UNIVERSITI PUTRA MALAYSIA

THERMAL CONDUCTIVITY OF METAL (Al, Cr, AND Ni) AND SEMICONDUCTOR (ZnS AND CdS) NANOFLUIDS DETERMINED BY A TRANSIENT HOT WIRE METHOD

ROSLINA MAT HUSSIN

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By

ROSLINA MAT HUSSIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of Requirements for Degree of Master of Science

July 2014

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Dedicated to
My dearest parent
For their extra ordinary love, and endless care
and
My sisters and brothers
For their encouragement and prayers
also
My soulmate
For his endless patience
not forgotten
My supervisor
For inspired me in countless of ideas

Thank You, Thank You and Thank You
For every do’a and motivations from all of you

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in Fulfillment of the requirement for degree of Master of Science

THERMAL CONDUCTIVITY OF METAL (Al, Cr, AND Ni) AND SEMICONDUCTOR (ZnS AND CdS) NANOFLUIDS DETERMINED BY A TRANSIENT HOT WIRE METHOD

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July 2014

Chairman : Professor W. Mahmood Mat Yunus, PhD

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In heat transfer application, the challenge in development of the nanofluids is in understanding on how the interactions between the particles and fluid affect thermal properties of the fluids. The main objective of this work is to determining the thermal conductivity of the metallic and semiconductor nanofluids. The specific objectives are to study the effect of volume fraction concentration, metal nanoparticles, base fluid, pH valueof Al, Ni, and Cr nanofluids and radiation doseof ZnS and CdSnanofluidson the enhancement of the thermal conductivity. The metallic nanofluidssamples were prepared at various volume fraction concentrations ranging from 0.01- 0.30 vol.% using a single step technique. For semiconductor nanofluids, the samples were prepared at different radiation dose range from 10-60 KGy. The thermal conductivity of the samples was measured using KD2 Pro Thermal Analyzer which employed transient hot wire (THW) method at the room temperature. The thermal conductivity of pure base fluids measured are 0.254, 0.614, and 0.168 W/m·K, for ethanol, distilled water and ethylene glycol and 0.551W/m·K for pure polyvinyl alcohol (PVA). The result shows that the thermal conductivity of all nanofluids samples was increased proportionally with the increment of volume fraction. The enhancement of thermal conductivity of Al nanoparticles in ethanol, distilled water, and ethylene glycol are increased up to 26.19, 16.48, and 5.62% at 0.02 vol.%. The enhancement of the thermal conductivity of Cr nanoparticles in ethanol, distilled water, and ethylene is 21.42, 17.42, and 15.66% at 0.20 vol.%and for thermal conductivity of Ni nanoparticles in ethanol, distilled water, and ethylene glycol increased up to 21.42, 13.52, and 9.64% at 0.03 vol.%.In measuring effect of pH concentration on the thermal conductivity of Al nanofluids theresults show that there exists an optimal pH value for the highest thermal conductivity. The optimal pH value the nanofluids containing a small amount of Al nanoparticles have noticeably higher thermal conductivity than that of the base fluid without nanoparticles. In this work, the optimal pH value were observed at pH 10 for 0.03, 0.05, and 0.10 vol.% with the percentage of enhancement are 8.63, 11.25, and 20.58%. . Interpretation from the results of the effect of radiation dose shows thatthe thermal conductivity of CdS and ZnS are decreased by increasing the dose of the radiation exposure on the sample. Thermal conductivity of CdSis 0.558 W/m·K and 0.561 W/m·K for ZnSrespectively, after been expose to the radiation at 20 KGy. While the thermal conductivity values is 0.0554 W/m·Kfor CdSand 0.555 W/m·Kfor ZnSrespectively, after been expose to the radiation at 50 KGy.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KEKONDUKSIAN TERMA LOGAM (Al, Cr, DAN Ni) DAN SEMI KONDUKTOR (ZnS AND CdS) BENDALIR NANO MENGUNAKAN KAEDAH WAYAR PANAS FANA SEKETIKA

By

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Julai 2014

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Fakulti : Sains

Dalam bidang aplikasi pemindahan haba , cabaran dalam pembangunan cecair nano adalah untuk memahami bagaimana interaksi antara zarah dan cecair menjejaskan sifat haba daripada cecair tersebut. Objektif utama dalam kajian ini adalah untuk menentukan kekonduksian haba logam dan bendalir nano semikonduktor. Objektif khusus kajian ini adalah untuk mengkaji kesan pecahan isipadu, logam zarah nano, cecair asas, nilai pH bendalir nano Al, Cr, dan Ni dan juga kesan dos radiasi pada peningkatan terhadapkekonduksian terma bendalir nano ZnS dan CdS. Sampel logam bendalir nano telah disediakan pada pelbagai kepekatan yang rendah di antara 0.01-0.30 vol.% menggunakan teknik langkah tunggal. Untuk bendalir nanosemikonduktor, sampel telah disediakan pada julat dos radiasi yang berbeza diantara 10-60 kGy. Kekonduksian terma bagi sampel telah diukur menggunakan KD2 Pro Thermal Analyzer yang menggunakan kaedah wayar panas fana seketika pada suhu bilik. Kekonduksian terma cecair asas tulen diukur adalah 0.254, 0.614, dan 0.168 W/m·K, untuk etanol, air suling dan etilena glikol manakala 0.551 W/m·K untuk polivinil alkohol (PVA)tulen. Hasil kajian menunjukkan bahawa kekonduksian haba semua sampel bendalirnano telah meningkat berkadaran dengan kenaikan pecahan kepekatan jumlah. Peningkatan kekonduksian terma zarahnanoAl dalam etanol, air suling, dan etilena glikol yang meningkat sehingga 26.19, 16.48, dan 5.62% pada 0.02 vol.%. Peningkatan kekonduksian haba zarahnano Cr dalam etanol , air suling, dan etilena glikol adalah 21.42, 17.42, dan 15.66% pada 0.20 vol. %. Untuk kekonduksian haba zarahnano Ni dalam etanol, air suling, dan etilena glikol meningkat sehingga 21.42, 13.52, dan 9.64 % pada 0.03 vol. %. Dalam mengukur kesan nilai pH ke atas kekonduksian haba bendalir nano Al, keputusan menunjukkan bahawa wujud nilai pH optimum untuk kekonduksian haba yang tinggi. Nilai pH optimum untuk bendalir nano yang mengandungi sejumlah kecil zarah Almempunyai kekonduksian yang lebih tinggi daripada itu cecair asas tanpa kehadiran zarahnano. Dalamkajian ini pH optimum yang diperoleh adalah pada nilai pH 10 untuk 0.03, 0.05, dan 0.10 vol. % dengan peratusan peningkatan adalah 8.63, 11.25, dan 20.58%. Tafsiran dari hasil kesan

dos radiasi menunjukkan bahawa kekonduksian terma Cds dan ZnS adalah menurun dengan meningkatkan dos pendedahan radiasi pada sampel. Kekonduksian terma CdS dan ZnS adalah 0.558 dan 0.561 W/m·K,masing-masingnya selepas didedahkan kepada radiasi 20 kGy. Manakala kekonduksiannya adalah 0.0554 dan 0.555 W/m·K, masing-masingnya untuk yang didedahkan pada radiasi 50 kGy.

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I certify that A Thesis Examination Committee has met on 16th July 2014 to conduct the final examination of Roslina Mat Hussin on her thesis entitle “Thermal Conductivity of Metal (Al, Cr, and Ni) and Semidonductor (CdS and Zns)NanofluidsDetermined by aTransient Hot Wire Method” in accordance with the Universities and University College Act 1971 and the constitutions of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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CHAPTER 1
INTRODUCTION

This chapter presents general overview and the concept of nanotechnology and definition of the nanofluids. The rationales of nanofluids with their application and advantages are also discussed elaborately in this chapter**.** This chapter also presents the problems statement, objective, scopes of research and the outline for this thesis.

1.1 Nanotechnology and Transient Hot Wire Method

Nanotechnology is a derivative of functional materials, devices and system by controlling the specific matter at nanosize level. The concepts that seeded nanotechnology were first discussed in 1959 by Richard Feynman, by his statement on the possibility of synthesis via direct manipulation of atoms (Rohrer, 1996). Rohrer also reported that the term nanotechnology was first used by Norio Taniguchi in 1974. In most industrial technologies, an ultrahigh-performance cooling is one of the crucial requirement. Unfortunately, the conventional fluids like distilled water and ethylene glycol has low thermal conductivity. Due to that it is became a primary goals in developing energy efficient heat transfers fluids which are required for ultrahigh-performance cooling. As a result, many research and development activities are being carried out to improve the heat transport properties of fluid.

Maxwell is the first person who develops an innovative idea in enhancing the thermal conductivity by adding solid particles into heat transfer fluids (Maxwell, 1873). At the same time, modern fabrications technology had also provide a great opportunity for an active material fabrication at nanometer size. Nanomaterials have a unique mechanical, optical, electrical, magnetic and thermal property. In the early twenty-first century, nanotechnology has given a big impact on our economy and society. Bharat (2004) stated that, the nanotechnology will be the next industrial revolution. Early review of research programs on nanotechnology in the United State, China, Europe, and Japan shows that nanotechnology will be an emerging and exciting technology in the twenty-first century and that is why many universities, national laboratories, small businesses and large multinational corporations have established their own nanotechnology research groups or interdisciplinary centers that focus on nanotechnology.

For determining the thermal conductivity of fluids with a high degree of accuracy Transient Hot Wire method has been widely used by many researchers since decades (Nagasaka and Nagashima, 1981; Castro et al., 1976; Mani, 1971; Haarman, 1969; Pittman 1968). Thermal conductivity of nanofluids can be measured by many optical technique as suggested by the previous researcher (Putman et al. 2006) such as hot wire laser beam (W.Mahmood et al., 2013; Faris et al. 2010) beam deflection technique and also transient hot wire method (Walvekar et al. 2012: Pang and Kang, 2012; Timofeeva et al., 2009; Garg et al., 2008; Singh, 2008).

Among of them, the transient wire method is the most common and popular technique which is widely employed among the researchers (Mursheed et al., 2006; Cyril et al.,

2010) due to its advantaged in eliminating the errors due to natural convection (Paul et al., 2010; Garg et al. 2010). THW method also require a simple and fast apparatus set up compare to other techniques (Hong et al. 2011: Kostic and Kalyan, 2009; Singh, 2008). It also low cost and easy implementation (Clement and Yu 2011). THW method is based on the measurement of the time dependent temperature rise in a heat sources such as hot wire which already been immersed in the fluid. The hot wire serves simultaneously as an electrical resistance heater and resistance thermometer (Gross and Song, 1996; Nagasaka and Nagasima, 1981; Anderson and Backstrom, 1976).

1.1.1 Nanofluids Concept

Nanofluids are a novel heat transfer fluid that had attracted great interest in recent years due to the report that nanofluids can greatly enhance thermal properties. These nanoparticles has gain an interest of researcher from around the world due to their application which can be widely used in many industries such as cooling system, nuclear reactor, transportation, electronics and as well as biomedicine (Faris, 2011). Meanwhile, the conventional fluids such as water, ethylene glycol and ethanol are currently being extensively employed as heat transfers fluid which has many applications in industry. These fluids have relatively poor thermal conductivity. Thus several methods and techniques have been proposed to enhance the abilities of their heat transfers performance such as adding particles, apply pressure and heat, changing the pH value and many others. Nanofluids is a fluid consisting of solid nanoparticles with sizes typically in the order 1-100 nm, disperse in a liquid (Keblinski, 2010).

Since solid materials have higher thermal conductivity compared with those of fluids (Touloukian et al., 1970), researchers have tried to improve the thermal conductivity of conventional fluids by suspending solid particles in them (Choi, 1995). The objective of the nanofluids is to enhance the thermal properties at the lowest concentrations by uniform dispersion and stable suspension of nanoparticles in the based fluids. Figure 1.1 shows the illustration of nanofluids in the sample cell. It consists of base fluid as a solvent and nanoparticles which has an additive around the particles as a stabilizer to make the nanoparticles well suspended.

For more than centuries, many scientist and engineers have made great efforts to enhance the inherently poor thermal conductivity of liquids by dispersing solid particles in the liquids. The situation changed when Choi and Eastman in Argonne National Laboratory revisited this field with their metallic particles and carbon nanotube suspension in 1992 (Choi and Estman 1995; Eastman et al. 1996). Both of them have tried to disperse various metal and metal oxides nanoparticles in several different fluids. Their efforts have produced interesting results in the enhancement of thermal conductivity value which is 30% (Choi et al. 2001; Chon et al. 2005).

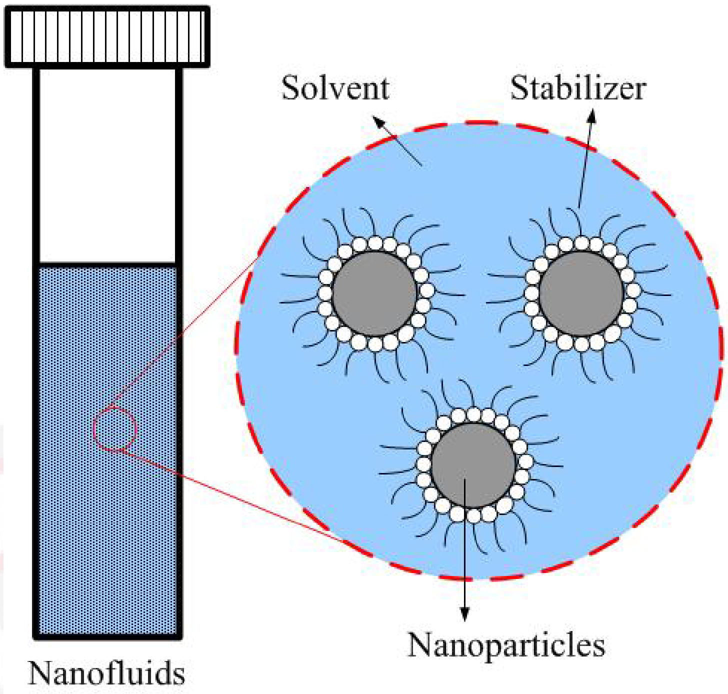

Figure 1.1. Illustrations of nanofluids

Stable suspensions of nanoparticles in conventional heat transfer are produced by two methods either single step technique or two step technique (Das et al., 2007). Single step technique is a process which involves a simultaneous process. A method in preparing nanofluids by using single step method is by dispersing the nanoparticles directly into the based fluids. However in the two step technique it involved two phase. First phase is the nanoparticle is prepared by using chemical or physical process and then followed by second phase by dispersing the nanoparticles into the based fluids. To stabilize the nanofluids after being prepared in both method, some surfactant will be added such as cetyltrimetrylammonium bromide (CTAB), changing the pH concentration and also by sonicate the sample for hours in a sonic clean machine.

1.1.2 Application of Nanofluids

Nowadays many industries around the world are facing the thermal challenge and there is pressing needs for ultrahigh performance substance. Therefore, nanofluids can be used to improve the heat transfers and energy efficiency in most thermal controls system such as high cooling rates, smaller and lighter cooling systems, improved wear resistance, decreased pumping power needs, and reduced inventory of heat transfers fluids. Even though it was still at the early stage, many works in the field of nanofluids is being done in national laboratories around the world.

Great industrial interest shows that the nanofluids can be used and applied in a wide range of industries such as in the industries of transportation, electronics, process heating and cooling, and also in medical application (Das et al., 2007). The most attractive characteristic of nanofluids is that even by a small addition of nanoparticles, they show anomalous enhancement in thermal conductivity which is over 10 times higher than the theoretically predicted using theoretical calculation. Eastman et al., (2001) reported a 40% thermal conductivity increase in ethylene glycol by adding only 0.3 vol% of Cu nanoparticles with a diameter smaller than 10 nm. However, more research work is needed for a more in depth understanding of the thermal conductivity and enhancement in the convective heat transfer of nanofluids.

As for the transportation field, a mixture of ethylene glycol and water is widely used vehicle coolant due to its lowered freezing point for anti freezing as well as the elevated boiling point. However, thermal conductivity of ethylene glycol is relatively low compared to water. At the same time, engine oils are even much worse heat transfer fluids than ethylene glycol in thermal transport performance. The addition of nanoparticles and nanotubes to these coolants to form nanofluids can increase the thermal conductivity, and has the potential to improve the heat exchange rates and fuel efficiency. The improvements can be used to reduce the size of cooling systems or remove more heat from the vehicle engine exhaust while maintaning the same cooling system.

Tseng and co-worker have studied the effects of nanofluids in the cooling of automatic transmission (Tseng et al., 2005). In his study, CuO and Al_2O_3 at 4.4 wt % of nanoparticles and antifoam agents were dispersed into transmission fluid and then the transmission fluid was used in a real-time four wheel automatic transmission. The results showed that by using nanofluids, more heat were removed from the transmission system and the automatic transmission can be kept at lower temperature distribution at both high and low rotating speeds. Gosselin and Silva (2004) carried out an investigation on the optimization of particle loading in attempt to maximize the thermal transport performance of nanofluids with appropriate constraint conditions. They found that when the volume faction is low, the improvement of heat transfer rate is small, however when more nanoparticles were added, the increase in viscosity led to large shear stresses and then larger pumping power is necessary.

Nanofluids have been considered as the working fluid in heat pipes for electronic cooling applications. In a recent study, Ma and co-worker investigated the effect of nanofluids on the heat transport capability of an oscillating heat pipe (Ma et al. 2006). Nanofluids at a nanoparticles loading of 1 vol.% have shows to be capable to reduce the temperature difference between the evaporator and the condenser from 40.9 to 24.3 ^{o}C. Nanofluids also have the capability to provide the required cooling capacity in such applications as well as in other military systems, including military vehicles, submarines and high-power lasers. Nanofluids for military applications sometimes involve multifunctional nanofluids by adding thermal storage materials or energy harvesting materials through chemical reactions.

For the applications in cooling and thermal management, nanofluids technology can be used to improve oils and lubricants. Recent nanofluids research demonstrates the potential of adding nanoparticles into lubricants to improve the tribological properties, such as load-carrying capacity, wear resistance and friction reduction between the mechanical components in motion. It has been verified by experimental results that the addition of surface-modified nanoparticles can be easily dispersed into lubricants to form stable nanofluids which are effective in reducing friction and improving load-carrying capacitance.

1.2 Problems Statement

Based on the previous study and development effort on the heat transfer enhancement, major improvement in cooling systems capabilities have been limited because of low thermal conductivity of the conventional heat transfers fluids such as water, ethanol, and ethylene glycol. Since solid materials have much higher thermal conductivities than fluids, it was a great idea to add particles in the fluid to enhance the thermal conductivities of the fluids. However, if solid particles of micrometer, even millimeter magnitudes are added into the base fluids it will cause many troublesome problems. Large particles and the agglomeration in fluid flows carry too much momentum and kinetic energy, which may cause damage to the surface. Thus it was very useful to replace micro particles with nanoparticles in this research.

Noticeable thermal conductivity enhancement is based on particle concentration of the liquid. Thus with the presence of nanoparticles will increase the thermal conductivity proportional to the volume fraction of the nanofluids. Even a numbers of articles published on thermal conductivity of nanofluids each year, there are very limited data reported on low volume concentration of nanofluids especially at below dilute limits of nanofluids. Dilute is a process of making a substance less concentrated by adding a solvent. For the nanofluids, the dilute limits is with a 0.20 vol.% of the nanofluid (Kwak and Kim, 2005). If the particles concentration is less than the dilute limit, the particles can move and rotate freely. However, if the concentration of the nanofluids is more than 0.20 vol.% the particles will be in the semi dilute form which will then affected the particles to become unable to move and rotate freely hence influence the heat transfer and the enhancement will be limited.

In addition, the thermal conductivity for metallic nanoparticles is higher than of the metal oxide particles. This gives an advantage to the metallic nanoparticles for material research because they can give a high rate in the enhancement of the thermal conductivity. Even though it was clear that the thermal conductivity of metallic particles is higher compare to the oxide particle, the data reported on the thermal conductivity of metallic nanofluids is still limited due to less publication by previous researcher.

There are several aspects that can influence the thermal conductivity of nanofluids such as, particle size, temperature, base fluid, pressure and viscosity. The viscosity of the liquid can also be controlled by the pH. Previous research also predicted that nanofluids synthesis by adjusting the pH of the solution will show the tendency of a larger enhancement. This implies that, by controlling the pH of the nanofluids will lead to enhancement of thermal conductivity. However, the effect of pH on thermal conductivity of nanofluids is still in the infant stage which is the same case with low volume fraction and metallic nanofluids. These affect the data analysis on thermal conductivity enhancement by these factors to be limited and less report were published.

Due to the limitation from the previous research and advantages of the nanoparticles, hence the main objective of this research is to study the effect of volume fraction on the enhancement on thermal conductivity of Al, Cr, and Ni nanofluids. At the same time, we also study the influence of metal nanoparticles and the base fluid on the enhancement of the thermal conductivity. To observe the behavior of thermal conductivity of nanofluids, we also investigate the behavior of thermal conductivity enhancement by manipulating the pH concentration on Al nanofluids in distilled water.

The publications and reports on semiconductor nanofluids on thermal conductivity also very limited. This reasn had brings this study to one step further which is expended this research by measuring the thermal conductivity of semiconductor nanofluids prepared at different radiation dose. In this study, the semiconductor nanofluids that had being prepared are CdS and ZnS nanofluid using PVA water base fluid prepared at different radiation dose from 10 - 60 kGy.

1.3 Objective

The main objective of this work is to study the enhancement of the thermal conductivity on metallic nanofluids that varies with the volume fraction concentration. To achieve the main objective, several objective needs to be complete as followed.

1) To study the effect of the volume fraction concentration of Al, Cr, and Ni nanoparticles in distilled water, ethanol, and ethylene glycol on the enhancement of thermal conductivity nanofluids.

2) To examine the optimum of the thermal conductivity Al nanoparticles in distilled water affected by the pH value.

3) To study the thermal conductivity of CdS and ZnS nanofluid using PVA water base fluid prepared at different radiation dose.

1.4 Scope of Research

This work has a scope of limitation in instrumentation and sample preparation. The measurement of the thermal conductivity metallic nanofluids were measured using transient hot wire (THW) method due to it advantages especially in sample preparation and experimental set up. In this experimental, we used KD2 Pro Thermal Analyzer supplied by Decagon Device was done at room temperature in the laboratory (27 ^{0}C).

For metallic nanofluids, the sample were only prepared using Al (18 nm), Ni (20 nm) and Cr (30 nm) of nanoparticles and used three type conventional fluid. The base fluids used in this study are ethanol, distilled water and ethylene glycol. For the experiment in

observing the pH effect on thermal conductivity of nanofluids, we only measured the thermal conductivity of Al/distilled water at five different pH value ranges 1-14.
In addition, this research only measured the thermal conductivity of nanofluids at the range 0.01 - 0.30 vol.% which mostly cover for dilute limits of metallic nanofluids. For semiconductor nanofluids, the samples were only subjected on CdS and ZnS nanofluids in PVA which had prepared using radiation dose range from 10-60 kGy.

1.5 Thesis Outline

Chapter 1 presents the general view and concept of nanofluids and the technique. The description on the concept of nanotechnology and definition of the nanofluids has been briefly introduced in this chapter. This chapter also includes the problems statement, objective, scopes of research and an outline for the thesis.

In Chapter 2, we will discuss on literature review of the method that we used in measuring the thermal conductivity of nanofluids from the previous researchers who had a success with the technique. The summary of published articles respecting to the effect of volume fractions, base fluids, particles size and pH of nanofluids on thermal conductivity enhancement were also present in this chapter.

Chapter 3 devoted to present the theories on the method that used in this work and explain the deviation of the thermal conductivity from the Fourier’s Law. We also present the theories from Maxwell and Hamilton Crosser in 1891 on thermal conductivity.

Chapter 4 presents the preparations of all sample and experimental set up were presented. The method was used in preparing the nanofluids present with details in this chapter. Besides that, this section also describes in detail in the procedure and instrumentation that we use in measuring the thermal conductivity of nanofluids.

Chapter 5 discussed the data collections and analysis in the experiment on thermal conductivity of metallic nanofluids and also the characteristic of the materials. The effect on volume fraction, base fluid, pH and metal particles were also discussed in this chapter.

Chapter 6 is devoted to present the main conclusion for this work. In addition, this chapter also presents some suggestion for future work and research to create more interest in nanofluids and expends the nanotechnology fields.

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