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Thermal Properties of Hybrid Nanofluid with Different Concentration

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ABSTRACT

Hybrid nanofluid is important as it has many applications in thermal related technology. The performance of a nanofluid is determined by its thermal properties. The thermal properties of the hybrid nanofluid are affected by many factors such as mixing ratio and temperature. The purpose of the study is to study the effect of different ratio concentration of hybrid nanofluid and temperature on the thermal properties. The thermal properties to be studied were thermal conductivity, viscosity, specific heat capacity and density. For this study, the mixing ratio concentration of Al_2O_3/TiO_2 hybrid nanofluid samples was varied in order to see the difference between the thermal properties of each sample. The effect of temperature toward the samples was also tested. Results showed that samples with the highest ratio concentration of Al_2O_3 have the highest thermal conductivity and density while also having the lowest measurement of viscosity. However, samples with the highest value of specific heat capacity were unable to be determined due to the minimal difference between the results of the sample. The other results show that the increase in temperature causes the thermal conductivity and specific heat capacity to increase while the viscosity and density decrease. From the findings, this research can help future studies regarding the preparation and thermal properties of the Al_2O_3/TiO_2. This research also can be a proof that this nanofluid be an alternative in any thermal related application.

1. Introduction

Nanofluid are fluids that have been used in many applications such as electronic cooling, engine cooling and vehicle thermal management, generator cooling, in machining coolants, welding, power systems, lubrication, thermal storage, solar heating, cooling and heating in buildings, biomedical, spacecraft devices and defense equipment [1]. Nanofluid is a base fluid such as water and ethylene glycol mixed with a nano-sized particle called a nanoparticle [6,7]. It will then mixed to form a nanofluid.

Research have been conducted by Moldoveanu *et al.*, [2] regarding the thermal properties of Al_2O_3 and SiO_2 and their hybrid. It was found that the hybrid nanofluid has better thermal conductivity enhancement than alumina nanofluid but lower thermal conductivity enhancement than silica nanofluid. The result shows that hybrid nanofluid with higher volume concentration ratio compares to silica volume concentration have the highest thermal conductivity in all temperatures.

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The result was also supported by another study by Shah *et al.,* [10]. Madhesh and Kalaiselvam [3] have conducted an experiment analysis on a hybrid nanofluid as a coolant. Cu/TiO_2 hybrid nanofluid with base fluid of de-ionized double distilled water from the Millipore distiller with different volumetric concentrations ranging from 0.1 - 1.0 %. From the study, the lower volume concentrations of less than 0.7 % hybrid nanofluid display better heat transfer behaviour compared to the higher volume concentrations of greater than 0.7 %.

Recently, hybrid nanofluid has had many applications and improving thermal properties can improve its performance. One of the usage of nanofluid is to enhance the coolant of a car radiator [15]. In another instance, by increasing the volume concentration of Al_2O_3/TiO_2 hybrid nanofluid to 1.5 %, it increases the energy efficiency of a double heat exchanger because thermal properties and viscosity also increased [14].

The thermal properties of nanofluid are affected by multiple factors. One of them is the volume concentration of nanoparticles inside the base fluids which can affect the thermal properties [8,9]. Another factor that can be considered is the ratio between the nanoparticles of the nanofluid [11,12]. Since a hybrid nanofluid consists of two or more nanoparticles inside, it is vital to determine which of the nanoparticles will be the major nanoparticle inside of a nanofluid since every nanoparticle has its thermal properties. By controlling the ratio between the nanoparticles, is it possible to create a sample of nanofluid with good thermal properties that can benefit the industry.

Hence, this study aimed to enhance the thermal properties of the base fluid by adding nanoparticles. Next, this study will investigate the effect of the different mixing ratios of hybrid nanofluid on the thermal properties. Lastly, this study also analyses the effect of temperature to thermal properties.

2. Methodology

2.1 Hybrid Nanofluid Preparation

In this experiment, the nanofluid samples that were prepared were Al_2O_3 / TiO_2 hybrid with the base fluid of water and ethylene glycol (75:25). The volume concentration of each hybrid nanofluid was fixed at 0.5 % while the mixing ratio concentration between the two different nanoparticles of Al_2O_3 and TiO_2 for each nanofluid were controlled. The reason for fixing the volume concentration is to focus more on the effect of the mixing ratio concentration of the hybrid nanofluid. Table 1 shows the details of the hybrid nanofluid sample.

Table 1
Hybrid nanofluid details

Base Fluid	Nanoparticle	Volume concentration (%)	Nanoparticle mixing Ratio
Water (75) + EG (25)	Al_2O_3/TiO_2	0.5	50:50
Water (75) + EG (25)	Al_2O_3/TiO_2	0.5	50:50
Water (75) + EG (25)	Al_2O_3/TiO_2	0.5	60:40
Water (75) + EG (25)	Al_2O_3/TiO_2	0.5	20:80
Water (75) + EG (25)	Al_2O_3/TiO_2	0.5	80:20

In order to ensure the stability of the nanofluid sample, sodium dodecylbenzene sulfonate (SDBS) surfactant was added into all the nanofluid samples. First, both of the nanoparticles will be mixed into the base fluid. After that, the SDBS surfactant was added. Then, the sample was mixed together using a mechanical stirrer with a speed of 350 rpm for 30 mins. The next step was to use the ultrasonic homogenizer to sonicate the sample for a total of two hours with a frequency of 20 KHz. Both of the equipment used are shown in Figure 1.

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2.2 Hybrid Nanofluid Stability

The stability of nanofluid is an important factor to consider when making a nanofluid. Nanofluid can have sedimentation leads to a reduction in the thermal conductivity of nanofluid. It is also very difficult to clean if the hybrid nanofluid sediment inside an enclosed space such as inside a radiator. However, the duration of the sedimentation is dependent on the stability of the nanofluid.

(a) (b)

Fig. 1. (a) Magnetic stirrer and (b) Ultrasonic homogenizer

The stability of nanofluid can be increased using the process of ultrasonication. In this experiment, the nanofluid undergoes an ultrasonication process using the ultrasonic homogenizer for two hours. During this process, the nanofluid is cooled down using cold water to ensure the probe of the ultrasonic homogenizer does not get too hot during the duration of the process as the constant vibration generates heat quickly.

Another method of enhancing the hybrid nanofluid is by adding surfactant to the samples. Surfactant helps to increase contact between two nanoparticles by reducing the surface tension of the base fluid and increasing the suspension time of nanoparticles. In this experiment, the SDBS surfactant was used.

By combining both stability enhancement methods, it helps to increase the stability of the samples. The duration of the samples to sediment becomes longer. The samples were monitored every week for any sedimentation.

2.3 Thermal Conductivity Measurement

For the measurement of thermal conductivity, a KD2 Pro was used. The KD2 Pro has a sensor that can measure the thermal conductivity of fluids. Figure 2 shows the equipment which is the KD2 pro.

Fig. 2. KD2 Pro

In order to fix the temperature for each sample, a water bath was used for the range temperature of 30 - 60 °C. The measurement was taken with the sample inside the water bath.

The measurement of thermal conductivity was very difficult especially when the samples were inside the water bath. This is perhaps due to the presence of a heating element causing unneeded interference to the reading of KD2 pro and also the gap open on an enclosed water bath causing heat to come out from the water bath. Therefore, it is important for the setup inside the water bath is controlled first before starting reading. If the reading starts to become illogical, the experiment will be halted for 15 mins before continuing on.

The measurement for thermal conductivity was fixed at the same temperature and in order to ensure the accuracy of the result, multiple measurements were taken and the average value was calculated. After a measurement for one specific temperature was done, the temperature measurement was changed in order to study the effect of increased temperature on the thermal conductivity of hybrid nanofluid samples.

2.4 Viscosity Measurement

For the measurement of viscosity, a viscometer was applied. The viscometer is simple to use for the measurement of viscosity however the challenge is to measure the viscosity at a fixed temperature.

Figure 3 shows the viscometer in the experiment. To measure the viscosity of the sample, the equipment uses the turning of a spindle in a cup. The viscosity is then determined through the measurement of the torque on a vertical shaft that rotates a spindle.

Fig. 3. Viscometer

The sample was first rinsed into a water bath at the desired temperature for a minimum of 5 mins in order to ensure the temperature of the nanofluid reached the desired temperature. After that, the samples then was quickly measured around 1 min using the viscometer to ensure minimal heat loss. The sample was rinsed again into the water bath.

The measurement for viscosity was fixed at the same temperature and in order to ensure the accuracy of the result, multiple measurements were taken and the average value was calculated. After a measurement for one specific temperature was done, the temperature measurement was changed in order to study the effect of increased temperature on the viscosity of hybrid nanofluid samples.

2.5 Theoretical Value of Specific Heat Capacity and Density

The measurement for specific heat capacity and density cannot be done due to the lack of proper equipment to measure both properties. The measurement for specific heat capacity is usually done by micro DSC. The equipment was not available nearby during the duration of the project. Another reason is that there is a lack of reference that relates to measuring the specific heat capacity of nanofluid.

Meanwhile, the density of nanofluid can be determined by finding its mass of a specific volume, the precise reading of volume cannot be obtained by using a measuring cylinder. The results were too similar and hard to distinguish which have the highest and lowest density.

To estimate the value of specific heat capacity and density of the samples, the formulae used by Sundar *et al.*, [16] were applied. The temperature range was determined to be from 30 - 60 °C. The result used a few data from the Engineering ToolBox website (2003) as a reference.

Table 2 shows the density and heat capacity for the Al_2O_3 and TiO_2 nanoparticle which were obtained from the seller of the nanoparticle, US Research Nanomaterials, Inc.

Table 2
Nanoparticle specific heat capacity and density

Nanoparticle	Average Particle size (nm)	Density (Kg/m^3)	Heat capacity (J/Kg.K)
Al_2O_3	20	3890	880
TiO_2	5	180	683

3. Results and Discussion
3.1 Thermal Conductivity of Samples

Figure 4 shows the result for thermal conductivity among the samples. For this result, the temperature was set at 35 °C.

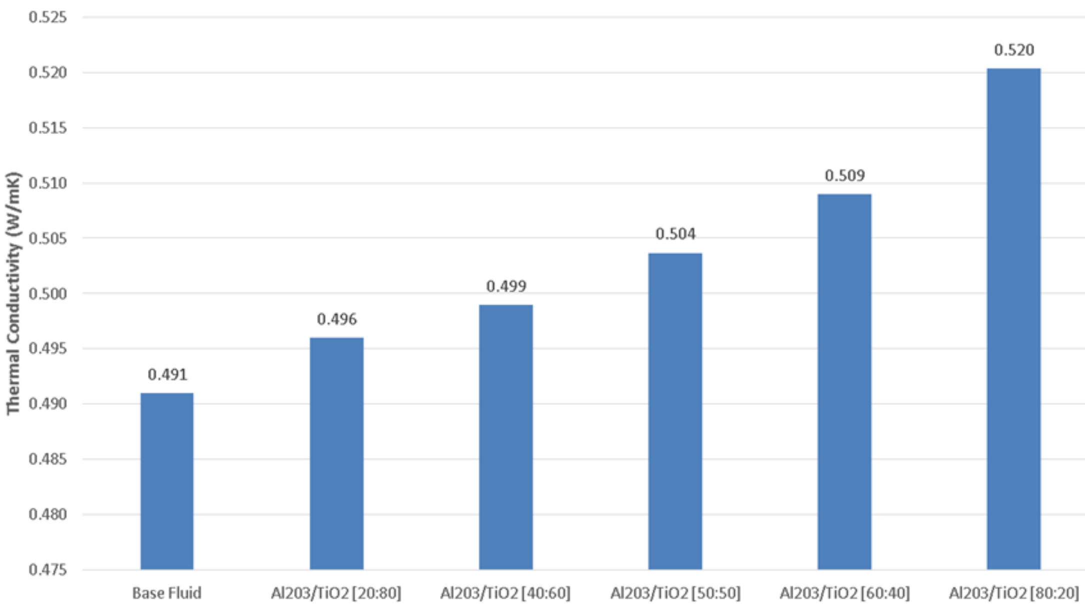

Fig. 4. Thermal conductivity of hybrid nanofluid and base fluid graph

The result shows that all of the hybrid nanofluid samples managed to enhance the thermal conductivity of the base fluid which is the mixture of water and ethylene glycol. The result also shows the Al_2O_3/TiO_2 (80:20) hybrid nanofluid have the highest thermal conductivity while the Al_2O_3/TiO_2 (20:80) hybrid nanofluid has the lowest thermal conductivity. It is shown that the hybrid nanofluid with higher ratio concentration of Al_2O_3 compared to TiO_2 have higher thermal conductivity from hybrid nanofluid with lower ratio concentration of Al_2O_3 compared to TiO_2. This is because the thermal conductivity for Al_2O_3 nanoparticle was higher compared to TiO_2 nanoparticles therefore increasing the ratio for Al_2O_3 will increase the thermal conductivity of hybrid nanofluid.

3.2 Effect of Temperature to the Thermal Conductivity

Figure 5 shows the result for the thermal conductivity of all the sample vs temperature. The temperature ranged between 30 - 60 °C and multiple measurements were taken. The result shows that the thermal conductivity of all of the samples steadily increases as the temperature increase. The explanation for why the temperature increase was due to the Brownian motion of particles increases. This, in turn increases the thermal conductivity as the temperature increase. This reason was supported by the fact that each of the thermal conductivity increased by the temperature.

From the graph, the thermal conductivity of Al_2O_3/TiO_2 (80:20) continuously remained as the sample with the highest thermal conductivity. This further confirms that the Al_2O_3/TiO_2 (80:20) hybrid nanofluid has the best thermal conductivity.

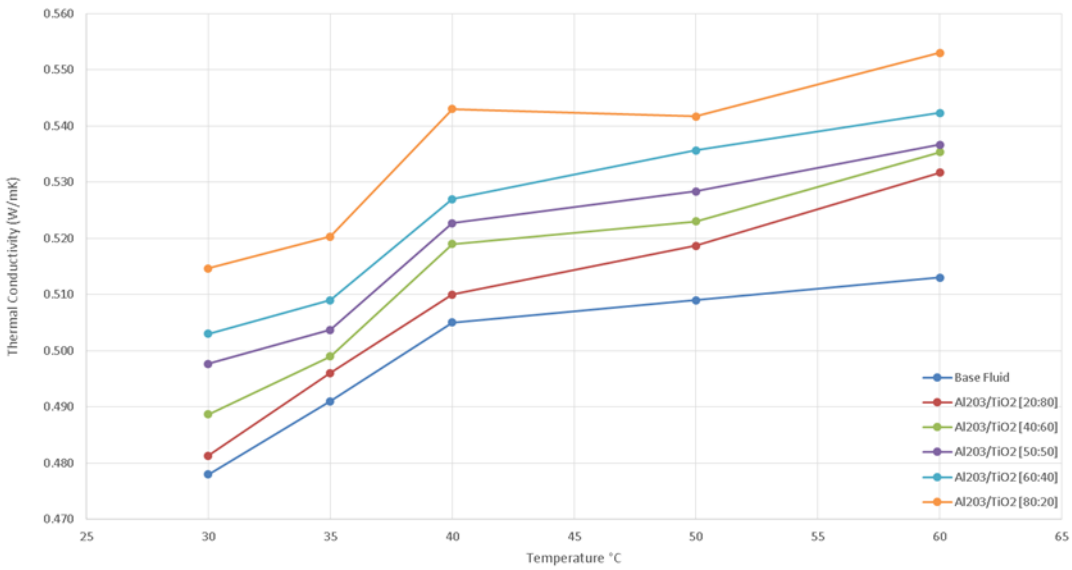

Fig. 5. Thermal conductivity vs. temperature graph

3.3 Viscosity of Samples

Figure 6 shows the result for viscosity between samples. For this result, the temperature was set at $35\ °C$.

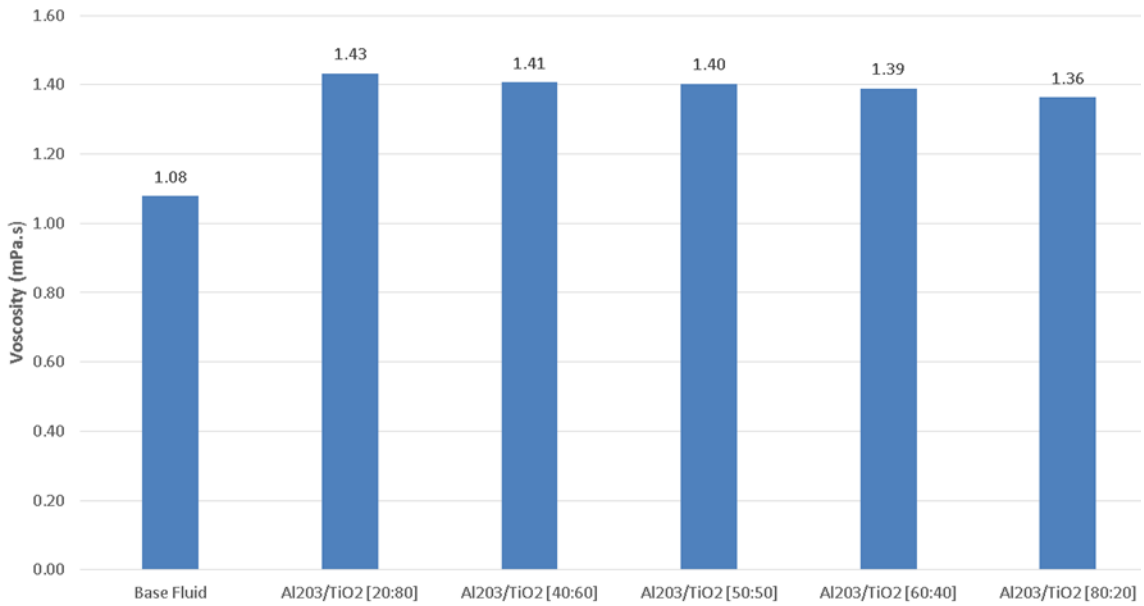

Fig. 6. Viscosity of hybrid nanofluid and base fluid graph

The results show that all hybrid nanofluid samples have higher viscosity than the base fluid. The result also shows the Al_2O_3/TiO_2 (20:80) hybrid nanofluid has the highest viscosity while the Al_2O_3/TiO_2 (80:20) hybrid nanofluid has the lowest viscosity. The reason is probably because of the particle size of Al_2O_3 is bigger than TiO_2. Therefore, with the same mass of Al_2O_3 and TiO_2, the latter will have more particles inside if compared to the former. However, the difference between all the hybrid nanofluid samples is minimal.

3.4 Effects of the Temperature to the Viscosity

Figure 7 shows the result for the viscosity of all the sample vs. temperature. The temperature range of 30 - 60 °C and multiple measurements was taken. The result shows that the thermal conductivity of all of the samples steadily decreased as the temperature increase. According to Baghbanzadeh *et al.*, [4] one of the reasons for this is that as the temperature increase, the molecular attractive forces decreases. From the graph, the viscosity of Al_2O_3/TiO_2 (80:20) continuously remained as the hybrid nanofluid sample with the lowest viscosity. Because hybrid nanofluid with lower viscosity is considered as a good hybrid nanofluid, the Al_2O_3/TiO_2 (80:20) can be considered as the base sample in terms of lower viscosity.

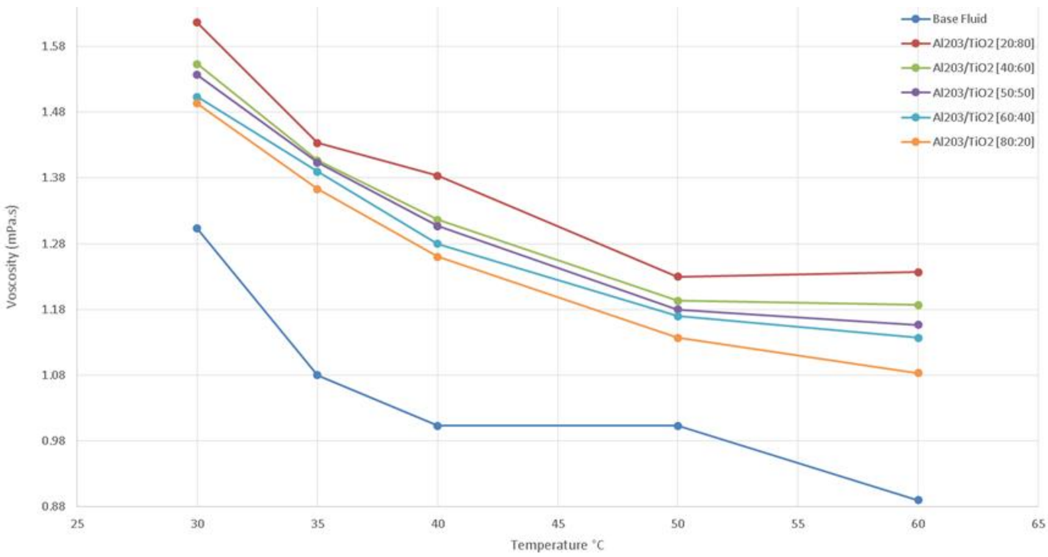

Fig. 7. Viscosity vs. temperature graph

3.5 Specific Heat Capacity of Samples

Figure 8 shows the result for specific heat between samples. For this result, the temperature was compared at 30 °C. The result shows that all hybrid nanofluid samples have lower specific heat capacity than the base fluid. This result was consistent with a study done by Tiwari *et al.*, [13]. According to Yarmand *et al.*, [5], because the surface area of hybrid nanoparticles is larger, the surface free energy has a greater impact on the overall heat capacity affecting the specific heat of the hybrid nanofluid. However, it is difficult to differentiate between all the hybrid nanofluid samples since all the readings are almost the same.

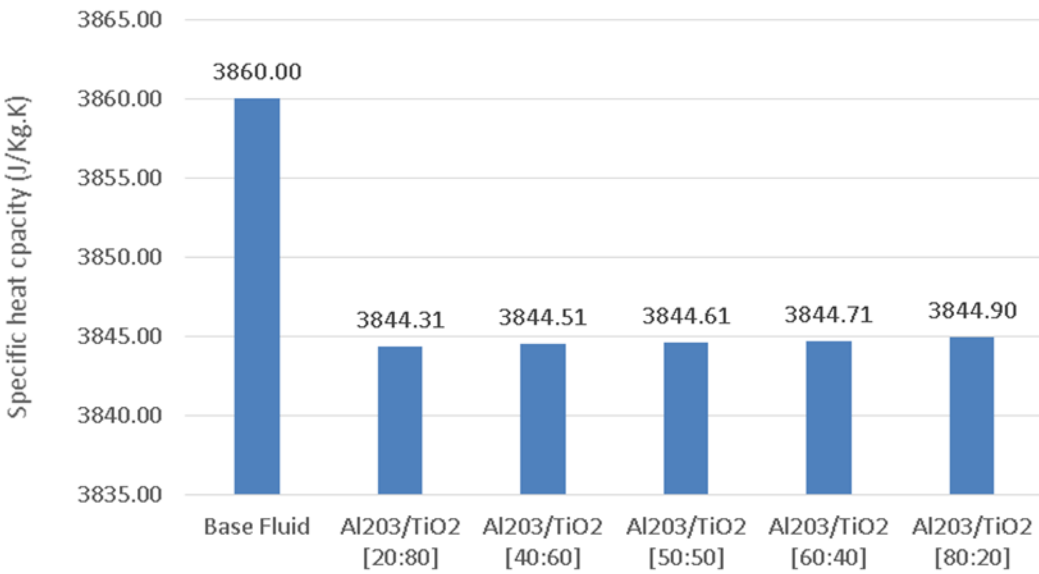

Fig. 8. Specific heat of hybrid nanofluid and base fluid graph

3.6 Effect of Temperature to the Specific Heat Capacity

Figure 9 shows the result for the specific heat of all the samples vs. temperature. The temperature range of 30 - 60 °C. The result shows that the thermal conductivity of all of the samples gradually increases as the temperature increases. There were six lines inside the graph, however, the due values of all the hybrid nanofluids were all almost the same and it was difficult to tell them apart.

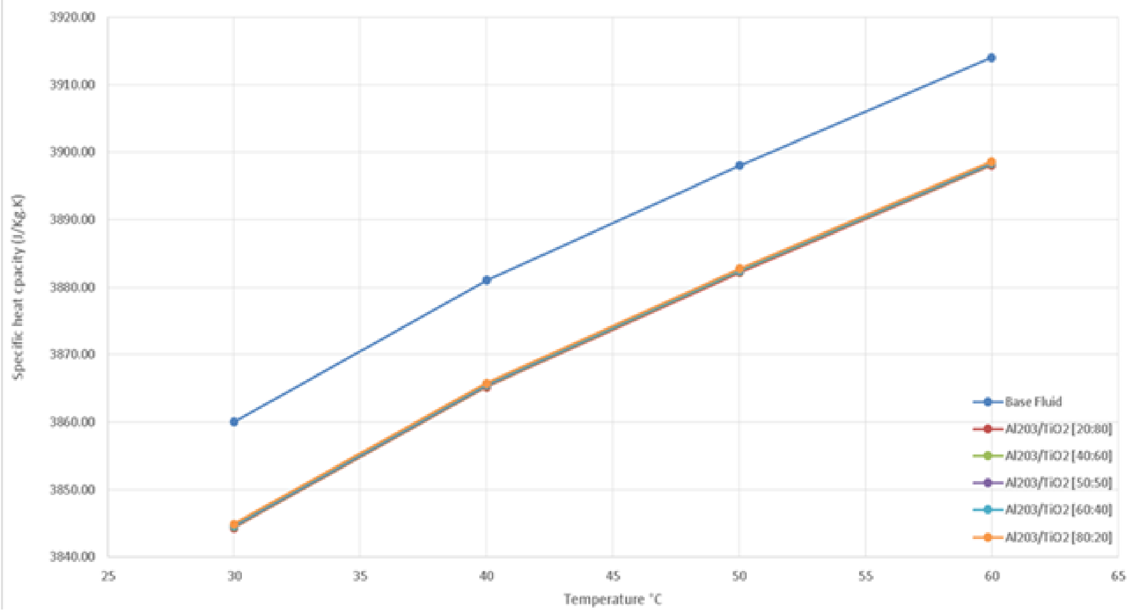

Fig. 9. Specific heat vs. temperature graph

3.7 Effect of Temperature to the Specific Heat Capacity

Figure 10 shows the result for the density of all the samples vs. temperature. The temperature range of 30 - 60 °C. The result shows that the density of all of the samples decreases as the temperature increases. The explanation for this is that as the temperature increases, the volume of the sample also increases. The increased amount of volume causes the density to decrease.

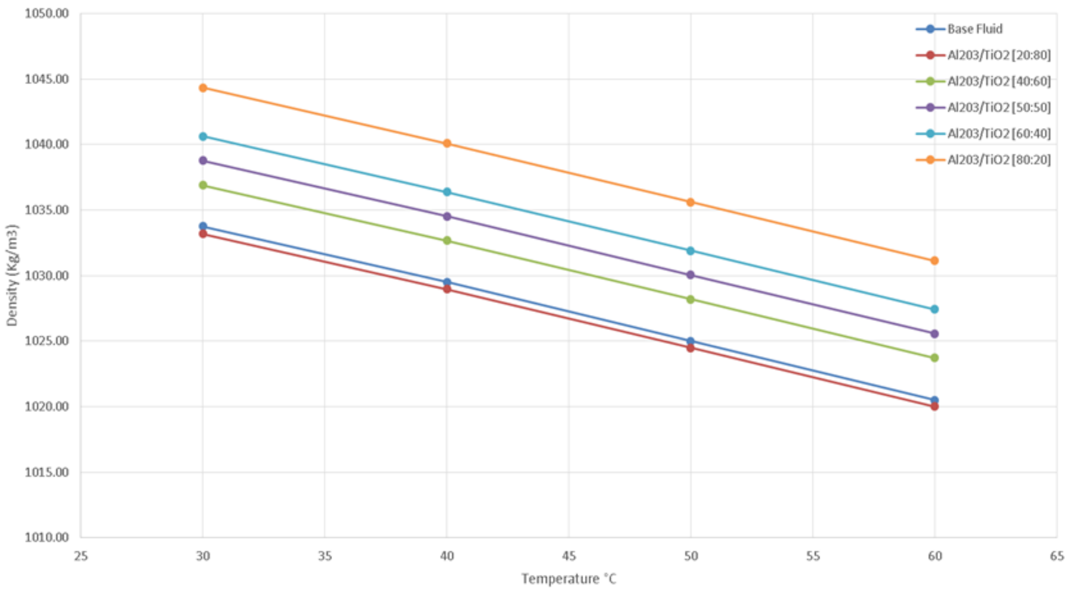

Fig. 10. Density vs. temperature graph

4. Conclusions

Sample of Al_2O_3/TiO_2 (80:20) had the highest thermal conductivity. Meanwhile, the measured thermal conductivity increases as the temperature increased. Al_2O_3/TiO_2 (80:20) hybrid nanofluid sample had the lowest thermal conductivity. Then, the viscosity of all the samples decreased as the temperature rose. For the specific heat capacity, all the hybrid nanofluid showed lower specific heat capacity compared to the base fluid. The Al_2O_3/TiO_2 (80:20) hybrid nanofluid had the highest density while the hybrid nanofluid sample of Al_2O_3/TiO_2 (20:80) resulted in the lowest density even lower than the base fluid. The density of the samples decreased with the escalating of the temperature.

From the findings, this research can help the future studies regarding the preparation and thermal properties of the Al_2O_3/TiO_2. This research can also be a proof that this nanofluid is good to be used in any thermal related application.

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