluids

a). Long term stability of nanofluid is a challenging task. They make agglomerate after some time due to strong Van Der Waals forces between molecules when dispersed. To get metastability in nanofluids some physical or chemical treatment is given. For example ultra sonication, surfactants (CTAB, SDBS).

b).High cost of production of nanoparticles.

c).High nanoparticle concentration and nanoparticle size pump power is more because viscosity is increased. As Reynolds number of nanofluid increases the pumping power is increases.

d). Lack of agreement of results obtained by different researchers and poor characteristics of suspensions.

II. EXPERIMENTAL SET-UP

Objective of the experiment was to study the **"Effect of TiO_2 / water nanofluids concentration on heat transfer and fluid flow characteristics in single pass cross flow compact heat exchanger".** Experimental set up was fabricated in DAV UNIVERSITY SARMASTPUR, JALANDHAR and experiments were done in Engine lab. Experimental setup consist of cross flow heat exchanger, duct, fan, pump, storage tank, heating element, thermocouples, U- tube manometer, display unit , rotameter, bypass valve, PID controller as shown in Fig. 5 below:

Fig.5 shows an experimental set-up

2.1 Layout of An Experimental Set-Up

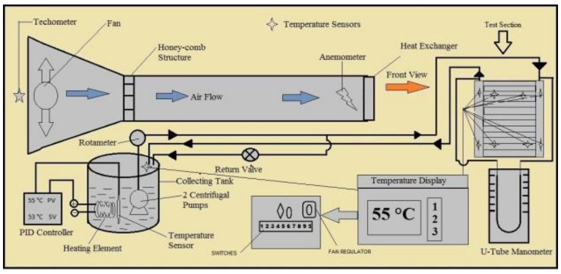

Fig.6 shows a layout of an experimental set-up

2.2 Requirements To Run An Experimental Set-Up

[1] Electricity, 220V, 50 Hz, 3 phase supply with voltage stabilizer.

[2] PID controller to regulate the current from heating element to maintained the temperature.

[3] Two pumps in water storage tank.

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Table 1 shows Technical Data.

S.No.	Product	Specification
1	Cross flow heat exchanger	Aluminum fins multi louvered type and single pass tube. 2 rows each contain 38 tubes.
2	Duct	Made of GI sheet 15 gauge.
3	U-tube manometer	Pressure drop across radiator.
4	Rotameter	Capacity 50-540 LPH.
5	Temperature sensor	RTD PT-100 type.
6	Water tank	GI sheet 12 gauge.
7	Heating element	3000W power.
8	PID controller	SELEC TC 303
9	Anemometer	LT lutron AM- 4201 Anemometer

2.3 Measuring Instruments And Controlling Devices

PROPERTIES	MEASURING DEVICE
Thermal conductivity	KD2 pro analyzer
Viscosity	Brookfield DV-III Rheometer
Density	Pycnometer
Agglomeration reduction	Ultra Sonicator water bath
Control and measure flow rate	Rotameter
Control temperature of hot fluid	PID controller
Pressure drop	U-tube differential manometer

Table 2 shows measuring instruments and controlling devices.

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III. EXPERIMENTAL WORK & CALCULATIONS

3.1 Introduction

Cross flow heat exchanger are widely used in power sector, automotive industries, HVAC, etc. Performance of heat exchanger plays very important role. Heat transfer from hot medium to cold medium is always a challenging task. Main aim of this study is to enhance the heat transfer rate between hot fluid and cold fluid. TiO_2 nanoparticles were used at different concentration for this purpose to enhance the thermo physical properties of hot fluid; as a result heat transfer enhancement is achieved.

3.2 Preparation of nanofluids

The TiO_2 nanoparticles of average size 15-25 nm were purchased from Intelligant Materials Pvt. Ltd, Panchkula. The properties of TiO_2 nanoparticles are given in table 3.

Chemical Name	TiO_2 nanopowder
Appearance	White powder
morphology	spherical
purity	>99.9%
Average particle size	20nm (15-25nm)
Density	3900kg/m^3
Thermal conductivity	67.6W/mk

Table 3 properties of TiO_2 nanoparticles [13]

Nanofluids are prepared by two step process. The nanoparticles are dispersed into the base fluid i.e. water. Make the volume concentration of 0.2%, and 0.3% by mixing 0.389 gm, and 0.5835 gm of nanoparticles in 50 ml of water respectively. To make the nanoparticles more stable and remain more dispersed in water ultra sonicator is used. Sonication had done for 3 hours before testing thermal conductivity& viscosity of the nanofluids. By this nanoparticles become more evenly dispersed in water. The TiO_2 samples prepared are as shown in Fig. 7 is as show below

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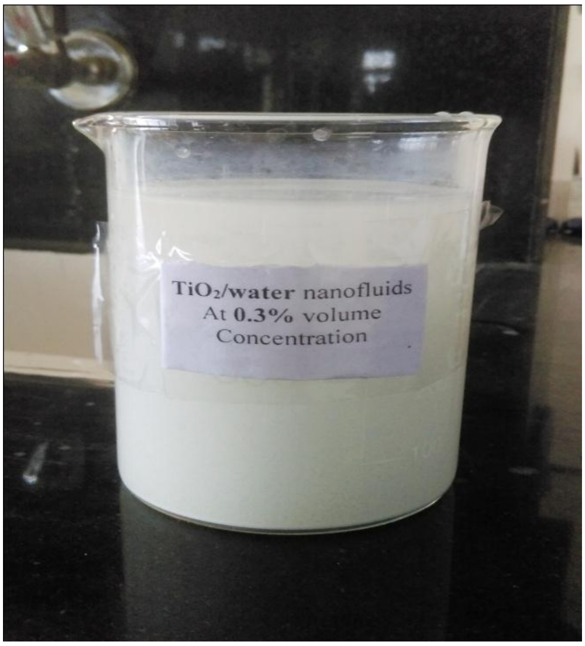

Fig.7: (a) 0.2%concentrations of nanofluids, (b) 0.3% concentrations of nanofluids.

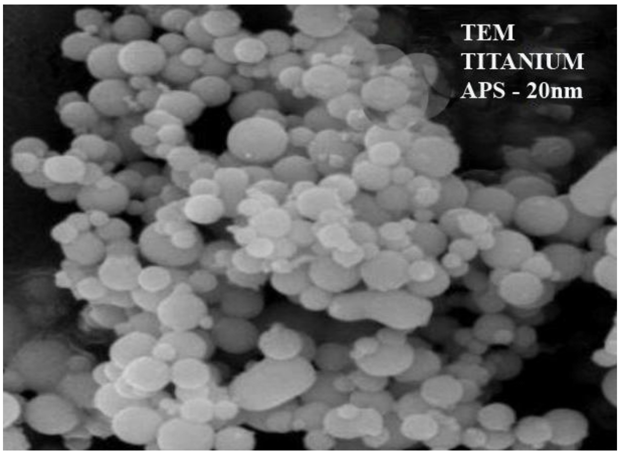

Fig.8 shows TEM image of Titanium nanoparticles

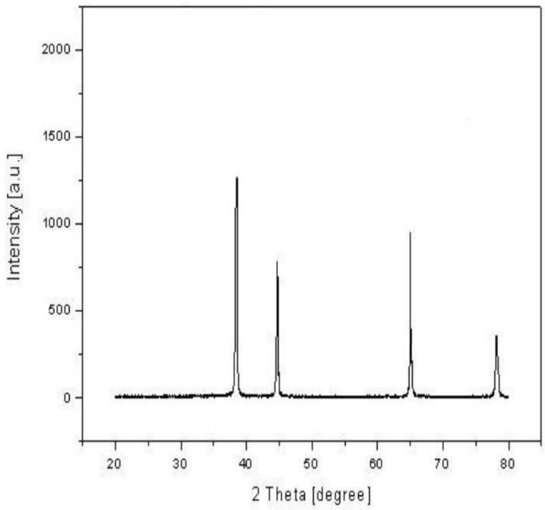

Fig.9 shows XRD images of titanium nanoparticles

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3.3 Experimental procedure

Experimental setup consist of a cross flow heat exchanger placed at one end of duct whose other end consist of force draft fan, having different rpm to change the velocity of air. Duct is1.3 m long to produce the uniform flow of air through cross flow heat exchanger. Water tank consist of heater of 3000W who's current and voltage is regulated by PID controller. Heater heats the fluid flowing to heat exchanger through a pump. Thermocouples are mounted on heat exchanger to get the air side temperature readings, and four thermo couples are inserted in heat exchanger to measure the hot fluid temperature at inlet and outlet. Two thermocouples are inserted in header of heat exchanger at inlet and two thermocouples are installed at outlet chamber of fluids. One thermocouple is implemented at the mixing point neat to the end of the cold side chamber. A U-tube manometer is used to calculate the water side pressure drop.

Above mentioned experimental setup is used for heat transfer rate calculations and pressure drop calculations which are described as follows.

1. Electrical heater is switched on which is connected with PID controller to maintain the target inlet temperature. Three temperatures are taken 45^{0}C, 50^{0}C, and 55^{0}C. First we take 45^{0}C temperature for readings.
2. Pump is used to circulate the hot fluid in heat exchanger circuit as described in previous chapter.
3. Hot fluid consists of simple distilled water and nanofluid which contain TiO2 nanoparticle at 0.2% conc. and 0.3% conc. in distilled water.
4. Another pump is used as agitator to regulate the suspension of nanoparticle in base fluid, and avoid the local heating phenomenon of fluid near the heater boundary to maintain the same temperature at every location in water tank.
5. First take distilled water as hot fluid for experimental procedure. Distilled water readings then compare with nanofluid readings to compare and see the enhancement in heat transfer rate.
6. Set the flow rate of hot fluid flowing in heat exchanger. Four different types of flow rates are taken i.e.180, 240, 300 and 360 LPH respectively. Now set 180 LPH flow rate for readings.
7. Set the bypass line valve to get minimum flow rate through it such that maximum flow occurs through rotameter which is set at a particular flow rate.
8. Switched on the fan and set the velocity at which the readings will be taken. There are seven different velocities of fan i.e. 2.78 m/sec, 3.38 m/sec, 5.89 m/sec, 6.45m/sec. For experimental readings set velocity at 2.78 m/sec.
9. Take reading after every 5 min of all the temperature sensors through a digital temperature indicator. Pressure drop readings are taken from U tube manometer for both hot fluid and cold fluid.
10. Repeat the process of readings till steady state is achieved.
11. Take two readings after steady state and note down all the values of temperature.
12. Change the flow rate of hot fluid 240, 300 and 360 LPH and repeat the same procedure at same speed.
13. Change the speed of fan to 3.38 m/sec after taking the values of temperature at all flow rate of hot fluid at steady state and repeat the procedure.
14. When all speeds are done then change the temperature to 50^{0}C and repeat the same procedure for given temperature.

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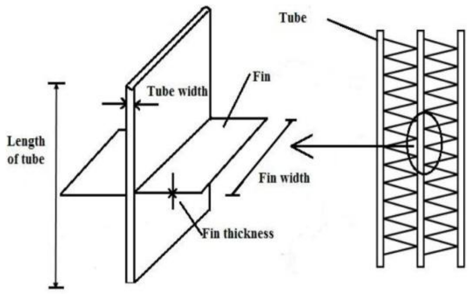
15. Repeat the same procedure for 55^{0}C temperature and take the readings at steady state.
16. Take readings with nanofluid at 0.2% conc. for all flow rates, all speed, and all temperature.
17. Repeat the experiment with 0.3% concentration of nanofluid at all flow rates, all speed, and at all temperature.

3.4 Experimental Calculations

Experimental calculations: calculations were done for both water side and air side at 45^{0}C temperature of hot fluids. Air side thermo physical properties were taken at bulk mean temperature of air passing through heat exchanger when hot fluid is flowing inside it. Hot fluid's thermo physical properties were taken at bulk mean temperature. Consider a control volume as shown in Fig.10 to calculate the different types of area.



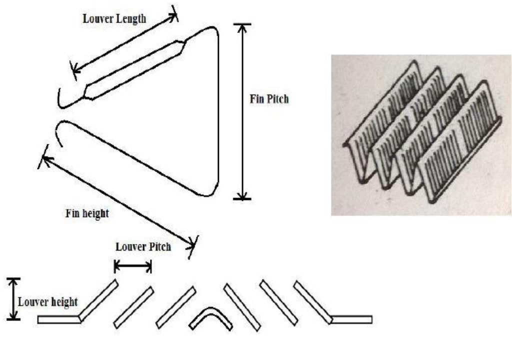


Fig. 10 shows tube fin control volume **Fig. 11 shows louvered fin geometry**

3.4.1 Tube Side Calculations [14]

Heat exchanger employed in this experiment work has 38flats tubes with semi circular ends. With the help of simple dividing wall, tubes are divided into two parts. For the calculations purpose one part of the tubes are considered. Flows of fluid, which are transfer from the hot side chamber to the tubes of exchanger, are assumed to be distributed uniformly in all the tubes. Fig. 4.6 shows the cross section view of one part of the tubes. Sample calculations for fluid at 55^{0}C at inlet temperature conditions are given. Nusselt number and friction factors are calculating for water side with varying parameters.

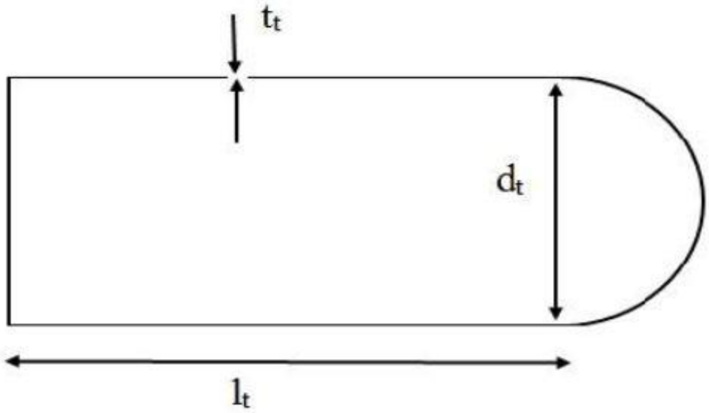


Fig. 11 shows Cross section view tubes

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$T_{bm} = 51.29^0C$

Water flow rate Q = 300 LPH or 5 LPM

Flow rate pre tube = $\frac{Q}{76}$

q = 1.09649E-06m^3/s.

Mean velocity of water $V_w = \frac{q}{Ac}$

V_w = 0.0086771781m/s

Thermo physical properties of water at 51.29^{0}C are given below [15]

ρ_w= 979.342 Kg/m^3 μ_w = 0.0006454Ns/m^2

C_{pw}=4181.51kJ/kgK Pr_w=4.1083

k_w= 0.6570W/mk

Hydraulic diameter of tube $D_{hw} = \frac{4 X Ac}{p}$

D_{hw} =0.002158m^2

Reynolds number, $R_{ew} = \frac{\rho w \cdot Vw \cdot Dhw}{\mu w}$

R_{ew}= 282.9569

Nusselt number given by Shah- London equation as follows [15]

$Nu_w = 4.364+0.0722(Re_{Dhw}\, Pr\, \frac{D}{L})$ Nu_w =5.4569

Heat transfer coefficient $h_w = \frac{Nu\ X\ Kw}{Dhw}$

h_w =1759.8541W/mk

Friction factor $f_w = \frac{82}{Re}$

f_w =0.2897967

3.4.2 Fin Side Calculations

Multi-louvered fins were employed on the air side of the heat exchanger. To calculate the various performance parameters on air side, a control volume was chosen as shown in Figure Also the various dimensions of a louvered fin are illustrated in Figure 11.Sample calculations for air side performance is given as follows. Properties of air were also taken at bulk mean temperature of the air.

Thermo physical properties of air are given below:

$\mu_a = 18.832 \times 10^{-6}$ Ns/m^2 , ρ_a= 1.115469kg/m3

Pr = 0.7275, K_a = 0.026061W/mK

$C_{p,a}$ = 1007 J/Kg k, Velocity of air V_a = 6.45m/s.

$D_{h,a}$ = 0.004988 m

Mass flow rate of air =W_a Kg/s

$W_a = \rho_a \times A_c \times V_a$

$W_a = 1.115469 \times 0.01263 \times 6.45$

W_a = 0.090870 Kg/sec.

Heat capacity rate = $W_a \times C_{p,a}$

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$W_a \times C_{p,a} = 94.5938$

Core mass velocity = G_a

$G_a = \frac{Wa}{Ac} = 7.4375$

$Re_a = G_a \times \frac{Dh,a}{\mu}$

$Re_a = 1969.7928$

Heat transfer co-efficient = $j_a \times G_a \times C_{pa} / (Pr_a)^{2/3}$

Where,

$j_a = 0.249 \times Re_{lp}^{-0.42} \times l_h^{0.33} \times H_f^{0.25} \times (\frac{Ll}{Hf})^{1.1}$

l_p = louver pitch l_h = louver height

l_l = louver length H_f = Fin height

Reynolds number louvered side = Re_{lp}

$Re_{lp} = \rho_a \times V_a \times l_p / \mu_a$

$Re_{lp} = 473.93092$

$j_a = 0.0063780$

$h_a = j_a \times G_a \times C_{p,a} / Pr_a^{2/3}$

$h_a = 59.055$

Fin efficiency $\eta_f = \tanh(ml) / (ml)$

Where $m = [2 \times h_a / k_{fin} * \delta]^{0.5}$

$\eta_f = 0972546$

Total surface temperature effectiveness of the fin,

$\eta 0 = 1.0 - (1.0 - \eta f) \times Af/A$

$\eta_0 = 0.978332$

Friction factor is given by the following correlations [16]

$f_a = 0.464 \times Re_{lp}^{-0.39} \times (\frac{Lh}{Hf})^{0.33} \times (\frac{Ll}{Hf})^{1.1} \times H_f^{0.46}$

$f_a = 0.032048$

3.4.3 HEAT EXCHANGER EFFECTIVENESS:

Heat exchanger effectiveness are calculated with the help of following formula [16]

Heat exchanger effectiveness $\acute{\varepsilon} = C_h \times (T_{h,in} - T_{h,out}) / [C_{min} \times (T_{h,in} - T_{c,in})]$

$\acute{\varepsilon} = 0.6675698$

3.4.4 OVERALL HEAT TRANSFER COEFFICIENT:

Neglecting small resistance, overall heat transfer coefficient based on fin side heat transfer area (U_a) are calculating using following relationship

$$\frac{1}{Ua} = 1/ n_o h_a + 1/ (\frac{aw}{aa})\, h_w$$

$$U_a = 34.2561 \text{ W/m}^2\text{K}$$

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IV. RESULTS & CONCLUSIONS

To study the effect of TiO_2/water nanofluid on the thermo-hydraulic performance of a single-pass cross-flow compact heat exchanger, initially nanofluid was prepared at 0.2%and 0.3% volume concentrations by adding titanium nanopowder into double distilled water. Experiments were performed to study the effect of TiO_2/water nanofluid concentration on the performance of a cross flow compact heat exchanger. Effect of Reynolds number of hot and cold fluids on the performance parameters such as Nusselt number and friction factor on the both hot and cold fluids was studied. Results obtained from experimental study are illustrated with the aid of graphs as follows.

4.1 Temperature dependence of thermo-physical properties of nanofluid

Various thermo physical properties of nanofluid such as thermal conductivity, density and viscosity were measured experimentally with the help of KD2 Pro thermal property analyzer, gravity bottle and Brookfield DV-III Rheometer respectively. Temperature dependence of various properties was also studied experimentally. Experimental values for thermo physical properties were compared with the mathematical models available in the literature.

4.1.1 Temperature dependence of thermal conductivity of nanofluid

From experimental data and theoretical model, it was found that the thermal conductivity of TiO_2/water nanofluid was significantly higher than that of water and strongly dependent on temperature of the fluid. Figure 12 exhibits that the experimental values of thermal conductivity of nanofluid increased significantly with the fluid temperature. The reason is that, fluid temperature strengthens the Brownian motion of nanoparticles and also drops the viscosity of the base fluid. With a strengthened Brownian motion, the influence of micro convection in heat transport rises and in consequence increased enhancement of the thermal conductivity of nanofluids. Results obtained were compared with the Hamilton and crosser model of thermal conductivity available in the literature [17].

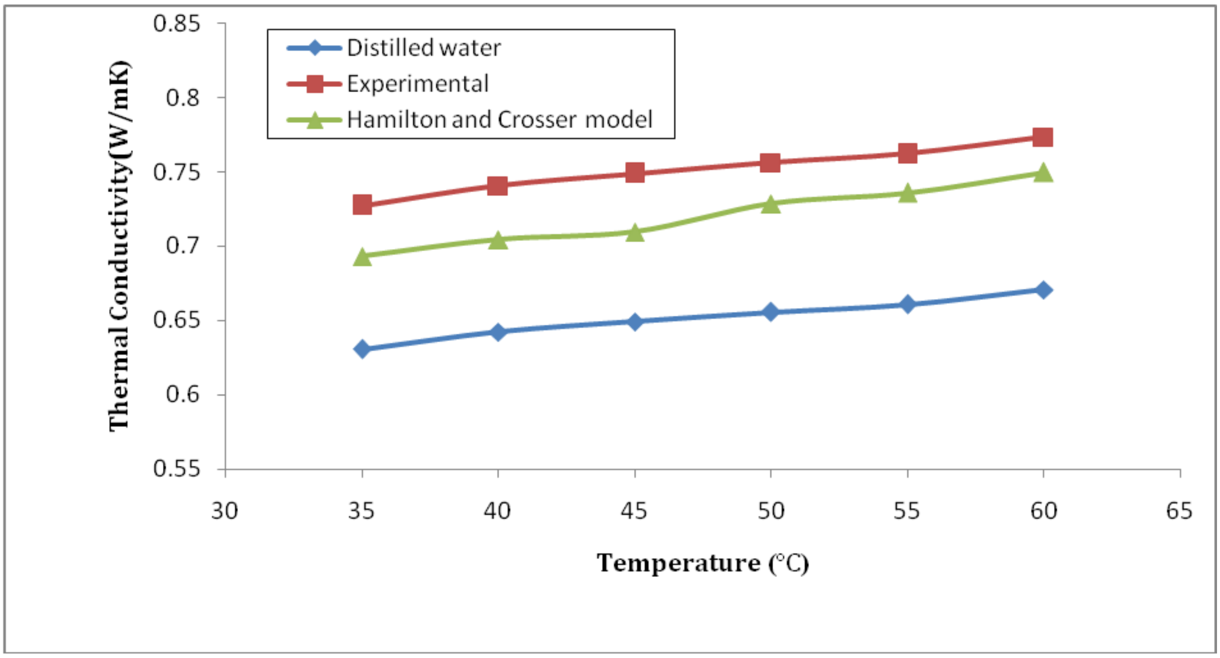

Figure 12: Variation of Thermal Conductivity of TiO_2/water nanofluids with temperature.

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4.1.2 Influence of temperature on the density of nanofluid

From Figure 13, it was concluded that, the density of nanofluid was significantly higher than that of water but it was declined slightly as temperature of the fluid was increased

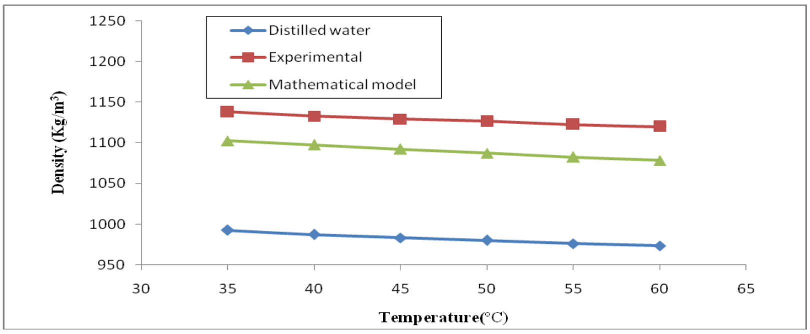

Figure 13: Effect of temperature changes on density of TiO_2/water nanofluids.

There was a variation of only 1.569% when temperature increased from 35^0Cto 60^0C .There was similar trend of variation in the density form theoretical model [18].

4.1.3 Temperature dependent viscosity data for Al/water nanofluid

From above data obtained by experiment and theoretical model following graph had been obtained. From Figure 14, it was concluded that viscosity of TiO_2/water nanofluid at 0.2% (vol.) concentration was slightly higher than that of water, simply because when solid particles are added to the liquid it increases the density of the mixture and consequently more force will be required to overcome the inertial forces, as a result viscosity increases but there was significant decrement of viscosity with temperature. Similar trends were obtained from experimental data when compared with mathematical model available in literature [19].

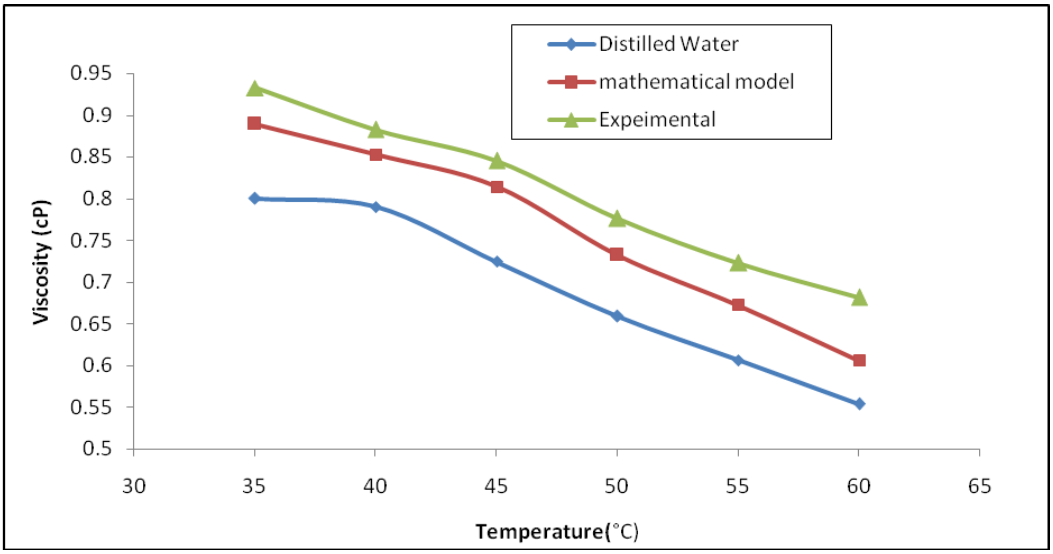

Figure 14: Influence of temperature on viscosity of TiO_2/water nanofluid.

4.2 Hot fluid side analysis

Experiments were performed at different temperatures and flow rates of hot fluid, using double distilled water and two different concentrations of TiO_2/water nanofluid. Heat transfer rate was increased with addition of nanoparticles into base fluid due to increased thermal conductivity of hot fluid. Nusselt number is a

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dimensionless heat transfer co-efficient. Friction factor, a measure of pressure drop is also another important parameter to be studied. Thermal performance of the heat exchanger increased significantly while a slight increase in the pumping power required with addition of nanoparticles. Tube side performance was studied by analyzing these two parameters. Effect of Reynolds number of hot fluid, inlet temperature of hot fluid and particles volume concentration on tub side and Nusselt number and friction factor are illustrated as follows.

4.2.1 Influence of Reynolds number and nanofluid concentration on the tube side Nusselt number

Nusselt number, a dimensionless heat transfer coefficient and is a function of Reynolds number and Prandtl number. Reynolds number is a measure of flow pattern and Prandtl number represents the fluid properties. Hence, Nusselt number directly dependent on flow and fluid properties. Figure 15 shows the effect of hot fluid Reynolds number and particle volume concentration on hot fluid side Nusselt number at 45°C inlet fluid temperature, similar trends were found for higher values of temperature. Nusselt numbers significantly increased with increasing Reynolds number. The enhancement of heat transfer with rising Reynolds number was observed by reduction of the thermal boundary thickness caused by increased turbulent intensity.

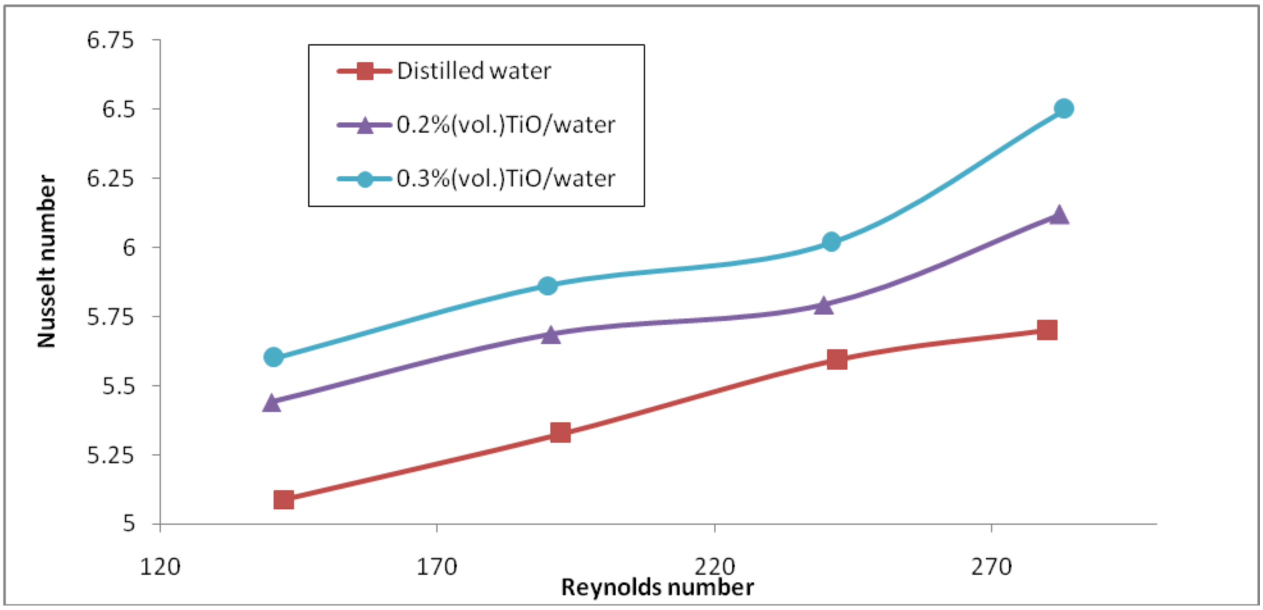

Figure 15: Influence of particle volume concentration and Reynolds number on tube side Nusselt number at 45°C inlet fluid temperature.

Also, Nusselt number of TiO_2/water nanofluid was higher than that of the distilled water and increased with nanoparticle concentration. The addition of nanoparticles into base fluid increased the thermal conductivity of fluid and also increased the nanoparticles collisions which are responsible for heat transfer enhancement. At same moment, addition of nanoparticles into base fluid increased the viscosity of fluid which declined the heat transfer rate. But the effect of increased thermal conductivity was dominant, hence Nusselt number increased with particle volume concentration.

4.2.2 Influence of Reynolds number and nanofluid concentration on tube side friction factor

Friction factor is a measure of pressure drop and consequently the pumping power required to circulate the hot fluid through heat exchanger. Friction factor decreased considerably with increasing Reynolds number, simply because at higher Reynolds number the inertial forces become dominant as compared to viscous forces.

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Addition of nanoparticles slightly increased the friction factor, which revealed that utilization of nanofluids for heat transfer enhancement have penalty of slightly increased pumping power. Figure 16 shows the effect of Reynolds number and particle volume concentrations on hot fluid side friction factor at 45°C inlet fluid temperature, similar trends were found for higher temperature values.

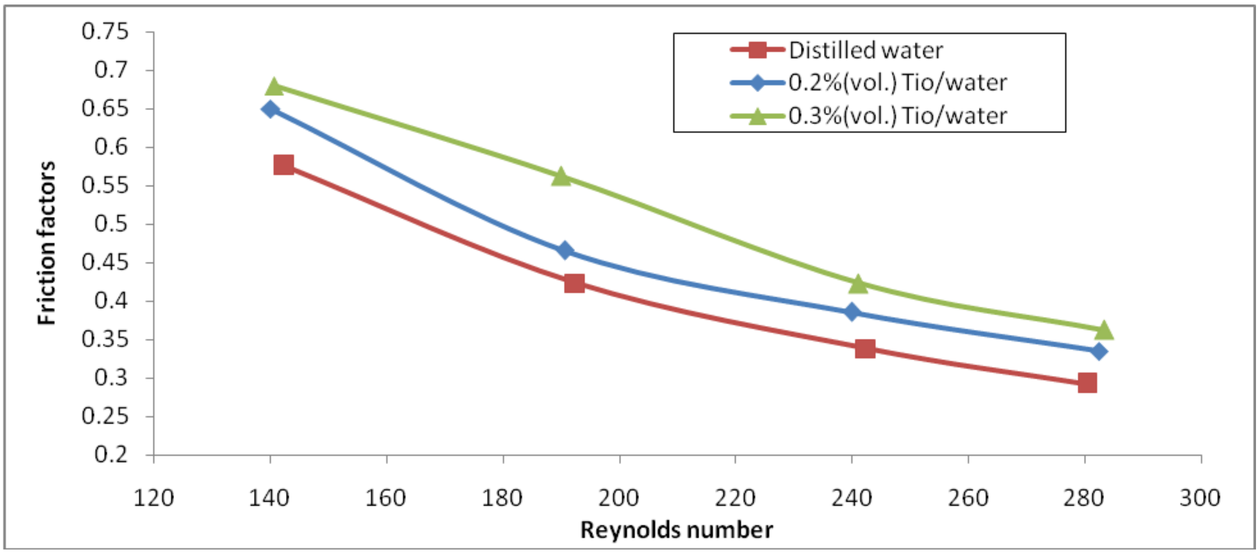

Figure 16: Influence of particle volume concentration and Reynolds number on tube side friction factor at 45°C inlet fluid temperature.

4.2.3 Effect of inlet fluid temperature on tube side Nusselt number

Nusselt number is a function of Reynolds number and Prandtl number. When inlet temperature of hot fluid was increased, Reynolds number increased because of significant effect of temperature on viscosity of fluid and at the same time Prandtl number decreased because of dominantly increased thermal conductivity of hot fluid and decrease of viscosity.

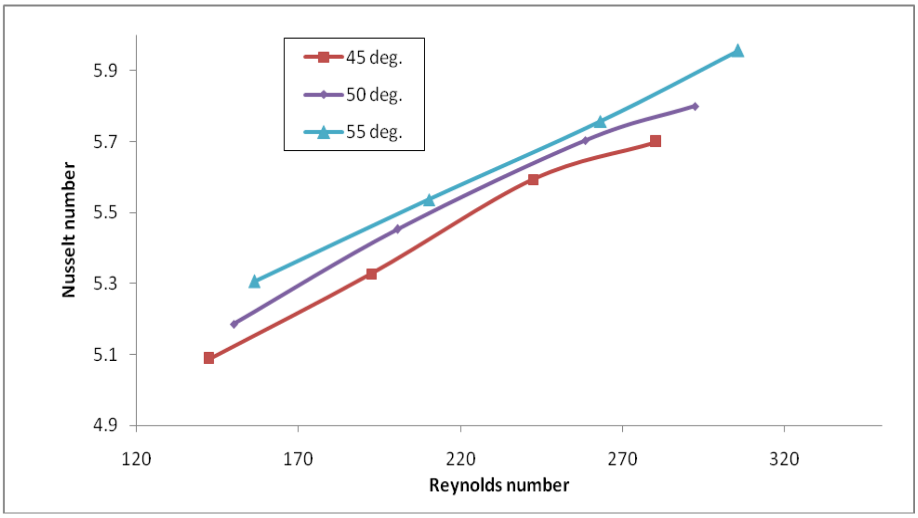

Figure 17: Effect of inlet temperature of water on tube side Nusselt number.

Nusselt number was increased due to dominant effect of increased Reynolds number. Figure 17 shows the effect of inlet temperature of water on Nusselt number, similar trends were found for 0.2% and 0.3% concentrations of TiO_2/water nanofluid.

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4.2.4 Effect of inlet fluid temperature on tube side friction factor

As inlet temperature of hot fluid increased, viscosity decreased slightly, consequently the friction factor decreased with increasing temperature of hot fluid. Viscosity of nanofluid was slightly higher than that of water but similar variation of friction factor with temperature were found for 0.2% and 0.3% particle volume concentrations. Figure 18 shows the variation of friction factor with inlet temperature of distilled water

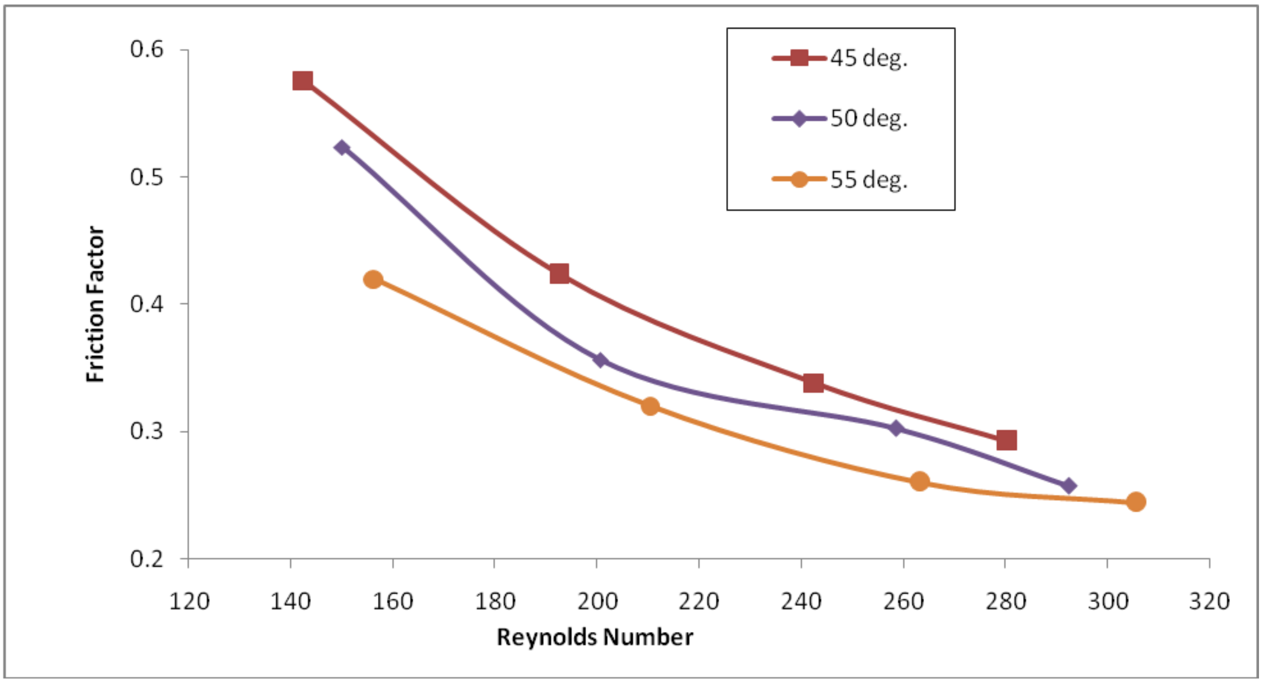

Figure 18: Effect of inlet temperature of water on tube side friction factor.

4.3 Cold fluid side analysis

Fins of heat exchanger under consideration are multi-louvered type and made of aluminium metal. Heat of hot fluid flowing inside the tubes carried away by air (cold fluid) passing over the fins. Friction between fins and air passing over the fins is also important parameters to be studied. Cold fluid side performance of heat exchanger was studied by Nusselt number, Colburn factor and friction factor. Effect of Reynolds number of cold fluid, nanoparticle volume concentration and inlet temperature of hot fluid on cold fluid side performance is illustrated as follows.

4.3.1 Influence of air Reynolds number and nanofluid concentration on cold fluid side Nusselt Number:

Heat transfer rate is highly depends upon the thickness of thermal boundary layer. Increasing the air velocity makes the boundary layer thick and thinner boundary layer leads to the increased heat transfer rate. Multi-louvered fins break the thermal boundary layer and hence increased rate of heat transfer. Nusselt number increased with increasing particle volume concentration because it increased thermal conductivity of hot fluid and consequently higher rates of heat loss to the air.

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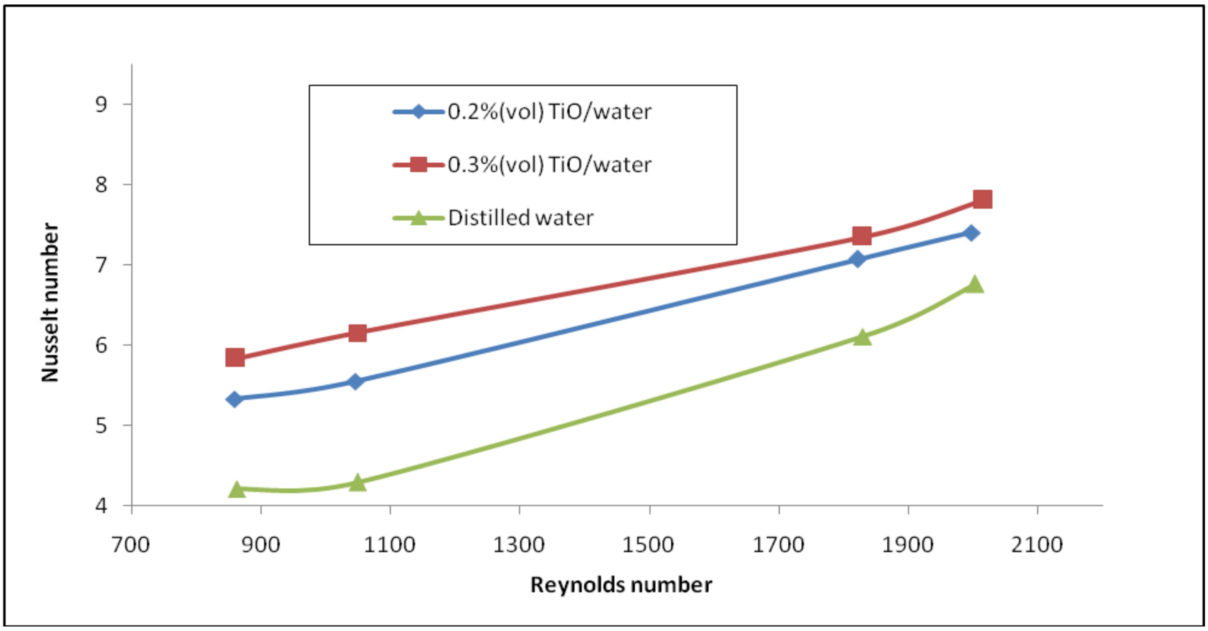

Figure 19: Influence of particle volume concentration and Reynolds number on coldfluid side Nusselt number at 45°C hot fluid inlet temperature.

4.3.2 Influence of air Reynolds number and nanofluid concentration on cold fluid side Colburn factor:

Colburn factor is also a dimensionless heat transfer coefficient and a function of Stanton number and Prandtl number [20]. Stanton number is a modified Nusselt number. Cold fluid side performance of the heat exchanger is usually studied by Colburn factor.

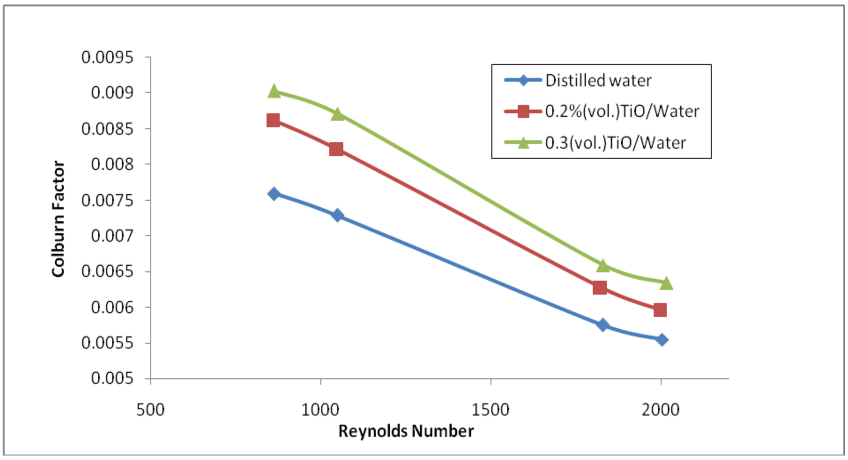

Figure 20: influences of particles volume concentration and Reynolds number on cold side Colburn factor at 45^0 hot fluid inlet temperatures.

As Reynolds number increased Colburn factor decreased due to decreased Stanton number. Colburn factor was increased slightly with increasing particle volume concentrations. Figure 20 shows the effect of Reynolds number of air and nanoparticles volume concentration on Colburn factor for 45^0C hot fluid inlet temperature, analogues trends were found for higher temperatures.

4.3.3 Influence of Reynolds number of air and nanofluid concentration on cold fluid side friction factor

Friction between air and fin is quite significant because of increased surface area in thecae of multi-louvered fins. Multi-louvered configuration increases the heat transfer rate at the cost of slightly increased pressure drop.

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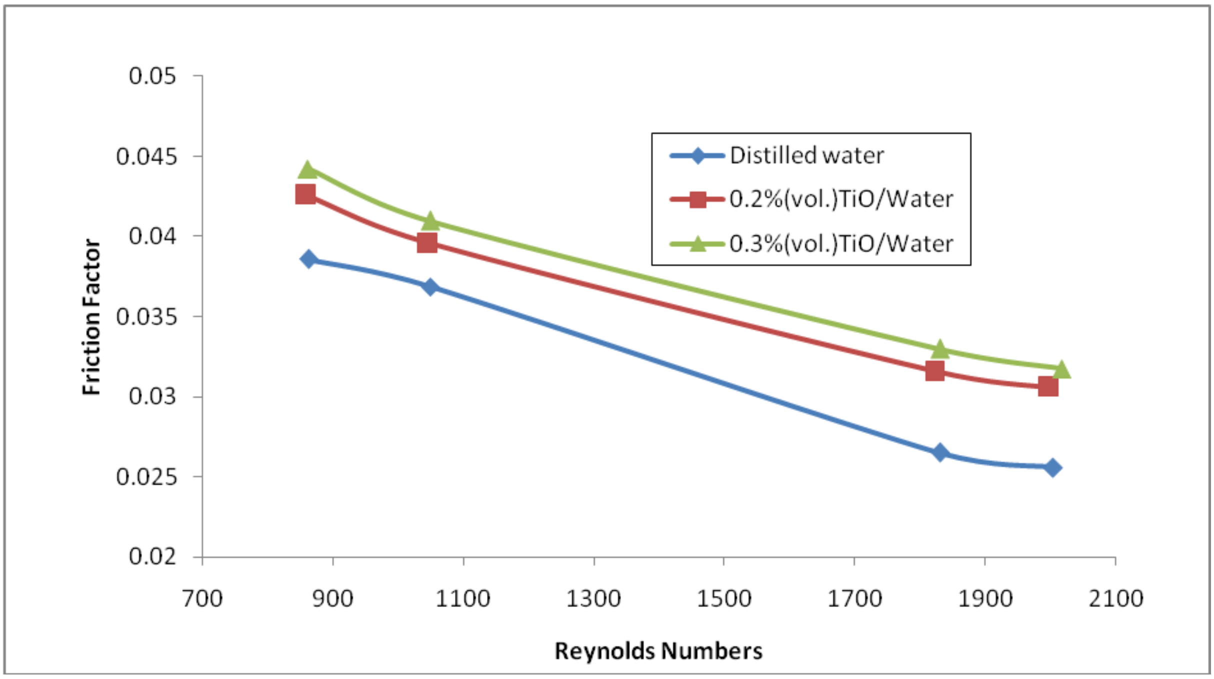

Figure 21: influence of particle volume concentration and Reynolds number on cold fluid side friction factor at 45^{0}C inlet fluid temperature.

Friction factor decreased with increasing Reynolds number of air because at higher Reynolds number, inertial effects were dominant as compared to viscous effects. With increasing particles volume concentration heat was lost to the higher rates consequently air temperature was increased. Viscosity of gases increases with temperature, hence friction between air and fin increased because of increased viscosity of air with increasing particle volume concentrations. Figure 21 shows the influences of particle volume concentration and Reynolds number on air side friction factor at 450 inlet fluid temperature, similar trends were observed for 50^{0}C and 55^{0}C temperature.

4.3.4 Effect of inlet hot fluid temperature on cold fluid side Nusselt Number

Nusselt number can be viewed as dimensionless temperature gradient at heat transfer surface. As inlet temperature of hot fluid inside the tube increased, consequently the surface temperature was increased. Due to increased surface temperature, the density of air was decreased and viscosity was increased [21]. Nusselt number is a function of both Reynolds number and Prandtl number. Prandtl number also decreased with increased inlet temperature of hot fluid. As a result, Nusselt number decreased with increasing hot fluid inlet temperature. Figure 22 shows the effect of inlet temperature of water on fin side Nusselt number, similar trends were obtained for 0.2% and 0.3% concentrations of nanofluid.

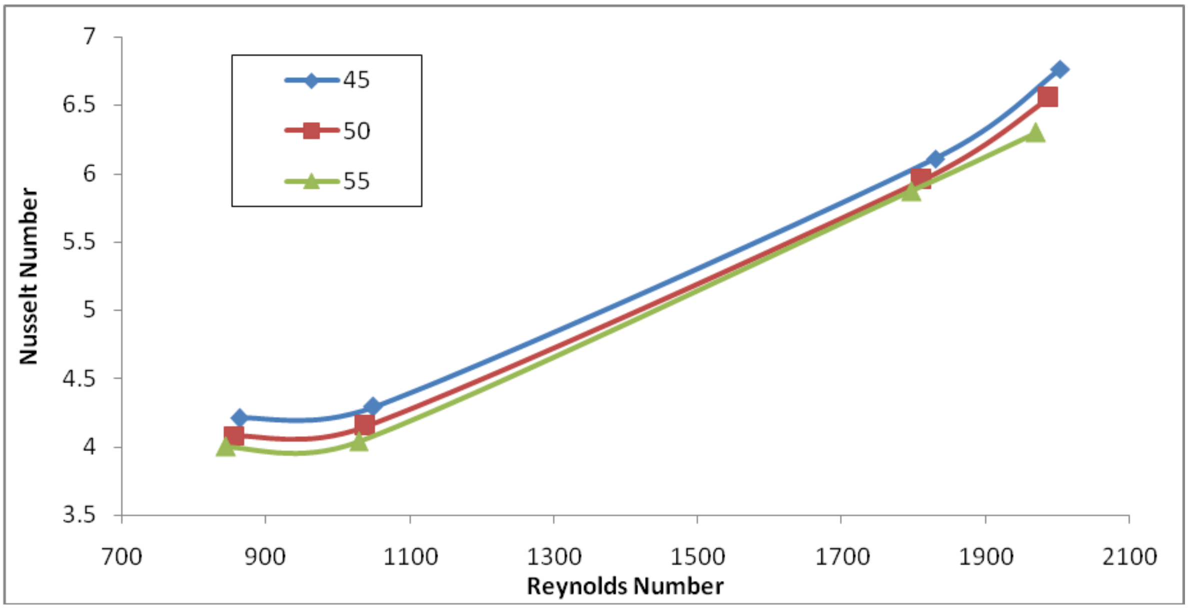

Figure 22: Effect of inlet temperature of water on cold fluid side Nusselt number

4.3.5 Inlet fluid temperature dependence of cold fluid side friction factor:

As temperature of hot fluid was increased, surface temperature of the heat exchanger was also increased. Viscosity of air increased due to increased temperature of air. Consequently the friction between fins and air passing over the fins was increased with increasing temperature of hot fluid.

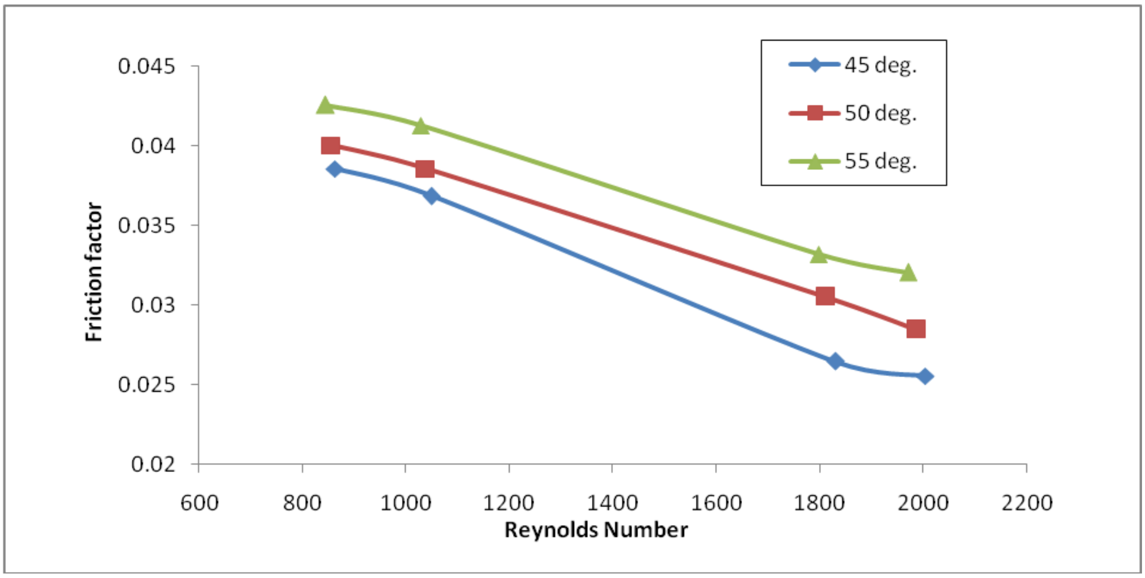

Figure 23: Effect of inlet temperature of water on cold fluid side friction factor

Figure 23 shows the effect of inlet temperature of water on air side friction factor. Similar trends were observed for 0.1% and 0.2% particle volume concentrations of nanofluid.

V. CONCLUSION

Experimental work has been conducted to study the effect of TiO_2 / water nanofluids on thermo hydraulic performance of a single pass cross flow compact heat exchanger by using double distilled water, 0.2 %(vol.)

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and 0.3 %(vol.) Concentration TiO_2/water as hot fluid passing through the tubes. The experiments are conducted under the laminar flow regime Experiments are conducted at three different temperatures ranging from 45^0 to 55^0 with step size of 5 each. Reynolds number for hot fluids and cool air passing over the heat exchanger are varied by four different values. Followings conclusions are generated from the experimental works.

5.1 Thermo physical properties of nanofluids

a).Thermal conductivity of base fluids is increases significantly by addition of nanoparticles. Also thermal conductivity observed to be a strong function of temperature. Enhancements of 18.724% in thermal conductivity are observed at 40. 13^0C and 21.107% at 56.19^0Cwith respect to the distilled water.

b).Densities of nanofluids are slightly higher than that of base fluids. As the temperature increases density decreases. Density is decreases by 1.569% as the temperature rises from 35^0C to 60^0C.

c). Viscosity of nanofluids is slightly higher than that of base fluids, but decreases significantly as the temperature increase. Viscosity of nanofluids is decreases by 31.829% as temperature increases from 35^0C to 60^0C.

5.2 Tube side performance of the heat exchanger

[1] Nusselt number of hot fluid is increased with Reynolds number of hot fluid and nanoparticles volume concentration. For 45°C inlet fluid temperature, average Nusselt number are higher than that of distilled water by 2.75% and 4.12% for 0.2% and0.3% concentration of nanofluid respectively.

[2] Nusselt number was also increased with increasing inlet temperature of hot fluid. For 0.2% particle volume concentration, Average value of Nusselt number was increased by 0.952% and 1.8613% when temperature increased to 50°C and 55°C respectively with respect to 45°C.

[3] Tube side heat transfer coefficients are increased by 19.187% and 23.425% for 0.2% and 0.3% particle volume concentrations respectively with respect to distilled water.

[4] Friction factor of hot fluid increased with addition of nanoparticles into base fluid. At 45°C inlet temperature of hot fluid, friction factor was increased by 12.91%and 19.12% for 0.2% and 0.3% nanoparticle volume concentrations respectively with respect to distilled water.

[5] Average friction factor of hot fluid was decreased by increasing inlet temperature of hot fluid. For 0.2% nanoparticle volume concentration, friction factor was decreased by 3.23% and 5.52%, when temperature was increased to 50°C and55°C respectively with respect to 45°C.

5.3 Air side performance of the heat exchanger

a).Nusselt number of air is increases with increasing Reynolds number and particle volume concentration in hot fluid in tube. Average value of Nusselt number are increased by 28.55% and 42.57% with 0.2% and 0.3% concentration of nanofluid respectively with respect to distilled water at 45°C inlet temperature of hot fluid.

b). Nusselt numbers of air are decreased by increasing the inlet hot fluid temperature. Nusselt numbers are decreased by 3.18% and 5.25% for 50°C and 55°C inlet fluid temperature respectively with respect to 45°C.

c). Colburn factor of air decreased with Reynolds number but it is increased with particle volume concentration. Colburn factor is increases by 13.57% and19.04% for 0.2% and 0.3% nanoparticle volume concentration respectively at 45°Cinlet fluid temperature with respect to distilled water.

d). Air side friction factor is increased with nanoparticles volume concentration while it is decreased with Reynolds number. Friction factor is increases by 9.77% and 13.63% with 0.2% and 0.3% particle volume concentration respectively with respect to distilled water at 45°C inlet fluid temperature.

e). Friction factor is increased with increasing temperature of hot fluid. When temperature of hot fluid are increased to 50°C and 55°C, friction factors are increased by 5.26% and 10.37% respectively with respect to 45°C.

5.4 Overall performance of the heat exchanger

a). Effectiveness of the heat exchanger is also increased significantly with the aid of Al/Water nanofluids. It is 68.76% for distilled water and increased to 75.36%and 79.49% for 0.2% and 0.3% particle volume concentration respectively.

b). Overall heat transfer co-efficient based on fin side heat transfer area is increased by 16.30% and 18.64% for 0.2% and 0.3% nanoparticle volume concentration respectively with respect to base fluid.

VI. FUTURE OUTLOOK

In the presented work, TiO2/water nanofluid was prepared by adding Ti (metal basis) nanoparticles of average particle size 20 nm into distilled water at two different particle volume concentrations i.e. 0.2% and 0.3%. Experimental work was performed to study the effect of nanofluid on thermo-hydraulic performance of a single-pass cross-flow compact heat exchanger in laminar flow regime. Future scopes of the presented work are listed as follows.

a). Effect of average particle size on the performance of heat exchanger can be studied using nanoparticles of different particle size.

b).Experiments can be performed for wide range of particle volume concentrations.

c).Numerical analysis can be performed to obtain more precise results and to validate the experimental results.

d).Experimental work can be performed in turbulent flow regime by using high flow rate capacity pump.

e).Different base fluids can be used to prepared nanofluid and the effect of various base fluid-nanoparticle combinations on the heat exchanger performance can be studied.

f). Study the performance of heat exchanger when couple with engine cooling system.

REFERENCES

[1] Das S.K., S.U.S. Choi, Wenhua Yu and Pradeep T., (2007), Nanofluids: Science and Technology. John Wiley & Sons, Inc. New Jersey.

[2] Maxwell J.C., (1881), "A treaties on electricity and magnetism", 2nd ed., Clarendon Press, Oxford, U.K., Vol 1.

[3] S.U.S. Choi, (1995) "Enhancing thermal conductivity of fluids with nanoparticles, Developments and Applications of Non-Newtonian Flows", FED-vol.231/MD-Vol. 66, 99-105.

[4] Eastman J.A., , S.U.S. Choi, S. Li, W. Yu, L.J12, (2001) "Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles" Applied Physics Letters Vol. 78, 718.

IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

[5] H. Xie, H. Lee, W. Youn, M. Choi, (2003) "Nanofluids containing multiwalled carbon nanotubes and their enhanced thermal conductivities" Journal of Applied Physics Vol. 94, 4967.

[6] S.U.S. Choi, Zhang Z.G., W. Yu, Lockwood F.E., Grulke E.A., (2001), "Anomalous thermal conductivity enhancement in nanotube suspensions" Applied Physics Letters Vol. 79, 2252.

[7] Frank P. Incropera, David P. Dewitt, Theodore L. Bergman, Adrienne S. Lavine,(2006), “Fundamentals of heat and mass transfer" John Wiley & Sons. Sixth edition.

[8] Keblinski P., Phillpot S.R., S.U.S. Choi, Eastman J.A., (2002), “Mechanism of heat flow in suspension of nanosized particles” , International Journal of Heat and Mass Transfer Vol. 45, 855-863.

[9] Jang S.P., S.U.S. Choi, (2004), "Role of Brownian motion in the enhanced thermal conductivity of nanofluids", Applied Physics Letters Vol.84, 4316.

[10] Eastman JA, Choi SUS, Li S, (2001), “Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles”, Applied Phys Letter Vol. 78, 718-720.

[11] Karthik V., Sahoo S., Pabi S.K., Ghosh S., (2012), “On the phononic and electronic contribution to the enhanced thermal conductivity of water based silver nanofluids”, International Journal of Thermal Sciences, 1-9.

[12] Jang S.P. and Stephen U. S. Choi, (2004), "Role of Brownian motion in the enhanced thermal conductivity of nanofluids", Applied Physics Letter volume 84, 4316.

[13] Intelligant material Pvt. Ltd. www.nanoshel.com.

[14] Gangacharyulu D, Sharma J.K., Singh G, “Performance evaluation of after cooler in diesel engines- A case study” , IE(I) journal-MC, Vol 80, May 1999.

[15] Bergman, T. L., Incropera, F. P., & Lavine, A. S. (2011). *Fundamentals of heat and mass transfer*. John Wiley & Sons.

[16] Shah, R. K., & London, A. L. (2014). *Laminar flow forced convection in ducts: a source book for compact heat exchanger analytical data* (Vol. 1). Academic press.

[17] Wang, X. Q., & Mujumdar, A. S. (2007). Heat transfer characteristics of nanofluids: a review. *International journal of thermal sciences*, *46*(1), 1-19.

[18] Pak, B. C., & Cho, Y. I. (1998). Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. *Experimental Heat Transfer an International Journal*, *11*(2), 151-170.

[19] Mahbubul, I. M., Saidur, R., & Amalina, M. A. (2012). Latest developments on the viscosity of nanofluids. *International Journal of Heat and Mass Transfer*, *55*(4), 874-885.

[20] Li, W., & Wang, X. (2010). Heat transfer and pressure drop correlations for compact heat exchangers with multi-region louver fins. *International Journal of heat and mass transfer*, *53*(15), 2955-2962.

[21] Peyghambarzadeh, S. M., Hashemabadi, S. H., Hoseini, S. M., & Jamnani, M. S.(2011). Experimental study of heat transfer enhancement using water/ethylene glycol based nanofluids as a new coolant for car radiators. *International Communications in Heat and Mass Transfer*, *38*(9), 1283-1290.