Study of Heat Transfer of Aluminium Oxide in Water and Ethylene Glycol based Nanofluid in Single Pass Multi Tube Cross Flow Heat Exchanger

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Abstract— **Experimental study was conducted to determine the change in overall heat transfer coefficient and the thermo hydraulic performance charactericties of a single pass multi tube cross flow heat exchanger using Al_2O_3 nanoparticles in a binary mixture of water and ethylene glycol. The base fluid was a mixture of water and ethylene glycol in 60:40% by vol. The concentration of Al_2O_3 nanoparticles was 0.05% and 0.1 % by volume and the temperature was varied from 45 °C to 55 °C with flow rate from 3, 4 and 5 LPM. Thermal conductivity and viscosity were also measured. Enhancement of 6.58 % in thermal conductivity was seen at 30 °C while it was 8.23 % at 60°C. The overall heat transfer co-efficient based on the fin side heat transfer area was increased by 12.64%. The friction factor increased by 13.9% and 20.81% for 0.05% and 0.1% nanoparticle volume concentrations respectively.**

Keywords— Nanofluids; Nanoparticles; Thermal conductivity; Viscosity; Density; Heat Transfer Coefficient

I. INTRODUCTION

Miniaturized and highly efficient thermal systems represent the current requirements of the automobile, industrial as well as residential cooling and heating systems. But the performance of the modern thermal systems is primarily limited by the lower conductivity of the fluids being used in these systems. As a result of research and technology advancements, the concept of Nanofluids was introduced. The term Nanofluids broadly refers to the fluids with particles of average size less than 100 nm dispersed in it. The presence of these particles drastically alters the thermal and transport properties of the base fluid due to which there is a wide scope of their applications. Primarily conventional fluids like water, lubricating oil and coolant additives like ethylene glycol etc. are employed as the working fluids for the heating and cooling systems. One of the major limiting factors for the low heat transfer performance of these fluids is their poor thermal conductivity. Hence the idea of dispersing solid particles in the fluid was introduced in order to improve the thermal conductivity of the fluid and thus improve their heat transferring characteristics. High conductivity of solids can be utilized in increasing the thermal conductivity of a fluid by the addition of small solid particles to the fluid. The feasibility and application of the usage of such mixtures of solid particles with sizes ranging from 10^{-9} to 10^{-7} meters was previously examined by many researchers.

Nanofluids may be prepared by One step method or Two step method. Because of the difficulties faced regarding stability during the mixing process in preparing nanofluids by Two-step method, the One-step method was developed. In order to reduce the accumulation of nanoparticles, Eastman et al. [2] suggested the one-step physical vapor condensation process for preparing Cu/ethylene glycol nanofluids. In this one-step method, it involves the simultaneous synthesis and dispersion of the nanoparticles in the base fluid. By this method, the drying, storage and transportation processes are removed, so the accumulation of nanoparticles is kept at a minimum. Thus the stability of fluids is greatly increased [1].

Further research was done to study stability of nanofluids and various techniques were suggested. Sedimentation method is the simplest method for evaluation of stability [3]. The sedimentation method was utilized by Zhu et al. [4] during experimentation in order to establish graphite suspension stability. Most researchers capture photographs of the samples at regular time intervals for 24 hours after the nanofluid sample is prepared to determine sedimentation and hence conclude its stability [5, 6]. Spectral absorbency analysis is also an efficient method to study the stability of nanofluids. It utilizes UV-visual spectral analysis. Its advantage is that it gives quantitative results with respect to concentration of nanofluids [8]. The values of zeta potential ranging from 40-60 mV are believed to be highly stable. Kim et al. [9] performed zeta potential analysis for Au nanofluids and observed acceptable stability. Zhu et al. [10] studied Alumina-water based nanofluids at various pH levels and at different surfactant concentrations. Zeta potential is defined as the potential difference between dispersion fluid and the layer of stationary attached to the surface of the dispersed particles.

Ultrasonic agitation can be utilized to break those clustered particles back into individual particles and it depends on how long the nanofluid sample was kept in the agitator as demonstrated by Manson et al. [11]. Wang et al. [6] Investigated two different nanofluids; carbon black-water and silver-silicon oil and they utilized high energy of cavitation for breaking clusters among particles and again it was observed that there were less clustered particles in samples that were kept in agitator for longer time durations [12]. Yang et al. [13] experimented with addition of silanes to the surface of silica nanoparticles in the solution. It was observed that there was no deposition layer formation on the heating surface after the pool boiling process. Another way to increase stability of carbon nanotubes is by adding hydroxyl groups onto their surface [14].

II. LITERATURES

Ali et al. [15] studied the effect of Alumina/water nanofluids on the thermal performance of cooling system of an automobile radiator. Al_2O_3/water nanofluids were prepared at five different concentrations viz. 0.1, 0.5, 1, 1.5 and 2 % by volume. The maximum percentage increase of the heat transfer rate, heat transfer coefficient, and Nusselt number of nanofluid was found 14.79, 14.72, and 9.51, respectively, which take place at maximum load of 1 KW and at particle volume concentration of 0.01. Jalal et al. [16] conducted the experiments to study the effect of CuO/water nanofluids on convective heat transfer performance of a heat sink. They concluded that increasing the particle volume concentration results in an increment in the heat transfer coefficient. Garg et al. [17] investigated the thermal conductivity and viscosity of ethylene glycol based copper nanofluids. Particle volume concentration was varied from 0.4 to 2%. They concluded that because of higher increment in viscosity as compared to thermal conductivity, the nanofluids are not suitable in the existing thermal system. However, the advantages of increased thermal conductivity could be beneficial by increasing the tube diameter in the application where the size of thermal equipments is of lesser importance.

Sheikhzadeh et al. [18] analyzed the thermal performance of a car radiator while using copper/ethylene glycol as coolant. They observed that when particle volume concentration increased from 0 to 5 %, overall heat transfer coefficient and heat transfer rate were increased by 64.3 % and 26.9 %, respectively. They also found that when Reynolds number increased from 4000 to 6000, overall heat transfer coefficient of air and nanofluid were increased by 4.5 % and 12.4 %, respectively. Leong et al. [19] investigated the performance of an automotive car radiator by using Cu/EG nanofluids as coolant. Results were compared by taking Reynolds number of air and coolant as 6000 and 5000, respectively. The heat transfer rate was increased by 3.8 % by adding 2 % of Cu nanoparticles. An increment of 42.7 % and 45.2 % was observed when air's Reynolds number was increased from 4000 to 6000 for ethylene glycol and Cu/EG nanofluid, respectively. They observed that frontal area of heat exchanger was reduced by 18.7 % by adding 2% of Cu nanoparticles into the base fluid. Pumping power for nanofluid was found 12.13 % higher than that with pure ethylene glycol, while keeping volumetric flow rate of nanofluid constant to $0.2m^3/s$.

Nieh et al. [20] employed Al2O3/water and TiO2/water nanofluids in air cooled radiator to improve the performance. Thermo-physical properties of nanofluids were measured at different nanoparticle volume concentration and then pressure drop and heat dissipation rate were measured at different Reynolds number. Efficiency factor and heat dissipation rate was greater for nanofluids as compared to that with ethylene glycol/water solution. They concluded that the TiO_2/water nanofluids showed the greater enhancement than Al_2O_3/water nanofluids. Elias et al. [21] experimentally investigated the thermo-hydraulic performance of car coolant system using nanofluids as coolant. It was observed that density, viscosity and thermal conductivity were enhanced with particle volume concentration while specific heat of nanofluids was decreased. With increasing temperature, thermal conductivity and specific heat were increased while density and viscosity were decreased. Enhancement in average thermal conductivity was observed 3.26 % and 8.30 % with temperature and particle volume concentration, respectively.

Sandesh S. Chougle et al. [22] done experiment on car radiator by using carbon nanotubes (CNT) and Al2O3 nanoparticles in water with four different concentration range from 0.15 to 1.00 vol.%. The results showed that at 1% vol. nanoparticle maximum heat transfer enhancement was 90.76% and 52.03% for CNT and Al_2O_3 nanofluid respectively was achieved. As the coolant mass flow rate increased heat transfer performance was increased for both the nanocoolant. CNT nanofluid showed massive enhancement as compared Al_2O_3 nanofluid. Leong et al. [23] investigated the performance of heat transfer coefficient of car radiator with water and ethylene glycol as coolant. There was 3.8% enhancement in heat transfer coefficient with 2% concentration of copper nanoparticle in water. When ethylene glycol was used as base fluid with 2% concentration of copper nanoparticles only 0.9% enhancement was observed. Pumping power was increased by 12.13 % and reduction in frontal area was 18.7%.

Murshed et al. [24] studied the thermal conductivity enhancement of $Ti0_2$ and Al_2O_3 nanoparticles with water as base fluid affected by surfactant and nanoparticle cluster formation in base fluid. Cluster formation was studied by using transmission electron microscope (TEM). It was observed that as the concentration of nanoparticles was increased the agglomerate or cluster formation between nanoparticles also increased. This cluster formation reduced the thermal conductivity enhancement. Agglomerate formation depended on particle size, shape, concentration, viscosity of base fluid. Large size of cluster formation at high concentration leads to free region in base fluid and provide high thermal resistance which reduce the enhancement in conductivity. Remedy suggested for nanofluid clustering was sonication and surfactant addition.

Jahar sarkar et al. [25] used 20% ethylene glycol and 80% water to form ethylene glycol/water mixture (EG/water). Four type of nanoparticles are used Cu, SiC, Al_2O_3, and TiO_2 to see the effect of these particle in coolant for improvement in cooling capacity, effectiveness and reduction in pumping power. Results showed that SiC yield best result in performance in radiator followed by Al_2O_3, TiO_2 and Cu respectively. Maximum 15.34% enhancement in cooling capacity for SiC, 14.33% for Al2O3, 14.03% for TiO_2, 10.20% for Cu. Results indicated that Cu based nanofluid had least cooling capacity and effectiveness when compare to others.

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III. EXPERIMENTAL SETUP

For this experimental study Al_2O_3 nanoparticles dispersed in a binary mixture of water and ethylene glycol in 60:40% by vol. were utilized to study effects on a single pass multiple tube cross flow heat exchanger. The experimental setup is arranged as shown in the figure 1. And the heat exchanger specifications are given in table 1.

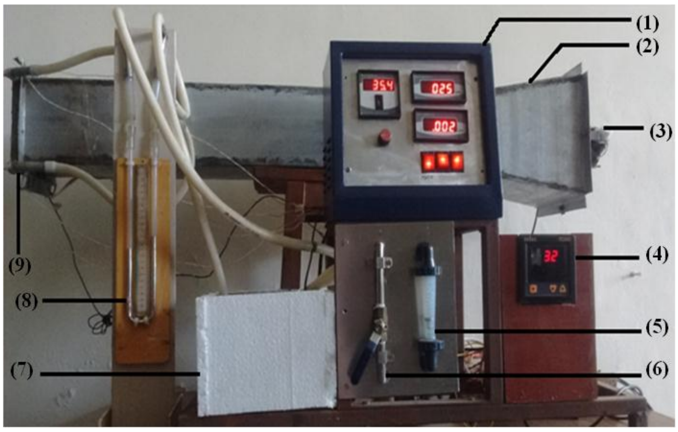

Figure 1: Experimental Equipment: (1) Display, (2) Air flow duct, (3) Forced draft fan, (4) PID controller, (5) Rotameter, (6) By pass valve, (7) Reservoir tank, (8) U tube manometer, (9) Heat exchanger.

As shown the setup consists of a cross flow heat exchanger fixed at the end of the duct through which air is supplied by a forced draft fan with speed regulator at the other end of the duct. Temperature sensors are positioned at different points on the heat exchanger and connected to a temperature display. Figure 2 shows the cross flow heat exchanger along with the positioning of 8 temperature sensors.

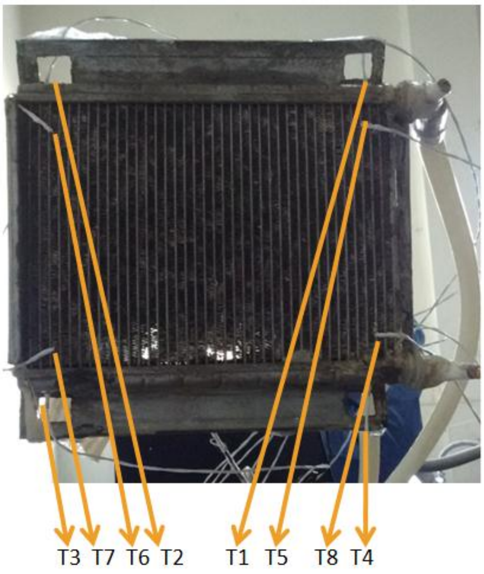

Figure 2: Heat exchanger with location of 8 temperature sensors.

Temperature sensors T1 and T2 measure the temperature if the fluid at inlet and T3 and T4 measure temperature of at the outlet. Sensors T5, T6, T7 and T8 measure temperature of hot air leaving the heat exchanger at four different locations. Highly sensitive Pt-100 temperature sensors were used. Pt is for platinum and 100 signifies its resistance value at 0^0C temperature. Platinum can withstand very high temperatures and is therefore the most commonly used. It provides high accuracy over a wide range of temperature. With change in temperature the resistivity of element changes, this change in resistivity correlates to the temperature change of fluid.

Table 1: Heat exchanger specifications

Cross flow core dimensions	Height	154 mm
	Width	194 mm
	Thickness	21 mm
Fins per inch	FPI	56
Heat exchanger Areas	Tube	0.255 m²
	Fin Area	1.106 m²
	Total	1.361 m²

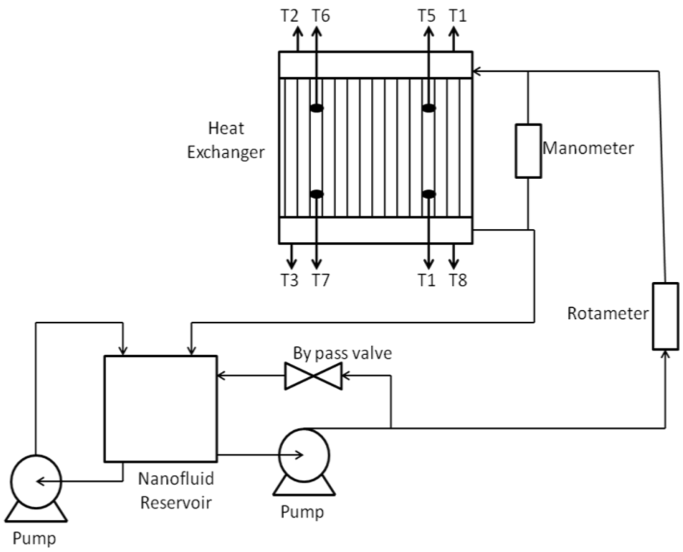

Figure 3: Experimental setup layout.

As shown in figure 3 above, for this experimental study a U-tube manometer, flow lines, two centrifugal pumps, bypass valve, reservoir with heating element and a PID controller complete the fluid flow circuit. Performance was evaluated at three different hot fluid inlet temperatures i.e. 45 °C, 50 °C and 55 °C at three different flow rates of 180, 240 and 300 LPH. Velocity of cold air by forced draft fan was varied at 3.4 m/s, 5.8 m/s and 6.4 m/s. First the experiment was carried out using distilled water as working medium, then mixture of water and ethylene glycol in 60:40% by vol. and then Al_2O_3 nanofluids of 0.05% and 0.1% by vol.

IV. PREPARATION OF NANOFLUID

The α-Al_2O_3 nanoparticles of average size 40nm were purchased from Intelligent Materials Pvt. Ltd, Panchkula. The properties of Al_2O_3 nanoparticles are given in table 2.

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Table 2: Specification of nanoparticles

Chemical Name	α-Al_2O_3 nanopowder
Appearance	White powder
Purity	>99%
Average particle size	40nm
p^H	6.6
Density (Kg/m^3)	3970

Nanofluids were prepared by two step method. The Two-step method is the most commonly used and economic method to prepare nanofluids in large quantities because the nanopowder manufacturing techniques have already started providing up to required industrial production levels. The powder form of nanoparticles has to be dispersed into a base fluid with the help of external mixing or stirring methods like magnetic agitators, ultrasonic agitators, high-shear mixers, homogenizing or ball milling. For this experimental study the nanoparticles were dispersed into the base fluid i.e. water and ethylene glycol mixture in 60:40 ratio. For the required volume concentrations of 0.05%, and 0.1%, fixed quantities of 2.0947 gm and 4.1980 gm of nanoparticles per 1000 ml of base fluid were dispersed respectively. The nanoparticle concentrations were selected because after studying literatures it was observed that up to 0.1% concentrations the nanofluids exhibited very good stability. To further hold the particles in suspension the nanoparticles, ultra sonicator was used. Sonication was done for 2 hours before testing thermal conductivity and viscosity of the nanofluids. After this process the nanoparticles were more evenly dispersed in base fluid. The Al_2O_3 samples prepared are as shown in Fig. 4.

Figure 4: 0.1% volume concentration Al_2O_3/water and ethylene glycol (60:40) nanofluid

The thermophysical properties, i.e. thermal conductivity, viscosity were measured by KD2-Pro and Brookfield DV-III Rheometer respectively. Thermal conductivity was measured at temperatures ranging from 30 °C to 60 °C with increments of 5°C. It was not measured at higher temperatures because at higher temperatures the base fluid starts to decompose and the 60:40 ratio of water and ethylene glycol will not be maintained. The viscosity was measured at 40°C, 45°C, 50°C and 55°C.

V. EQUATIONS AND FORMULAS USED

Experimental calculations were done for both water side and air side at 45^0C temperature of hot working fluid. Air side thermo physical properties were considered at bulk mean temperature of air passing across the heat exchanger. Hot fluid thermo physical properties were also considered at bulk mean temperature. The control volume considered for calculations is shown below in Fig.5 which was used to calculate the different types of areas.

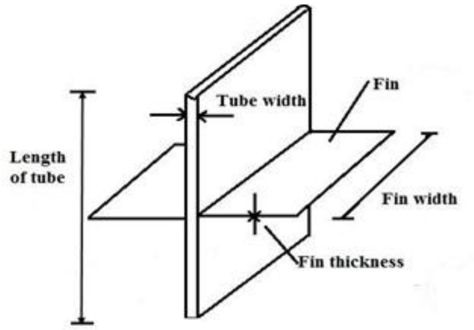

Figure 5: Tube fin control volume

Hydraulic diameter was calculated as shown below

$$D_h = 4A_c/P \quad (1)$$

Where A_c is cross section are and P is the perimeter of the heat exchanger tubes.

Reynolds number represents the ratio of inertia force to the viscous force and is given by

$$Re = \rho v D_h/\mu \quad (2)$$

Where ρ represents density, μ represents dynamic viscosity, v represents fluid velocity through the tube, D_h is hydraulic diameter.

Colburn factor (J_a) is dimensionless representation of heat transfer coefficient [26]

$$J_a = 0.249 \text{ x } Re^{-0.42} \text{ x } l^{0.33} \text{ x } H^{0.26} \text{ x } l^{1.1}/H \quad (3)$$

Where Re is the Reynolds number, l is length of fin and H is the height.

Core mass velocity [26] is also calculated as shown below.

$$G_a = W/A_c \quad (4)$$

Where G_a is the core mass velocity, W represents the mass flow rate amd A_c is the cross section area.

The heat transfer coefficient h_a is calculated using core mass velocity and Colburn factor as shoen below.

$$h_a = J_a \text{ x } G_a \text{ x } C_p/Pr^{2/3} \quad (5)$$

Where C_p represents the specific heat capacity and Pr represents the Prandtle number.

For calculating fin efficiency the following relations were used as given below.

$$m = (2 \text{ x } h_a/(K_a \text{ x } \delta))^{0.5} \quad (6)$$

$$\eta_f = (\tanh (m \text{ x } l)) / (m \text{ x } l) \quad (7)$$

Where η_f represents the fin efficiency and m represents the slope of heat transfer line for the fins.

The heat rejected (Q) by the fluid was calculated using the given formula.

$$Q = W \text{ x } C_p \text{ x } (T_i - T_o) \quad (8)$$

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Where W is the mass flow rate as mentioned above, Cp is the specific heat, Ti is inlet temperature of nanofluid and To is the outlet temperature.
The specific heat capacity of the nanofluid was measured using the relation given below.

$$(\rho C_p)_{nf} = (1 - \Phi)\,(\rho C_p)_f + \Phi(\rho C_p)_p \qquad (9)$$

Where is ρ density, Φ is particle volume fraction, Cp represents the specific heat capacityand subscripts nf, f, p represent nanofluid, base fluid and nanoparticles, respectively.

VI. RESULTS AND DISCUSSION

Various thermo physical properties of the nanofluid namely the thermal conductivity, density and viscosity were measured experimentally with the help of KD2 Pro thermal property analyzer, specific gravity bottle and Brookfield DV-III Rheometer respectively. Temperature dependence of these properties was also studied experimentally which were then compared with those of the base fluid.

A. Temperature dependence of density of nanofluid

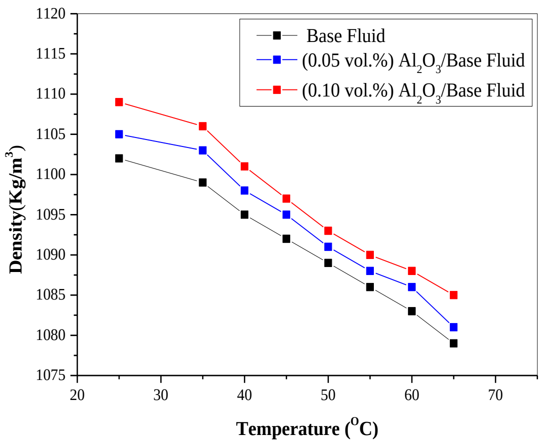

Figure 6: Effect of temperature variation on density of Al_2O_3/water and ethylene glycol nanofluid

From Figure 6, it could be concluded that nanofluid density was higher than that of water as was expected but it decreased slightly with increase in temperature of the fluid. There was a maximum variation of only 1.01% when temperature increased from 25 °C to 65 °C . The trend of change in density was similar to the trend shown by the base fluid which was mixture of water and ethylene glycol in 60:40 ratio.

B. Temperature dependence of thermal conductivity of nanofluid

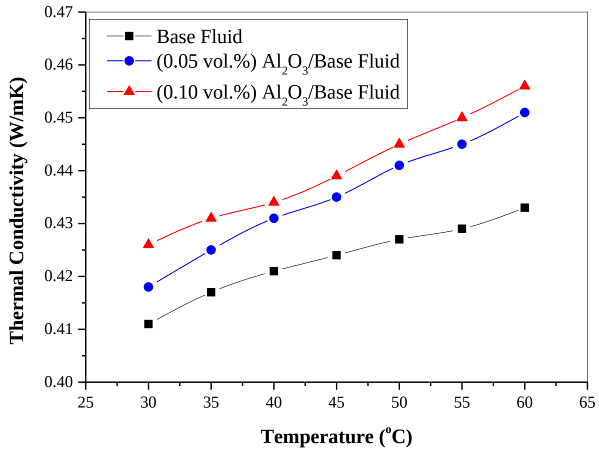

Figure 7: Effect of temperature variation on Thermal conductivity of Al_2O_3/water and ethylene glycol nanofluid

From experimental data it was observed that the thermal conductivity of Al_2O_3/water and ethylene glycol nanofluid was higher than that of water and ethylene glycol which was the base fluid. Also it showed strong dependency on temperature of the fluid. Fig. 7 shows the experimental data of thermal conductivity of nanofluid which increased significantly with the base fluid temperature. The reason can be attributed to the fact that increase in fluid temperature further strengthens the Brownian motion of dispersed nanoparticles and also reduces the viscosity of the base fluid. Along with a strengthened Brownian motion of particles, the effect of micro convection in heat transport increases and as a result it increased the thermal conductivity of nanofluids.

C. Temperature dependence of viscosity of nanofluid

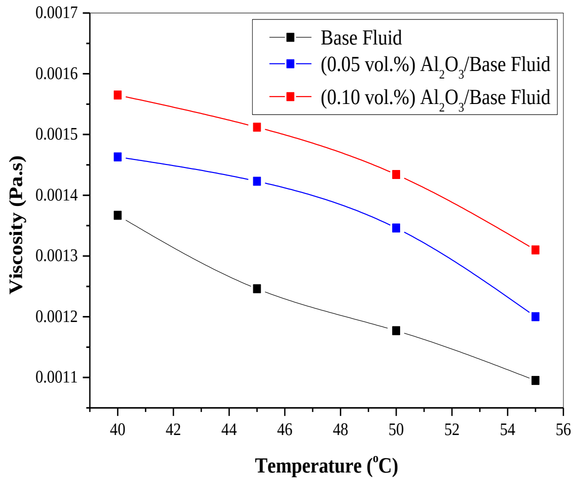

Figure 8: Effect of temperature variation on viscosity.

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From the experimental data obtained, it was observed that viscosity of nanofluid at 0.1% (vol.) concentration was slightly higher than that of water, simply because when solid particles are added to the base fluid, it increased the density of the mixture and as a result it required more force to overcome the inertial forces. Hence the viscosity increased but there was significant variation in viscosity with changes in temperature. The trend of change in viscosity was similar to the trend shown by the base fluid as shown by the fig. 8 above.

D. Heat transfer coefficient variation with nanofluid concentration

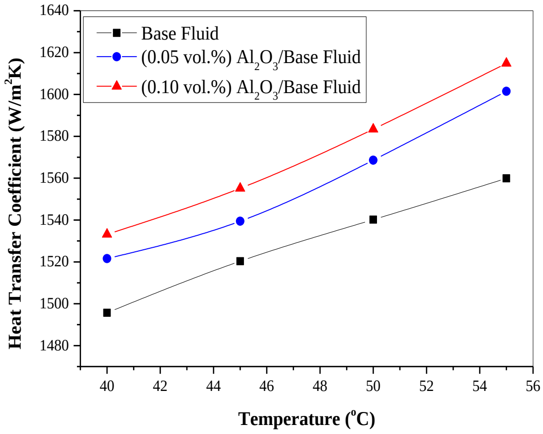

Figure 9: Effect of temperature variation on heat transfer coefficient.

The tube side heat transfer coefficient increased as the nanoparticle concentration was increased as shown in fig. 9. It was also observed that with increasing inlet temperature of the fluid the heat transfer coefficient increased with a maximum enhancement of 3.54% for 0.1% vol. concentration and a minimum enhancement of 1.87% for 0.05% vol. concentration of Al_2O_3 nanoparticles. The minimum enhancement was observed at 40 °C temperature and maximum enhancement was observed at 55 °C temperature. From the graph it was also observed that for 0.1% vol. concentration the increase in enhancement was relatively small over 0.05% vol. concentration as compared to the base fluid.

E. Variation in pressure drop

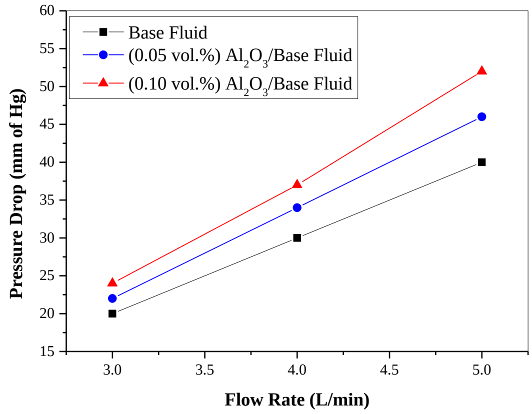

Figure 10: Effect on pressure drop at different concentrations.

The experiment was conducted with a U tube manometer connected across the inlet and outlet of the heat exchanger to measure the direct pressure drop through it. The data is plotted in fig. 10 as shown above. It was observed that the pressure drop increased with the increasing concentration of nanoparticles as was expected. The maximum increase in pressure drop was observed to be 20% for 0.1% vol. concentration of Al_2O_3 nanoparticles. Whereas for 0.05% vol. concentration the maximum pressure drop was observed to be around 12%.

F. Variation in Reynolds number

Reynolds number is a measure of flow pattern. For laminar flow through pipes and tubes its value is below 2000. The graphs in Figure 11 show the effect on Reynolds number for base fluid and particle volume concentrations of 0.05% and 0.1 % at different inlet temperatures of 45°C, 50°C, 55°C along with different flow rates of 3, 4, 5 Litre per minute (LPM).

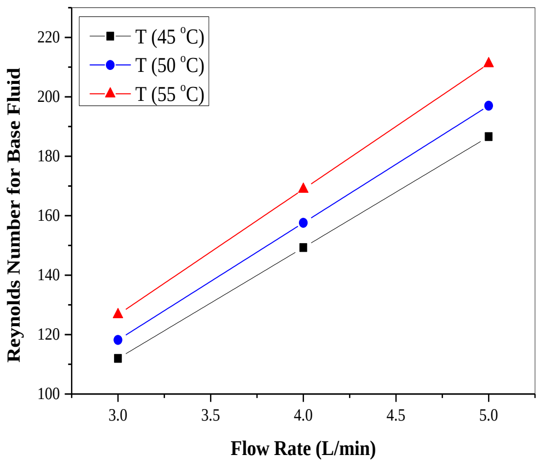

Figure 11(a): Reynolds number for base fluid

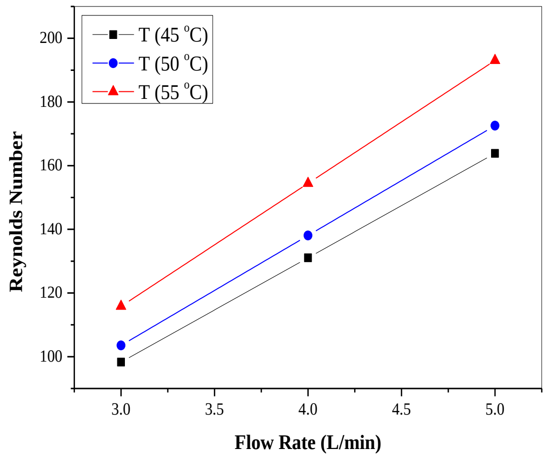

Figure 11(b): Reynolds number for 0.05% Al_2O_3

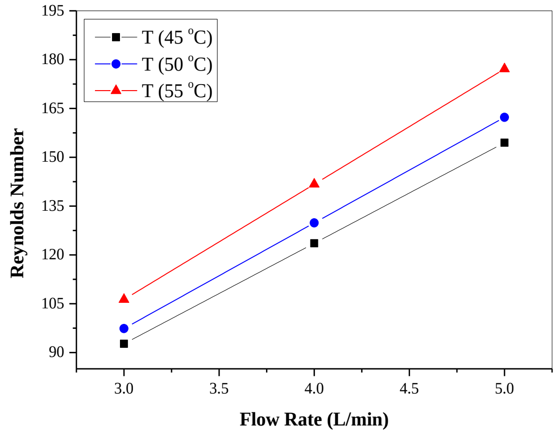

Figure 11(c): Reynolds number for 0.1% Al_2O_3

Similar trends were found for higher values of temperature. The enhancement of heat transfer with rising Reynolds number was observed primarily due to reduction of the thermal boundary layer thickness. From the data it was observed that although the trends were similar but the actual values of Reynolds number were different due to different fluid properties of the base fluis at different temperatures namely the viscosity and density.

VII. CONCLUSIONS

The experiments were conducted on a single-pass multiple tube cross-flow heat exchanger to study the effect of Al_2O_3/water and ethylene glycol nanofluid on the thermo hydraulic performance characteristics of the heat exchanger. The experiments were conducted using mixture of water and ethylene glycol in 60:40 ratio as base fluid, 0.05% (vol.) and 0.1% (vol.) concentration Al_2O_3/water and ethylene glycol nanofluid as hot working fluid flowing through the heat exchanger tubes. The tests were carried out in laminar flow regime and the following conclusions were made based on the data from the experiment performed.

- Thermal conductivity of base fluid was increased with the addition of nanoparticles. Also it was observed that thermal conductivity showed dependence on temperature. Enhancement of 6.58 % in thermal conductivity was seen at 30 °C while it was 8.23 % at 60°C.
- Density of nanofluid was observed to be slightly higher than the base fluid. But with increasing the temperature its density decreased. Density showed a variation of 1.01% as temperature increased from 25°C to 65°C.
- Viscosity of nanofluid was also higher than that of base fluid as was expected, and it followed a decreasing trend with increase in temperature. Viscosity of nanofluid showed a variation of 9.57% as temperature increased from 40°C to 55°C with a maximum increase of 19.1% over the base fluid for 0.1% vol. concentration sample.
- The effectiveness of the heat exchanger was increased with the aid of Al_2O_3/Water and ethylene glycol (60:40) nanofluids. It increased by 11.19 % and 18.72% for 0.05% and 0.1% vol. concentrations of nanofluids respectively.
- The overall heat transfer co-efficient based on the fin side heat transfer area was also increased by 7.21% and 12.64% for 0.05% and 0.1% vol. concentrations respectively as compared to the base fluid.

VIII. FUTURE SCOPE

The presented work was done utilizing Al_2O_3/water and ethylene glycol (60:40) nanofluid which was prepared by two step method. Al_2O_3 nanoparticles of average particle size 40 nm were dispersed into the base fluid at 0.05% and 0.1% volume concentrations. Future scopes of the work are as follows.

- Experiments can be performed using smaller sized particles, less than 40 nm, as it would help in stabilizing the nanofluid and avoid settling down of particles.
- CFD analysis needs to be done extensively to get results comparable to the experimental results.
- Better understanding required for Two phase CFD analysis because single phase analysis gives comparable results only for very low particle concentrations.

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