STABILITY AND THERMAL CONDUCTIVITY OF GRAPHENE AND BARIUM TITANATE (IV) NANOFLUID WITH DIFFERENT VOLUME CONCENTRATIONS

By

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ENDORSEMENT

I, Noor Nazirulsyahmi bin Zulkifli hereby declare that I have checked and revised the whole draft of dissertation as required by my supervisor.

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DECLARATION

This thesis is the result of my own investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

(Signature of Student)

Date : 16 July 2021

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ABSTRACT

The emerging of nanofluid as great potential coolant to be implemented in various of applications due to its superior thermal properties has attracted many researchers to studies this technology. This experiment aims to evaluate the stability and thermophysical characteristic of the graphene and barium titanate (IV) nanoparticle in distilled water as nanofluid for electronic cooling application. Synthesis of both nanofluid was done through two-step method, where the mixture of nanoparticles will be stirred using magnetic stirrer for 15 minutes, followed by probe sonication for 40 minutes under 0.5 cycle and 50% amplitude. Based on visual observation, since after 1 day from the sonication process, graphene nanofluid shows sedimentation while barium titanate (IV) shows no sedimentation until 7 days where the height of white layer reduced for barium titanate (IV) with 0.3% vol concentration gradually occurs. Graphene and barium titanate (IV) nanofluid with 0.3% vol concentration shows the highest thermal conductivity enhancement of 34.9% and 39.16% respectively. While graphene with surfactant for both % vol concentration shows the same trend of thermal conductivity enhancement with the range of 1.49% up to 30.57%. The addition of surfactant assists in term of particle suspension in the fluid however SDBS surfactant is not suitable with barium titanate (IV) due to the diverse affect in thermal conductivity. The thermal conductivity increased as the nanoparticle concentration increases.

KESTABILAN DAN KONDUKSI TERMA BENDALIR NANO GRAPHENE DAN BARIUM TITANAT (IV) DENGAN KEPEKATAN ISIPADU BERBEZA

ABSTRAK

Kemunculan bendalir nano sebagai penyejuk berpotensi hebat untuk dilaksanakan di dalam pelbagai aplikasi disebabkan oleh sifat terma yang unggul telah menarik ramai penyelidik untuk mengkaji teknologi ini. Eksperimen ini bertujuan untuk menilai kestabilan dan sifat termofizik bagi nanopartikel graphene dan barium titanat (IV) di dalam air suling sebagai bendalir nano untuk aplikasi penyejukan elektronik. Sintesis bagi kedua-kedua bendalir dilakukan melalui kaedah dua langkah, dimana campuran nanopartikel akan dikacau menggunakan pengadun magnetic selama 15 minit, diikuti dengan sonikasi probe untuk 40 minit pada keadaan 0.5 kitaran dan 50% amplitud. Berdasarkan pemerhatian visual, sejak selepas 1 hari dari proses sonifikasi, bendalir nano graphene mula menunjukkan pemendapan sementara barium titanat (IV) tidak menunjukkan pemendapan sehingga hari 7 di mana ketinggian lapisan putih barium titanat (IV) dengan 0.3% isipadu kepekatan secara beransur-ansur berlaku. Bendalir nano graphene dan barium titanat (IV) dengan 0.3% isipadu kepekatan menunjukkan peningkatan konduksi terma sebanyak 34.9% dan 39.16% masing-masing. Sementara graphene dengan surfaktan bagi kedua-dua % isipadu kepekatan menunjukkan trend poeningkatan konduksi terma dengan julat sebanyak 1.49% sehingga 30.57%. Penambahan surfaktan membantu dalam penggantungan partikel di dalam bendalir namun surfaktan SDBS tidak sesuai dengan barium titanat (IV) kerana kesan sebaliknya dalam konduksi terma. Konduksi terma meningkat selagi kepekatan nanopartikel meningkat.

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LIST OF ABBREVIATIONS

DI	Deionized
TEM	Transmission Electron Microscope
PVD	Physical Vapor Deposition
VEROS	Vacuum Evaporation onto a Running Oil Substrate
EDL	Electrical Double Layer
HLB	Hydrophilic/lipophilic balance
SDBS	Sodium Dodecyl Benzene Sulphonate
SDS	Sodium Dodecyl Sulphate
CTAB	Cetyl Trimethyl Ammonium Bromide
CNT	Carbon Nanotube
MLC	Multi-Layered Capacitors

LIST OF NOMENCLATURE

f_v Particle volumetric fraction

V_{np} Volume of nanoparticle

V_{bf} Volume of base-fluid

ρ_{nf} Density of nanofluid

ρ_{np} Density of nanoparticle

ρ_{bf} Density of base-fluid

$\emptyset$ Volumetric fraction

m_n Mass of nanoparticle

m_f Mass of fluid

CHAPTER 1

INTRODUCTION

1.1 Overview

Researchers throughout the world has examine the viability of the nanofluids utilization in various equipment and phenomenon. As the nanofluid emerges as potential coolant to be implemented in various of engineering application, the characteristic of the nanofluid is still yet to be discovered in order to be effectively utilized in vast range of application as well as improve the energy effectiveness. Although many has conducted a research about nanofluid characteristic such as in term of the type of nanofluid, there is plenty more of criteria that need to be discovered to exploit the superior thermal properties. The characterization of determining the stability and correlation with the thermophysical properties of the nanofluid should be highlighted. Nevertheless, the stability enhancement method such as the addition of surfactant is another aspect to be determined for the utilization in many applications. Therefore, the characterization of different types of nanofluid in term of stability and thermal conductivity with various surfactant will be discussed as well as the objectives of the study in the later sections.

1.2 Background

Electronic devices use electric current to operate and nowadays this device has practically involved in ours daily life, from appliance to high-power computer. The First Law of Thermodynamic states that energy is always conserved, it cannot be created or destroyed. Fundamentally, energy can be converted from one form into another and in this process of energy transfer, some energy will dissipate as heat. This heat dissipation causes unavoidable heat buildup and a subsequent temperature rise at and around the electronic component (Kirui, 2013). Subsequently, the failure rate of electronic component increases exponentially with the increase in temperature and this has become liability to the component. In addition, demand of having a greater performance of the electronic chips in miniaturized size has led to the exponential increment of heat flux acting on the small chips. Since thermal management of the electronic devices has now become the critical aspect, some of the conventional active and passive cooling method are used to avoid the excessive levels of heat and reduce temperature.

Active methods such as forced ventilation using electric fans, liquid cooling through micro-channels and heat pipes in fan-less systems required power to work. While passive cooling methods can initiate the cooling without power and no mechanical moving parts are used. Some of the conventional cooling methods are radiation and free convection, forced air-cooling, forced liquid cooling (forced convection) and liquid evaporation, study by Scott and Allan in 1974 compared between this conventional cooling method implementation to the maximum temperature reduction of 80°C and the results are summarized in Figure 1.1.

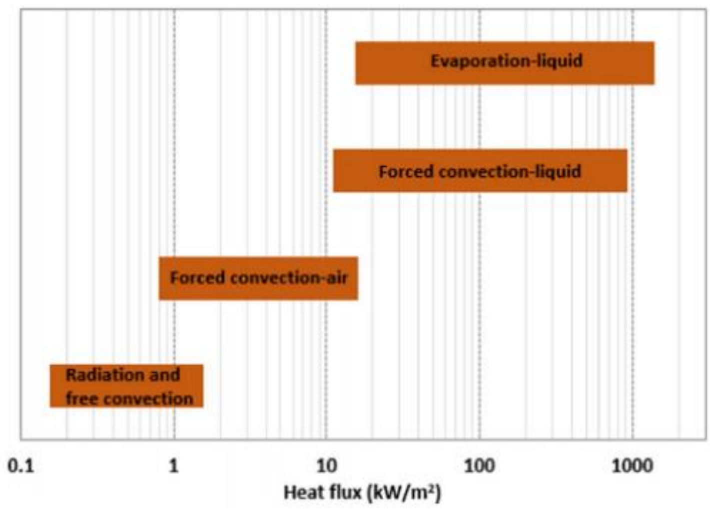

Figure 1. 1: Comparison of heat transfer effectiveness of conventional methods. (Scott and Allan, 1974)

Liquid evaporation cooling method is the best to be applied since the findings show that it has better heat flux whereas forced liquid cooling places second followed by forced convection by air and lastly, radiation and free convection. Due to safety and cost issues, the forced air cooling has been widely used by industries even though the heat transfer effectiveness capability is relatively low. A passive heat exchanger that transfers the heat generated by a chip to a lower temperature fluid medium known as heat sink (Lasance et al., 2005) is one of the forced air-cooling methods that widely been used. A study about the heat sink performance under three different heat fluxes 1250, 2500 and 5000 (W/m^2) at 26°C as ambient temperature (Ibrahim et al., 2018) has been conducted and the results are as shown in Figure 1.2.

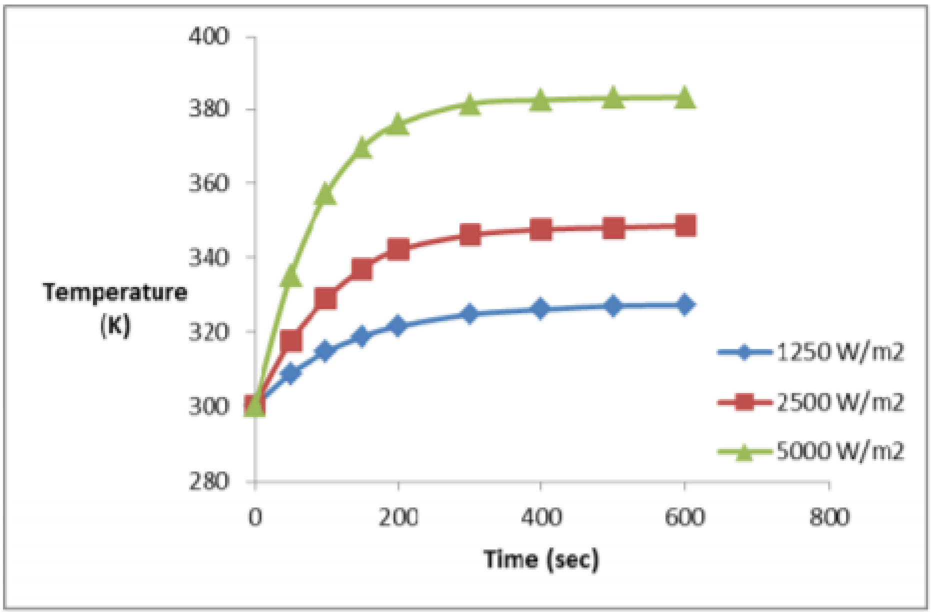

Figure 1. 2: Variation of temperature of heat sink walls with function of time under 1250, 2500 and 5000 (W/m2). (Ibrahim et al., 2018)

Based on Figure 1.2, clearly shown that as the heat flux increases, the steady state temperature also increases up to 322K, 348K and 383K for 1250, 2500 and 5000 (W/m^2), respectively. At 5000 W/m^2, the steady state temperature is almost reached the harmful maximum allowable temperature (393K), thus heat sink alone is not sufficient for the chip to operate safely.

Due to the ever-increasing heat loads that generated exceed the harmful allowable temperature, this will necessitate the use of liquid cooling. Studies by other researchers all resulted that liquid cooling is more efficient than air cooling method (Ali et al., 2017), (Chethana and Sadashive, 2020), (Wen Yang et al., 2020). The implications of nanofluid as working fluids in liquid cooling method is a very promising new generation in heat transfer. Many advantages are clearly highlighted by researchers with the implementation of this nanofluid although there is still some un-answered problem emerges. There are many variables that are difficult to control that hugely contribute in the thermal performance of nanofluids. Nanofluid can be classified into two main categories which is known as single material nanofluids and hybrid nanofluids. Single material nanofluids is where a single type of nanoparticles used to be suspended in the base fluid while hybrid is the combination of more than one type of nanoparticles suspended in the base fluid and this is more advanced categories of nanofluids. Nanoparticles can further be classified such as single element (Cu, Fe, and Ag), single element oxide (CuO, Cu_2O, Al_2O_3, and TiO_2), alloys (Cu-Zn, Fe-Ni, and Ag-Cu), multielement oxides ($CuZnFe_4O_4$, $NiFe_2O_4$, and $ZnFe_2O_4$), metal carbides (SiC, B_4C, and ZrC), metal nitrides (SiN, TiN, and AlN), and carbon materials (graphite, carbon nanotubes, and diamond) (Naser et al., 2018).

Pure metal material such as Au and Ag has been known having a high thermal conductivity and the usage of this material into the fluid for heat transfer application would be expected to achieve a greater performance this goes the same for the carbon material as well. Table 1.1 has summarized the result of selection of thermal conductivity measurement from several nanofluid studies.

Table 1. 1: A selection of thermal conductivity measurement from several nanofluid studies (Wisut Chamsa-ard et al., 2017)

Nanoparticle	Particle Size (nm)	Working Fluid	Fraction	Thermal Enhancement (%)
Metals				
Ag	<100	Water	0.3–0.9 vol %	30 at 50 °C
Ag	100–500	Ethylene Glycol	0.1–1.0 vol %	18
Cu	50–100	Water	0.1 vol %	24
Cu	<10	Ethylene Glycol	0.01–0.05 vol %	41
Fe	10	Ethylene Glycol	0.1–0.55 vol %	18
Metal Oxides				
Al_2O_3	9	Water	2–10 vol %	29
Al_2O_3	28	Water/Ethylene Glycol	3–8 vol %	41
Al_2O_3	650–1000	Transformer oil	0.5–4 vol %	20
CuO	100	Water	7.5 vol %	52
TiO_2	15	Water	0.5–5 vol %	30
SiO_2	12	Ethylene Glycol	1–4 vol %	23
Carbons				
Carbon Black	190	Water	4.4–7.7 vol %	10 at 35 °C
carbon/graphene oxide	Not specified	Ethylene Glycol	0–0.06 wt %	6.47 at 40 °C
SWCNT	Dia. 10–50 Len. 0.3–10 μm	Diesel Oil	0.25–1 vol %	10–46
MWCNT	25 nm × 50 μm	Oil	1 vol %	150
MWCNT	Dia. 10 Len. 5–15 μm	Gum Arabic & Water	0.14-0.24 vol %	10

From the result, we can observe that thermal enhancement percentage increases for all type of nanoparticles used however metal type nanoparticle as expected possesses greater value in term of thermal enhancement percentage than other types. However, the thermophysical property of the nanofluid itself is not just based on the type of nanoparticles used, Figure 1.3 highlighted the main parameter that impact in the effective thermal conductivity of any nanofluids.

Figure 1. 3: Parameters influencing nanofluids effective thermal conductivity (Naser Ali et al., 2018)

1.3 Problem Statement

In order to overcome the heat management issues that mostly faced by the industries especially in small chips and semi-conductor, nanofluid has showed a great potential for the past two decades in becoming the liquid coolant that can bring the balance in the thermal management due to the high effectiveness in various heat transfer applications. As mentioned before, the emergence of nanofluids as a new field of nanoscale heat transfer in liquids is related directly to miniaturization trends and nanotechnology. Therefore, in order to adapt with the development of the energy-efficient of heat transfer fluids, the thermal conductivity of the heat transfer fluids plays a vital role.

Despite showing great potential in heat transfer properties, numerous researchers had conduct experimental and numerical investigation in order to demonstrate the thermal performance of various nanofluids under the influence of various prominent factor. The variation in nanoparticle's size, shape and concentration tends to yield different value of thermal conductivity. The increment in volume fraction enhances the thermal conductivity to a greater extent. This was showed by the experimental study to demonstrate the dependence of thermal conductivity on size and phase content of TiO_2 nanoparticles (Mitra et al., 2020). However, the augmentation of nanoparticles concentration has led to increment in viscosity of nanofluids which can be a deleterious in term of pressure drop and pumping power. Attari et al., in 2017 has demonstrated the variation in viscosity of crude-oil based nanofluids having oxide nanoparticles due to the influence of temperature and nanoparticles concentration. The finding showed that there is a significant decline in nanofluid to base-fluid viscosity ratio with the enhancement in temperature, in addition, increase in nanoparticles concentration provided higher viscosity ratio. Thus, the optimal value of temperature concentration of nanoparticles is imperative to avoid higher viscosity. Further studies on the various impact of prominent factors such as nanoparticle size, temperature and concentration on viscosity and thermal conductivity was done and concluded that concentration of nanoparticles has positive correlation with viscosity and thermal conductivity of nanofluids unlike the particle size and shape (Yang et al., 2017).

Until now, nanofluid performance influenced under various factor is still being investigated in order to expand the development of nanofluids. Hence, this study will explore the characterization and performance of different type of nanofluids distinguished by the molar mass of nanoparticles, so that the result can be used to improve devices work efficiency and life-expectancy.

1.4 Research Objectives

This study will be focusing on the evaluation of performance for the nanofluids that is different in term of the molar mass in term of stability. After a brief introduction of problem statement, the objectives of the project must also be well defined. The project objective is to observed the characterization of metal and carbon type of nanoparticles dispersion into a base fluid. Objectives that are to be achieved in this project, include:

1. To characterize the DI base nanofluid stability and thermal conductivity for different volume percentage of graphene and barium titanate (IV).
2. To determine the effects of addition of different surfactant to the stability and thermal conductivity of the nanofluid.

1.5 Thesis Outline

This thesis is subdivided into five chapters and structured as stated below:

Chapter 1 discussed the emerging trend of miniaturization to electronic devices as well as the impact in the thermal management and control system of the electronic devices. This chapter also brought out readers about the difference conventional cooling methods that has been widely used and the potential coolant to be used to overcome the increment of heat flux in electronic devices. Also, the best method for the electronic cooling to be implemented has been suggested.

The related literature is reviewed in Chapter 2, to present what have been done by researchers so far in the efforts to developed and improved the thermophysical properties of coolants. The reviews are not just limited to the characteristic of the nanofluids but also on how the nanofluid can impacted in the heat performances improvement in electronic applications. To study the challenges and feasibility of nanofluid and in real-life scenarios, the interaction of the surfactant and stability of nanofluids are discussed. Last part of the chapter discussed some of the experimental results done by others for the past few years included the simulation on the model of flows of some nanofluid cooling.

Next, Chapter 3 discusses the methodology and techniques applied as well as the governing equation that is crucial in this project. It consists of the stable nanofluid preparation procedure, the characteristic of Graphene and Barium Titanate (IV) nanoparticles, and the setting of the experiment to fulfill the objectives of the project.

The experimental and simulation data as well as the discussion of the project will be covered in Chapter 4. The result is to be compared with various mathematical models that had been established by other researchers. The correlation between various manipulated variables is studied based on the results.

In the end, Chapter 5 will be the foundation to produce better cooling nanofluid in the future by presenting the significance of the study. The conclusion is to be drawn based upon the correlation parameters in the experiments. Some of the future research suggestions are made to further experiment so that the future researchers have the idea to improve and enhancing the stability and nanofluid characteristic.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review will be covering about the current conventional coolant that are generally known and their properties. Next, the emerging of a great potential future coolant which is nanofluid will be elaborate further. As the background of nanofluid has been discovered, the various method of synthesis of nanofluid will also be covered. Following then is the important concept on understanding the stability of nanofluid and various method to evaluate the stability of nanofluid. Addition of surfactant is also part of the literature review to illustrate a clearer image on how the stability of the nanofluid can be enhance by the method aforementioned. Lastly, the key mechanism of thermophysical properties and the application of nanofluid in electronic cooling based on previous researches and studies will be discussed.

2.2 Conventional Coolant

Many types of aqueous and non-aqueous coolants were introduced and utilized for removing heat from the electronic system, these coolants such as the water, air or oil are known as traditional coolant. An ideal coolant is said to have a high thermal capacity, low viscosity, low cost, and not bring any harm either chemically or technically to the cooling system. Air cooling system has the advantages of simple structure, lightweight, low cost and so on. However, due to the low thermal conductivity and low specific heat capacity of air, the cooling capacity of air is limited, the cooling performance is not as good, and the ability in reducing the maximum temperature and maintaining the temperature uniformity in a system are poor (Yuanwang et al., 2018). The effectiveness of traditional coolant however is depending on the type of coolant and heat transfer method. Liquid cooling or water is an efficient cooling method because of the high thermal conductivity and high specific heat capacity of liquid. Moreover, the liquid cooling system has a more compact structure which makes it take less volume and can be placed in a narrower space. (Liu et al., 2017). Due to these factors, liquid cooling is recognized as a preferable strategy and high practicability.

Table 2. 1: Comparison of thermal physical properties of different coolant. (Yuanwang et al., 2018)

Property	**Air**	**Mineral oil**	**Silicone oil**	**Water/Glycol**
Density (kg/m^3)	1.225	924.1	920	1069
Specific heat capacity ($J/(kg \cdot K)$)	1006	1900	1370	3323
Thermal conductivity ($W/(m \cdot K)$)	0.0242	0.13	0.15	0.3892
Kinematic viscosity (m^2/s)	1.46×10^{-5}	5.60×10^{-5}	–	2.58×10^{-6}

As shown in Table 2.1, water has higher specific heat capacity and thermal conductivity and lower viscosity coefficient compared to others coolant, which ensures that water can transfer heat more efficiently while consuming less pumping power. Thus, water is often used as the working coolant of liquid cooling and play an important role in the cooling system of various applications especially in electronic cooling (Bayomi et al., 2016). Despite having a good heat transfer capability, due to the rapid development in modern technology, current electronic systems generate a huge amount of heat which deteriorates the performance the devices and decreases their reliability (Saidur et al., 2011). Which means, mostly various electronic-cooling systems used conventional coolant are no longer able to cope with the requirement of high heat flux dissipation

(Wang & Peng, 1994). One of the promising coolants that expected for thermal management system of next generation high heat dissipation electronic system is nanofluid.

2.3 Nanofluid

Nanoparticles are tiny materials having size ranges from 1 to 100 nm. They can be classified into different classes based on their properties, shapes or sizes. These nanoparticles exhibit properties different from those of conventional solids. In contrast with micron-sized particles, nanophase powders have much larger relative surface areas and a great potential for heat transfer enhancement (Xuan & Li, 2000). Figure 2.1 shows the image of Zinc Nanoparticles at different scale under Transmission Electron Microscope (TEM).

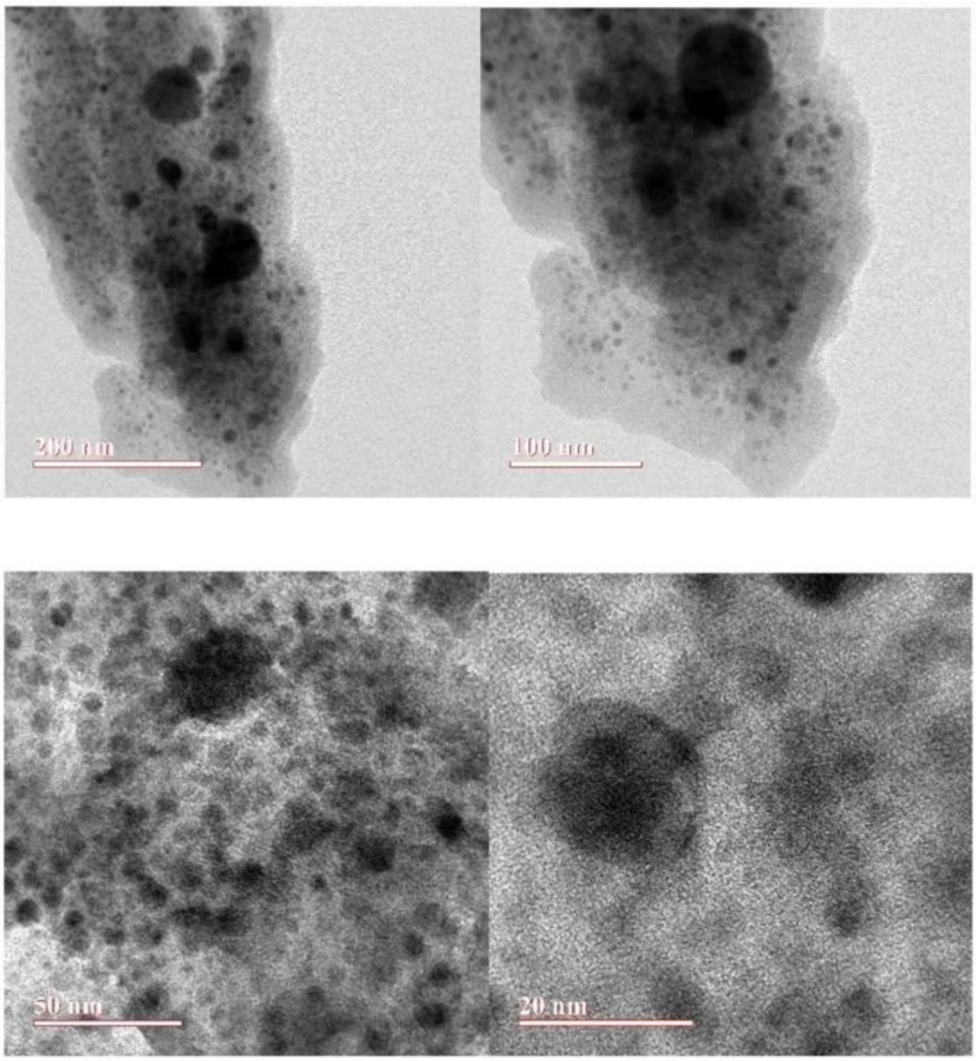

Figure 2. 1: TEM images of Zinc Nanoparticles at different scale (Tailor et al., 2019)

During the past decades of researches, various types of nanoparticles have been discovered and produced. Nanoparticles are then divided into a few classifications based on physical and chemical characteristics, which are carbon-based nanoparticles, metal nanoparticles, ceramic nanoparticles, semiconductor nanoparticles, polymeric nanoparticles and lipid-based nanoparticles. Generally, out of those aforementioned classification, metal even in solid form will have thermal conductivities higher than others (Khan et al., 2017). This can be proven by comparing the thermal conductivity of copper at room temperature which is about 700 times greater than that of water and about 3000 times greater than that of engine oil. By all means, metal nanoparticle is the classification that will be suitable for the electronic cooling purposes due to its relatively higher thermal properties aspect compared to others. Maxwell (1891) via his theoretical work proposed the idea of dispersing solids in fluid, this achieved by Choi in 1995 that has developed a promising effective classification of heat transfer fluids that rely on the suspending nanoscale particles of metallic origin with an average particle size of less than 100nm into conventional heat transfer fluids and namely "nanofluids" (Choi et al., 1995). The difference in thermal conductivity of substances in solid form cohabits between liquids, due to metallic liquids have higher thermal conductivity that non-metallic. Thus, the thermal conductivity is expected to be enhanced by suspending the metallic particles in fluid. (Ali et al., 2018). Nanofluids is a recent advance in nanotechnology development of a new category of liquids where the base fluid such as water and coolant are fused with a nanosized solid particle with considerably amount of volume fraction and then remained suspended in the base fluid, with thermal conductivities, orders of magnitude higher than base liquids, and with size significantly smaller than 100nm (Huminic, 2012). Common nanoparticles that have been used to prepare nanofluids are metallic particles (Cu, Al, Fe, Au, and Ag), nonmetal particles

(Al_2O_3, CuO, Fe_3O_4, TiO_2, and SiC), carbon nanotube and nanodroplet. The base fluids commonly used are water, oil, acetone, decene and ethylene glycol. Table 2.2 show the thermal conductivity additives and base fluid used; Table 2.3 represented the nanofluids systems produced.

Table 2. 2: Thermal conductivities of additives and base fluid used in nanofluids (Li et al., 2009)

Material		**Thermal conductivity (W/Mk)**
Metallic solids	Cu	401
	Al	237
	Ag	428
	Au	318
	Fe	83.5
Nonmetallic solids	Al_2O_3	40
	CuO	76.5
	Si	148
	SiC	270
	CNTs	~3000(MWCNTs) ~ 6000(SWCNTs)
	BNNTs	260 ~ 600
Base fluids	H_2O	0.613
	Ethylene glycol (EG)	0.253
	Engine oil (EO)	0.145

Table 2. 3: Nanofluids systems developed (Li et al., 2009)

System	Synthesis process	Particle loading (vol%)	Particle size (nm)	Increase in thermal conductivity (%)
Cu/EG	Single-step	0.3	10	40
Cu/H_2O	Single-step	0.1	75 ~ 100	23.8
Cu/H_2O	Two-step	7.5	100	78
Fe/EG	Single-step	0.55	10	18
Ag/toluene	Two-step	0.001	60 ~ 80	16.5 (60 °C)
Au/toluene	Two-step	0.00026	10 ~ 20	21 (60 °C)
Au/ethanol	Two-step	0.6	4	1.3 ± 0.8
Fe_3O_4/H_2O	Single-step	4	10	38
TiO_2/H_2O	Two-step	5	15	30–33
Al_2O_3/H_2O	Two-step	5	20	20
Al_2O_3/EG	Two-step	0.05	60	29
CuO/H_2O	Two-step	5	33	11.5
SiC/H_2O	Two-step	4.2	25	15.9
NCTs/engine oil	Two-step	2.0	20 ~ 50 nm	30

2.4 Preparation of Nanofluid

The main scope to utilize the nanoparticle to improve the thermal conductivities of fluids is the preparation of the nanofluids itself. The preparation method used will determined the uniformity of the particles dispersion and it can significantly affect on the thermophysical properties of the nanofluids. Nanofluids requires a special condition to be present in the suspension such as homogeneity, physical and chemical stability, durability and dispersibility. For instance, two similar nanofluids are to be produced with two different methods, their thermophysical properties and tendency to agglomeration are most likely to vary from each other. Mainly, researchers used two techniques to fabricate nanofluids which is the single-step (one-step) method and the other is a two-step method. The single-step approaches are a process which nanoparticles are directly prepared by physical vapor deposition (PVD) technique or chemical liquid method, it is a process where the preparation of nanoparticles and synthesis of nanofluids are combine together as shown in Figure 2.2.

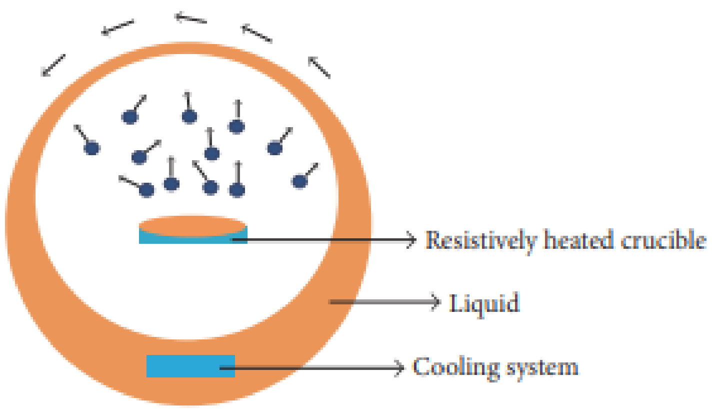

Figure 2. 2: Preparation of nanofluid using one-step vapor deposition method (Kong et al., 2017)

There are some other differences in this procedure, such as direct evaporation one-step approach named the Vacuum Evaporation onto a Running Oil Substrate (VEROS) method where it depends on solidifying nanoparticles that are initially in gaseous phase inside the base fluid itself (Akoh et al., 1978). This method is expected to produce nanoparticles however it is extremely difficult to gained a dry form of nanoparticles from the produced fluid mixture. A modified VEROS process is proposed by Wagener in 1997, where a high-pressure magnetron sputtering to synthesis dispersion containing Fe and Ag nanoparticles. Eastman and Choi (2001) also used one-step physical method in which Cu vapor was directly condensed into nanoparticles by contact with a flowing low vapor pressure liquid (ethylene glycol). The first chemical reduction method was developed to synthesized nanofluids containing Cu nanoparticles in water by Liu (2006). There is various procedure of one-step method with all aims to minimize the agglomeration of nanoparticles in the base fluid. But a disadvantage of this method is the presence of contaminations that are difficult to dispose of and only low vapor pressure fluids are compatible with the process (Chamsa-ard et al., 2017).

Another approach for preparing the nanofluids is called as the two-step method. Initially, the nanoparticles, nanofibers or nanotubes used in this method will be produced as a dry powder by various techniques available commercially followed by the nanosized powder is then dispersed into a fluid in a second processing step. Usually, equipment employed for dispersing the nanoparticles in the base fluid is magnetic stirrers, ultrasonic bath, high-shear mixers, homogenizers and bead mills. Instead of going with one-step method, two-step method is favorable to be used in fabricating the nanofluid due to the lower processing cost and availability of nanoparticles supplied by several companies commercially. On the other hand, the disadvantages of this method are the agglomeration of nanoparticles may take place both steps, especially in the process of drying, storage, and transportation of nanoparticles. The agglomeration result in decreasing the thermal conductivity as well as the settlement and clogging of microchannels. The stabilization of the suspension prepared is an important problem needs to be solved. Despite the flaws, two-step method is still the most popular method used to produce nanofluids and can be used to produced almost any kind of nanofluids (Sun et al., 2017). Fe nanofluids are prepared by dispersing Fe nanocrystalline powder in ethylene glycol through two-step procedure. The Fe nanoparticles were synthesized by a chemical vapor condensation process and in order to avoid the congregating in nanofluids, an ultrasonic cell disrupter generating ultrasonic pulses of 700 W at 20 kHz were used (Hong, 2006). Cu/H_2O, Cu/Oil nanofluids are prepared by two-step method. Surfactant and ultrasonic agitation were employed in order to avoid nanoparticle aggregation (Xuan, 2000). Some researchers implied intensive ultrasonication and magnetic force agitation to avoid nanoparticle aggregation (Xie, 2002). Others claimed that nanofluids containing oxide nanoparticles are more compatible for two-steps method, while for metallic origin it will be less effective (Eastman et al., 2001). Figure 2.3 illustrates the procedure of the two-steps nanofluid preparation.

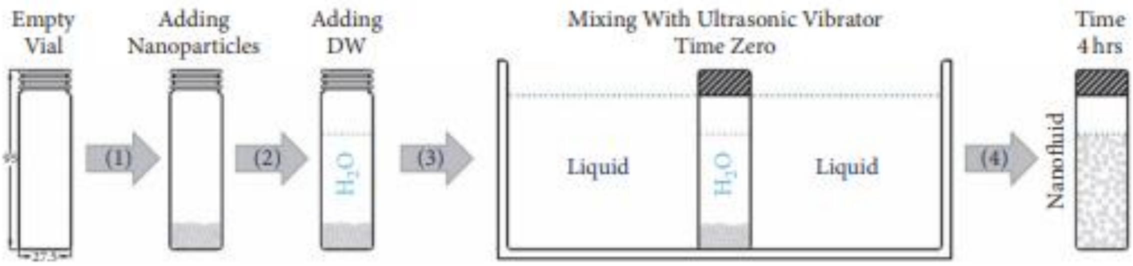

Figure 2. 3: Procedure of the two-step nanofluids preparation (Ali et al., 2018)

2.5 Stability of Nanofluids

Generally, the main challenges in commercializing nanofluid are because of their poor stability. The existence of Van der Waals attractive forces on the particle surfaces triggered the agglomeration of particles which separates them from the base-fluid and form sedimentation that will be settle at the bottom due to the gravitational force (Ali et al., 2018). Another type of forces known as electrical double layer repulsive forces that tends to separate the particles from each other through steric and electrostatic repulsion mechanism. In order to produce a stable nanofluid, the electrical double layer repulsive forces must be able to overcome the Van der Waals forces. To achieve the stability of a nanofluid, various method either in context of physical or chemical treatment has been conducted. For instances, the addition of surfactant, ultrasonication, controlling the pH or the surface modification techniques. It is certain impossible for the nanoparticle to directly dispersed into the fluid such as water and ethylene glycol due to the hydrophobic characteristic of the nanoparticles itself unless by the aid of the chemical and physical treatment to produce a stable nanofluid. The importance to produce a stable nanofluid is to ensure there is no clogging, aggregation and sedimentation happen that will cause declining of suspension characteristics like thermal conductivity, viscosity and increasing specific heat (Ghadimi et al., 2011). In this study, the suitable method to enhance the stability is by addition of surfactant into the nanofluid.

Addition of surfactant is widely been used because of the simplicity and not expensive chemical method, which prevents the agglomeration of nanoparticle within the fluid. The stability of the nanofluid then can be evaluated by various method that were discussed by different researchers. The suitable stability evaluation method to be implemented in this study are the sedimentation photograph capturing method and the zeta potential analysis.

2.5.1 Sedimentation Photograph Capturing Method

It appears that sedimentation method is the elementary method for the evaluation of the nanofluids dispersion stability. A prepared nanofluids will be filled in a transparent glass vial, then followed by the observation of sediments at equal interval of times. The stability of the nanofluids are indicated by the weight or the volume of the sediment and it is considered to be stable if the concentration of the supernatant particles remains constant with time (Mukherjee, 2013), which means no sedimentation occurs.

Figure 2.4 displays the measurement methods were used by Abdullah et al. (2018) in order to analyze the stability of alumina nanoparticle in ethanol-water mixture with and without mixture. The studies shows that the sedimentation from the photographic techniques have a great correlation with other characterization method such as zeta potential analysis.

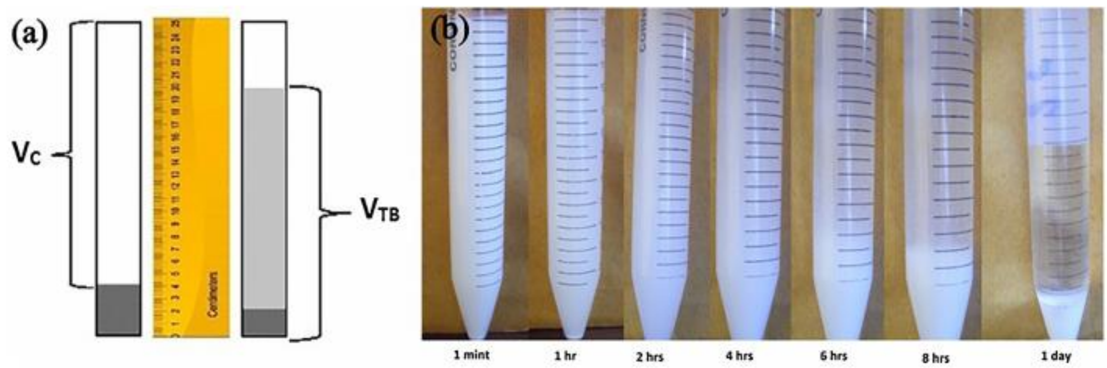

Figure 2. 4: (a) shows the illustration of sedimentation measurement method. (b) shows the actual sedimentation of dispersion at different intervals of time (Abdullah et al., 2018)

Another studies on stability of the nanofluid by using photograph capturing method were done by Wei & Wang (2010) to observe the stability of nanofluid based on the effect of reactant concentration, flow rate and additive. Based on Figure 2.5, the result indicates that all the nanofluid are very stable within 24 hours standings. However, after 48 hours, only nanofluid of molar concentration 0.02M and flow rate of 30 μL/min remains no separation compare to others.

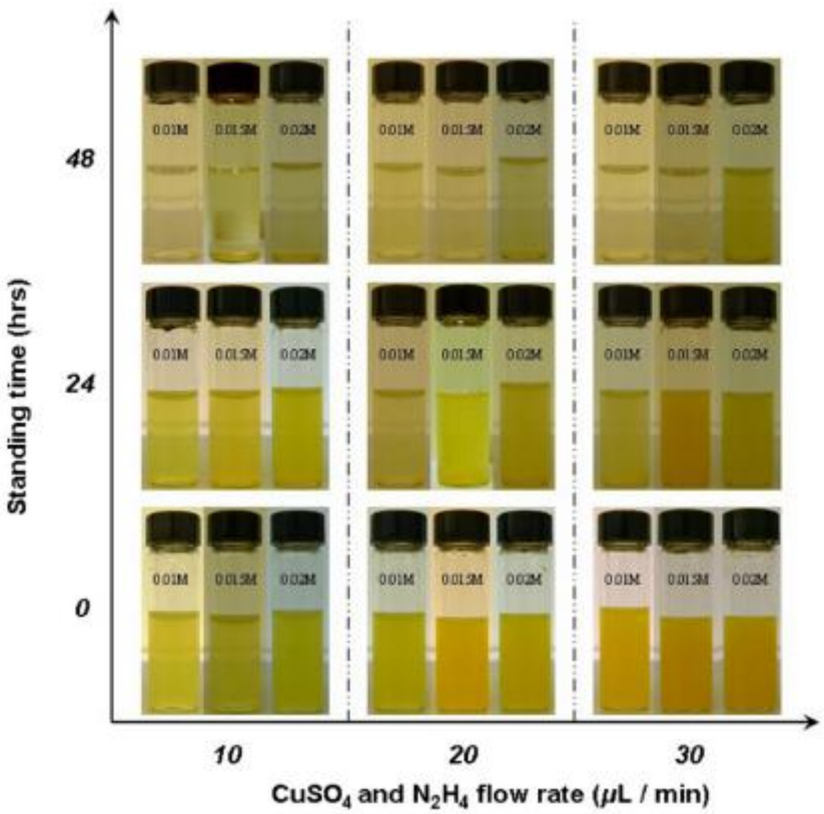

Figure 2. 5: Visual observation of nanofluid with different value of molar concentration of N_2H_4 solutions (Wei & Wang, 2010)