EXPERIMENTAL ANALYSIS OF STABILITY AND THERMAL CONDUCTIVITY FOR SILICA NANOFLUID IN WATER BLOCK HEAT SINK

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UNIVERSITI SAINS MALAYSIA

2019

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by

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Thesis submitted in fulfillment of the requirements for the

Bachelor Degree of Engineering (Honours)

(Aerospace Engineering)

June 2019

ENDORSEMENT

I, Rahmah binti Zulkeflee hereby declare that I have checked and revised the whole draft of dissertation as required by my supervisor.

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Date: 21 June 2019

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DECLARATION

I, Rahmah binti Zulkeflee hereby declare that all corrections and comments made by the supervisor and examiner have been taken consideration and rectified accordingly.

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ACKNOWLEDGEMENT

First and foremost, my most profound gratitude to Allah SWT for giving me the life and the opportunity to write this report. He gave me the power to believe in myself, and without His guidance, it will be a hard time for me to complete this report and may not finish within time.

I offer my sincere thankfulness to Ir. Dr. Hussin bin Mamat as my supervisor for his sustained enthusiasm and efforts in helping me to understand the fundamental knowledge in nanofluid as well as in life. Through his broad knowledge and experience, he has brought great values to me. He has the willingness in motivating me as well as sacrificing his time to explain any uncertainties and giving constructive comments.

Finally, yet importantly, I am eternally grateful to my beloved family, lecturers and friends for their unconditional love, encouragement, from both physical and emotional, and respects toward my decision in choosing aerospace engineering as my field of study. Although, they know the difficulties in the field in Malaysia, yet they are selfless and continue to support me.

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ABSTRACT

Thermal performance has become one of the main issues in electronic industries in line with prevailing development. Conventional working fluid often used by electronic devices has some shortcomings on the efficiency of transferring heat for cooling purposes. Hence, nanofluid is used as replacement is a promising alternative as it will be able to help improvising and more competent than subsist working fluid. In this experiment silica-water based nanofluid with Gum Arabic as surfactant is used. The main purpose of this study is to investigate the effect of different volume concentration of nanoparticles in working fluid of cooling water block on thermophysical properties and stability. Various volume concentration of SiO_2 nanoparticles (0.1, 0.3, 0.5) % is used through two step method for dispersion process and nanofluid was dispersed using sonication process for 20 minutes. Temperature distribution on heat sink water block with range of flow rates (0.05 to 0.1) m^3/hr and heating power of (20-60) W will be used to determine the efficiency of nanofluid as heat transfer fluids. The effect of different volume concentrations on base temperature of heat sink was found to be decreased up to 7.7%, increment of convective HTC by 4.3% and highest thermal reduction of 26.6% for volume concentrations of 0.3% SiO_2 compared to distilled water as conventional fluid. Silica nanofluid shows most stable in GA with ratio of 1:5 surfactant and silica nanoparticles to the extends of 30 days without sedimentation for 0.1% volume concentration. Therefore, silica nanofluid possessed better thermophysical properties than conventional fluid (distilled water) and had the ability to work as thermal fluid in heat transfer system.

KAJIAN ANALISIS KESTABILAN DAN SIFAT TERMOFILIK UNTUK NANOFLUID SILICA DI DALAM SIRIP PENYEJUK BLOK AIR

ABSTRAK

Prestasi terma telah menjadi salah satu isu utama dalam industri elektronik, dan ini selaras dengan perkembangan semasa. Cecair kerja konvensional yang sering digunakan oleh alat elektronik mempunyai kekurangan kecekapan untuk memindahkan haba bagi tujuan penyejukan. Oleh itu, nanofluid digunakan sebagai alternatif kerana ia lebih cekap dan dapat membantu dalam penambahbaikan pemindahan haba berbanding cecair yang sedia ada. Kajian ini mengunakan silica nanofluid bersama Arabic gum sebagai surfactant. Tujuan utama penyelidikan ini adalah bagi menyiasat kesan dan perbezaan ketika mengunakan partikel nano yang berbeza kepekatan didalam cecair kerja ke atas sifat termofilik dan kestabilan. Pelbagai kepekatan bagi partikel nano SiO_2 (0.1, 0.3, 0.5) % digunakan untuk proses penyebaran. Cecair nanofluid dibiarkan menyerap mengunakan proses sonikasi selama 20 minit. Pengedaran suhu pada sirip peyejuk blok air pada kadar (0.05 to 0.1) m^3/hr dan kuasa pemanasan sebanyak (20-60) watt digunakan untuk menentukan kecekapan nanofluid sebagai pengalir haba cecair. Kesan terhadap kepekatan yang berbeza menunjukan penurunan sehingga 7.7%, peningkatan HTC sebanyak 4.3% dan penurunan haba paling tinggi sebanyak 26.6% bagi kepekatan 0.3% SiO_2 jika dibandingkan dengan air suling sebagai cecair kerja. Silica nanofluid menunjukkan kestabilan terbaik di dalam GA dengan nisbah 1:5 surfactant dan partikel nano silica sehingga 30 hari tanpa pemendapan untuk 0.1% kepekatan isipadu. Oleh itu, silica nanofluid mempunyai konduktiviti thermal yang tinggi berbanding cecair konvensional dan mempunyai kemampuan untuk bertindak sebagai cecair terma didalam pasaran bahan pemindahan haba.

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LIST OF ABBREVIATIONS

SDBS	Sodium Dodecyl Benzene Sulfonate
SDS	Sodium Dodecyl Sulfate
CTAB	Cetyl Trimethyl Ammonium Bromide
SH	Sodium Hexametaphosphate
PEG	Polyethylene Glycol
WO_3	Tungsten (III) Oxide
$Mg\ (OH)_2$	Magnesium Hydroxide
DI	De-Ionized
Conc.	Concentration
GA	Gum Arabic
Vol.	Volume
Nu	Nusselt number
Re	Reynolds number
HTC	Heat transfer coefficient
SiO_2	Silica/Silicone dioxide
TiO_2	Titania/Titanium dioxide

LIST OF SYMBOLS

A_b	Base area of heat sink (m^2)
A_c	Channel area of heat sin (m^2)
A_{sf}	Surface area (m^2)
D_h	Hydraulic diameter of fluid flow (m)
ε_h	Heat transfer effectiveness
h	Heat transfer coefficient ($W/m^2.K$)
h_{bf}	Heat transfer coefficient of base fluid($W/m^2.K$)
h_{nf}	Heat transfer coefficient of nanofluid($W/m^2.K$)
H_b	Height of base (m)
H_{ch}	Height of channel (m)
k_{hs}	Thermal conductivity of heat sink (W/m.K)
k_{nf}	Thermal conductivity of nanofluid (W/m.K)
L	Length (m)
$\dot{m}$	Mass flow rate (kg/s)
m_{bf}	Mass of base fluid (kg)
m_{np}	Mass of nanoparticles (kg)
n	Number of grooves in heat sink
η_{fin}	Fin efficiency (%)
$\emptyset$	Volume concentration (%)
ρ_{bf}	Density of base fluid (kg/m^3)
ρ_{nf}	Density of nanofluid (kg/m^3)
ρ_{np}	Density of nanoparticles (kg/m^3)

$\dot{Q}$	Total heat dissipation from heater (W)
R_{th}	Thermal resistance of nanofluid (K/W)
T_{avg}	Average temperature of heater contacts with base of heat sink (°C)
T_b	Base temperature of heat sink (°C)
T_{in}	Inlet temperature of heat sink (°C)
T_{mean}	Mean temperature of nanofluid (K)
T_{out}	Outlet temperature of heat sink (°C)
u_m	Mean fluid velocity (m/s)
μ	Dynamic viscosity of base fluid (Pa.s)
μ_{nf}	Dynamic viscosity of nanofluid (Pa.s)
$\dot{V}$	Volume flow rate (m^3/hr)
W_{ch}	Channel width of heat sink (m)
W_{fin}	Fin width of heat sink (m)

CHAPTER ONE

INTRODUCTION

1.0 Research Background

Day by day, heat transfer in industry has become more intense and demand worldwide as it become one of the most crucial tasks that can enhance the efficiency of heat transfer devices. Fluid with the ability to transmit abundant amount of heat either into the system or remove by the system with slight amount of temperature difference is known as heat transfer fluid. A wide scope of applications commercially use fluid regarding temperature oriented in order to have a better cooling or heating process in a system, for instance ventilation, air-conditioning, electronics, energy harvesting, transportation, metallurgy operations and pharmaceuticals usually ranging from -80°C to 340°C. Amongst the fluid used as heat transfer medium are water, steam, helium, minerals oil, ethylene glycol, silicones, molten salt and all of them have different properties prior to correlate with specific parameters.

Viscosity, density and specific heat are the major characteristic that need to be suitably possessed by heat transfer fluid regarding the process as it will affect the performance of a system. Thus, recent studies have integrated heat transfer area by introducing the application of nanofluid to anticipate early on failure and boost dependability. The deficiency conventional heat transfer fluid act as the main drawback to provoke researches in finding improvements in thermal performance. Thus, by dispersing millimeter, micrometer sized particles at the early stage leaded to slight enhancement of thermal conductivity despite clogging and uncertain stability of working fluids in mini or macro system and sedimentation due to weight of solid particles. Previous studies had been a major stepping stone in solving limitations faced by conventional working fluid by knowing dispersion of metals or metal oxides have higher potential in heat transfer industry. Thus, more experiments and elaborations had been made which lead to present researches whereas the size of solid particles influence the properties of working fluid chemically. The evolution of solid particles lead to nanometric size particles ($\leq$100nm) known as nanoparticles have the ability to significantly affect thermal performance of a base fluid (Ding, 2005).

Nanofluids are categorized based on types of chemically stable nanoparticles suspended in the base fluid such as metal, carbon based, ceramics, semiconductor, polymeric and lipid based. Besides, nanoparticle is not a single unit, it is made up of three layers, surface, shell and core. The surface layer consists of variety of other small molecules and ions, whereas the shell layer has different chemical aspect compared to the core layer that usually refer to the nanoparticles itself (Khan, 2017).

Although nanofluid has efficient thermal properties, factors such as Brownian motion, thermophoresis, nanoparticles clustering and liquid layering on the nanoparticles-liquid interface need to be highlighted as they are the main reasons nanofluid has such ability (Gupta, 2018). In addition, specific rheological properties of nanofluid majorly influenced by type of base fluid, size and shape of particles, particles concentration, temperature and shearing time (Abbasi, 2015). Previous studies showed numerous combinations of nanoparticles and base fluids to establish the finest nanofluid as more benefits and advantages can be obtain which will lead to optimization and further development.

Terms two are better than one can be applied in this situation whereas mono nanofluid which contain single type of nanoparticle submerge in base fluid has inadequacy either in rheological or thermal properties as each material has mandatory characteristics specified to certain purposes. Thus, to overcome the shortcomings, recent studies have led to the innovation of nanofluid, hybrid nanofluid. Hybrid nanofluid consist of two dissimilar nanoparticles disperse in base fluid and yield new physical and chemical bond due to synergistic effect. The effect induces upgrade in thermophysical, hydrodynamic, mechanical resistance, physical strength, chemical stability and heat transfer properties that single type of material unable to acquire (Ranga, 2017). Despite the fact hybrid nanofluid is proposed to administer more desirable thermal conductivity, lack of compatibility between nanoparticles may lead to inadmissible result (Azwadi, 2016).

The main material used in the experiment is silica or silicon dioxide. Carbon group or group 14 in periodic table of element consist of carbon, silicon, germanium, tin and lead. Silicon is an intermediate between metal and non-metal or known as metalloids basic to all electronic devices. Semiconductor is developed due to electron numbers produce by the combination of silicon and oxygen. Besides silicon, germanium also has semiconductor properties and had been used before, but the differences are, silicon is widely used as semiconductors because it can be operated at high temperature and significantly cheaper compared to germanium. Silica also known for its good rheological property enhancement in base fluid. Thus, to exhibit a compatible hybrid nanofluid, addition of nanoparticles with high thermal conductivity will be best for desired properties (Amini, 2018).

Other than silica, carbon-based nanoparticles was widely used in heat transfer industry such as MWCNT. It is a carbon allotrope made from rolled-up graphene sheets with exceptional electronic and has thermal conductivity of 1500W/m K, high physical strength and chemically stable. Unfortunately, high van der Waals interaction between nanotubes result by large surface area of CNT make the material become hydrophilic. The interaction will make synthesis process harder due to aggregation and reduces the optimum properties of CNT (Sidik, 2017). Thus, an addition of surfactant will help in dispersibility and stability of nanofluid without disrupting the internal electronic structure as it will decrease the interfacial surface tension created by van der Waals (Bystrzejewski, 2010)

In this experiment, usage of silica SiO_2, and water as base fluid are tested to investigate the differential occurrence in thermal conductivity between conventional working fluid and nanofluid as compatibility effect of nanoparticles in nanofluid need to be carefully handled.

1.1 Problem Statement

Industries and field of study related to heat transfer seek ameliorations to enhance and widen the purpose and application of working fluid. In electronic industry, water block or equivalently heat sink is not an extraneous component related to heat management in one complete device. In water block, vaporization cause the heat from high temperature components permeate by flowing working fluid in the water block then go through radiator to cool down and flow back into reservoir before it repeats the process all over again. Thus, working fluid especially in cooling water block used by computer components need to have high specific heat capacity and thermal conductivity in order to dissipate heat faster and more efficient.

However, the current conventional working fluid has low specific heat capacity and thermal conductivity such as water 4.1855 kJ/(kg·K) and 0.608 W/(m·K), air 1.00 kJ/(kg·K) and 24.35 mW/(m·K) respectively. These types of thermal fluid have some shortcomings on the efficiency of transferring heat for cooling purposes within short period of time. For the time being, the industries use the same medium because study had shown there is no standard procedure to validate variety of working fluid.

Decisively, nanofluid is one of the alternative as it is more competent to improve the subsist working fluid by experimentally analyze the enhancement of thermal conductivity, using nanofluid as heat transfer working fluid in cooling water block. The fusion of conventional working fluid with materials with higher specific heat capacity will result in better heat transfer and thermal conductivity.

1.2 Research Objectives

The purpose of this study was to find out heat transfer of hybrid nanofluid. The specific objectives of the research were,

i. To investigate the effect of different volume concentration of silica nanoparticles in working fluid of cooling water block on thermal conductivity and heat transfer.

ii. To investigate the stability of silica nanofluid in various types of surfactant and ratio of nanoparticles and surfactant.

1.3 Thesis Outline

This thesis is separated into five chapters that includes an introduction, literature review, methodology, results and discussion, and conclusion. Chapter 1 describes the general overview of the study done in this thesis. It explains nanofluid and hybrid nanofluid as one of heat transfer fluid. In addition, a general introduction of material selection of nanoparticles also given.

Chapter 2 presents the previous studies in nanofluid and hybrid nanofluid. This gives a valuable concept and idea that are useful to this study. More than that, a different type of nanoparticles used to study the thermal conductivity enhancement via nanofluid are discussed.

Chapter 3 describes the procedures and techniques implemented throughout the study starting with material selection, synthesis of nanofluid and experimental setup. The range selection of nanoparticles concentration in base fluid are referred from previous study.

In Chapter 4, the results of temperature distribution on specific parts, heat transfer coefficient and thermal conductivity by using different concentration of nanofluid are calculated and discussed. Comparison of different volume concentrations are given to show the significance of the contribution to this research.

Chapter 5 summarizes the research and recommends an outlook for future work. A list of publications contribution is also given at the end of this chapter.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

Throughout these years, research on Nanofluid as heat transfer fluid has become the new generation compared to conventional base fluid such as oil, ethylene glycol, water, etc. It is done by suspending high thermal conductivity solid particles in poor thermal conductive conventional fluid in order to improve the thermal conductivity. Generally, solid nanoparticles usual size within range 1-100nm. Based on (Gupta, 2018), the order-of-magnitude these nanoparticles possessed on thermal conductivities nearly three times higher than base fluids. This is because strong Brownian motion influenced by the dispersion and its movement can offset their sedimentation due to gravity and it will take some time due to the nanoparticle aggregation initiated by Van Der Waals forces (Azizian, 2016). Both of sedimentation and aggregation phenomenon is related to stability in nanofluid that eventually affect its thermo-physical properties (Devendiran, 2016).

The ability to conduct heat in nanofluid is highly depend on several parameters such as nanoparticles size and shape, particle volume fraction, type of nanoparticles and base fluid, pH value and type of particle coating are reviewed by (Devendiran, 2016) (Ranga, 2017, Haddad, 2014) Although it has broad applications in cooling and heating, but few challenges that it needs to overcome for future development. Mainly the difficulties come from the material itself, the production cost, the ability for the nanoparticles coagulate automatically due to high surface energy, disagreement between experimental data and findings and poor characterization of Nano suspension.

2.1 Nanofluid

Nanofluids has two major classes, mono and hybrid. Mono nanofluid contain single type of nanoparticles dispersed in conductive fluid. The nanoparticles are made up of metals with chemical stability, oxides, non-metals, nitrides of metals and carbides of metal (Gupta, 2018). All of them has their specific strength with certain purposes. This past few years, researchers tried to experiment using mono nanofluids on the thermal efficiency based on different volume concentrations of nanofluids.

As studied by (Gunnasegaran, 2015) used silica nanoparticles SiO2 with water as base fluid stated that major aspect of optimum thermal resistance is nanoparticles mass concentration. The experiment proves that by increasing the concentration to 0.5%, thermal resistance decreases and beyond that, it starts increasing back. The results are optimized and optimum mass concentration of 0.48% produce optimal thermal resistance of 2.66°C/W (Wan, 2015) supported the results by stating the decrement of total thermal resistance for about 21.7% and 12.8% for evaporator wall temperature. Besides that, when 1.0wt% of Cu nanoparticles dispersed in ionize water for heat load of 100W, the increment of heat transfer coefficient by 19.5% is calculated. Whereas (Gunnasegaran, 2014) recorded that although minimum value of 3.15°C/W for thermal resistance with 3% concentration, the average decrement of 3.7% - 5.5% at nanoparticle mass concentration 0.5% - 3.0% shows that the decreasing value becomes insignificant after it reach 1%. Thus, he concludes that thermal resistance decreasing proportionally until it reaches optimal particle mass concentration of 1%.

Literatures on hybrid nanofluid by (Amini, 2018) analyze experiment on SiO2 /MWCNT disperse in glycerol stated that, at volume fraction of 2% and volume proportion of 90-10, thermal conductivity of hybrid nanofluid increased by 12% compared to SiO2 mono nanofluid. In 2014, (Chen, 2014) conducted an experiment on thermal conductivity of hybrid nanofluid iron oxide/multi-walled carbon nanotube (Fe2O3 /MWCNTs) by varying volume concentration of the iron oxide. The increment of 27.7% of thermal conductivity was obtained by the combination of 0.02 wt% Fe2O3 and 0.05% MWCNTs. Beyond 0.02 wt%, thermal conductivity decreases due to the nanoparticles that confine the formation of effective heat transfer networks due to excess aggregation. On the other hand, Megatif et al. (Megatif, 2016) synthesize CNT-TiO_2 together and find that it has higher thermal conductivity about 2.5% compared to CNT nanofluid.

2.2 Mono Nanofluid

Mono nanofluid consist of single type of nanoparticles in one type of base fluid. Nanofluid is proposed due to the enhancement of thermophysical properties compared to base fluid or conventional working fluid. Although mono nanofluid might possessed better thermal properties, at least one issue will be a drawback such as stability and vice versa. Thus, for this problem, the help from chemical or mechanical method to increase stabilization during synthesis or dispersion process.

Earlier age of nanofluid experimentation, Maxwell correlation was used, but the correlation was specified for micrometer-scale particles, so many researchers after that produced their own correlation with respect to their experimental results. (Sarafraz, 2016) experimented CNT nanofluid with weight percentage of 0.1% to 0.3% was tested in double-pipe heat exchanger and proved to improve the performance of the heat pipe by increasing the heat transfer rate at the inlet temperature for higher concentration of nanoparticles. Whereas (Esfe, 2014), (Saedodin, 2014) and (Khanafer, 2011) also came out with new correlation for mono nanofluid for MgO-water, MWCNT-water and Al_2O_3-water respectively.

2.3 Preparation of Nanofluid

Nanofluids are synthesize using two types of method, either one-step method or two step method. Researches usually pick either one to synthesize the nanofluid, but some of them combine both methods together based on the types of nanoparticles they used. One-step method include nanoparticles production and nanofluid preparation is carried out in one go. Metals with high thermal conduction is one of the best examples to use this method to avoid oxidation, but due to complicated processes, it becomes a drawback to produce the nanofluid at commercial scale in terms of cost effectiveness in mass production (Ranga, 2017). Despite the hindrance, Haddad prepared AG- WO_3 hybrid nanofluid in three distinct weight fractions of 1%, 2% and 4% with transformer oil as the base fluid by using one-step method known an Electrical Explosion of Wire (E.E.W)(Haddad, 2014). This method operates by using PNC1K device to control the high current and electric voltage in order to produce an explosion in container of base fluid with thin wire to obtain the nanofluid. The results showed that hybrid nanofluid possessed 41% increment of thermal conductivity in higher weight fraction and zeta potential measurement found out that these combination of nanoparticles and base fluid produce a very stable nanofluids with reading of zeta potential 46mV to 54mV.

Two-step method in the other hand separate the production of nanoparticles and nanofluids. It is done by mixing nanopowders that are available commercially in the base fluid and disperse it by using various kind of dispersion technique. Esfe prepared Ag-MgO/water hybrid nanofluid by dispersing the nanoparticles in distilled water using single step and two-step method. Stabilization of the solution was perform using various method including addition of surfactant, changing pH value, and using ultrasonic vibrator. Cetyl Trimethyl Ammonium Bromide, CTAB was used as surfactant to ensure better stability and preventing agglomeration in solution and it was found stable for a few days (Esfe, 2015a). Esfe also used two-step method synthesizing hybrid nanofluid of Cu/ TiO_2 -water/EG nanofluid in another experiment. The dispersion occurs in various solid concentration (0.1-2%) by using magnetic stirrer for three hours for thorough mixing of the nanoparticles. Then, ultrasonic processor was used for superb dispersion and breaking the agglomeration. No signs of sedimentation through naked eyes mean stable suspension was obtained. Both experiment conduct by the same person but on different experiment (Esfe, 2015c).

2.4 Stability of Nanofluid

Physics law states that stability is defined as forces that is developed to restore the original position when it is disturbed. Whereas, stability in nanofluid is inversely proportional to terminal velocity of the suspended solid particles. It can be divided by three features (Mukherjee, 2018),

1. Kinetic stability: Brownian diffusion of nanoparticles in base fluid is strongly affecting sedimentation by equalizing the gravitational attraction and mobility of nanoparticles. Sedimentation can be prevented by shrinking the size of nanoparticles but will accumulate the chance of particle aggregation due to higher surface energy.
2. Dispersion stability: The aggregation of nanoparticles in nanofluid will increased with the elapsed time due to degradation of dispersion stability.

3. Chemical stability: It occurs when there is no chemical reaction between nanoparticles or nanoparticles and base fluid, but the reaction is not acceptable for cooling application.

The stability of nanofluid is achievable by using two types of method, chemical and physical. Chemical methods can be done either by adding surfactant, controlling pH of base fluid or modification of nanoparticles' surfaces to prevent the clustering of nanoparticles. Whereas physical methods consist of the mechanical application of high-energy force such as sonication, magnetic stirring, homogenization, ultrasonic bath, etc. Usually, research that consist of addition of surfactant which is chemical method usually followed by at least one physical method to achieve optimum dispersion of nanoparticles in base fluid.

Stability is important because it directly affects thermophysical properties of a nanofluid. The reason being, thermal properties of a nanofluid depends on the suspension period of nanoparticles in base fluid, the longer the better. Therefore, the most important aspects to be considered in stability is the tendency of nanofluid to sediment and aggregate. Aggregation or coagulation happens due to the strong force of van de Waals attraction among nanoparticles and it may cause clogging and do not show consistent cooling performance (Pradhan, 2016). (Bystrzejewski, 2010) performed a comparative study on CNT's dispersion in two types of anionic surfactant, SDBS and SDS with different concentration sonicated for 5 hours at 20°C. The sample with SDBS has 26-45% higher dispersing power compared to SDS.

2.5 Surfactant in Nanofluid

Ideal stability of nanofluids should have compatible nanoparticles and base fluid. The reason being, there is two types of nanoparticles hydrophilic and hydrophobic, whereas base fluids can be divided by two characters, polar or non-polar. The combination of hydrophilic nanoparticles and polar base fluid or hydrophobic nanoparticles with non-polar base fluid can go through dispersion process without the addition of surfactant but can prolong the period of stable suspension of nanoparticles in base fluid. However, if the opposite thing happens, help from dispersant is a must to create a link between nanoparticles and base fluid (Mukherjee, 2018).

Surfactant, surface active agent or dispersant is used to enhance the shelf-life (stability) of nanofluid by increasing the electric double layer that results in modified electro-kinetic characteristic of nanoparticles. Thermal conductivity and stability optimization can be reached by having appropriate amount of surfactant. The ability to reduce interfacial tension generate repulsive force between suspended nanoparticles and base fluid lead to high zeta potential. Zeta potential is essential in behavior of nanofluids especially dispersion. Nanofluids are obliged to exceed 30mV to be declared as physically stable whereas lower than that, suspensions have higher tendency to coagulate and flocculate due to van der Waals forces (Kumar, 2018). However, surfactants may have some drawbacks such as increment of thermal resistance, effecting the purity of heat transfer medium and surfactant with low thermal conductivity may affect the thermal conductivity enhancement of nanofluid (Yu, 2018). Besides, gravitational force also affects the nanoparticles in base fluid because there is tendency to deposit at the bottom. Surfactants can be categorized into four groups, anionic (SDBS (Ganeshkumar, 2017), SDS (Haque, 2015, Choudhary, 2017)), cationic (CTAB), amphoteric (Lecithin, Hydroxysultaine) and non-ionic (GA, PVP). Table 2.2 indicate recent researches on nanofluids subjected to various types of surfactant.

Table 2-1 Researches on nanofluids subjected to various types of surfactant

Reference	**Nanofluids**	**Surfactant**	**Method**	**Results**
(Leon, 2018)	TiO_2-water (0.2, 0.4, 0.6 and 0.8 vol.%)	SDBS, GA, PVP (1:1 and 2:1 nanoparticle to surfactant ratio)	Two-step Method (Magnetic stirrer - 5 minutes at 500 rpm) (Sonication – 30 minutes)	-TiO_2-water nanofluid at 0.8 vol% added with 1:1 nanoparticle to surfactant ratio SDBS exhibit highest thermal conductivity followed by GA and PVP. Thermal conductivity of TiO_2-water nanofluid with surfactant is lower compared to non-surfactant, assumed because of the increment of thermal resistance between nanoparticles and water due to addition of surfactant.
(Seong, 2018)	Graphene-water (0.1 wt%)	SDBS, SDS (3:1, 2:1, 1:1, 2:1 and 3:1 nanoparticle to surfactant ratio)	Two-step Method (Graphene nanoparticles prepared by ball-milling with ball size of 1 mm and speed of 200 rpm - 60 minutes)	Graphene nanofluids with SDS showed higher thermal conductivity at ratio 2:1 and 3:1 compared to distilled water whereas SDBS displayed lower thermal conductivity compared to distilled water for all ratio.

			(Sonication - 40 minutes)	The highest thermal conductivity approximately 627 mW/m.K was procured when ratio of nanoparticles to surfactant SDS was 2:1 (0.05g).
(Al-Waeli, 2019)	SiC-water/ EG / PG/ EG + water/ PG + water (Sic weight ratios 0.1, 0.5, 1, 2 and 3%) (EG + water - 5, 10, 15, 20, 25, 30 and 35% of EG mix with water) (PG + water - 5, 10, 15, 20, 25, 30 and 35% of PG mix with water)	CTAB (0.1 ml)	Two-step Method (SiC nanoparticles were heated for 15 minutes in a furnace at 200 °) (Ultrasonic shaker – 6 hours)	Thermal conductivity of EG and PG-water with an addition of SiC nanoparticles indicate clear increment compared to water. At 25 and 60 °C, thermal conductivity increased by 1.66% and 2.29% respectively. EG + water recorded highest density of 0.015% at 25 °C and PG + water recorded highest viscosity of 0.09% at 25 °C.
(Zhang, 2016)	SiO_2-water	SH, SDBS, SDS, PEG (1.0 wt %)	Two-step Method	SDBS with 1.0 wt% in silica-water nanofluid reached maximal value of

	(SiO_2 weight percentage - 1.0 wt %)		(SiO_2 nanoparticles were synthesized by using rice husk ash) (Sonication – 2 hours)	zeta potential, 42.3 mV and remain unchanged for 7 days storage.
(Asadi, 2017)	Mg $(OH)_2$-water (Mg $(OH)_2$ solid concentration – 0.1, 0.2, 0.4, 0.8, 1, 1.5 and 2%) (Temperature – 25, 30, 35, 40, 45 and 50 °C)	CTAB, SDS, Oleic Acid	Two-step Method (Sonication – 10, 30, 50, 80 and 160 minutes)	CTAB provide the best stability of nanofluid with 30 minutes sonication. The highest thermal conductivity took place at the solid concentration 2% with temperature 50 °C by approximately 28%. Trend of the results showed decreasing thermal conductivity as sonication time increased.

2.6 Base Temperature

Base temperature is a temperature located between heating element and base surface of heat sink. It indicates the amount of heat absorbs by fluid pass through the area by knowing the temperature difference between heating element and the base temperature. Theoretically, the increment of temperature will increase the energy of particle and the molecules of base fluid, thus the energy to be transferred from one place to another is already available (Rasheed, 2016). In experimental investigation, heat transfer coefficient, thermal resistance and thermal conductivity can be obtained base on the temperature difference. The temperature is varied by the amount of heat dissipates from heating element. Higher power from power supply will increase the temperature of heating element and base temperature simultaneously. Besides, temperature of the thermal conductivity of base fluid and nanoparticles govern the thermal conductivity of nanofluid. In addition, the change in temperature will affect clustering and Brownian motion which eventually alter the thermal conductivity of nanofluid. Clustering is not desirable as it can reduce the effective area of thermal interaction of nanoparticles which will deduct the thermal conductivity of nanofluid (Gupta, 2017).

Literatures show, the increase in temperature will increase the thermal conductivity of nanofluid. (Chandra, 2013) experimentally studied the effect of nanoparticles concentration and temperature on thermal conductivity by using TiO_2dispersed in combination of ethylene glycol and water as base fluid. The study proved the dependency of thermal conductivity on temperature and volume concentration. The results were supported by (Elias, 2014) and proved by (Chandrasekar, 2010) with the same conclusion by using the same base fluid with Al_2O_3. Correspond to the findings, conclude his results with an increment of thermal conductivity by 25-48% at 2.0% volume concentration of Fe_3O_4 -water with temperature range 20-60 °C.

2.7 Heat Transfer Coefficient

Heat transfer is the locomotion of thermal energy from one medium to another of different temperature. Whereas, heat transfer coefficient is a quantitative measurement heat transfer mainly used in thermal convection. Thermal convection is the transferring of thermal energy by using fluid such as water or air if they are heated by flowing away from the source of heat to lower temperature area (Hussein, 2013). Heat transfer coefficient is proven by many researchers as one of the most important parameters to predict the efficiency of nanofluids as an optional fluid in heat transfer applications. The reason being, heat transfer depends on the thermal properties of the medium, the hydrodynamic characteristics of its flow, the thermal and hydrodynamic boundary condition. In the application of heat transfer, traditional thermal fluids have poor ability to transfer heat compared to solids. Thus, some suggest that the addition of certain amounts of nanoparticles which exhibit higher thermophysical properties will eventually improve the performance of a system by increasing the overall heat transfer coefficient (Chamsa-ard, 2017).

(Hosseini, 2017) enhance the convective heat transfer coefficient of C-MWCNT-DI water nanofluid by 12.38.24.1 and 35.89 for concentration of 0.075, 0.125 and 0.175 wt% respectively. This is due to the thermal conductivity enhancement of nanofluid and decreasing value of thermal resistance between nanofluids and inner wall surface at higher flow rate that affect the size of thermal boundary layer. Whereas (Mehrali, 2016) establish an eco-friendly novel model of the reduction process of graphene oxide in red wine polyphenol solution to produce graphene based nanofluid. The investigation of nanofluid thermophysical properties results in the enhancement of heat transfer coefficient exceeds the thermal conductivity enhancement of 45.1% for a volume fraction of 4% which indicates a method to maximize the performance of nanofluid as ‘smart’ measurement.

2.8 Thermal Conductivity

Thermal conduction is when molecules in a material produce motions, they can transfer energy (heat) across a temperature gradient. Whereas, thermal conductivity of a material is defined as its ability to conduct heat by conduction. Every material has different value of thermal conductivity based on their properties. High heat transfer coefficient means high thermal conductivity. In heat transfer application, conventional fluid has low thermal conductivity, but nanofluids have superior thermal properties based on the theoretical researches. The thermal behavior of nanofluids is controlled by a mechanism called Brownian motion and interfacial layer on the surface of nanoparticles. These nanolayers intensify the thermal conductivity by acting as thermal bridge between base fluid molecules and solid particles (Gupta, 2017).

Thermal conductivity is governed by various factors such as particle size, shape, material, temperature, additives, acidity (pH) and clustering. Before nanoparticles, microparticles was introduced but causing operational problems such as sedimentation that lead to lower heat transfer rate, clogging in narrow channels, erosions and increase flow resistance and large pressure drop (Chamsa-ard, 2017). Thus, nanometer-scale particles were tested of various size ranging from 5 and 100nm. (Teng, 2010) tested Al_2O_3-water with various nanoparticles size (20, 50, 100) nm and weight concentration of 0.5-2.0wt% at 10-50°C operating temperature. The result indicated smaller nanoparticles, higher concentrations and temperature lead to higher thermal conductivity. Whereas (Yeganeh, 2010) proved that thermal conductivity increase by

7.2% with 3 vol% of nanodiamond nanoparticles loading at a temperature of 30^0C. At 50^0C, the conductivity also increases up to 9.8%.

2.9 Thermal Conductivity Efficiency

Thermal conductivity enhancement is the efficiency of nanofluid compared to base fluid. Literatures that want to prove the thermophysical properties of nanofluids usually will measure the thermal conductivity enhancement with respect to certain parameters. A thermal conductivity enhancement of Cu-gear oil nanofluids with oleic acid as surfactant for 2 vol% of Cu nanoparticles is 24% compared to base fluid proved by (Kole, 2013). (Yu, 2009) conducted an experiment of ZnO-EG nanofluids with volume concentration range from 0-5% at temperature 10-60°C. The maximum thermal conductivity enhancement was recorded to be 26.5% with 5.0 vol% of ZnO nanoparticles. Whereas (Mostafizur, 2014) presented three different nanoparticles Al_2O_3, SiO_2 and TiO_2 with volume concentration of 0.15 vol% disperse separately with methanol as base fluid at temperature 20°C. The enhancement of thermal conductivity of nanofluid is 29.41%, 23.03% and 24.51% compared with base fluid for Al_2O_3, SiO_2 and TiO_2 respectively.

2.10 Application of Nanofluid

Experimental on the usage of nanofluids as working fluid in heat pipes were conducted by many, with different types of parameter to measure but mainly to improve the properties of working fluid on thermal conductivity. Ninolin recorded that silver-water nanofluid is compared with water in compact loop heat pipe for different heat input ranging from 30W to 500W with low concentration of silver nanoparticles (0.03% and 0.09%) in vertical orientation (Ninolin, 2016). The results are obvious for nanofluid, 26.45% reduction in thermal resistance and enhancement of 25.23% for convective heat transfer coefficient compared to water.

The results were supported by Leon et al. experimented on working fluid of Al_2O_3/CuO-DI water with various combinations in meshed wick heat pipe (Leon, 2018). There were four different heat pipes charged with different working fluid such as DI water, Al_2O_3 -DI water, hybrid nanofluid Al_2O_3 50% /CuO 50% and Al_2O_3 25% /CuO 75% -DI water with 0.1% volume concentration of nanoparticles dispersed by using sonication method for one hour. The heat pipes were using Cu tubes and screen mesh for the wick and coolant temperature was maintained at 20 °C with flow rate of 12 liter per hour. The outcome of the experiment indicate decreased thermal resistance of heat pipe imply that thermal conductivity increased by 38.34% for Al_2O_3 -DI water, 41.47% for Al_2O_3 50% /CuO 50% -DI water and 79.35% Al_2O_3 25% /CuO 75% -DI water compared to base fluid.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter presents topics regarding material and apparatus specifications, preparation of nanofluid and experimental setup comparing with some past researches to identify the differences or similarities. Equations and correlations to analyse heat transfer, thermal resistance effective thermal conductivity is also stated in this chapter.

3.1 Traits and details

Silica-water based nanofluid was used in the experiment as a heat transfer medium to be compared with distilled water as one of the conventional working fluid due to its availability, low cost (Zhang, 2016) and accuracy of thermo-physical properties due to its good nanoparticles dispersion with great stability in water base (Haddad, 2016). The specifications of silica nanoparticles and distilled water was listed below in Table 3.1 and Table 3.2.

3.1.1 Silica Nanoparticles

The silica nanoparticles were purchased commercially from Sigma-Aldrich chemical company with details listed in Table 3.1. The nanoparticles came in form of white powder as fine form can disperse even better in polar solvent like water and ethanol to form nanofluid (Yu, 2008). Specifically, silica nanoparticles are divided by two types, P-type (porous particles) and S-type (spherical particles) based on their rheological properties. This experiment use S-type particles because it has larger specific surface area that lead to a better thermal conductivity compared to P-type, mainly used by energy source and electronic fields. However, P-type is essentially used in biological application such as drug delivery for its low toxicity and biomedical imaging due to manifest higher ultraviolet reflectivity of >85%, around 15% more than S-type.

Table 3-1 Details of SiO_2

Traits	**Details**
Assay	99.8% trace metals basis
Form	Nanopowder
Average article size (nm)	12
Surface area (m^2/g)	160
Melting point (°C)	>1600
Boiling point (°C)	2230
Density (g/ml)	2.3
Thermal conductivity (W/m.K)	1.4
Specific heat (J/kg.K)	705

3.1.2 Distilled Water

Distilled water as the base fluid was obtained from Universiti Sains Malaysia Integrated Lab of Material School together with these specific details in Table 3.2. The distilled water was already deionized by using Favorit W4L Water Stills and free from impurities and chemicals that might affect the experimental results.

Table 3-2 Details of distilled water

Traits	**Details**
Density (kg/m^3)	1000
Thermal conductivity (W/m.K)	0.6
Specific heat (J/kg.K)	4182

3.2 Nanofluid Preparation

In the experiment, nanofluid was prepared using two-step method, as suggested by the open literature due to its oxide nanoparticles. This method required the base fluid to suspend the nanoparticles that were prepared first in the form of powder frequently purchased from the industry. Besides two-step method, one step method was an option but rarely used in experiment due to complexity although the nanoparticles are suspended in base fluid directly and mostly used chemical methods (Kumar, 2018).

The nanofluid contains certain amounts of nanoparticles and base fluid, thus calculation to determine the volume concentration of nanoparticles by using equation (1):

$$\emptyset = \frac{\frac{m_{np}}{\rho_{np}}}{\frac{m_{np}}{\rho_{np}} + \frac{m_{bf}}{\rho_{bf}}} \tag{1}$$