Investigation of Rheological Behaviour and Heat Transfer Performance of Alumina Nanofluid

D. Raghulnath,
PG Scholar,
Department of Mechanical Engg,
Government College of Technology,
Coimbatore, Tamilnadu, India.

R. Surendran,
Asst Professor,
Department of Mechanical Engg,
Government College of Technology,
Coimbatore, Tamilnadu, India.

Abstract — **In this work, Al_2O_3 Nanoparticles with mean diameter of 25nm, surface area 180m^2/g dispersed in base fluid using two step method with the nanoparticles volume concentrations 0.1%, 0.2%, 0.3%, 0.4% and 0.5% using magnetic stirrer and sonicator. Two different base fluids were used, Distilled Water (DW) and Distilled Water:Ethylene Glycol (EG) mixture (70:30%, 80:20% & 90:10%). 40 samples were prepared with the four base fluids with and without capping agent (Cetyltrimethyl Ammonium Bromide-CTAB). First part of the work is Rheological investigation of all samples. Thermal conductivity, viscosity and density were measured. Obtained values were compared in three ways, Nanofluids with and without capping agent, Nanofluids with different percentages of ethylene glycol and without ethylene glycol. It was observed that capping agent plays a vital role in keeping good stability of nanofluids and in the case of Water:Ethylene glycol base fluid, capping agent is very useful to reduce the agglomeration of nanoparticles and in turn increases thermal conductivity. Decreasing ethylene glycol percentage in base fluid increases the thermal conductivity. Second part of the work is the experimental investigation of heat transfer performance of nanofluids on double pipe counter flow heat exchanger. Results show that with the increasing nanoparticle concentration in nanofluids heat transfer coefficient increases. Heat transfer augmentation at 0.5% volume concentration of Al_2O_3 is higher than the other volume concentrations.**

Keywords—Nanofluid; Volume concentration; Alumina nanoparticle; Base fluids; Heat transfer; Heat exchanger.

I. INTRODUCTION

Heat exchanger is a device used for transferring heat from one or more high temperature fluids to low temperature fluid. Heat exchangers are used in numerous applications. Whatever the application, elevating heat transfer rate is the elemental concern. Heat transfer augmentation can be achieved in two ways, the active methods, requiring auxiliary power to keep the enhancement mechanism and the passive methods involves some permanent design modifications. Nanoparticles dispersion in conventional heat transfer fluids (water, EG, oil) is one method in active techniques which is focused by many researchers. Initially the concept of dispersing nano sized solid particles in conventional fluid was proposed by Choi in 1995 [1]. Nanoparticles are the smaller particles of bulk materials that are in the size from 1 to 100 nm. Nanoparticles have high specific surface area than the bulk material (in micro meter) as the diameter reduced to nano meter. So the atoms at the surface increased that makes the particle more reactive with the other molecules. To disperse in base fluid nano sized particles were chosen because of its reactivity at the surface with the solvent is strong enough to overcome the density difference. The high surface area to volume ratio of nanoparticles provides an enormous driving force for diffusion chiefly at increased temperature. Chandrasekar et.al [2] performed experimental investigations and theoretical determination to find effective thermal conductivity and viscosity of Al_2O_3/H_2O nanofluid. The nanoparticle was prepared by synthesizing Al_2O_3 nanoparticles using microwave assisted chemical precipitation method and then dispersed them in distilled water using a sonicator. The thermal conductivity and viscosity of nanofluids were measured using KD2-PRO thermal property analyzer and Brookfield cone and plate viscometer and it was found that the viscosity increase is substantially higher than the increase in thermal conductivity. Both the thermal conductivity and viscosity of nanofluids increased with the increase in nanoparticle volume concentration. Theoretical models were developed to predict thermal conductivity and viscosity of nanofluids. Mondragón et.al [3] compared the nanofluids acquired in liquid state with nanofluids prepared by dispersing the dry nanoparticles (SiO_2 and Al_2O_3) in water at three different volume fractions (0.5%, 1% and 5%) and characterized the nanofluids to use in heat transfer applications by conducting experiments for thermal conductivity, viscosity, specific heat and stability at three different temperatures (40^{o}C, 60^{o}C and 80^{o}C). Thermal conductivity of all samples was determined using KD2 PRO conductimeter and showed good improvement as the solid particle concentration increased. From the values of thermal conductivity, viscosity and specific heat, optimal concentration was selected as 5%. And stability of all samples was found good for 48 h, which was measured by using light scattering technique.

Rabienataj Darzi et.al [5] investigated the effects of Al_2O_3 nanofluid with a mean diameter of 20 nm on heat transfer, pressure drop and thermal performance of a double tube heat exchanger with the nanoparticle volume concentrations up to 1%. The effective viscosity of nanofluid was measured by the Viscolite 2700

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viscometer and found that viscosity decreased by increasing temperature and increased for higher concentrations. A new correlation for Nusselt number and friction factor as a function of Reynolds number ranging from 5000 to 25,000 was achieved and maximum enhancement of 20% in Nusselt number was observed for 1% vol. nanoparticle concentration. For convective heat transfer coefficient, a correlation was obtained based on Reynolds and Prandtl with the maximum deviation less than 5%. Pressure drop increased with increase in nanoparticle concentration. At the investigated range Reynolds number and nanofluid concentration it was observed that heat transfer augmentation was higher than the pressure drop penalty. Syam et.al [6] investigated the thermal conductivity of magnetic nanofluid. Magnetic Fe_2O_3 nanofluid was prepared by dispersing particles into the water ethylene glycol based mixture (20:80%, 40:60% and 60:40% EG:W) in the volume concentrations from 0.2% to 2%. Nanoparticles were synthesized by chemical co-precipitation method. Thermal conductivity of nanofluids were measured using the transient hot wire method and result showed that thermal conductivity for 20:80% EG/W based nanofluid was 46%, 40:60% EG/W based nanofluid was 42% and 60:40% EG/W based nanofluid was 33% at 2.0% particle volume concentration at a temperature of 60°C. From the observation suggestion given that the use nanofluids in heating applications is effective, as the thermal conductivity intensifies at elevated temperature.

Jaafar et.al [7] reported an experimental study on the forced convective heat transfer and flow characteristics of a nanofluid consisting of water and different volume concentrations of Al_2O_3 nanofluid (0.3–2)% flowing in a horizontal shell and tube heat exchanger counter flow under turbulent flow conditions. Al_2O_3 nanoparticles of 30 nm diameter were used to prepare nanofluid. Result showed that at particular volume concentration (2%) the use of Al_2O_3/water nanofluid given significantly higher heat transfer characteristics. For example at the particle volume concentration of 2% the overall heat transfer coefficient was 700.242 W/m^2K and for the water it was 399.15 W/m^2K for a mass flow rate of 0.0125 L/s. So the enhancement ratio of the overall heat transfer coefficient was 1.754 that means the amount of the overall heat transfer coefficient of the nanofluid was 57% greater than that of distilled water. The value of Nusselt number for 2% volume concentration was 587 and for the distilled water it was 367.759 so the maximum enhancement ratio at 0.0125 L/s was 1.596 that means the Nusselt number of the nanofluid was 62.6% greater than that of distilled water.

Sahooli e.al [8] investigated the CuO nanopaticles dispersed in water/EG mixture. The effect of pH, weight percent of the nanoparticles and the temperature are studied. Zeta potential, absorbance and thermal conductivity were measured. Copper oxide nanoparticles synthesized and dispersed in base fluid, 65% volume of EG and 35% volume of water using two step method. According to the zeta potential values of CuO nanopowders, pH 7.8 was selected as an operating pH for CuO/EG-water nanofluid. As pH increased, the absolute zeta potential of the nanoparticles' surface increased. The absorbance also became higher as the pH increased, improved the stability CuO nanofluids. From the analysis, the optimum CuO concentration was 0.045 because in that concentration the absolute value of zeta potential and absorbance for nanofluid were higher than the other concentrations, thereby nanofluid was more stable. Coming to investigation of thermal properties, with increase in weight percentage of CuO nanoparticles at the nanofluid, the stability of nanofluid increased, thereby thermal conductivity was increased. But beyond some level thermal conductivity decreased, which is because of agglomeration of nanoparticles thereby nanofluid was not stable.

Yones Afshoon et.al [9] compared the improved rate of heat transfer coefficient and friction factor of CuO/Water nanofluid with water based fluids in the shell and tube heat exchanger for the Reynold's number ranging from 6000 to 31000. Experiments showed that increase in volume concentration of CuO and Reynold's number, increases the local heat transfer coefficient, overall heat transfer coefficient and pressure drop of nanofluids. The heat transfer increases by 25% and pressure drop by 20%, from this it can be concluded that the best volumetric concentration is 0.078% because at this proportion, the percentage increase in pressure drop was less than the percentage increase in heat transfer. At the highest volume concentration (0.236%) and the Reynolds number (3000), the Nusselt number of Cu-O water nanofluid increased by 32% compared to the base fluid and this increased by 17% in the optimal volume concentration.

Sudarmadji Sudarmadji et.al [10] investigated the convective heat transfer and pressure drop of Alumina-water nanofluids under laminar flow regime in double pipe heat exchanger with constant wall temperatures. The particles were taken in the sizes of 20-50 nm and at the volume concentrations of 0.15%, 0.25% and 0.5%. Experiment showed that the convection heat transfer increased remarkably with the increase of the nanoparticles concentration under various values of Reynold's number. The Nusselt number increased about 40.5% compared to pure water under 0.5% volume concentration. The pressure drop of nanofluid increased slightly with increasing volume concentration. However, compared with using pure water the difference of the pressure drop is insignificant, so that the use of nanofluid has little penalty on pressure drop. Chavda et.al [11] investigated the effect of various concentrations of Al_2O_3 nano-dispersion mixed in water as base fluid on heat transfer characteristics of double pipe heat exchanger for parallel flow and counter flow arrangement. Al_2O_3 Nanofluid was prepared using two step method with the volume concentrations from 0.001 % to 0.01 %. The conclusion derived for the study was that overall heat transfer coefficient increased with increase in

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volume concentration of Al_2O_3 nano-dispersion compared to water up to volume concentration of 0.008 % and then decreased. Mohammad et.al [12] examined the thermal conductivity of Al_2O_3–EG nanofluids using a KD2-Pro thermal analyzer to get more experimental and fundamental understanding of the thermal behavior of nanofluids. The effects of temperature and concentration on thermal conductivity of nanofluid were investigated. The experiments performed at temperature ranging from 24^{o}C to 50^{o}C while volume fractions up to 5%. Al_2O_3-EG nanofluid was prepared using two step method without using any surfactant using magnetic stirrer and ultrasonic processor. Thermal conductivity of nanofluid measured using KD2 PRO thermal analyzer. The experimental results exhibited that the thermal conductivity of nanofluids enhanced significantly with increase in concentration and temperature. Also, attempts were made to propose new accurate correlations for estimating thermal conductivity at different temperatures and concentrations.

Usria et.al [13] investigated the effect of Alumina nanoparticles dispersed in 60:40 water to ethylene glycol based nanofluids towards heat transfer enhancement. Nanofluids were prepared using Alumina nanoparticles with average diameter of 13 nm suspended in 60:40 of water to ethylene glycol by volume percentage. 22 L of the nanofluid was synthesized using two step method and homogenized using magnetic stirrer and ultrasonic homogenizer for 2 hours to lengthen the suspension, for the volume concentrations of 0.2 %, 0.4 % and 0.6 %. Thermal conductivity and viscosity was measured for each concentration using KD2 Pro thermal analyzer and Brookfield LVDV-III Ultra viscometer respectively. The properties showed positive increment in thermal conductivity and viscosity. The convective heat transfer enhanced using Al_2O_3 dispersed in mixture base. As loading of nanoparticles increased, Nusselt number increased. For volume concentration of 0.2 % and 0.4 %, the percentage of enhancement in heat transfer was observed similarly by 6.9% and 7.3% respectively. However, the highest enhancement was found with 0.6 % by 14.6 %. To sum up this argument, Al_2O_3 nanofluid dispersed in mixture base (60:40) water to ethylene glycol was recommended to use with volume concentration of 0.6% for working temperature of 50^{o}C. Vinodkumar et.al [14] investigated the improvement of heat transfer coefficient in a shell and helical tube heat exchanger using Water/Al_2O_3 Nanofluid with the nanoparticle volume concentrations of 1%, 2% and 4%. Improvement of shell side heat transfer coefficient and net heat transfer were focused without much pressure loss. The model designed using ANSYS WORKBENCH 15 then meshed and solved in STARCCM+ solver for various concentrations of nanofluids. Thermal conductivity increased with increase in nanoparticle concentration and good increment in heat transfer coefficient and heat transfer were observed from 0.5% to 2% nanoparticle volume concentration and after that there is no appreciable change. The suggestion given that varying the sizes of nanoparticle and optimization of heat transfer with wall shear stress and friction factor effects will be the better future work.

Haoran Li et.al [15] prepared Nanofluids by dispersing ZnO nanoparticles of mass fraction 5.25% in different base fluids including 75:25, 85:15 & 95:5 (by volume) of Ethylene glycol (EG) and Deionized water (DW) mixtures. Thermal conductivity and viscosity experiments were conducted at temperatures between 15 to 55°C and natural convection characterisitics of EG/DW based ZnO nanofluids were also investigated. Found that the thermal conductivity of nanofluid with more DW is higher and viscosity of nanofluid increases with increase in concentration of EG. Natural convection experiment showed that the presence of nanoparticles detoriates the natural convection heat transfer.

Amir Qashqaei et.al [16] compared the heat transfer and pressure drop characteristics of CuO/Water nanofluid in a helically coiled heat exchanger, in horizontal and vertical positions under turbulent region. The properties of nanofluid at different Reynold's numbers and at different volume concentration of CuO were calculated. With increasing volume concentration of CuO nanoparticle and Reynold number, the Nusselt number was increased. Aphichat Danwittayakul et.al [17] discussed the overall heat transfer coefficient of alumina/water nanofluids in a counter current flow shell and tube heat exchanger. The stability of Alumina nanoparticles using the capping agents such as Sodium Polyacrylate (PA), Sodium dodecyl sulfate (SDS) and Hexadecyl thimethyl ammonium bromide (CTAB) were investigated and found that Sodium polyacrylate is the best capping agent. Specific heat capacity, heat transfer of cold water line, hot water line and overall heat transfer efficiency were investigated when using different percentage by weight of Alumina nanoparticles with the most suitable type and weight ratio of capping agent and compared with the experiments conducted without the capping agent to ensure that the stabilized polymers does not prohibit heat transfer process. The PA stabilized 0.25% alumina nanofluids exhibited the highest overall heat transfer coefficient with about 10% better than the base fluid and concluded that this proportion can be continuously used for long run without any change in efficiency. Mohammad Hemmat Esfe et.al [18] discussed the effects of solid volume fraction and temperature on the thermal conductivity of MgO/Water-EG (60:40) nanofluid. Experiments were performed to find thermal conductivity at different temperatures ranging from 20 to 50°C at different volume concentration of MgO from 0.1 to 3%. With increase in solid volume fraction of MgO and temperature thermal conductivity of nanofluid increased.

II. EXPERIMENTAL PROCEDURE

A. Nanofluid preparation

γ-Al_2O_3 (Gamma Alumina) procured from Otto chemie pvt ltd, Mumbai. Aluminium oxide nanofluid used in this study is prepared by using two step method. Four different types of base fluids used in this work as follows, 70% DW and 30% EG mixture, 80% DW and

20% EG mixture, 90% DW and 10% EG mixture and Pure DW. The required quantity of nanoparticles for each percentage volume concentration is calculated using the equation (1).

$$m_{np} = \rho_{np} \times \varphi \times V_{bf} \times 10^{-5} \qquad (1)$$

After the measurement, nanoparticles dispersed in base fluid using magnetic stirrer for 2 hour with 1500 rpm, and then sonicated for 1 hour using Probe Sonicator PRO-500 at 50°C. Nanofluids prepared with CTAB and also without adding CTAB for the purpose of comparison.

B. *Thermal conductivity and viscosity measurement*

Thermal conductivity of prepared nanofluids was measured using KD2 PRO thermal properties analyzer at room temperature. It consists of handheld microcontroller and sensor needles. The sensor needle was located inside the nanofluid sample of 10 ml in such a way that the needle fully covered by nanofluid to avoid the contact with surrounding air. All the measurements are repeated for three times for getting accuracy. Viscosity of all nanofluid samples were measured using Brookfield viscometer.Measurements were taken at 100 rpm at 30°C.

C. *Double pipe counterflow heat exchanger*

Heat transfer performance of Al_2O_3 nanofluid is examined using double pipe counter flow heat exchanger. The specifications of the heat exchanger are given in TABLE I. The working parameter ranges that are used during the experiment in heat exchanger using Al_2O_3 nanofluid are given in TABLE II.

TABLE I Dimensions of double pipe heat exchanger

Dimensions	Values
Length of the pipe (m)	1
Outer tube (cold flow)	GI
Inner tube (hot flow)	Copper
Outer diameter of the GI pipe (mm)	32.5
Inside diameter of the GI pipe (mm)	28.5
Outer diameter of copper pipe (mm)	12.5
Inside diameter of copper pipe (mm)	9.5

D. *Density and stability of nanofluid*

Density of nanofluids was measured using hydrometer. 500 ml of each nanofluid was taken in measuring tube. And the Hydrometer was inserted into the measuring tube. By reading the level of the indication the values of density measured. Stability was observed stable after three days from preparation when the capping agent was not added. After the addition of capping agent it was extended to five days.

TABLE II Range of operating paramater

Parameter	**Values**
Inlet temperature of hot fluid (°C)	50
Inlet temperature of cold fluid (°C)	27
Outlet temperature of hot fluid (°C)	38 – 42
Outlet temperature of cold fluid (°C)	33 – 35
Flow rate of cold fluid (kg/s)	0.2
Flow rate of hot fluid (kg/s)	0.1

III. RESULT AND DISCUSSION

Thermal conductivity of nanofluids with different base fluids and with and without capping agent is given in the figures 1 to 4. Similarly from figure 5 to 8 the values of viscosity of nanofluids given. For 70/30, 80/20 and 90/10 DW/EG base fluids we can see the difference in the thermal conductivity and viscosity as the effect of addition of CTAB.

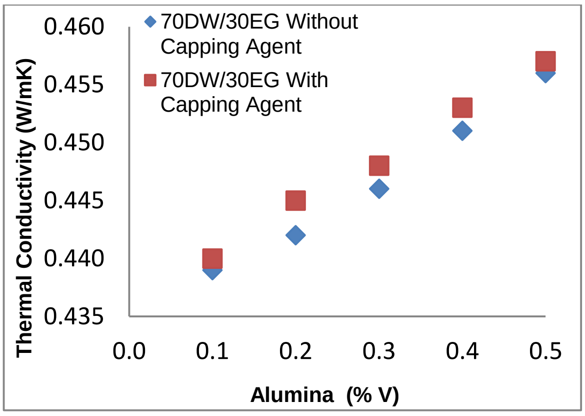

Fig. 1. Thermal conductivity of 70/30 DW/EG Al_2O_3 Nanofluid

Thermal conductivity is increasing and viscosity decreasing for each concentration with the addition of capping agent. This is due to the reduction in agglomeration of nanoparticles which is due to the presence of capping agent. For 100/0 DW/EG base fluid thermal conductivity nearly same in both cases. The presence of EG is increasing the agglomeration of nanoparticles in nanofluid.

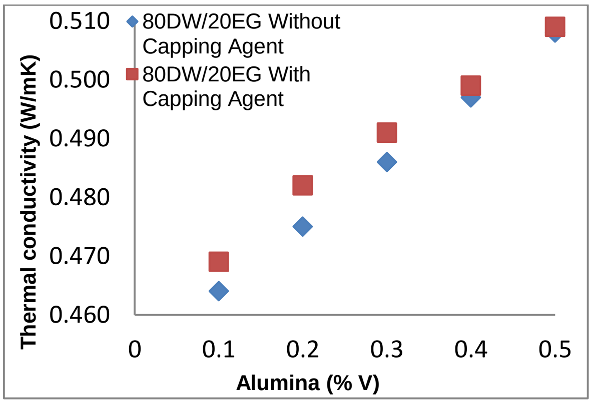

Fig. 2. Thermal conductivity of 80/20 DW/EG Al_2O_3 Nanofluid

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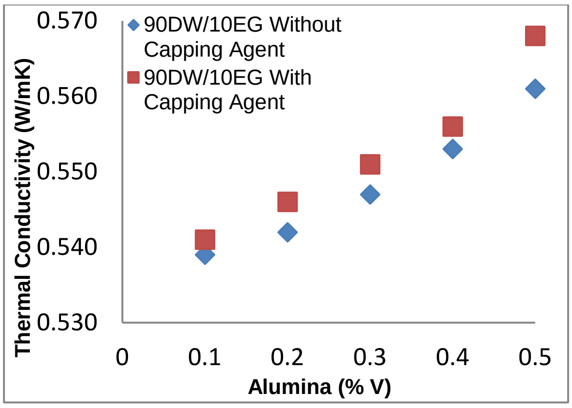

Fig. 3. Thermal conductivity of 90/10 DW/EG Al_2O_3 Nanofluid

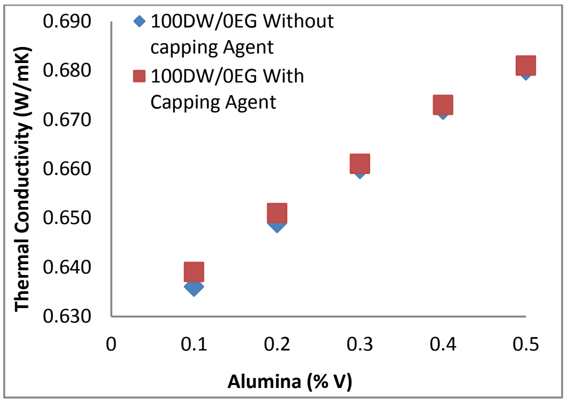

Fig. 4. Thermal conductivity of 100/0 DW/EG Al_2O_3 Nanofluid

Figure 9 and figure 10 show the comparison of thermal conductivity without capping agent and with 2% CTAB respectively. Thermal conductivity increases as the loading of nanoparticles increases in all cases of basefluids.

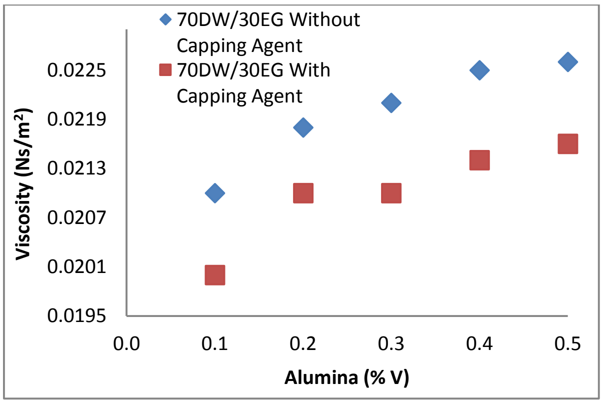

Fig. 5. Viscosity of 70/30 DW/EG Al_2O_3 Nanofluid

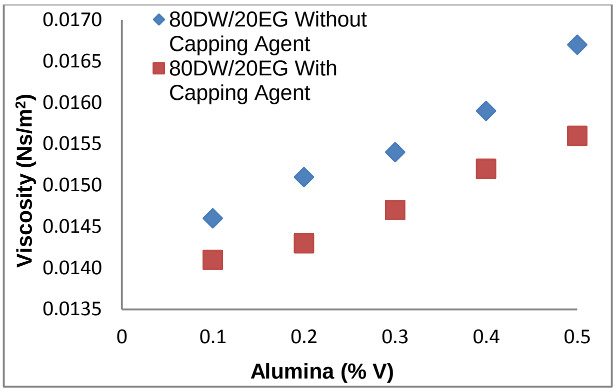

Fig. 6. Viscosity of 80/20 DW/EG Al_2O_3 Nanofluid

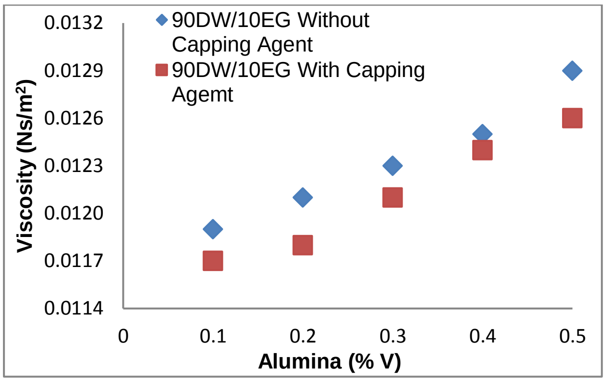

Fig. 7. Viscosity of 90/10 DW/EG Al_2O_3 Nanofluid

Figure 11 and figure 12 show the viscosity value for all base fluids. Viscosity increases with the increase in nanoparticle concentration. Nanofuids with higher volume concentration of alumina nanoparticles has higher viscosity than the lower concentration fluids. It is clear that the addition of EG in the base fluid increases the viscosity which may cause higher pressure drop while using in heat exchangers. So, using DW as base fluid is the effective way. But when the applications are in below freezing point of DW, it is advisable to use EG based basefluids.

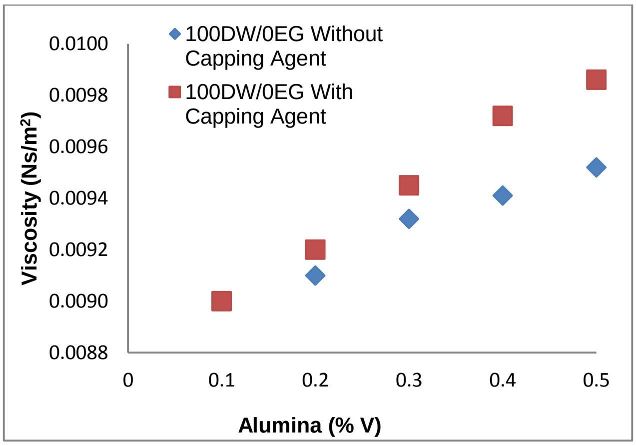

Fig. 8. Viscosity of 100/0 DW/EG Al_2O_3 Nanofluid

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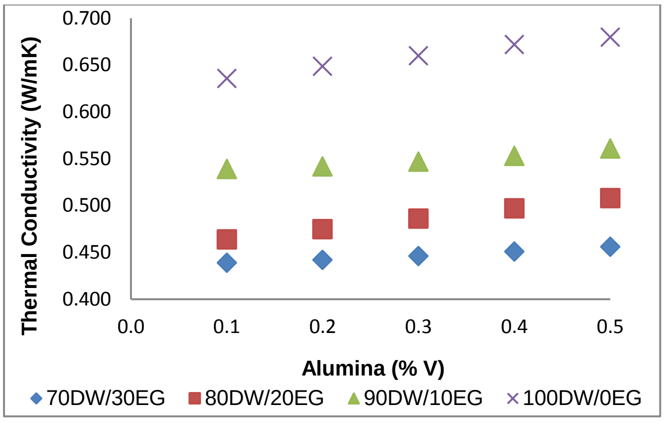

Fig. 9. Thermal conductivity of Nanofluids without Capping agent

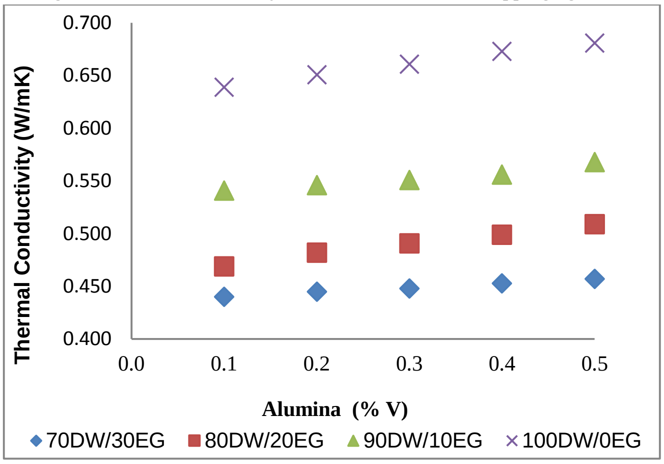

Fig. 10. Thermal conductivity of Nanofluids with 2% CTAB

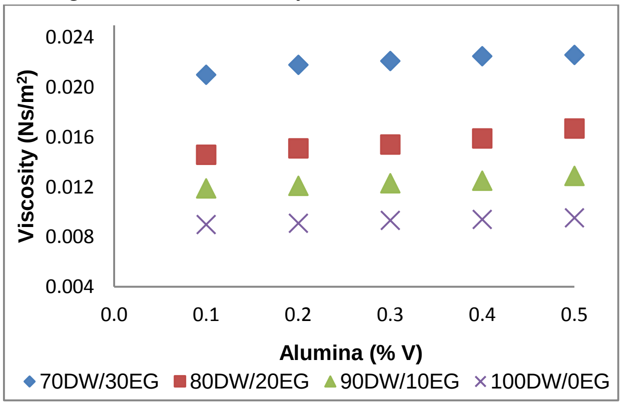

Fig.11. Viscosity of Nanofluids without Capping agent

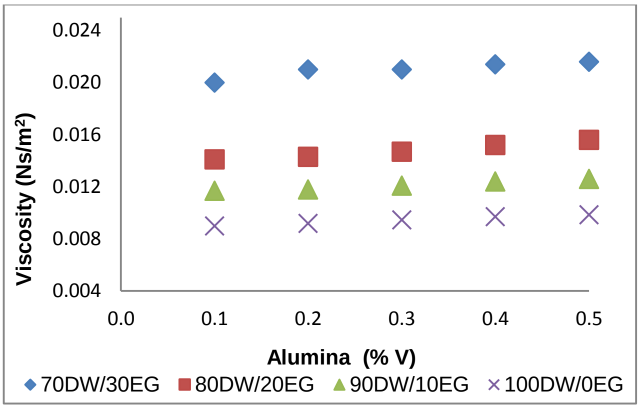

Fig. 12. Thermal conductivity of Nanofluids with 2% CTAB

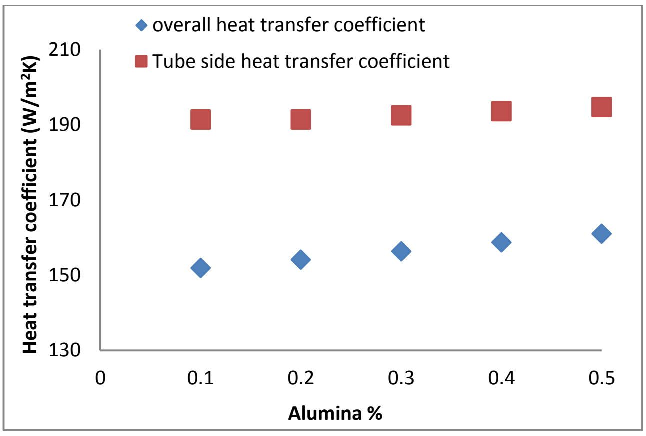

Fig. 13. Heat transfer coefficient for different nanoparticle percentage concentration

The value of heat transfer rate increases with increase in Alumina nanoparticle concentration in Nanolfuid. Actual heat transfer rate is lower than the theoretical heat transfer rate, but the difference is very less. The value of the heat transfer rate at 0.5% nanoparticle volume concentration is nearer to the value of heat transfer rate at 0.4% nanoparticle concentration. The percentage increase in heat transfer rate comparing with water is goes on increasing and the maximum percentage increase in heat transfer rate is 34.56% which is achieved with the 0.5% Alumina nanoparticle concentration. Similarly, the overall heat transfer coefficient and hot fluid side convective heat transfer coefficient are also giving the same manner of results. In both these values comparing the values for 0.5% and 0.4% is nearer.

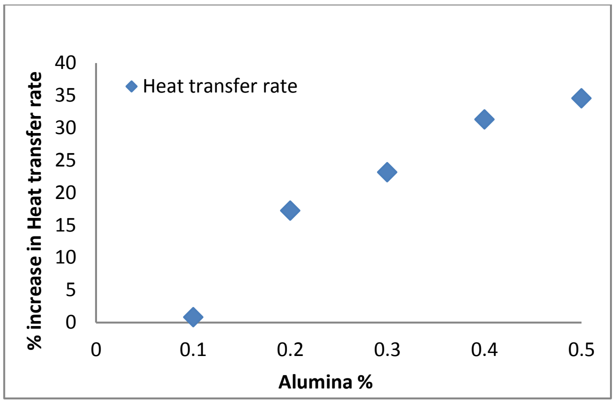

Fig. 14. Percentage increase in heat transfer rate for different nanoparticle percentage concentration

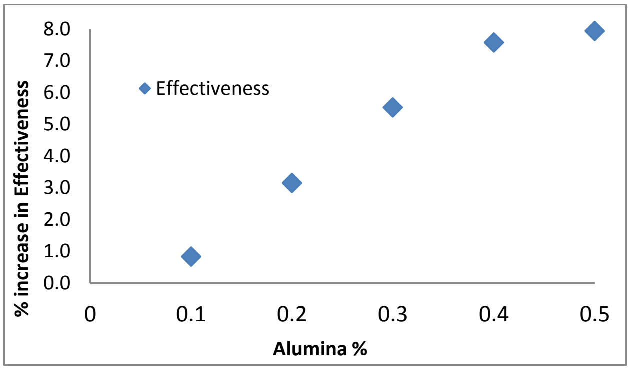

Fig. 15. Percentage increase in Effectiveness of Heat exchanger

IV. CONCLUSION

In this study, Al_2O_3 nanofluids with different base fluids were used. Thermal conductivity, viscosity and density of all nanofluid samples were determined experimentally. Different base fluids 70/30, 80/20/, 90/10 and 100/0 DW/EG were used to investigate the effect of EG in base fluids. Results showed that the use of EG in base fluid is increase the agglomeration of nanoparticles in nanofluid which is giving some undesirable results. Adding capping agent is reducing the agglomeration and increases the performance of EG based nanofluids. DW based nanofluids used to perform in double pipe heat exchanger, resulted in 34.5% increase in heat transfer rate. Effectiveness of heat exchanger increased to 7.6 and 7.9 with the volume concentrations of 0.4% and 0.5% of Al_2O_3 nanopartilces respectively. From the experiments, the use of 0.5% Al_2O_3 Nanoparticles with DW as base fluid and CTAB capping agent is suggested in double tube heat exchanger.

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