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Thermal Performance of Nanofluid in Automobile Radiator

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ABSTRACT

The use of nanofluids as a coolant in automobile radiators is getting more attention for the radiator's better performance. Continuous development in automotive industries has increased the demand for higher efficiency car engines. The addition of a radiator fin is one way to improve the efficiency of car engines. However, this study aims to prepare stable nanofluid and analyze the thermal physical and thermal performance of the nanofluid. Stable nanofluids were prepared using the two-step method, and the sedimentation of nanofluid was recorded to evaluate the nanofluids' stability. Single material nanofluid was compared to hybrid nanofluid and the most stable nanofluid based on the nanoparticle's sedimentation was decided. Nanofluid with less sedimentation was concluded as the most stable nanofluid among the mixture. KD2 Pro measured the thermal conductivity of nanofluid after confirmation of the nanofluid stability. A nanoparticle and base fluid chosen were based on the previous study. Al_2O_3 and TiO_2 were dispersed in ethylene glycol and graphene: TiO_2 dispersed in the mixture of EG: Distilled water (48:32) have been proposed in this study to improve the radiator performance. The factors affecting the thermal conductivity were studied, and the effect of volume concentration on the thermal conductivity of a nanofluid to transfer heat was also highlighted. An increase in volume concentration would also increase the thermal conductivity of nanofluid and thus increase radiator performance. The equation correlation of volume concentration and weight percentage equation was also proposed and investigated, hence used to prepare the sample of nanofluid.

1. Introduction

Overheating car engine happened when the cooling system is not functioning well. Continuous development in automotive industries has increased the demand for higher efficiency car engines. Generally, car engine can operate at a temperature range of 80 - 200°C. The radiator is a heat exchanger used as a cooling system. In an automobile, the radiator is used to ensure the car engine operates at an optimum temperature. Otherwise, the engine overheats and prone to being inflamed. According to Dwivedi *et al.,* [1] addition in fins is one of the approaches to increase the cooling rate

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of the radiator. However, the addition of radiator fins increased size and weight of a car. Therefore, innovation heat transfer fluid called nanofluid was introduced.

Base fluid such as water, ethylene glycol and glycerol have been used as the conventional fluid in automobile radiators, but these fluids have low thermal conductivity compared to nanofluids [2]. Nanofluid is a fluid containing dispersed solid particles and has a higher thermal conductivity compared to the base fluid itself. High in thermal conductivity and has a higher rate in the transfer of the heat.

Overheating car engines are caused by low performance of the radiator to transfer heat. If the radiator performance does not improve, the car engine becomes inflammable and endangers the car users. To ensure the car engine operates at optimum temperature and avoid overheating, improving coolant performance of the car radiator is one of the ways to improve the efficiency of the radiator. The improvement of the coolant is using nanofluid as a coolant in the radiator. Thus, the focus in this paper is to study the thermal performance of the nanofluid in the radiator. Using nanofluid as a coolant in the radiator increases the efficiency of the radiator and enhances the heat transfer.

Thermal-physical properties are one of the thermal performances of the nanofluid e.g., the thermal conductivity and volume concentration of nanofluid. Nanofluids with high thermal conductivity can increase the performance of radiator. To ensure that, the thermal conductivity of nanofluids must be measured. However before the measurement can take place, a stable nanofluid must be prepared using a suitable method using different nanoparticle and base fluids with different volume concentrations.

Some researches that have been conducted revealed that better performance of the radiator increases the efficiency of the car engine. However, it is not only based on its performance but also for a better fuel economy and less emission [1]. The point of view is by increasing the efficiency of the radiator using nanofluid as a new heat transfer coolant will not only increase the engine performance but also for saving fuel consumption. Therefore, the goal of this research is to increase the performance of radiator in the car by replacing the coolant liquid using nanofluid with better thermal conductivity.

2. Literature Review

Use of nanofluid as a coolant in automobile radiator has been studied in the last 10 years. Nanofluid is an innovation of a base fluid for better heat transfer in a cooling system. In this paper, the focus is on the study of the thermal performance of nano-based fluid in an automobile radiator. Thermal performance is to show the efficiency of transferring the heat. Therefore, reviewing the type of nanofluid and its physical properties is one of the focuses in this section.

Thermal performance of nanofluid is also depended on the thermal conductivity. Thermal conductivity shows the rate of heat transfer of nanofluid. Heat transfer rate of a radiator using nanofluid is higher than that of a radiator using ethylene glycol, the base fluid itself [3]. Hence, the heat transfer coefficient of nanofluid also is reviewed in this section.

The effect of nanofluid volume concentration on its thermal performance is also one of the focuses in this chapter. Heat transfer enhancement increases with increasing of volume concentration and the inlet temperature respectively, the value of heat transfer enhancement is from 31 - 46 % with increasing of nanofluid volume concentration in the range of 1 - 2.5 % [2]. This volume concentration was decided before preparing the nanofluid.

At the same time, the stability of nanofluid is essential to transfer heat efficiently, especially when the nanofluid is used as a coolant in the radiator. The sedimentation of nanoparticles is not only on the settlement and clogging of microchannel but also decreasing the thermal conductivity of nanofluids [4]. Hwang *et al.*, [5] reported that the stability of nanofluid is strongly affected by the characteristic of the suspended particle and the base fluid, also the addition of surfactants can improve the stability of the nanofluid.

2.1 Types of Nanofluids

Nanofluid types depend on the nanoparticle dispersed in the base fluid. There are two types of nanofluid, including single material nanofluid that was first proposed by [6]. Single material nanofluids have a single type of nanoparticle used to disperse in the base fluid. Hybrid nanofluid has a combination of more than one type of nanoparticle dispersed in the base fluid [7]. Chamsa-ard *et al.*, [8] have categorized the types of nanofluids based on the nanoparticles used.

2.1.1 Pure metal and metal oxide nanoparticles

Pure metals nanoparticles consist of gold (Au), silver (Ag), copper (Cu), aluminium (Al), iron (Fe) and more. Meanwhile, metal oxide nanoparticle consists of copper oxide (CuO), alumina (Al_2O_3), Ti02 (TiO_2) and more. However, for this paper, nanofluids were prepared with the alumina (Al_2O_3) pure metal oxide nanoparticle.

2.1.2 Carbon nanomaterial

Chamsa-ard *et al.,* [8] said carbon is the most abundant element in the earth's biosphere. When a carbon atom forms covalent bond varieties of carbon material, or the allotropes will also form. Carbon materials are black in color and quite high in thermal conductivity.

2.1.3 Graphite and graphene nanoparticles

Llobet [9] proposed that natural grape are polyerystalline form of carbon comprised of layer planes referred to as grapheme layers substantially parallel to one another and containing hexagonal arrays of carbon atoms. Graphite nemyurticles have a good thermal conductivity and it can reduce density which stands as a potential material to enhance the heat transfer [10].

2.2 Physical Properties

Physical properties are something decides before preparing a stable nanofluid. Physical properties of nanofluid are significant to enhance the heat transfer behaviour and these properties are including density, viscosity, specific heat capacity and thermal conductivity.

Table 1
Physical properties of each type of nanoparticles [11,12]

Material	Density (kg / m^3)	Thermal Conductivity (W / m.k)	Specific Heat (J / kg.k)
Sliver	10490	429	710
Copper	8954	380	390
Aluminium	2700	237	910
Diamond	3510	3300	425
Carbon nanotubes	2250	3000	410
Silicon	2330	1.48	710
Alumina ($Al2O_3$)	3880	36	773

Silica (SiO_2)	2220	1.4	745
Titanium dioxide (TiO_2)	4175	8.4	692
Water	998.9	0.613	4181
Ethylene glycol	1110	0.253	2200
Engine oil	890	0.145	1800

2.2.1 Viscosity

According to Gupta *et al*., [13] viscosity is a thickness of a fluid that deform under shear stress. A test on TiO_2 and Al_2O_3 dispersed in water and SiO_2 dispersed in ethylene glycol by [14]. The result showed when the temperature increase, the viscosity of nanofluid was reduced. Addition of the surfactant augment viscosity of nanofluid is one of the ways to increase the viscosity of nanofluid. Figure 1 below shows the Al_2O_3 dispersed in water, with the addition of surfactants and the volume concentration the viscosity increases (Figure 2).

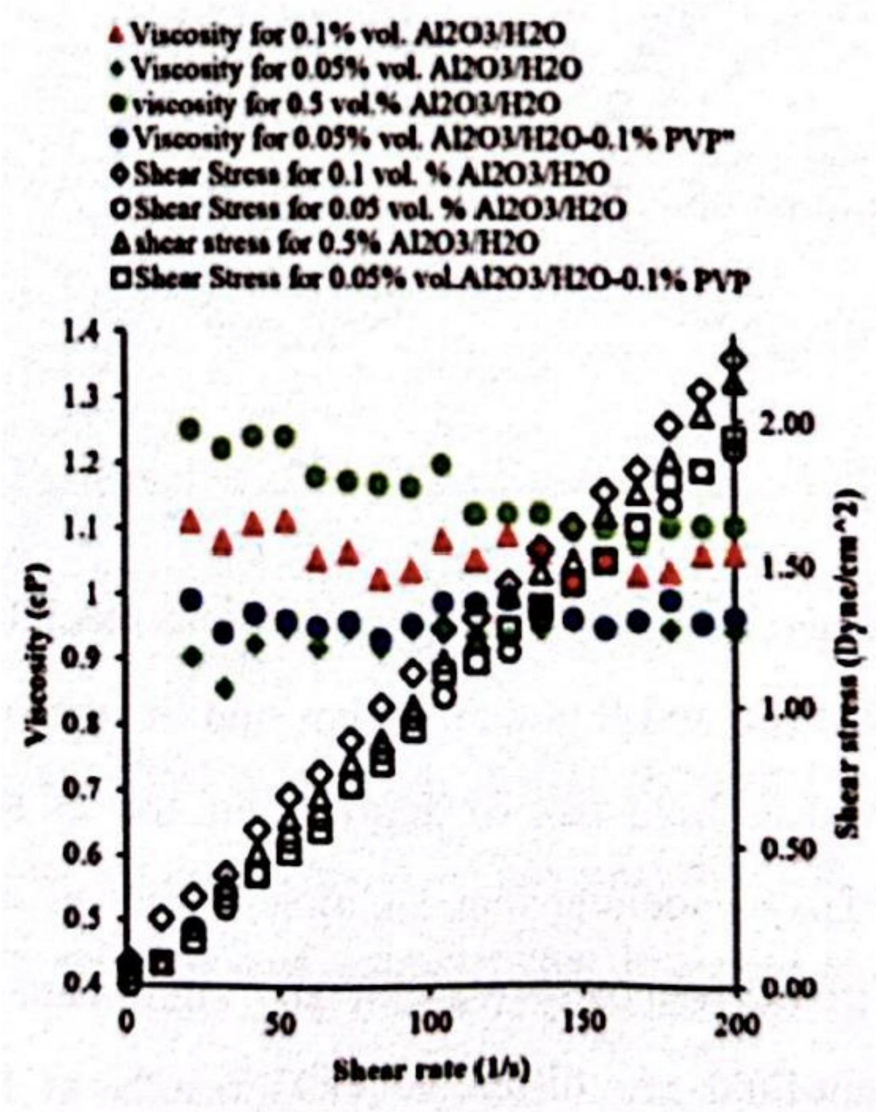

Fig. 1. Effects of addition surfactants and volume concentration on viscosity

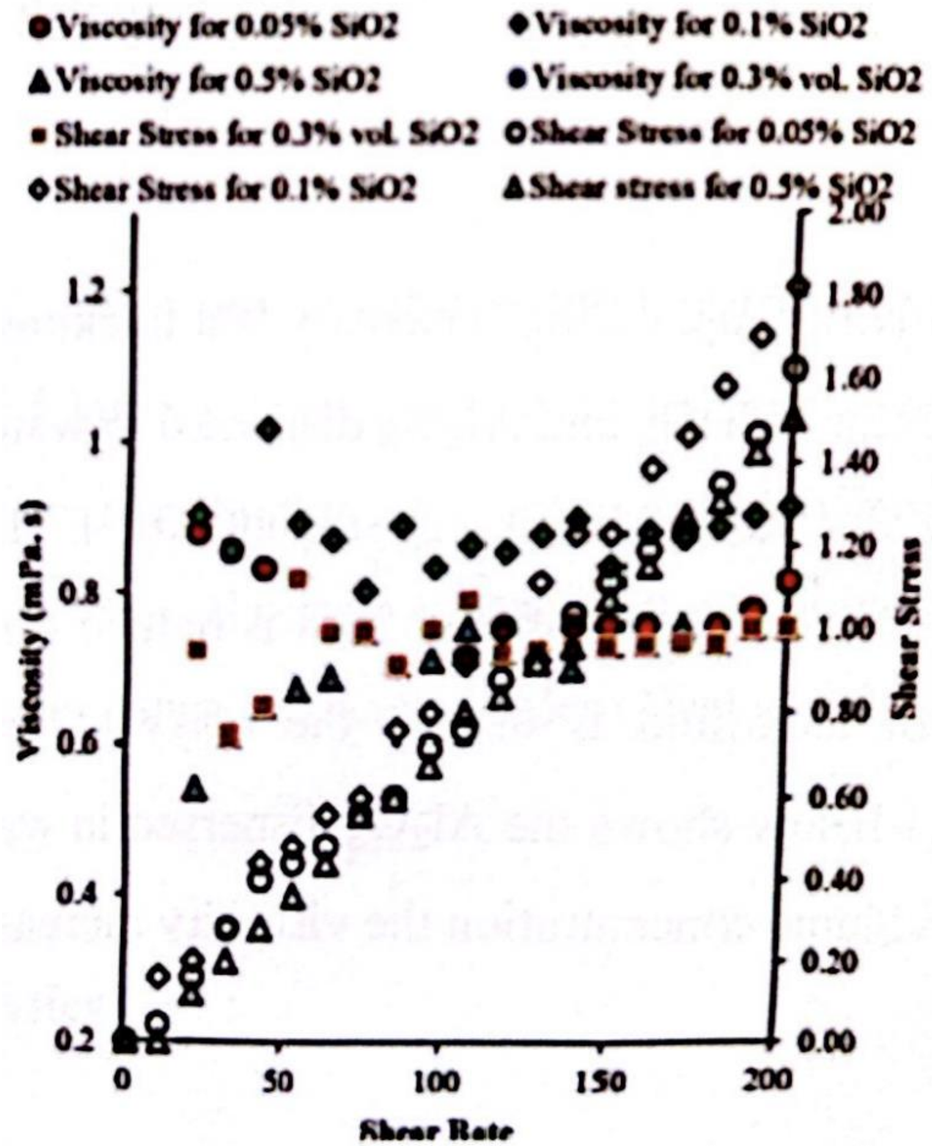

Fig. 2. Effects of volume concentration on viscosity

The viscosity keeps increasing until the concentrations reach 0.1 % and remain unchanged after wards. Umi *et al.,* [14] said the reason is that SiO_2, is not a stable nanofluid due to its high rate of aggregation and its sedimentation of nanoparticles takes place. They concluded that addition of surfactant in nanofluid can cause a minor increment in the viscosity without any significant changes in the stability. Viscosities of nanofluid are different, TiO_2 results in higher viscosity followed by Al_2, O_3 and SiO_2. The viscosity of nanofluid depending on the nanoparticle properties such as size and density. Mondragon *et al*., [15] said that it is a general rule that the viscosity of nanofluid increase with reliable content (nanoparticle) and decrease with temperature. Figure 3 below shows the factors that affects the viscosity of a nanofluid proposed by [6].

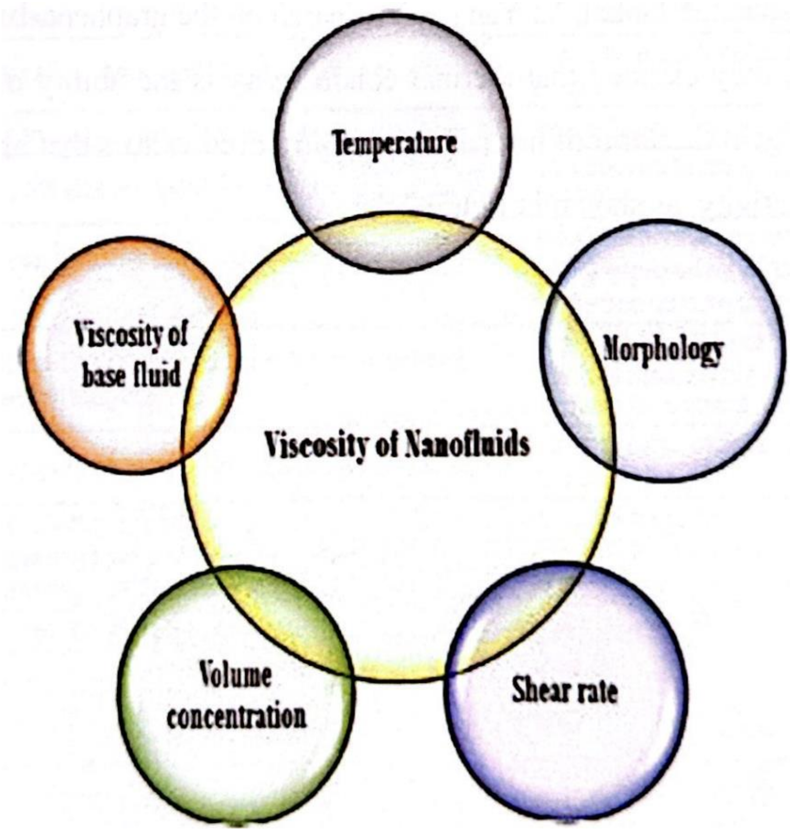

Fig. 3. Factors that affects viscosity of a nanofluid

Yashawanta *et al.,* [10] study results showed that dynamic viscosity remains the same as increasing of the shear rate. They also discovered that the increase in viscosity was because of the resistance of nanoparticles dispersed in the base fluid.

2.2.2 Thermal conductivity

Yashawanta *et al.,* [10] studied on graphite dispersion in ethylene glycol. The results showed lower volume concentration of graphite nanofluid and the higher thermal conductivity compared to the base fluid itself (ethylene glycol). Their study results also showed the thermal conductivity increased when the particle size was lesser. It is because of the uniform distribution of graphite nanoparticle in the base fluid. Therefore the particle size has a significant effect on thermal conductivity of nanofluids.

Arshad *et al.*, [6] conducted a research on the graphene-based nanofluid. In their study, they claimed that thermal conductivity is the ability of a material lo transport energy in the form of heat. They also proposed factors that affects the thermal conductivity as shown in Figure 4.

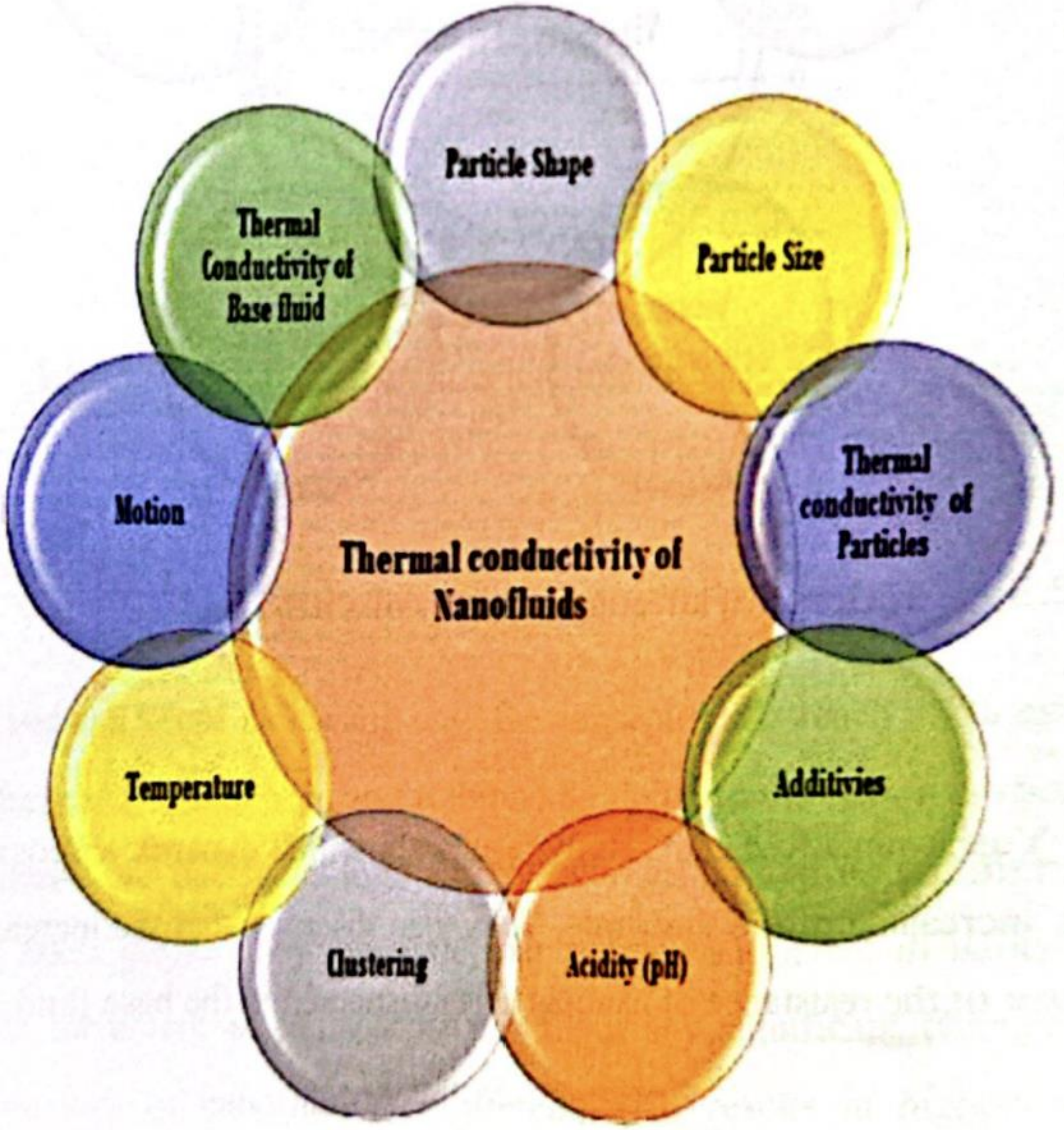

Fig. 4. Factors affecting thermal conductivity of a nanofluid

2.2.3 Volume concentration

Volume concentration is one of the physical properties of a fluid. The concentration is something that is decided before preparing the nanofluid. Table 2 shows the previous studies that were conducted on different volume concentrations and nanoparticles to enhance the thermal conductivity [15].

Table 2
Previous studies on different volume concentration nanofluids for heat transfer enhancement

Year	Nanofluid	Used studies conducted
1993	4.3 % (Al_2O_3 SiO_2 and TiO_2) dispersed in water	26 %, 7 % and 11 % enhancement in thermal conductivity
1999	4 % CuO_2, Al_2O_3 dispersed in water	20 % enhancement in thermal conductivity
2000	2.5-7.5 % (Cu nanoparticles) – water	Thermal conductivity ratio varies from 1.24 - 1.78 %
2001	Cu nanoparticles dispersed in ethylene glycol	Effective thermal conductivity of ethylene glycol improved by up to 40 % through the dispersion of 0.3 % Cu nanoparticles

2007	CuO_2, Al_2O_3 nanoparticles dispersed in water (effect of temperature)	4 vol % Al_2O_3 dispersed water nanofluids thermal conductivity raise 9.4 - 24.3 % at increase in temperature from 21 - 51°C
2006	5 % dispersing TiO_2 sphere rod	30 – 33 % enhancement in thermal conductivity
2006	1 % CuO - ethylene glycol	5 % enhancement
	Dispersing 1 voL % SiO_2 – water	3 % enhancement in water based nanofluid
	Dispersing 1 voL % carbon nanotube	7 % enhancement in water based nanofluid
2007	(0.1 - 2 %) Graphite 106 nm + water	10 - 37 % thermal conductivity enhancement
2008	Water + EG	31 % thermal conductivity enhancement
2009	4 % Al_2O_3 (15 - 50 nm) + water	13 % enhance thermal conductivity
	4 % Cu (25 - 60 nm) + water	15 % enhance thermal conductivity
2010	0.5 % Al_2O_3 water	Enhancement thermal conductivity 31 %
2013	0.1 % alumina dispersed in ethylene glycol and propylene glycol	Thermal conductivity enhancement ratios are 38.71 % and 40.2 % respectively for ethylene glycol and propylene glycol
2012	Cu dispersed with aqueous solution	Thermal conductivity increases with increasing temperature and increasing particle volume fraction
2013	Al_2O_3 water	Thermal conductivity and specific heat enhancement

2.2.4 Stability

According to Ahmed *et al.*, [2] particle structure is an essential determinant of nanofluid stability. Stability of the nanofluid is essential to prevent sedimentation during experiments when the smaller size of nanoparticles are better opted for stability. Long term stability of nanofluids is an essential requirement for the application [16]. Chemical and physical methods such as surfactants addition and homogenization respectively are used to sustain the long-term stability as well as the thermal properties of nanofluids.

Stability of nanofluid is strongly affected by the characteristics of the suspended particle and base fluids [17]. Reed *et al.,* [18] said that the agglomeration of nanoparticles does not only cause the clogging in the tube of the radiator but also decreases the thermal conductivity.

The stability mechanism of nanofluids delimits as the rate of aggregation of nanoparticles dispersed in base fluid [6]. The collision frequency and probability of cohesion during the collision when the nanoparticles start to adhere together and form aggregates at a larger size, results in sedimentation or phase transition between the base fluid and nanoparticles.

Stability of nanofluids is a critical factor in the evaluation of nanofluids that can alter the thermal physical properties of nanofluids for the application. Nanofluid can lose their ability to transfer the heat due to their proneness to agglomeration [19].

3. Methodology

The focus on this study is to analyze the thermal performance of the nanofluid in the radiator by experimental method. Nanoparticles used for this research was Alumina or aluminium oxide, TiD and graphene. The base fluid used were ethylene glycol and water.

These experiments included the preparation of a stable nanofluid with three different volume concentrations decided in the range of 0.1 - 0.9 % for single material nanofluids, Alumina and TiO_2 dispersed in ethylene glycol. Meanwhile, graphene and TiO dispersed water and ethylene glycol with surfactants, cetrimonium bromide (CTAB) were used to prepare hybrid nanofluids in the range of weight percentage 0.025 - 0.1 %.

3.1 Proposed Method

There were two methods used to prepare the nanofluids, which are one-step method and two-step methods. Preparation of nanofluids is the key step in the use of nanoparticles to improve fluid performance, especially in heat transfer.

3.1.1 One-step method

One-step method is a direct evaporation method. In this method, the direct evaporation and condensation of the nanoparticles in the base fluid were obtained to produce a stable nanofluid. This method was to eliminate the stages of drying, storage, transportation and dispersion which can cause oxidation of metal nanoparticles. Therefore, this method is suitable in preparing a metallic nanofluid. This method however, was higher in production cost and is applicabile to low vapour pressure base fluid only. This method has a limitation on control of several important parameters, including nanoparticles size.

3.1.2 Two-step method

In this method, the nanoparticles were obtained by different physical and chemical methods and then are dispersed in the base fluid. This method is the most common method to disperse nanoparticles in base fluid and break down the agglomeration to obtain a proper suspension and a stable nanofluid. Advantages of this method were low in production cost and higher in production capacity. Generally, two procedures are involved in this method. The first is the synthesis of nanomaterial, usually in the form of dry powder. The second is the dispersion of nanomaterial in the base fluid. During this procedure, the addition of dispersant or sonication were carried out to enhance the stability of the resulting nanofluid.

3.1.3 Stability evaluation methods

Many methods have been developed to evaluate the stability of nanofluids. Firstly, sedimentation and centrifugation method. This method is the simplest method used to evaluate the stability of nanofluids. The sediment weight or volume of nanoparticles in a nanofluid under an external force is an indication of the stability of nanofluid considered to be stable when the concentration of particle is kept at constant.

Zeta potential analysis is an electric potential analysis between nanoparticle and base fluid. The value of zeta potential can be significant to the stability of nanofluids. High in zeta potential value (positive or negative) means electrically stabilized, while low in zeta potential tend to coagulate or sediment. Generally, zeta potential lower than 25 mV is considered as a low value. Zeta potential in the range of 40 – 60 mV is believed to have good stability.

Spectral absorbency analysis is another efficient method to evaluate the stability of nanofluid. In general there is a linear relationship between the absorbency intensity and the concentration of nanoparticle. It is easy and a reliable method to evaluate the stability of nanofluids. The Figure 5 below shows a summary of all variables in the synthesis of nanofluid by [16].

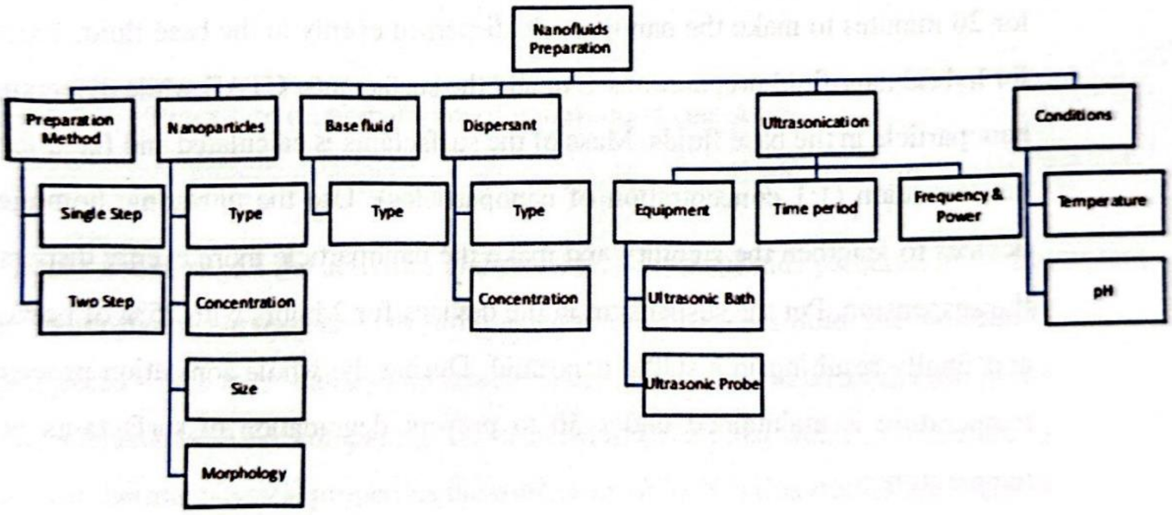

Fig. 5. Summaries on nanofluid preparation

After doing some more research, the most suitable methods to prepare nanofluid in this study is the two-step method. Nanoparticle use was Alumina, TiO_2 and graphene, which is the non-metallic nanoparticle, and because this method is low in production cost.

Activities for the preparation of the nanofluid in this study firstly was decided on the nanoparticles, the base fluid which used in this study were ethelyne glycol and water as the base fluid. Secondly was deciding the volume concentration or weight percentage and temperature range of the nanofluid, 0.1 - 0.9 %, 0.025 - 0.1 % and 30 - 60^{o}C respectively.

Hybrid nanofluid were prepared with four different ratios of nanoparticles; graphene (50 %) + TiD-(50 %) and ratio of the base fluid 32 : 48 (DW : EG). Next, calculation of the nanoparticle mass needed to prepare the nanofluid using correlation equation. The calculated mass was then applied using the mechanical stirrer for 20 mins to make the nanoparticle dispersed evenly in the base fluid. Extra step for hybrid nanofluid preparations was to add the surfactants, CTAB while dispersing the nanoparticle in the base fluids. Mass of the surfactants was calculated and fixed for each concentration (1:1 concentration of nanoparticles). The ultrasonic homogenizer devices was used to lengthen the stability and make the nanoparticle more evenly dispersed in the suspension. The suspension then was put in the device for 2 hours with 75 % of power rate and finally resulting in a stable nanofluid. During the whole sonification process, the temperature was maintained under 50°C to prevent degradation of surfactants at high temperature.

However to ensure the stability of the nanofluid, the observation of sedimentation of nanoparticles in the nanofluid was done with the time interval in one week or more. Stability is important to avoid sedimentation when testing the nanofluid in the radiator which can cause the tube clogging.

The Figure 6 shows the activities and procedure of nanofluids preparation in this study. After the preparation and stability confirmation of the nanofluid, the nanofluids were then compared for being most stable to less stable in the factor of material used, base fluids and the surfactants. After comparing the suspensions, the most stable mixtures were chosen for thermal physical properties measurement. Devices (Figure 7) were used to measure the thermal conductivity of the nanofluid.

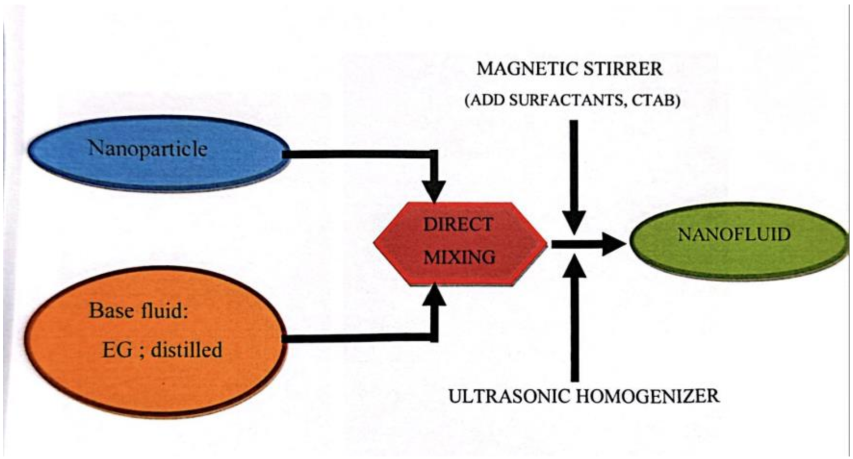

Fig. 6. Procedure on preparation of nanofluid in this study

3.2 Tools and Platforms

The Figure 8 below show the nanoparticle used to prepare single, hybrid nanofluids and type of surfactants used in hybrid nanofluids.

Fig. 7. KD2 Pro used to measure thermal conductivity value

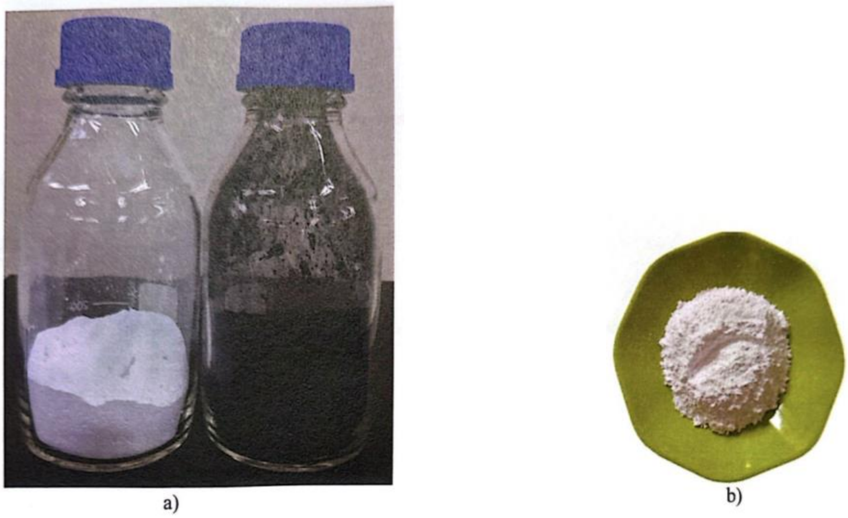

Fig. 8 (a) Graphene and TiO_2 nanoparticle powder **Fig. 8 (b)** Al_2O_3 nanoparticle powder

Figure 9 depicts the experimental setup to measure thermal conductivity of nanofluid.

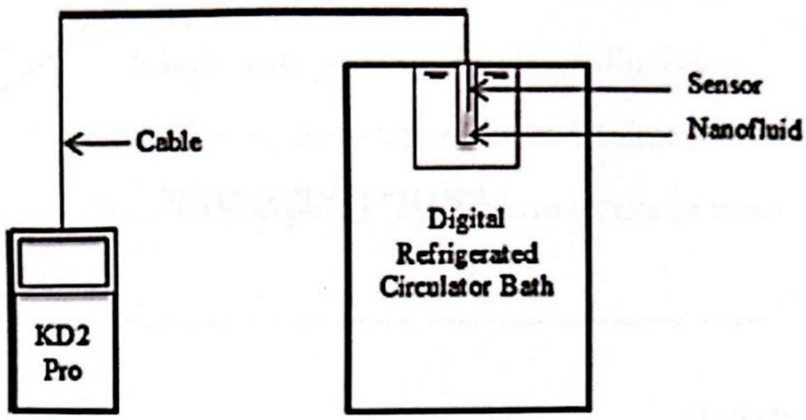

Fig. 9. Experimental setup to measure thermal conductivity of nanofluid

The two-step method is the most suitable method used for the single material and hybrid nanofluids. Time and power rate of the ultrasonic devices was wisely decided to prevent the degradation of the surfactants as a result of too long sonication and high temperatures.

4. Results and Discussion

Figure 10 shows the sedimentation time with the relative concentration of different types of nanofluids, 0.1 (wt %) for hybrid nanofluids and 0.1 % volume concentration for single material nanofluids. The sedimentation time was taken every five days after preparation for a month (30 days) or more. From the figure, it shows graphene with 0.1 (wt %) had the slowest sedimentation time, which meant it had the most stable nanofluids. Meanwhile, the sedimentation time for hybrid nanofluid graphene (70 %) + TiO_2 (30 %) + CTAB and graphene (30 % + TiO ≥ (70 %) + CAB were almost the same. Sedimentation for Al_2O_3 + EG rapidly went down to 0.5 on the 5th day and almost fully sediment on day 25 same for TiO + EG.

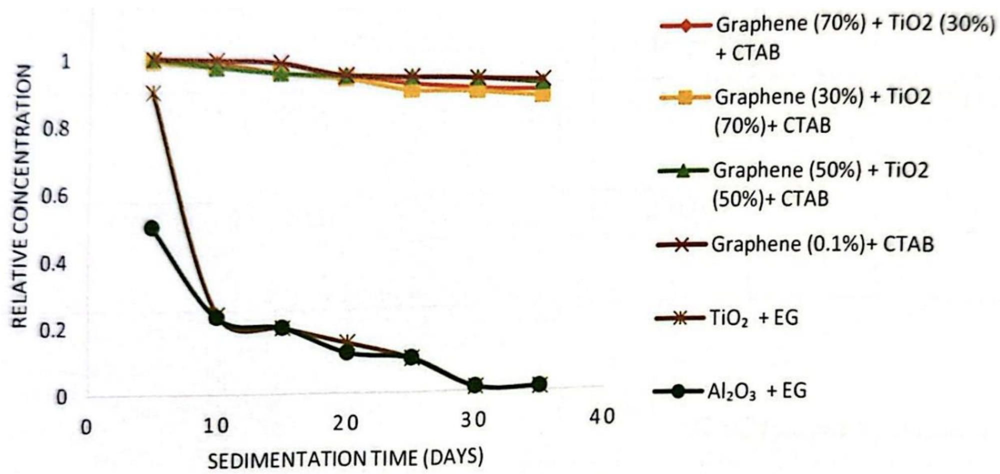

Fig. 10. Relative concentration of different nanofluids with sedimentation time (0.1 %)

In Figure 11 however, Graphene (50 %) + TiO_2 (50 %) + CAB sedimentation time was almost the same as graphene (0.025 %) + CTAB. Which meant it had almost the same stability as graphene (0.025 %) + CTA with 0.025 (wt %). Hybrid nanofluids with surfactants have the highest stability compared to the available material nanofluids. Single material nanofluids were almost fully sedimented at days

20 and become fully sediment at day 30 compared to hybrid nanofluids, it still sediment after days 40 but not fully as single nanofluids.

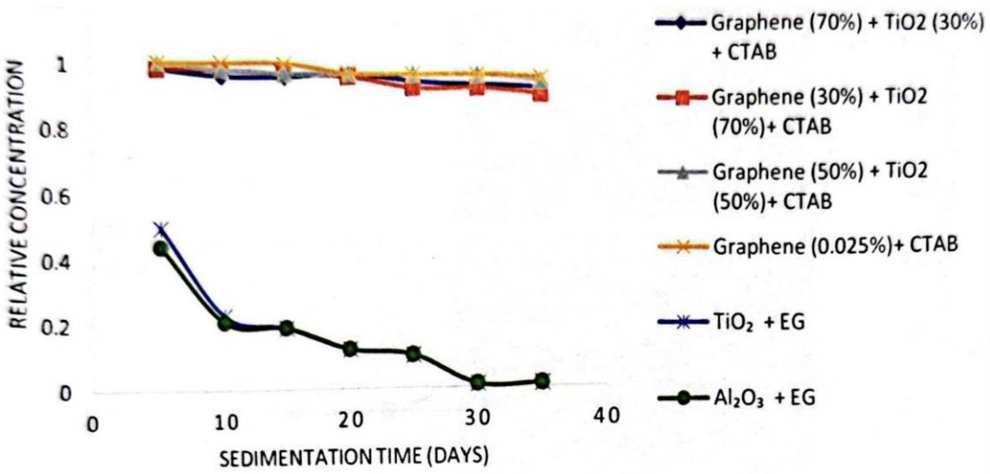

Fig. 11. Relative concentration of different nanofluids with sedimentation time (0.025 %)

Shown in Figure 12 is the sedimentation of single material nanofluids at 0.9 % volume concentration. The nanoparticle was fully sedimented at day 20.

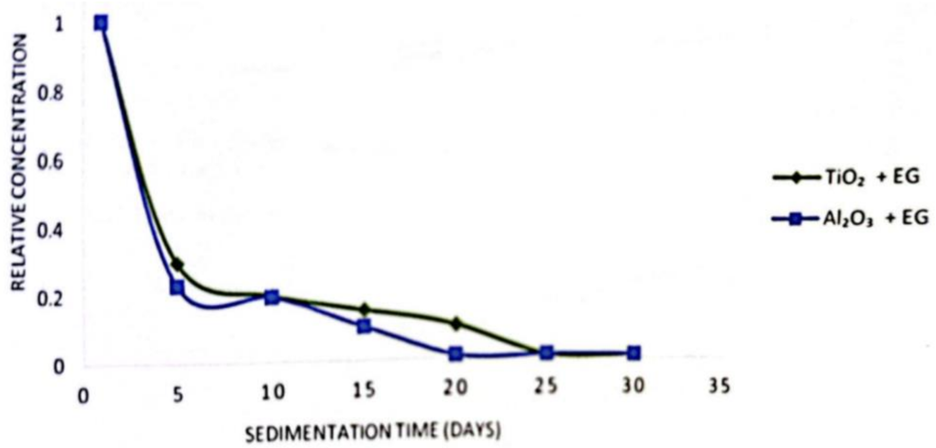

Fig. 12. Relative concentration of different nanofluids with sedimentation time (0.95)

High in concentration can cause the nanofluid to sediment faster. On the other hand, sonification time also affects the sedimentation time of nanofluids and the surfactants used to enhance the stability of nanofluids.

5. Conclusions

The result clearly showed single material nanofluid stability only persisted for half a month (15 days), and the hybrid nanofluid stayed stable for over a month (35 days). Single material nanofluid (AlO_3 and TiO_2 dispersed in EG) were compared with the hybrid nanofluid (Graphene (0.1 % and 0.025 %) + CTAB, Graphene : TiO_2 (70 % : 30 %) + CTAB, Graphene : TiO_2 (50 %: 50 %) + CTAB, Graphene: TiO_2, (30 % :70 %) + CTAB to get the result of the most stable nanofluid. Graphene (0.1 % and 0.025 %) + CTAB nanofluid sample was the most stable when referred to the stability table result.

This study focussed on one of the thermophysical properties of nanofluid, which is thermal conductivity (K). Graphene (0.1 %) nanofluid had the best result of thermal conductivity (W / m.K). The K value obtained was in the range of 0.39 - 0.6 W / m.K and above at each temperature. The K value was considered to be in the highest range for the sample. High in thermal conductivity may improve the automobile radiator as the thermal performance of nanofluid in high conductivity will be excellent.

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