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Effect of Copper Particles as Additives in Deionized Water as Heat Transfer Fluid: Preliminary Study

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ABSTRACT

The purpose of this study was to determine the effect copper particle as additive in deionized water as heat transfer fluid. Four different samples were being prepared; one sample acted as the reference fluid and the other samples with weight of 2.5, 5.0 and 7.5 mg copper particles was dispersed in deionized water. The scope of research covers the rheological behavior test to study the viscosity effect to shear rate at ambient temperature (25ºC) by using a Brookfield Viscometer. In this study, the viscosity effect to shear rate test was performed by increasing the number of rotation per minute (rpm) of cylindrical spindle which varied from 10.01 until 200.00 rpm with 10.00 rpm increment. The result demonstrated that these fluids had a shear stress and behaved as shear-thickening non-Newtonian fluid which means the viscosity of the fluids was increasing with increased of shear rate. Besides, by adding copper particles in deionized water, the viscosity of the fluid was reduced below the viscosity of reference fluid. The performance of all samples was determined by measuring area under a curve for each sample from the graph plotted. The sample that produced the largest area under a curve represented as the best performance of heat transfer fluid. From the result obtained, it was found that deionized water without copper particles produced the largest area under the curve compared to other samples which was 569.7. However, this fluid demonstrated a high viscosity profile. Thus, a sample of deionized water with 5.0 mg of copper particles which had a low viscosity and high area under the curved which is 513.4 had shown the increased of performance in heat transfer fluid. This is because lower viscosity fluid is more desirable to be applied as a coolant in heat transfer hardware due to the smooth flow of the fluid under the effect of shear stress. In a conclusion, the blended of copper particles with deionized water as heat transfer fluid were found to be suitable to effectively improved the tribological of the fluid. Next, the three samples for the mixture of deionized water and copper particles had shown to lower the viscosity of the fluid compared to base deionized water. However, the viscosity tends to increase when a larger amount of copper particles was added.

KEYWORDS: Copper, Particle Suspension, Heat Transfer Fluid, Viscosity, Deionized Water.

INTRODUCTION

Heat transfer fluids or thermofluids provide an environment for adding or removing energy to systems and their performance depend on their physical properties such as thermal conductivity, density, viscosity and heat capacity [24]. As reported by [9], fluids such as water, air, ethylene glycol and mineral oils are normally used as heat transfer media in various applications either industrial or non-industrial such as power generation, chemical production, automobiles, computing process, refrigeration and air conditioning. The thermal conductivity and heat capacity of thermofluid plays important role in the improvement of energy-efficient heat transfer equipment. However, the problem arises when the fluids' heat transfer capability is limited by their very low thermal conductivity and heat capacity. Low thermal conductivity of process fluid hinders high conciseness and effectiveness of heat exchangers, although a range of techniques is applied to enhance heat transfer [23]. In that regard, the development of advanced thermofluids with higher thermal conductivity, higher heat capacity and low viscosity is becoming a strong demand.

Application of nanoparticle technology is of considerable interest to solve the related problem and as an effective approach to enhance heat transfer characteristics of fluids. Spreading or suspension of nanoparticles of high thermal conductivities in thermofluids is one of the ideas for improving the thermal conductivity of the mixtures and thus rising their heat transfer coefficient in various applications [24]. A decade ago, with the technological improvement of modern nanotechnology, particles of nanometer size are used instead of micrometer size for dispersing in base heat transfer fluids and they are called nanofluids [1]. Many researchers had performed the experimentally study to determine the heat transfer performance and flow characteristics of

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various nanofluids with different nanoparticles and base fluid materials. Some of the accessible published articles by researchers, which related with the use of nanofluids are described in the next sections.

In [23] developed a preparation method of nanofluids and using the hot-wire method to measure the thermal conductivity of water-copper nanoparticles suspension. The measurement results illustrate that the thermal conductivity of nanofluids remarkably increased with the volume fraction of ultra-fine particles. For example, if the volume fraction of water-copper nanoparticles increases from 2.5% to 7.5%, the thermal conductivity of the nanofluid will varies from 1.24 to 1.78. This is due to high surface area of nanoparticles increase the heat capacity of the fluid, the thermal conductivity of the fluid can be effectively increase with the aid of suspended nanoparticles, intensified collision occurs among fluids, nanoparticles and the flow passage surface, increase in the mixing fluctuation and turbulence of the fluid and the transverse temperature gradient of the fluid becoming flat due to the dispersion and suspension of nanoparticles [23]. Besides, other researcher such as [6] had performed the study on thermal conductivity of copper nanoparticles in ethylene glycol using commercially available equipment. The result shows that a nanofluid consisting of copper nanoparticles dispersed in ethylene glycol has higher thermal conductivity than pure ethylene glycol. For example, when 0.3 vol% Cu nanoparticles of mean diameter <10 nm was used, the effective thermal conductivity of ethylene glycol was shown to increase by up to 40%. Study performed by [17] also dispersed TiO_2 in deionized water. They found that the thermal conductivity increases with an increase of nanoparticle volume fraction.

Next, in [14] conducted a study on a chemical reduction method to chemically synthesized Cu-water nanofluids. They found that when Cu nanoparticle at a concentration of 0.1 vol%, the thermal conductivity was enhanced by up to 23.8%. With no surfactant and dispersant added, the thermal conductivity of the nanofluid shows a time-dependent characteristic which decreased considerably with elapsed time [14]. This means that the shelf-life and performance of the heat transfer fluid depend on the time and stability of the nanoparticles in the fluid. For this reason, in [5] has investigated the stability of the colloidal particles and time evolution of the optical absorption. The results show that the colloidal copper in ethylene glycol was generally stable even after 2 months, while in water, it was fairly precipitated after 22 days. This implies that thermofluid with additives have shorter life span than expected to be used as a coolant in industry. However, many factors that affect the performance of the thermofluid must be considered before concluding this situation; one of the factors includes the temperature of the heat transfer fluid. For this purpose, in [11] carried out a numerically studied on buoyancy-driven convection heat transfer of copper-water nanofluid in a square enclosure under the different periodic oscillating boundary temperature waves. The results show that under the oscillating temperature boundary, copper nanoparticles in water can strengthen natural convection heat transfer and the larger the solid volume fraction, the greater the heat transfer strength. In [2] also investigated the heat transfer performance of heat pipe using silver-deionized water nanofluid with volume concentrations of 0.003%, 0.006% and 0.009%. The results show that the thermal resistance of heat pipe decreases when silver-deionized water nanofluid was used which in turn increases the effective thermal conductivity by 42.4%, 56.8% and 73.5% respectively with the volume concentration. In addition, some experimental results [7] displayed that increase in thermal conductivity of 60% can be obtained for the nanofluid consisting of water and 5 vol % CuO nanoparticles as compared to water without nanoparticles.

Since the rheological properties can provide the knowledge on both dynamic and static conditions, the study on the rheological behavior of nanofluid may reveal the route to understand the mechanism of heat transfer enhancement, hence, design the heat transfer fluid for the maximum heat transfer enhancement [13]. There have been some studies and reports on the rheological behavior or viscosity of suspension of nanoparticles in nanofluid. In [24] studied the convection heat transfer performance of the graphite nanofluids in laminar flow through a circular tube. The results show that the heat transfer coefficient of the fluid in laminar flow had increased, but the increased was much less than that predicted by them. They also proposed that further investigation is needed for non-spherical nanoparticle dispersions. In response to this situation, other researcher had come out with different flow characteristic of the heat transfer fluid. For example, in [1] investigated experimentally on the convective heat transfer performance and flow characteristics of Al_2O_3/water nanofluid that flow in the horizontal shell and tube heat exchanger. The result shows that the heat transfer coefficient of nanofluid was slightly higher than the base liquid, which was conducted at the same mass flow rate and at the same inlet temperature. They also reported the convective heat transfer coefficient of the nanofluid increased with increased in the mass flow rate and with increased in the volume concentration of the Al_2O_3/water nanofluid, however, raising the volume concentration of the nanofluid had because some increased in the viscosity and lead to the increased in friction factor [1]. In previous study by [9] investigated the viscosity and thermal conductivity of copper nanoparticles in ethylene glycol. The result display that viscosity increased was higher than the thermal conductivity of the nanofluid. Therefore, nanofluids with these characteristics would be poorer coolants as compared to the base fluids if applied in the heat transfer hardware because high viscosity will increase the pumping power of the thermofluid so as the operation cost. However, they proposed that if the pipe diameter is increase, the nanofluid can be benefit as coolants. This is due to the higher thermal conductivity of the nanofluid. The study of the viscosity and volume concentration also was being investigated by [18], who reported experimental observations on the effects of the shear rates and nanoparticle volume fractions on the viscosity of a Fe_2O_3-deionized water nanofluid. The result implies that the shear viscosity depends on the shear rate, and concentration. This shows that the higher concentration of nanoparticle, the greater the viscosity of the nanofluid. As being mentioned earlier, the higher viscosity of thermofluid is not desirable as a coolant. To overcome this problem, a little increment of temperature can be applied to the thermofluid to reduce its viscosity. As for this, in [10] had studied the thermal conductivity and viscosity of silver-deionized water nanofluid with 0.3, 0.6 and 0.9% of volume concentrations for temperatures between 50°C and 90°C. The results show that the thermal conductivity increases, the viscosity decreases with increases in temperature and particle concentrations. This is because the increase in temperature will result in increase of the kinetic energy, which can accelerate the movement of particles in thermofluid, thus reduce its viscosity. An increase in temperature can leads to an increase in the transport phenomena [22].

In recent studies, in [12] determined the effect of nanoparticle volume fractions on thermal conductivity and dynamic viscosity of Ag-MgO with water hybrid nanofluid. Based on the result, increase in the nanoparticle volume fraction will increase the thermal conductivity and dynamic viscosity of nanofluid. They also stated that the thermophysical properties of nanofluid afford engineers a good option for nanofluid in various applications like electronics, automotive and nuclear applications. Next, in [3] demonstrated studies about the effect of surface tension of nanofluids where Al_2O_3 (13nm and 50nm), TiO_2 (21nm) and SiO_2 (5~15nm and 10~20nm) nanoparticles were dispersed in Distilled Water (DW). The experimental results reveal that the surface tension of the nanofluids increases with increase in nanoparticle sizes. Besides, they stated that TiO_2-DW nanofluids exhibit higher surface tension than Al_2O_3-DW and SiO_2-DW nanofluids respectively. In addition, in [19] studied the cooling performance of Al_2O_3-H_2O nanofluid with volume fraction varied from 0.05 vol % to 0.2 vol % and increased volume flow rate from 0.50 L/min to 1.25 L/min. The results indicated that the nanofluid successfully has minimized the heat sink temperature when the volume flow rate increased compared to the conventional coolant. They also noticed that the thermal entropy generation rate reduced around 11.50% compared to the pure water. In varying the flow rate of nanofluid, in [15] had studied on the heat transfer characteristics of impinging jet with water and Al_2O_3/water nanofluids by performing a varied range of Reynolds number, nanofluids concentration and varied nozzle to plate distance. The result was obtained by using thermal imaging technique to measure the temperature of the hot foil during impingement. They stated that the time taken to cool the hot foil from 500°C to 100°C was found to be 0.4s, 0.35s and 0.2s for water, nanofluids concentration of $\Phi=0.15\%$ and $\Phi= 0.60\%$ respectively [15].

Another property that can affect the heat transfer fluid performance is heat capacity or thermal capacity. It is the measurable physical quantity that characterizes the amount of heat required to change a substance's temperature by a given amount [20]. Therefore, heat transfer fluid with high heat capacity will carry more heat away from the engine and preventing engine damage due to overheating. In addition, high boiling point liquid will deal with the problem of overheating in hot weather. This is because a higher boiling point means that the coolant can cool better as the engine gets hotter [8]. Thus, clean passages, appropriate viscosity and low contamination can provide sufficient flow rate of the heat transfer fluid and effective cooling [20].

Many criteria must be examined and analyzed before recommending a thermofluid, and selection is important to obtain the heat transfer fluids which can last for more than 10 years [4]. One of the most important factors when deciding a liquid cooling technology is the compatibility of the thermofluid with the wetted surfaces of the cooling components or system and the application [21]. Heat transfer fluid compatibility is crucial in ensuring long-term system reliability. Some other requirements for a heat transfer fluid or thermofluid may include high thermal conductivity and heat capacity, low viscosity, low freezing point, high flash point, low corrosivity, low toxicity and thermal stability [16]. Based on these criteria, the most commonly used coolants for liquid cooling applications are; water, deionized water and ethylene glycol.

According to [21], water is one of the best choices for liquid cooling applications due to its high heat capacity and thermal conductivity. Water is also well-matched with copper, which is one of the best heat transfer materials. However, they reported that water or tap water is likely untreated and contain impurities. These impurities could cause corrosion or clog the fluid channels. Therefore, using good quality water is recommended in order to minimize corrosion and optimize thermal [21]. Next, it is also being reported that deionized water is an excellent inhibitor and has a high resistivity compared to tap water and most fluids. However, as resistivity increases, the corrosivity increases as well. Deionized water pH was 7.0 but will quickly turn to acid when exposed to air; this is due to the carbon dioxide gas which dissolved in water. Therefore, we suggested using a corrosion inhibitor or stainless-steel tubing in making cold plates or heat exchanger when deal with deionized water. Finally, in [21] reported that ethylene glycol has desirable thermal properties including a high boiling point, low freezing point, stability over a wide range temperature and high specific heat and thermal conductivity. The low viscosity characteristic will reduce pumping requirements. However, they stated that automotive glycol should not be used in a cooling system or heat exchanger because it contains silicate-based rust inhibitors. These inhibitors can reduce the efficiency of heat exchanger by coating the heat exchanger surfaces.

Therefore, in this study, the effects of copper particles as additives in deionized water mainly in viscosity was analyzed.

METHODOLOGY

Preparation of Sample

Deionized water was used in the experimental works. Copper particles as additives were weighted in electronic balance prior to be dispersed in deionized water. Next, four samples were prepared; one sample acts as reference fluid (refer as C1) and the other samples with weight of 2.5, 5.0 and 7.5 mg copper particles was dispersed in 500 ml of deionized water each as listed in Table 1. The three samples were then stirred by a stirrer for two hour at ambient temperature and 200rpm agitation speed was set to uniformly disperse all particles in the samples.

Table 1: Composition of samples

Name of Samples	Weight of Copper Particles (mg)
C1	0.0
C1-S1	2.5
C1-S2	5.0
C1-S3	7.5

Viscosity Behavior Test

A rheological behavior test was carried out by using Brookfield Viscometer, a simple rotational viscometer, which used a torsion spring to measure the torque required to rotate a cylindrical spindle with diameter of 3.101cm and the effective length is 6.51cm. Brookfield Viscometer deals with liquids and semi-solid, which has low viscosity apparently. Besides, this viscometer measures the viscosity, shear rate and shear stress, therefore functions as a rheological instrument which enable us to conduct a detailed analysis of deionized water with copper particles. In this experiment, 7 ml of sample was prepared in a sample holder and a rheological behavior test was performed to study the viscosity effect to shear rate at ambient temperature (25^{o}C). The shear rate was obtained from the viscometer when the number of rotation per minute (rpm) of cylindrical spindle was varied from10.01 to 200 rpm with 10 rpm increment. The test was carried out in four minutes for each test and the shear stress was recorded for each test by means of shear rate to determine the viscosity of samples. The performance of rheological behavior test was characterized using 1/3 Simpson's Rule by determining area under the curve.

RESULTS AND DISCUSSION

Comparison between Control Sample and Sample 1

Based on Figure 1, the graph shows the comparison between viscosity of control sample and sample 1 with increasing value of shear rate which varied from 13.21 until 264 s^{-1} with increment of 13.20 s^{-1}. Both samples show that the viscosity increases with shear rate which means the fluid is experienced shear thickening behavior. From the graph plotted, we can see that the viscosity of C1-S1 is lower than C1 which implies that adding additives will improve the fluid's performance by lowering its viscosity. By calculating the area under the graph with the aid of Simpson's Rule, it is found that C1 has larger value of area than C1-S1 which is 569.7 and 498.2 respectively. This indicates that C1 is more efficient than C1-S1 due to the higher value of area under the graph.

Comparison between Control Sample and Sample 2

Based on Figure 2, the graph shows the comparison between viscosity of control sample and sample 2 with increasing value of shear rate which varied from 13.21 until 264 s^{-1} with increment of 13.20 s^{-1}. Both samples show that the viscosity increases with shear rate, which means the fluid is experienced shear thickening behavior. From the graph plotted, we can see that the viscosity of C1-S2 is lower than C1 which implies that adding additives will improve the fluid's performance by lowering its viscosity. The viscosity of C1-S2 is low at the beginning but as the shear rate increases, the viscosity increases about the same as C1. By calculating the area under the graph with the aid of Simpson's Rule, it is found that C1 has slightly larger value of area than C1-S2 which is 569.7 and 513.4 respectively. This indicates that C1 is more efficient than C1-S2 due to the higher value of area under the graph.

Comparison between Control Sample and Sample 3

Based on Figure 3, the graph shows the comparison between viscosity of control sample and sample 3 with increasing value of shear rate which varied from 13.21 until 264 s^{-1} with increment of 13.20 s^{-1}. Both samples show that the viscosity increases with the shear rate. Both samples are observed to experience shear thickening behavior. From the graph plotted, we can see that the viscosity of C1-S3 is lower than C1 which implies that adding additives will improve the fluid's performance by lowering its viscosity. However, the viscosity starts to increase with the increasing amount of copper particles in deionized water. The C1-S3 shows viscosity value of 0cP due to the low speed of shear rate at the beginning, but as the shear rate increases, the viscosity increases about the same as C1. By calculating the area under the graph with the aid of Simpson's Rule, it is found that C1 has larger value of area than C1-S3 which is 569.7 and 502.1 respectively. This indicates that C1 is more efficient than C1-S3 due to the higher value of area under the graph.

Comparison between Control Sample, Sample 1, Sample 2 and Sample 3

Based on Figure 4, the graph shows the comparison between viscosity of control sample and the other three samples with increasing value of shear rate which varied from 13.21 until 264s^{-1} with increment of 13.20s^{-1}. Based on the graph plotted, deionized water which consists of copper particles has lower viscosity than base deionized water. However, with increasing amount of copper particles in the deionized water, the solution shows that the viscosity value also increases. Besides, all samples show that the viscosity increases with increasing the shear rate. This means that the solution now is a non-Newtonian fluid that has the same properties as a dilatant or shear thickening fluids. In other words, the experimental parameters of viscometer model, spindle and speed all influence the viscosity measured of a non-Newtonian fluid. The measured viscosity is called the apparent viscosity of the fluid and is only accurate only when explicit experimental parameters are furnished and adhered. Besides, the higher shear rate means that the higher the friction and the greater the amount of force required in moving such fluid. Therefore, high viscous liquid will require more force to being move than less viscous liquid. However, from the data collected, it shows that the highest viscosity is 1.2 cp which can be consider small and do not require much force to move the fluid. From the graph, it shows that control sample is more efficient due to the highest area under the graph which is 569.7. Although it has highest value of area under the graph, it does not mean that another sample is inefficient. From our studies, it shows that lower viscosity is more desirable to apply as a coolant in heat transfer hardware. By adding additives, the viscosity value is reduced which improved the fluid's performance. Hence, with low viscosity and high area under the graph values, sample 2 which contain 5.0 mg of copper particles in deionized water exhibit the best performance with area under the curve value of 513.4. Thus, adding copper particles in deionized water can improve the quality of heat transfer fluid. In addition, heat conductivity also can be improved by adding copper particles in heat transfer fluid. This implies that copper particles can be good additives to increase the performance of heat transfer fluid due to the high thermal conductivity of copper. However, some other factor must be considered to get a better result regarding the good performance of heat transfer fluid. In this case, heat capacity analysis should be done to analyze the amount of heat that can be absorbed in each sample. If the sample has higher heat capacity, the performance will become greatly enhance. In completing this experiment, we cannot do the heat capacity analysis due to the inability of equipment to perform the task. For future studies, heat capacity test should be done together to identify the performance of heat transfer fluid.

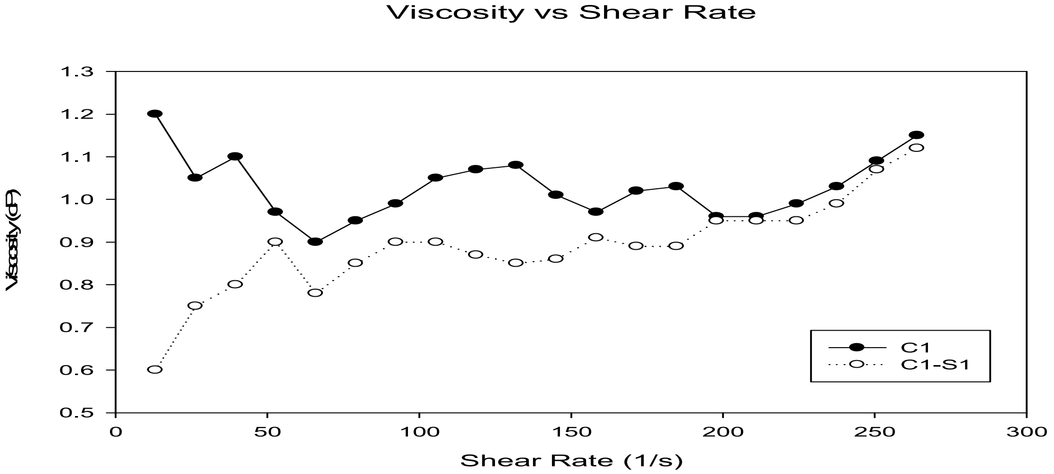

Figure 1: The relationship between shear rate (1/s) and viscosity (cP) of control sample and sample 1

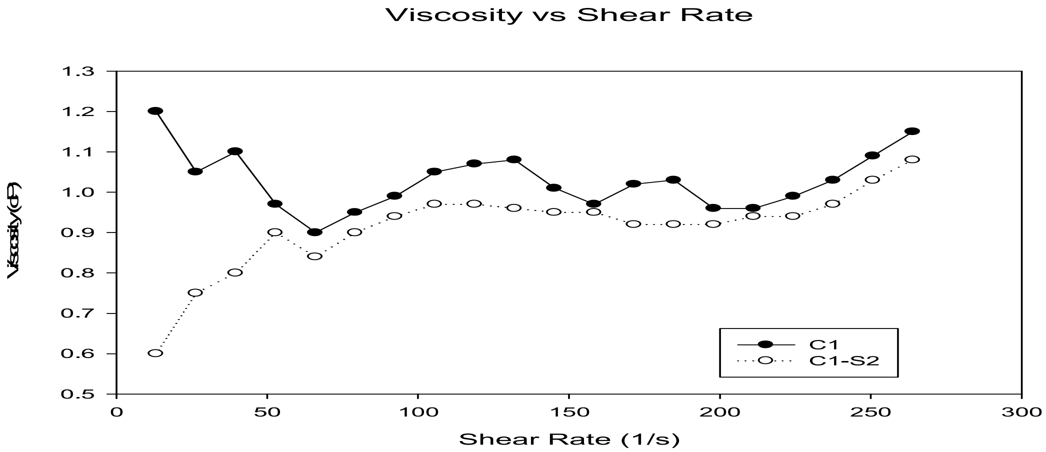

Figure 2: The relationship between shear rate (1/s) and viscosity (cP) of control sample and sample 2

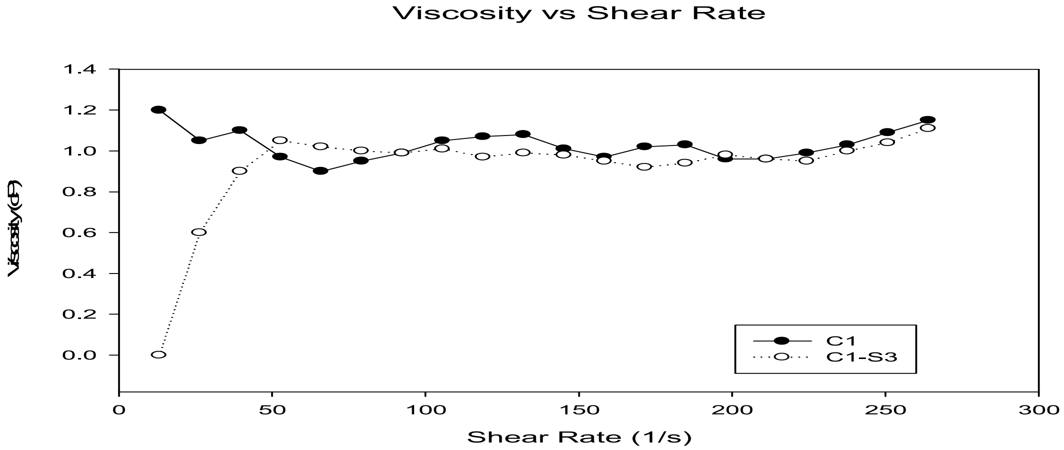

Figure 3: The relationship between shear rate (1/s) and viscosity (cP) of control sample and sample 3

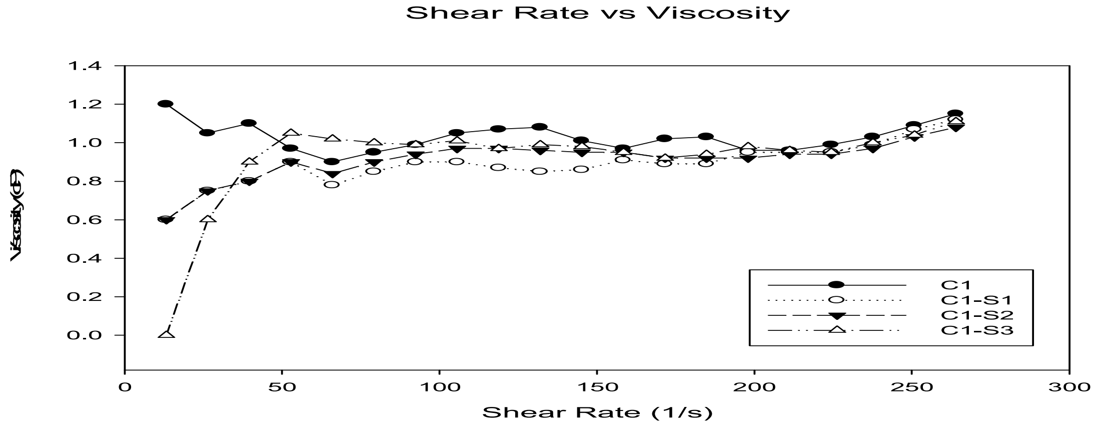

Figure 4: The relationship between shear rate (1/s) and viscosity (cP) of control sample, sample 1, sample 2 and sample 3

CONCLUSION AND RECOMMENDATIONS

The effect of copper particles as additives in deionized water as heat transfer fluid has been experimentally investigated. The experiment conducted is the rheological behavior test toward pure deionized water and mixture of deionized water with different amount of copper particles as additives. The experimental result clearly shows the existence of shear stress for these fluids, and implies that the value of viscosity depends on the shear rate and amount of copper particles added in the deionized water. In conclusion, the blended of copper particles with deionized water as heat transfer fluid are found to be suitable to effectively improve the tribological of the fluid. The three samples for the mixture of deionized water and copper particles in the amount of 2.5, 5.0 and 7.5 mg have shown to lower the viscosity of the fluid compared to base deionized water. However, the viscosity tends to increase when a larger amount of copper particles is added. From the experiment data, the dissolution of 5.0 mg of copper particles produced high value of area under the graph which is 513.4 with low viscosity profile compared to reference fluid which produces highest area under the graph, 569.7 but with higher viscosity. In this case, low viscosity will allow the fluid to flow smoothly under the effect of shear stress and more desirable to be applied as a coolant in heat transfer hardware. Hence, the addition of 5.0 mg copper particles in deionized water is more efficient. Next, the result of the experiment is found that the viscosity of the sample increased when the shear rate is increased from 13.2 to 264 s^{-1}.It is concluded that all samples are non-Newtonian fluid as the viscosity changed according to the shear rate. The viscosity value of pure deionized water changed slightly, but the mixture of deionized water and copper particle changed more than pure deionized water. However, further studies are necessary to determine the limitation that need to be optimized as additive.

As for the recommendation to improve the result in the study of the effect of copper particles as additives in deionized water as heat transfer fluid, the usage of incubator shaker is preferred instead of local stirrer in order to ensure that the additives are completely dispersed in deionized water. Besides, high quality of deionized water should be used to achieve the best result. Next, more advanced devices or equipment should be designed so that more accurate reading can be obtained, Finally, the experiment carried out must be repeated for a several times and find the average to get a better result.

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