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EXPERIMENTAL STUDIES ON THERMOPHYSICAL AND RHEOLOGICAL PROPERTIES OF GRAPHENE BASED NANOCOOLENT

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ABSTRACT

In this study graphene nanoparticle is added as an additive in water ethylene glycol solution which is used in cooling systems. Experimental investigations are conducted on nanocoolant based on thermal and rheological properties at different volume fractions (0.2%, 0.4%, 0.6%, 0.8%, 1%) and at different temperatures (15˚C, 25˚C, 35˚C, 45˚C, 55˚C, 65˚C, 75˚C, 85˚C). A correlation for predicting the values of thermal conductivity at various temperature and composition is proposed. The relevance of the project is to study a solution that has thermal conductive properties similar to that of water but at the same time has an extended usability range.

KEYWORDS: Graphene, Water ethylene glycol, Nanocoolant, Thermal conductivity.

1. INTRODUCTION

Growing energy demands, precision manufacturing, miniaturization, nuclear regulations and critical economies demand high efficient coolants and lubricants in large quantity. The performance of such huge quantity of coolants directly affects global energy consumption, wear and tear of machines and vehicle components. For this reason enhancing the thermo-physical properties of coolants and lubricants is imperative. While lubricants are mainly employed to reduce friction and wear, coolants are primarily used to dissipate heat from a system,. The addition of chemical compounds has been a well-known practice to enhance the thermal efficiency of coolants and lubricants.

The development of various nanoparticles has opened new opportunities in various fields like lubrication, medicine, composite, and space. Metallic and metal oxide nanoparticles, carbon family nano structures, have been used to formulate nano fluids and coolants. In recent years, nanofluids have attracted more and more attention. The main driving force for nanofluid research lies in a wide range of applications. Although some review articles involving the progress of nanofluid investigation were published in the past several years [1-8], most of the reviews are concerned of the experimental and theoretical studies of the thermo-physical properties or the convective heat transfer of nanofluids. In this study we are studying graphene based nano coolants. Graphenenano particles are mixed with water ethylene glycol solution at different compositions and its thermal conductivity and viscosity are determined at different temperatures.

Nanofluids are engineered colloidal suspension of nano particles in a base fluid. The size of nanoparticles varies from 1 to 100 mm. Nanoparticles exhibit properties that are considerably different from those conventional solids. The enhanced properties of nano piece materials come from the relatively high surface area to volume ratio which is due to the high proportion of constituent atom at the grain boundaries. The thermal, mechanical, optical, magnetic and electrical properties of nano phase materials are superior to those of conventional materials with coarse grain structures. They are thought to be the next generation heat transfer fluids because the thermal conductivity can be significantly enhanced by adding small amount of nano particles. Extensive studies have been conducted to investigate the enhanced thermal conductivity in nano fluids since the theoretical work of Maxwell in the last decades.The enhanced thermal conductivity of nanofluid is mainly due to Brownian motion of particles, molecular level layering of the liquid effect of nanoparticle clustering. The thermal conductivit0y of nanofluids has a good corresponding relation with the stability of nanofluids. Better is a dispersion behavior, higher will be the thermal conductivity. But the largest specific areas of nano particles and relativity of particle surface would easily result in high level agglomeration and form agglomerates in nanofluids. When the size of agglomerates grows, they will deposit due to gravity and lost the characteristics of nanofluids. Experimentally it is found that surfactants are effective in displacing nanofluids in the base fluids and weakening the agglomeration behavior in nano suspensions surfactants are changing reactants. Inclusion of surfactant in nanofluids will help to change the surface from hydrophobic to hydrophilic nature.

Graphene is a single atomic layer of graphite which is an abundant mineral. It is an allotrope of carbon that is made up of very highly bonded carbon atoms organized into a hexagonal lattice. Graphene has sp2 hybridization, which makes it very special and very thin atomic thickness (of 0.345Nm). The above properties enablesgraphene to break so many records in terms of strength, electricity and thermal conduction (as well as many other). The carbon atoms are bound by strong bonds in a plane into a honeycomb array comprised of six-membered rings. Stalking these layers on top of each other makes the 3-dimensional graphite crystal. It is a basic building block for graphite materials of all other dimensionalities. It can be wrapped up into OD fullerenes, rolled into ID nanotubes or staked into 3D graphite. Thus, graphene is nothing else than a single graphite layer. The thermal conductivity value of graphenenano particle is 3000W/mK.

A coolant is a substancewhich is mainly liquid or gas that is used to reduce or regulate the temperature of a system. An ideal coolant has high thermal capacity, low viscosity, non toxic, is low cost, chemically inert and neither cause nor promotes corrosion of the cooling system. Water is the most common coolant. Its low cost and high heat capacity makes it a suitable heat transfer medium. But due to its low freezing as well as boiling point, it cannot be used at extreme conditions. So antifreeze (ethylene glycol) is used in water as coolant in most of the vehicles. But the thermal conductivity of the mixture decreases as compared with that of water. In order to enhance these thermo-physical properties, nanoparticles are added so that heat transfer takes place not only by convection but also by conduction. This nanoparticle added base fluid has enhanced rheological and thermo-physical properties than water as well as water ethylene glycol coolant. The nanoparticles used in nanocoolant are typically made of metals, oxides, carbides, or carbon nanotubes. They can be classified as metallic, metallic/nonmetallic oxides, carbon nano tube, nano droplets, which are currently used with base fluids to enhance the thermal performance of the cooling systems. Common base fluids are water, ethylene glycol and oil.

2. MATERIALS AND METHODS

Nanofluid preparation by two step method

There are two methods for preparation of nano fluids, they are

a. Single step method

To reduce the agglomeration of nano particles, Eastman et al. developed a one- step physical vapour condensation method for preparing Cu/ethylene glycol nanofluids. This process consists of simultaneously making and dispersing the particles in the fluid. In this method, the process of drying, storage, transportation and dispersion of nanoparticles are avoided, so the agglomeration of nanoparticles is minimized, and the stability of fluids is increased. The one-step process can prepare uniformly dispersed nanoparticles, and the particles can be stably suspended in the base fluid.

b. Two step method

The most widely used method for preparing nanofluids is two step method., Nano fibers, nanoparticles, nanotubes, or other nano materials used in this method are first produced as dry powders by physical or chemical methods. Then, the nano sized powder will be dispersed into a fluid in the second processing step with the help of intensive ultrasonic agitation, magnetic force agitation, , high-shear mixing, homogenizing and ball milling.

Here we used two-step method for preparing nanofluids. First calculate the required mass of nanoparticle for each volume concentration. By using the Shimadzu Decta apparatus the accurate amount of nanoparticle is measured. Then it is dispersed in the base fluid water ethylene glycol. The base fluid contains 30ml ethylene glycol and 20ml of water. Then the prepared solution is agitated with magnetic agitator for half an hour. After

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that it is agitated for 6 hours in ultra-sonic agitator with magnetic agitator for half an hour. After that it is agitated for 6 hours in ultra-sonic agitator at 40kHz. The most economic method to produce nanofluid in large scale is two step method, because nano powder synthesis techniques have already been scaled up to industrial production levels. Due to the highsurface activity and highsurface area,nanoparticles have the tendency to aggregate.

Determination of thermal conductivity

The thermal conductivity is the most important factor that can be investigated to prove the heat transfer enhancement of a prepared nanofluid. The thermal conductivity of the prepared nanofluids were measured using a KD2 Pro is a battery operated, menu-driven device that measures thermal conductivity and resistivity, volumetric specific heat capacity and thermal diffusivity.

This instrument works on the principle of classical transient hot wire method which is the most commonly used technique in measurement of thermal conductivity of liquids in general and nanofluids in particular. The instrument was then tested for uncertainty using distilled water, glycerin (provided as test fluid by manufacturer) and ethylene glycol and was found to be less than ±1%. Care was taken to ensure vertical positioning of the probe without any shake or vibration, which may cause uncertainty in readings due to convention heat transfer.
The required temperature of the sample is achieved by a constant temperature bath and it is tested for conductivity. The experiment is carried out for different volume fraction (0.2%, 0.4%, 0.6%, 0.8% and 1%) and at different temperatures (15˚C, 25˚C, 35˚C, 45˚C).

Determination of viscosity

The viscosity measurements for the nanofluids were carried out using a Brookfield DV11+ Pro Cone/Plate Rheometer (viscometer). It is a precise torque meter which is driven at discrete rotational speeds. The system is accurate to within +/-1% of full scale range. Reproducibility is within +/-2%. Working temperature range is from 0˚C to 100˚C. The torque measuring system, which consists of a calibrated beryllium copper spring connecting the drive mechanism to a rotating cone, senses resistance to rotation caused by the presence of sample fluid between a stationary plate and a cone. The resistance of the fluid to the rotation of the cone produces a torque that is proportional to the shear stress in the fluid. This reading is easily converted to absolute centipoises units (MPa-S) from pre calculated range charts.

The required temperature is achieved through a JULABO F25 constant temperature bath/circulator and it is tested for viscosity. The experiment is carried out for various shear rates ranging from 2-100 1/s and at different temperature (20˚C, 30˚C, 40˚C, 50˚C, 60˚C, 70˚C, 80˚C)

3. RESULTS AND DISCUSSION

Thermal conductivity vs temperature

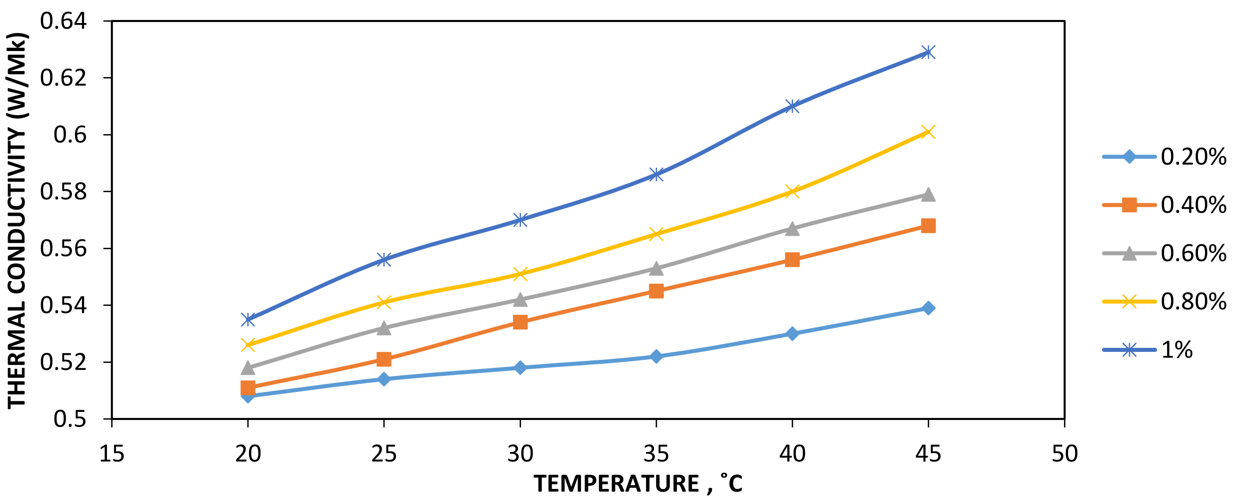

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Figure 1: variation of Thermal conductivity with Temperature at different volume fraction.

The graph is obtained by plotting thermal conductivity obtained from the KD2 Pro thermal property analyser against the temperature. The temperature varied from 20˚C to 45˚C.It also shows the variation of thermal conductivity with different volume fractions (0.2%, 0.4%, 0.6%, 0.8%, 1%)

The graph shows that the thermal conductivity of graphene based water ethylene glycol solution increases with increase in temperature and we can also see that the thermal conductivity of the fluid increases with increase in volume fractions.

The thermal conductivity enhancement depends on the Brownian motion, particle size, nano layer and particle surface. The elevated heat transfer surface between particles and fluid and the interaction and collision between the nanoparticles led to the enhancement of thermal conductivity. Therefore thermal conductivity will increase with amount of particle added. That's why the graph shows such a behavior.

From this graph we can make sure that, adding nanoparticle enhances the thermal conductivity of the fluid and we can also see that the thermal conductivity of the 0.2% graphene based water ethylene glycol solution is very low comparing with other samples and 1% graphene based water ethylene glycol solution has the highest thermal conductivity. Even though it has highest thermal conductivity, from visual inspection conducted, it is observed that the nanoparticles settle down due to gravity quickly than other samples.

In real cases, at the down time of the engine the particles will settle down due to gravity, on restarting the engine sonication of the fluid occurs within the engine but we can't predict the thermal conductivity of the new fluid formed. So the settlement of the particle must be avoided and this problem v=can be avoided by adding surfactant into the solution.

So through this study we can observe that the samples with 0.2% and 1% of graphene based water ethylene glycol solutions are not suitable for cooling purpose.

Temperature vs viscosity

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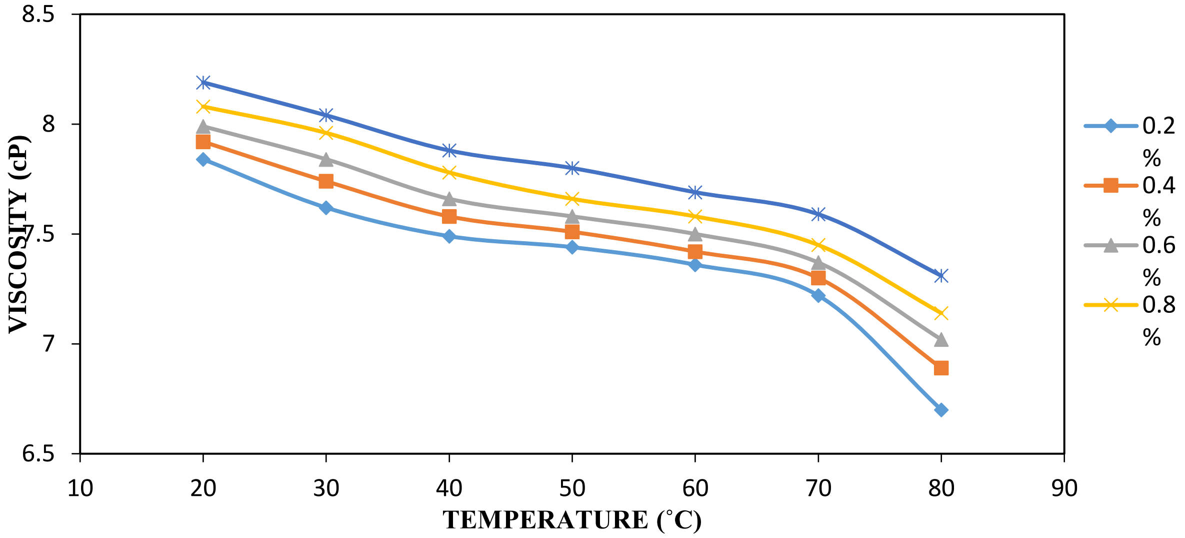

Figure 2: variation viscosity with temperature at different volume fraction

The graph of the thermo-physical properties of the graphene based water ethylene glycol solution can be drawn by plotting viscosity obtained from Brookfieldviscometer against the temperature varies from 20˚C to 80˚C at different volume fraction (0.2%, 0.4%, 0.6%, 0.8% and 1%). The viscosity is in Cp. Different temperature is attained using constant temperature bath.

From the graph we can see that the viscosity of the graphene based water ethylene glycol fluid decreases with increase in temperature and viscosity increases with increase in volume fraction.

This behavior of the graph can be explained as increasing temperature helps the particle to overcome Vander Waals attractive forces and which may disintegrate the clusters of nanoparticles suspended in the base fluid and hence the intermolecular interactions between the molecules become weak and this phenomenon leads to decrease in viscosity. That’s why this graph shows such a behavior.

By this graph we can make sure that the viscosity will decrease with increase in temperature. The graphene nanoparticle has no negative effect on the fluid. Viscosity of the 0.2% graphene based water ethylene glycol is the least among the different volume fraction and 1% graphene based water ethylene glycol solution has highest viscosity. High viscous fluid can’t be used for making coolant because the easy and fast movement of the coolant inside the system is essential for proper heat transfer. That is another reason why we can’t use 1% graphene based water ethylene glycol solution. Even though 0.2% graphene based water ethylene glycol fluid has lowest viscosity it can’t be used for applications because the thermal conductivity of the sample is very low comparing to other samples.

Through this study we can observe that the samples with 0.2% and 1% of graphene based water ethylene glycol solutions are not suitable for application.

Viscosity vs shear rate

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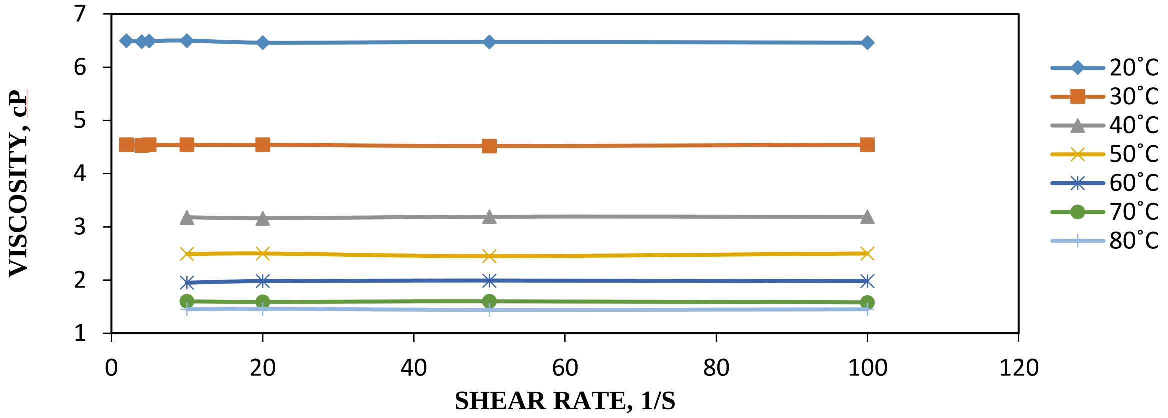

Figure3: Rheological property of base fluid (0% graphene) at different Temperature

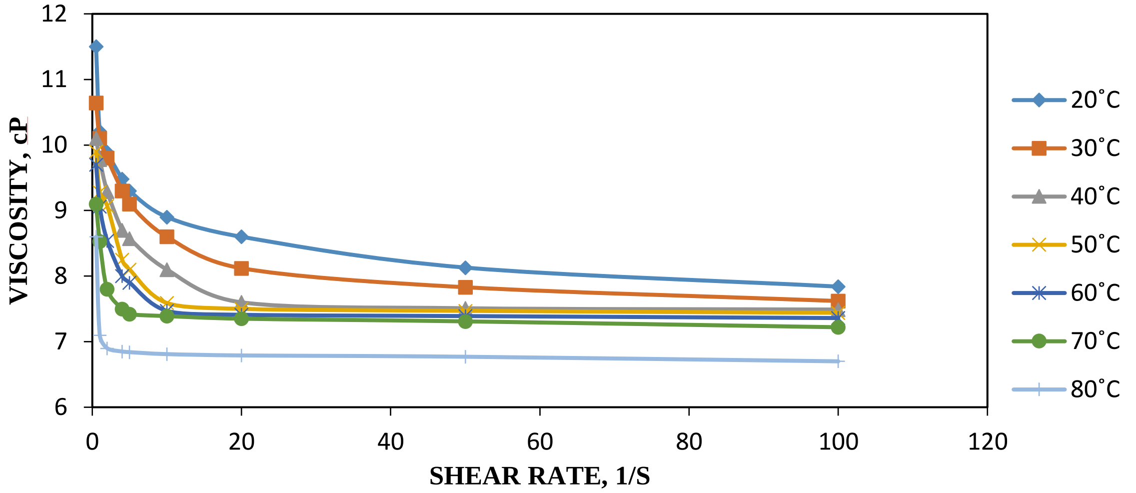

Figure 4: Rheological property of 0.2% graphene based WEG solution at different Temperature

This graph has viscosity in Y-axis and shear rate in X-axis. This graph is plotted for different temperature varying from 20˚C to 80˚C at 0% and 0.2% graphene based water ethylene glycol solutions. The figure 3 is for fluid with 0% graphene in it, which means it is a solution of distilled water and ethylene glycol, there is no graphene in it and figure 4 is for fluid with 0.2% graphene in it.

The graph of water ethylene glycol with 0% graphene shows that viscosity does not changes with change in shear rate. The graph follows a constant viscosity line and from the graph we can see that even though the viscosity does notchange with time, it increases with decrease in temperature. It means, at 20˚C the fluid shows maximum viscosity at high temperature, the viscosity will be minimum.

The graph of water ethylene glycol solution with 0.2% graphene shows that the viscosity decreases with shear rate to a constant value. The graph follows a curved path. At high temperature the viscosity of the fluid is lesser compared to other temperatures and at 20˚C the sample shows highest viscosity.

Water and ethylene glycol is of Newtonian nature that's why the first graph shows such behavior. We know that for a Newtonian fluid viscosity is independent of the shear rate. When nanoparticle is added to the fluid the Newtonian nature of the fluid changes to non-Newtonian behavior, which means the viscosity is no longer independent of shear rate. The graph follows a curved path because of the shear thinning of fluid when shear rate increases.

The study of the fluid is essential so that we can understand that, addition of the nanoparticle does not increase the viscosity and its viscosity does not increases with increase in shear rate. In real case when the nanocoolant hits bends, engine parts and pipes, shear happens and if the viscosity increases with shear rate, the flow of the fluid will be obstructed. Thus heat transfer will not be efficient therefore we need to make sure that the viscosity will not decrease on addition of the nanoparicle. From this graph we can make sure that the fluid will flow smoothly in the system.

Formulae:

$$\emptyset = \frac{\frac{m_{np}}{\rho_{np}}}{V_{basefluid} + \frac{m_{np}}{\rho_{np}}}$$

Tables:

Table 1.Properties of Graphene nanoparticles

Property	values
Purity	>99%
Thickness	5-10 nm
Length	5-10 micron
Avg.Number of Layer	4-8
Surface area	190 m²/g
Thermal conductivity	3000 W/mK
Tensile modulus	>1000 GPa

Table 2.Properties of Ethylene Glycol And Water

	ETHYLENE GLYCOL	WATER
Density (gm/cc)	1.1132	1
Molar Mass (gm/mol)	62.07	18.02
Freezing point (^oC)	-12.9	0
Boiling point (^oC)	197.3	100
Viscosity (Ns/m2)	$1.61*10^{-2}$	$1.002*10^{-3}$
Thermal conductivity (W/mK)	0.258	0.609

4. CONCLUSION

Thermal conductivity and viscosity of the graphenenanocoolants have been studied. The experimental investigations show that the thermal conductivity of graphene based water ethylene glycol solution increases with increase in temperature. The thermal conductivity value is higher than water ethylene glycol mixture for all concentrations. The maximum thermal conductivity of 0.63w/mK is obtained for 1% volume concentration at a temperature range of 20C to 45C. But larger concentration of graphenenanoparticle makes it settle in 6 days and it has to be re agitated for further use. The less graphene concentrated 0.2% volume fraction has a maximum thermal conductivity of 0.53w/mK which is less compared to water. So the optimum performance should be at a volume fraction range of 0.4% to 0.8%. Volume concentrations and temperatures have significant effects over the viscosity of graphene based water ethylene glycol solution. Viscosity of the base fluid i.e.water ethylene glycol solution always remains constant with rise in shear rate. But viscosity of graphene based water ethylene glycol mixture rapidly decreases and then gradually reaches to a constant rate for every volume concentration. At lower shear rate the nanocoolant behaves as Newtonian fluid and at high shear rate the behavior changes to non-Newtonian nature. From the studies conducted the optimum concentration of graphene nanoparticle to be added in the water ethylene glycol coolant is found to be 0.4% to 0.6%. Further tribological studies on graphene based nanocoolant are required to extent the present work.

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