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"I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Thermal-Fluids)"

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PR24-HHT CARBON FIBER NANO-COOLANT FOR COOLING SYSTEM

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This report is submitted in partial fulfillment of requirement for the award of Bachelor of Mechanical Engineering (Thermal Fluid)

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DECLARATION

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"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

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Date :…………………………………….

For my beloved and inspiring

Parents and Siblings

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ABSTRACT

A coolant is the most crucial component for a cooling system where currently the predominant coolant utilized is fluids such as water, oil and ethylene glycol. Generally solids have a higher thermal properties compared to fluids thus in order to increase the efficiency of the coolant, an idea was instigated of combining solid particles with fluid. However large size particles in the mixture can cause negative impact on the cooling system such as erosion. The aim of the research is to formulate a nano-coolant from carbon nanofibres and a commercial coolant with a goal to enhance the coolant's thermal properties in terms of thermal conductivity, heat capacity and heat transfer efficiency through the use of dispersing agent and external agitation to achieve well dispersed nanofluids. The formulation of the nanofluids planning of the percentage weight and synthesizing of the samples (0.1wt%-1.0wt%) tested on variable temperature (3 °C, 6 °C, 25 °C, 45 °C and 60 °C) with the aid of a dispersing agent (Polyvinylpyrrolidone) and external agitations process via homogenizers and ultrasonication. Improvements on the standard coolant through the dispersion of PR24-HHT nanoparticles, is observed in terms of thermal conductivity and heat transfer coefficient whereby the factors of enhancements are the increment of heat and the percentage weight of the nanoparticles with an anomalous effect. The highest enhancements of thermal conductivity of the samples compare to the standard coolant is recorded at 72.5% at the temperature of 60 °C while the highest enhancements of heat transfer coefficient is at 155.56 % at the temperature of 25 °C in which both is at the percentage weight of PR24-HHT particles of 0.9wt%. However the heat capacity of the nanofluids undergoes degradation as the percentage weight of the nanoparticles increases. It is determined then that the NC023 sample with a 0.9wt% of PR24-HHT particles exhibits the greatest improvement on the standard coolant properties in terms of thermal conductivity and heat transfer coefficient with ensured stability.

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ABSTRAK

Cecair penyejuk adalah komponen yang penting untuk sistem penyejukan dan contoh cecair yang biasa digunakan adalah air, minyak dan etilena glikol. Secara amnya pepejal mempunyai sifat haba yang lebih tinggi berbanding cecair. Bagi meningkatkan sifat haba cecair penyejuk tersebut, penggabungan zarah pepejal dan cecair penyejuk dihasilkan. Namun begitu, kesan negatif seperti hakisan dalam sistem penyejukan akan timbul dari zarah pepejal bersaiz besar. Fokus kajian bertujuan menghasilkan sejenis cecair penyejuk nano menggunakan gentian nano karbon dan cecair penyejuk komersil untuk meningkatkan sifat haba cecair penyejuk dari segi kekonduksian termal, muatan haba dan kecekapan pemindahan haba melalui penggunaan ejen pengurai dan proses perolahan untuk mencapai kestabilan. Penghasilan bendalir nano melibatkan perancangan peratusan berat zarah nano dan mensintesiskan sampel (0.1wt% - 1.0wt%) dan diuji pada suhu berbeza (3 °C, 6 °C, 25 °C, 45 °C and 60 °C) dengan bantuan ejen pengurai (Polyvinylpyrrolidone) dan aplikasi proses perolahan melalui penggunaan alat penyeragaman dan ultrasonikasi. Kekonduksian termal dan kecekapan pemindahan haba terhadap bendalir nano yang dihasilkan direkodkan mempunyai peningkatan dimana faktornya adalah dari peningkatan haba dan peratusan berat zarah nano yang menunjukkan kesan kejanggalan. Peningkatan tertinggi dalam kekonduksian termal direkodkan pada 72.5% pada suhu 60 °C manakala untuk kecekapan pemindahan haba pula direkodkan pada 155.56% pada suhu 25°C dimana kedua-dua peningkatan dicapai oleh cecair bendalir mengandungi peratus berat zarah PR24-HHT pada 0.9wt%. Namun, sifat muatan haba bendalir nano mengalami degradasi pada kadar peningkatan peratusan berat zarah nano di dalam bendalir nano tersebut. Hal ini ditentukan kemudian bahawa sampel NC023 mengandungi 0.9wt% zarah PR24-HHT mencapai peningkatan terbaik dari piawai cecair penyejuk dimana peningkatan

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dicapai pada kekonduksian termal dan kecekapan pemindahan haba disertakan jaminan kestabilan.

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LIST OF SYMBOLS

C	=	Specific Heat Capacity, J/kg·K
ρ	=	Density, kg/m^3
ΔT	=	Temperature Difference, °C
K	=	Thermal Conductivity, W/m.K

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CHAPTER I

INTRODUCTION

1.0 INTRODUCTION

Cooling system is an important aspect dealt in many fields that utilizes heat energy such as transportation and power generation. The most commercial coolant used in cooling systems is water and oil. High-performance cooling is crucial to the industrialized technology resulting in continuous research on improving the performance of the coolant. Thus ongoing research is conducted to gain enhancements on coolants in terms of thermo physical properties specifically thermal properties. Thermal conductivity of the working fluid is one of the major parameters in terms of heat transfer. As of now the most dominant coolant utilized for cooling are fluids such as water, ethylene glycol and engine oil which have less thermal conductivity compared to solid particles that is metallic, non-metallic and carbon based. This subsequently stirs up the idea of combining both solids and fluids to enhance the thermal properties of the coolant for an efficient cooling system.

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1.1 PROBLEM STATEMENT

A cooling system requires a coolant to increase its cooling performance whereby commercial coolant such as water is generally used as it has high thermal conductivity and heat capacity. In order to further increase the cooling performance of said cooling system, a more efficient coolant is proposed by altering the properties of the commercial coolant by mixing it with a solid which will improve its thermal conductivity. However the large size particles in the mixture can cause negative impact on the cooling system such as erosion. Thus a study on the formulation of nanofluid from PR24-HHT carbon nanofibre and commercial coolant is to be done to find its performance on thermal conductivity, heat capacity and heat transfer efficiency.

1.2 OBJECTIVE

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The main objective of this project is to formulate highly efficient carbon based nano-coolant from PR24-HHT carbon nanofibre, dispersing agent and commercial coolant.

1.3 SCOPE

i. To formulate a stable nanofluid coolant from the mixture of PR24-HHT carbon nanofibre and Ethylene Glycol.
ii. To find a suitable ratio of the base fluid, carbon nanofibre (CNF) and dispersing agent for the stability of the nanofluid mixture.
iii. To analyze the thermal properties of the nanofluid on thermal conductivity, heat capacity and heat transfer capacity efficiency.

CHAPTER II

LITERATURE REVIEW

2.0 INTRODUCTION

Nanotechnology is the design, characterization, production and application of materials, devices and systems by controlling shape and size at the nanoscale whereby the nanoscale itself is from the range of 1 to 100 nm. The International Standards Organization defines nanotechnology as understanding and control of matter and processes at the nanoscale typically, but not exclusively, below 100 nm in one or more dimension where the onset of size-dependent phenomena usually enables novel application; and utilizing the properties of nanoscale materials that differs from the properties individual atoms, molecules, and bulk matter, to create improved materials, devices, and system that exploit these new properties (Ramsden, J. R, 2009). Nanotechnology is considered as a stepping stone for a more progressive world in the years ahead as it benefits on fabricating new material for vast application but it also raises concerns on its impact to the environment.

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2.1 NANOFLUID

2.1.1 Definition of Nanofluid

According to Yu, W. and Xie, H. (2012), nanofluids are a new class of fluid engineered by dispersing nanometer sized particles through the base fluid which is basically a nanoscale colloidal suspensions containing condensed nanomaterials. Thermal conductivity, viscosity, heat transfer coefficient, and thermal diffusivity which are thermo physical properties are enhanced in nanofluids compared to conventional base fluid such as water, oil and ethylene glycol. Nanofluid is a kind of new engineering material consisting of solid nanoparticles with sizes typically of 1 to 100 nm suspended in base fluids where solving problems such as sedimentation, cohesion and corrosion which happen conventionally in heterogeneous solid/liquid mixture with millimeter or micrometer particles, but also increase the thermal performance of base fluids remarkably is possible (Zhu, D. et al. 2009). According to Wang, X. Q. and Mujumdar, A. S. (2008), a much larger relative surface area due to nanoparticles are present in nanofluids when compared to conventional fluids mainly coolant and both stability of the colloidal suspension as well as the thermal conductivity will be increased. Moreover, the interaction between the nanoparticles and fluids responds to their local environment in terms of heat is efficient due to the high thermal conductivity it possesses and the also improve the abrasion relation of those properties when compared to the conventional coolant. Besides that nanofluid is a mixture of nanoparticles and fluid which have enormous potential to improve the efficiency of heat transfer fluids.

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2.1.2 Application of Nanofluids

As of now there are many applications of nanofluids to various fields due to the capabilities in thermal properties and energy efficiency. This section specifies on the applications of nanofluids in different areas based on available research.

2.1.2.1 Nuclear Reactor

The prevention of severe accidents due to the core meltdown is crucial as the molten fuel shifted to the base of the reactor vessel at extremely high temperature. It is the in the best interests to sustain the molten fuel within the vessel by expelling heat from the outer vessel surface. Through the use of nanofluids, the retention capabilities of nuclear reactors can be increased by 40% from the standard use of cooling process, (Buongiorno, J. et al. 2009). You et al. (2003) also discovered that usage of nanofluids can double or triple the critical heat flux (CHF) in pool boiling. Other than that, Kim et al. (2006) discovered that nanoparticle deposition causes high surface wettability and increases the thermal properties of the nanofluid. The nanofluid greatly increases CHF which is the upper heat flux limit in the nucleate boiling system.

2.1.2.2 Automotive

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Many research were conducted on the usage of nanofluids in automotive to improve the performance and efficiency of in terms of heat. Singh, A. K. et al. (2006), have found that utilizing nanofluids with high thermal conductivity in radiators leads to a reduction in the frontal area by up to 10% which will lead to fuel savings of up to 5%. In their test it is observed that no erosion when utilizing nanofluids made from base fluid ethylene and tri-chloroethylene glycols with velocities up to 9 m/s at an impact angle of 90º to 30º. Other than that, Tzeng et al. (2005) conducted research in application of nanofluid in vehicle power transmissions system as cooling agent via dispersing Copper (II) Oxide and Aluminium Oxide particles in transmission oil. Other research include the works of Zhang, Z. and Que, Q. (1997), reduces wear and enhances load carrying capacity in vehicles through dispersing surface modified nanoparticles into lubricants.

2.1.2.3 Electronic Cooling

The usage of nanofluids vast greatly and extends towards electronics cooling which is performed in various research such as of Tsai et al. (2004) where water based nanofluids is used as coolant for heat spreader in a CPU of desktop PC. Other than that, Ma et al. (2006) researched the heat transport capability of heat pipes that oscillates and shows promising results were at 1 vol% of the nanoparticles in the nanofluid decreases the temperature between evaporator and condenser by 16.6 °C at 80 W. Other related research includes the works of Nguyen et al. (2007) whereby they utilizes nanofluids flowing inside closed system to be used for micro-electronic component cooling.

2.1.3 Stability of Nanofluid

Due to gravity, dispersed particles will adhere together and aggregates and thus form clumps of increased size. Stability of a nanofluid is where the nanoparticles do not exhibit aggregation at as significant rate. The stability of the nanofluid is vital as agglomeration of nanoparticles can occur which can cause sedimentation and clogging in micro channels that utilizes the nanofluid. Agglomeration due to unstable nanofluids can also cause the decrease in thermal conductivity of nanofluids thus research on the stability of the nanofluids is an importance aspect to be considered.

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2.1.3.1 Stability Evaluation Method

Various methods have been developed for stability evaluation of nanofluids and the most common method would be the sedimentation and centrifugation method. The method of sedimentation balance is used by (Zhu, H. et al 2007) to evaluate the stability of graphite suspension by immerging the sedimentation balance tray to the graphite suspension. The weight of the sedimentation is then measured from time to time. This method is obsolete as long periods is required to complete the observation of the sedimentation thus centrifugation method is developed. Singh, A. K. et al. (2008) utilized the centrifugation method to measure the stability of silver nanofluids prepared from reduction of $AgNO_3$ with PVP as dispersing agent via microwave synthesis in ethanol. A more advanced method for stability evaluation is the zeta potential analysis where according to Yu, W. and Xie, H. (2012), electric potential within the interfacial dual coating of the area in a sliding plane as oppose to a place within the mass liquid from the actual user interface exhibits possible distinction in between the actual distribution moderate and the fixed coating associated with the liquid mounted to the actual spread particle. These can be implemented to the actual balance associated to the colloidal dispersion of nanofluid. Thus, colloidal along with higher zeta potential in negative and positive value tends to be electrically stable while coagulation occurs on reduced zeta potential of colloids. Another methods of stability evaluation is by spectral absorbency analysis by analyzing the linear relationship of the absorbency strength and the focus of the nanoparticles within the nanofluid. (Yu, W. and Xie, H. 2012).

2.1.3.2 Stability Enhancement

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Adding surfactants called dispersant can significantly increase the stability of nanofluids as dispersants can influence the surface characteristics of a system in a small quantity. Generally dispersants increases the contact of two materials which is known as wettability. In a two-phase system, a dispersant locates the interface of the two phase which in this case is the nanoparticles and base fluid and introduces a degree of continuity between the two, Yu, W. and Xie, H. (2012). Another method of to enhance the stability is by surface modification techniques through the usage of functionalized nanoparticle as shown in the research of (Yang et al. 2010) where they produces functionalized silica (SiO_2) nanoparticle via grafting silanes straight to the associated silica nanoparticle within a unique nanoparticles options. Hwang et al. (2007) introduces a hydrophilic functional nanoparticles through mechanochemical response which put together surfactant-free nanofluid. Other works that include surface modification techniques is performed by Chen et al. (2010) where it was demonstrated the outcomes of the infrared range of the zeta possible dimension of the hydroxyl group introduced to the treated CNT area.

2.1.4 Synthesis of Nanofluid

The preparation method is crucial in determining the stability of where two methods are developed which is the two-step method and the one-step method.

2.1.4.1 Two-Step Method

This is the most commonly used method to synthesize nanofluids as it is the most beneficial method to produce nanofluids in large scale due to the industrial scale production of the nanoparticle powder. Through the use of chemical and physical methods, nanoparticles are mainly produced as dry powders first. With the assists of intensive magnetic force agitation, high shear mixing, ultrasonic agitation, mechanical homogenizing, and ball milling, the nanoparticles is then dispersed into the base fluid as the second step of processing the nanofluid which coined the term two-step method. Nanofluids have tendency to aggregate due to high surface area and surface activity thus surfactants is required to ensure the stability of the nanofluid. A more advanced techniques are develop due to difficulties in the two-step method as the surfactants used can affect the characteristics of the nanofluid, (Yu, W. and Xie, H. 2012).

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2.1.4.2 One-Step Method

Invented by Akoh, H. et al. (1978), this technique involves direct condensation of metallic vapor into nanoparticles by contact with a flowing low vapor pressure liquid direct condensation of metallic vapor into nanoparticles is utilized through the use of contact of flowing low vapor. The one-step process consists of simultaneously making and dispersing the particles in the fluid. In this method, the processes of drying, storage, transportation, and dispersion of nanoparticles are avoided, so the agglomeration of nanoparticles is minimized, and the stability of fluids is increased (Li, Y. et al. 2009). This method was used by Eastman, J. A. et al. (2001) in order to disperse nanocrystalline copper particles into ethylene glycol with minimal agglomeration. The one-step method is being develop further as although it is efficient compared to two-step method, it is cost inefficient and unable to produce nanofluid at a large scale. Zhu, H. et al. (2004) presented a novel one-step chemical method for preparing copper nanofluids by reducing Copper

(II) Sulfate and Sodium Hydrophosphite in ethylene glycol under microwave irradiation which results in a well-dispersed and stable suspended nanofluids. Laser ablation is the technique that simultaneously makes and disperses nanoparticles directly in water. There are various nanofluids that has been prepared by laser ablation method by ablating solid metals, semiconductor and others. This method is very useful for further splitting of nanoparticles present in nanofluids to study effect of nanoparticles present in nanofluid, (Phuoc, T. X. et al. 2011).

2.2 Carbon Nanotube and Carbon Nanofibre

According to Dresselhaus et al. (2004), carbon nanotubes (CNTs) are tubular structures that are typically of nanometer diameter and commonly micrometers in length. Carbon nanotubes are made up of nanoparticles that can be in the form of spherical and cylindrical. However, only nanoparticle that exists in cylindrical form and tubular structures which in nanometer in size of diameter is called carbon nanotube, (Paritosh et al. 2009). Based on Chen, L. et al. (2011), CNTs possess unique electronic, chemical, and mechanical properties that make them leading materials for a variety of potential applications. Patel, H. E. et al. (2008) states that liquids containing suspended nanoparticles with the size of less than 100 nm are called nanofluids, whereas liquids with suspended graphite particles or carbon nanotubes (CNT) are known as CNT nanofluids.

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Based from Rosolen, J. M. et al. (2006) carbon nanotubes are categorized as single-walled nanotubes (SWNTs), multi-walled nanotubes (MWNTs), and cup-stacked nanotubes (CSNTs). Through electric arc-discharge, laser vaporization, and chemical vapor deposition, carbon nanotubes can be produced where these growth methods are basically the transformation of carbon compounds to atomic carbon through the usage of decomposition. This is then followed by the growth of carbon nanostructures on catalytic particles such as Co, Mo, Ni, and Fe. In chemical vapor decomposition, the catalytic particles may be supported either on a substrate (e.g., Al_2O_3, Zeolite, Si and MgO) or on carbon materials, as illustrated in Figure 2.1.

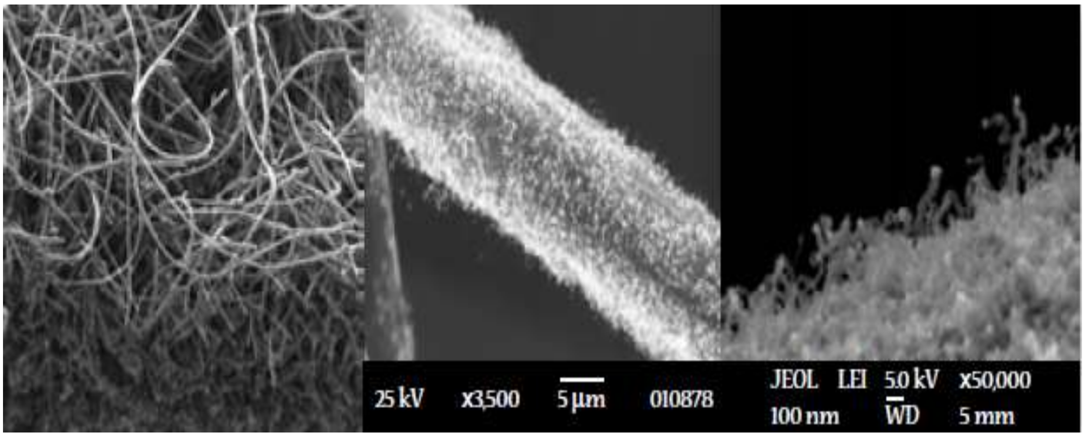

Figure 2.1: Growth of carbon nanostructure on catalytic particles

(Source: Rosolen, J. M. et al. 2006)

Carbon nanofibres differs from carbon nanotubes in terms of physical properties. According to Chee, S. L. (2010), CNF are hollowed core filament that consists of single layer or double layer of graphite planes stacked at a certain angle or parallel to the fibre axis. There are several stacking geometry of the graphite plane where different structures which is the parallel, bamboo-like and cup-stacked CNF to be obtained. CNF possesses high nano-scale diameter compared to Single-Walled CNT and Multi-Walled CNT which can be observed in Table 2.1.

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Table 2.1: Comparison of physical properties of CNT and CNF

Material	Diameter (nm)	Length (µm)
CNF	60-200	30-100
SWCNT	0.6-1.8	0.5-30
MWCNT	5-50	10-50

(Source: Chee, S. L. 2010)

In this research, carbon based nanoparticles specifically CNF are chosen due to its characteristic and its effect on the properties of the base fluid. Based on the research of Choi, S. and Eastman, J. A. (1995), enhancements of thermal conductivity using carbon based nanoparticles is up to 160% due to properties of carbon based where carbons have large thermal conductivities combined with low densities compared to metal. Other materials exhibit a large thermal conductivity when its densities are large however, in carbon based nanoparticles low densities increases its thermal conductivity and fluids it is dispersed into. This anomalous characteristic were proven by Eapen, J. et al. (2007) based on the analytical predictions of Maxwell mean-field theory which is that for a given base fluid, temperature, and nanoparticle size, the enhancement in the thermal conductivity depends on the nanoparticle density , and for nanoparticles with low density, the thermal conductivity can be largely positive. Using suspensions of silica and perfluorinated nanoparticles that are low in density, they succeeded in synthesizing nanofluids with enhancements of thermal conductivity.

2.2.1 Types of CNT

2.2.1.1 Single-Walled Nanotube (SWNT)

A single-walled carbon nanotubes as shown in Figure 2.2 consists of a single sheet of grapheme rolled seamlessly to form a cylinder with diameter of order of 1 nm and length up to centimetres based on the research of Iijima, S. et al (1993) and Bethune, D. S. et al. (1993). Common methods for synthesizing a SWNT are via laser ablation and chemical vapor deposition which is demonstrated in the research of Puretzky, A. A. et al (1999) and Hernadi, K. et al. (1996). In the research of Moisala (2006), due to lower cost, simpler dispersability and easier accessibility, the MWNTs are hugely utilized as conductive fillers instead of the SWNTs. However, additional reduction within the filler content material can be achieved by utilizing SWNTs due to its higher innate electrical and thermal conductivity associated with the enhancement of the composite qualities.

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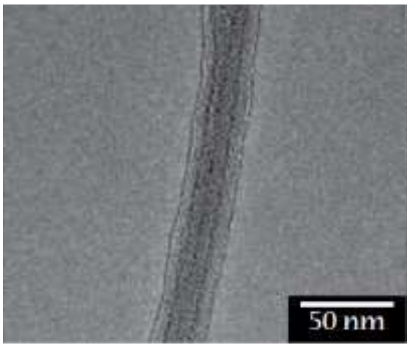

Figure 2.2: HRTEM of beams of four single-walled carbon nanotubes

(Source: Rosolen, J. M. et al. 2006)

2.2.1.2 Multi-Walled Nanotube (MWNT)

The structure of the multi-walled carbon nanotube consists of double concentric tube in a single configuration where the concentric tube around the common central hollow subjected to separation between the layers close to the graphite interlayer spacing, (Tang, W. et al 2003). These separation is due to the central cavity of a nanotube is traversed by graphitic layers, effectively capping one or more of the inner tube and reducing the total number of layers in the tube as shown in Figure 2.3 based on Harris, P. J. F. (1999).

According to Coleman, J. N. et al. (2006), a common production method for MWNT is the chemical vapor deposition due to its low cost and large scale production but this method have a large quantities of defects causing its physical properties suffer in terms of thermal, electronic and mechanical properties. MWNTs have a current carrying capacity equal to that of the SWNTs but SWNTs have lower thermal conductivity than MWNTs. This is because MWNT have a simpler fabrication due to easier control of the growth process. Moreover, MWNTs are polymers of pure carbon and can be reacted and manipulated using the rich chemistry of carbon.

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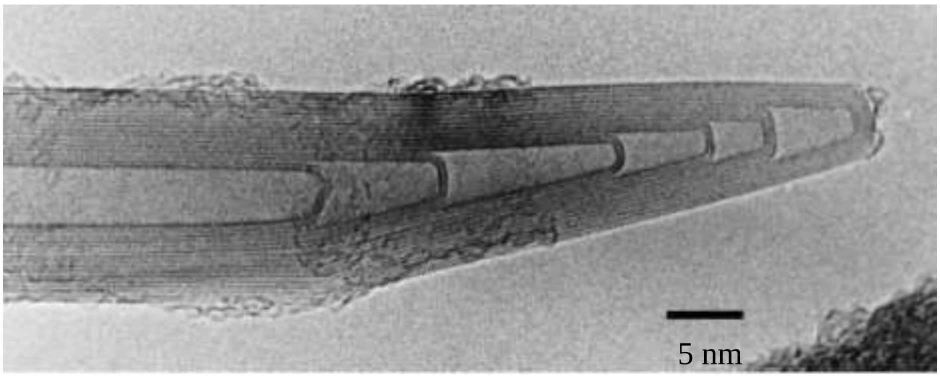

Figure 2.3: Multi-walled nanotube with 'internal cap'.

(Source: Harris, P. J. F. 1999)

2.2.2 Carbon Nanofibre (CNF)

2.2.2.1 PR24-HHT CNF

Two types of carbon nanofibres, PR19-HHT and PR24-HHT is developed by Pyrograf Products Inc. for thermal usage and PR24-HHT is chosen to be used for the nanoparticles in this research whereby it is the most suitable nanoparticle for the usage in terms of thermal transport in a fluid due to PR24 having a higher surface area compared to PR19 (Pyrograf Product Inc.). Through the research of Tessonier et al. (2009), it is observed that PR19 and PR24 contains no impurities of other particles and the structure is tubular with a large outer diameter as large as 5 μm. Improvements of thermal properties is implemented using CNF in various literatures, whereby carbon nanofibre type PR24-HHT at 16 wt% loading showed a 70% increase in thermal conductivity, (Wang, C. S. and Alexander, M. D. 2004). Previous research on the dispersion of PR24-HHT on base fluid to produce nanofluid shows increase in thermal properties as observed in the work of Wan Harun, W. M. H. (2013) whereby the thermal conductivity of the nanofluid is enhanced to approximately 47.93% from the base fluid which is water.

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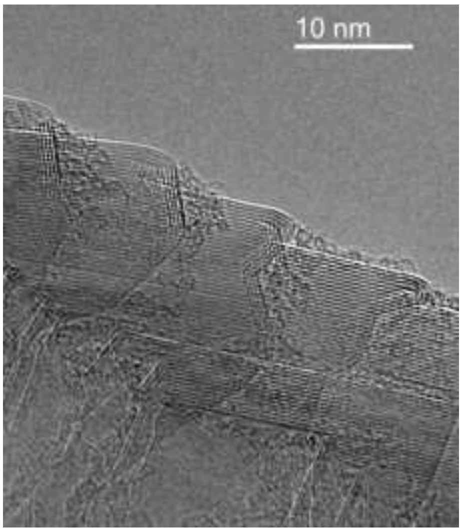

Figure 2.4: HRTEM image of PR24-HHT with a schematic structure

(Source: Tessonier et al. 2009)

2.3 Dispersing Agent

Dispersing agent or surfactant is a compound having both polar and a polar groups, adsorb at the interface between immiscible bulk phases, such as oil and water or particles or solution, act to reduce the surface tension based on Murshed, S. M. (2008). According to Huang, Y. Y. and Terentjev, E. M. (2012), the hydrophobic block of the surfactant is relatively small, thus multiple surfactant molecules can pack around the circumference of a CNT. On the other hand, biomolecules and some polymeric surfactants such as Polyvinylpyrrolidone tends to wrap around the CNT center through their flexible or semi-flexible backbones.

2.3.1 Polyvinylpyrrolidone (PVP)

Polyvinylpyrrolidone (PVP) which are commonly called Polyvidone or Povidone is a water-soluble polymer and manufactured from the monomers of N-vinylpyrrolidone. Improvements in terms of agglomeration utilizing the PVP is effective as dispersing agent, (Zhu, H. et al 2007). Based on Singh, A. K. and Raykar, V. S. (2008), PVP is a polar polymer that is protective and is employed as a stabilizer of colloidal silver which also acts as reducing agent for silver in solution, thus producing metallic silver in solution. The structure of the PVP is as shown in Figure 2.5. The dispersing agent introduced to the hydrophobic nanoparticle and base fluid causes electrostatic repulsion between surfactant-coated carbon nanotubes, thus reducing the particle agglomeration due to van der Waals forces, (Hwang et al. 2008).

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According to Zhu et al. (2007), the preparation of nanofluid with graphite nano-powder suspension is dispersed inside a distilled water with the pH value of the nanofluid modified at 9.5 along with ammonia 0.5 wt% Polyvinylpyrrolidone (PVP-K30) as a dispersant. Previous research of Mohamad, M. K. M. (2013) states that, in comparison of two types of dispersing agent which the PVP and Sodium Dodecyl Sulphate (SDS), it is discovered that nanoparticles dispersed in water with dispersing agent of PVP exhibits a more stable nanofluid and more enhancements in terms of thermal conductivity. The advantages of using PVP instead of SDS is that the usage of SDS induces foam during the homogenization process of the nanofluid.

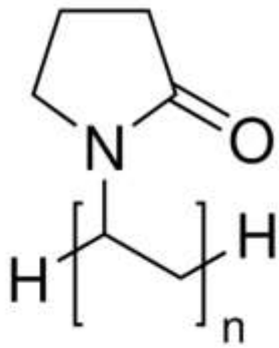

Figure 2.5: Polyvinylpyrrolidone (PVP)

(Source: Sigma-Aldrich Co. 2013)

2.4 Thermal Conductivity

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As a measure of the property of a material to conduct heat, thermal conductivity is defined as the quantity of heat transmitted through a unit thickness in a direction normal to a surface of unit area due to a unit temperature gradient under steady state conditions and when the heat transfer is dependent only on the temperature gradient by Alam, M et al. (2012). Estimation of enhancement in thermal conductivity analytically is inaccurate due to breakdown at nanosize. In various literatures, the enhancements in thermal conductivity of the base fluid were enhanced more than 50% when dispersed with nanoparticles specifically metallic nanoparticles, (Singh, A. K. 2008). Dispersions of carbon based nanotubes in base fluid exhibits anomalous characteristics on the enhancements of thermal conductivity where Choi, S. and Eastman, J. A. (1995), achieved 160% enhancement in thermal conductivity of the nanofluid. The principal behind the increase in thermal conductivity of the nanofluid lies in several factors such as the volume fraction of the nanoparticles as observed by Choi, S. et al. (1999) where experiments are conducted on heat transport system with CuO and Al_2O_3 in ethylene glycol and discovered that the nanoparticles enhance the heat transport by 20% and the improved thermal conductivity can be observed in Figure 2.6. The volume fractions also exhibits anomalous effect on the enhancements of thermal conductivity of the nanofluid as suggested by Eastman, J. et al. (2001).

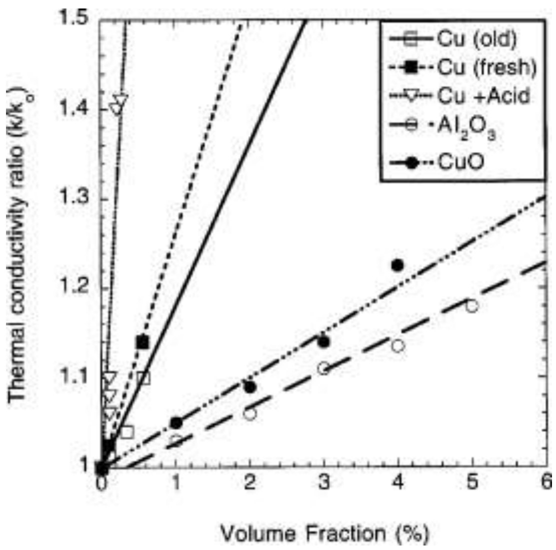

Figure 2.6: Thermal conductivity ratio of increasing volume fraction of nanoparticles (Source: Eastman, J et al. 2001)

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Other factors of the enhancements of thermal conductivity is the Brownian motion of the nanoparticles suspended in the base fluid with the increase in volume fraction of the nanoparticle and increase in heat. According to the research of Choi, S. and Seok, P. J. (2004), they proposed a theoretical model to predict the effects of volume fraction and heat on the thermal conductivity of nanoparticles suspended in a base fluid through the Brownian motion of the particles. The result is in line with the experimental data whereas the volume fraction and heat increases, the viscosity of the base fluid decreases thus inducing the Brownian motion of the nanoparticles to increase and consequently the convection like effects are increased resulting in the dramatic increase of the thermal conductivities. This pattern is also achieved recently by Mohamad, I. S. et al. (Mohamad, I. S. et al. 2013; Mohamad, I. S. 2012; Mohamad, I. S. et al. 2011) as an increase in thermal conductivity for nanofluid as the temperature increases which is shown in Figure 2.7, whereby most enhancement occurs with higher wt% nanocarbon loading and the highest recorded enhancement occurs at NC300 nanocarbon with 1 wt% at 45 °C giving a 31.15% (0.812 W/m.K).

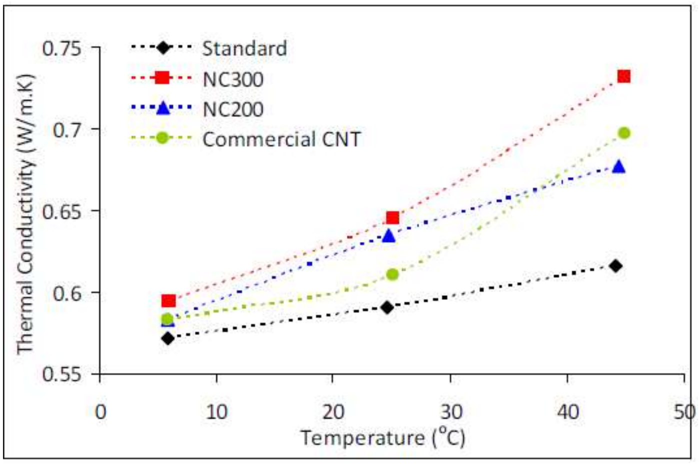

Figure 2.7: Thermal conductivity data of nanofluid-based NC300, NC200 and Commercial CNT.

(Source: Mohamad, I. S. et al. 2013)

2.5 Specific Heat Capacity

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The specific heat capacity, C (J/kg·K) of a matter is defined as its ability to store thermal energy and is determined through evaluating the amount of energy in the form of heat required to increase the temperature of a unit mass of a matter by one degree. According to Gunn et al. (2005), specific heat capacity is the material property that determines the amount of energy absorbed or released, or the enthalpy change in a body before its temperature will change. The specific heat capacity in nanofluids in various literatures reports that minute concentration of nanoparticles can exhibit dramatic change in the values of specific heat capacity as can be observed in the research of Zhou, S. and Ni, R. (2008), where the specific heat capacity of water decreases as Al_2O_3 nanoparticles are dispersed. Several other aqueous nanofluid in various research also experienced degradation in the specific heat capacity as observed in Namburu et al. (2007) research where a 60:40 ratio of ethylene glycol and water as base fluid is dispersed with 10% concentration of Silica nanoparticles and resulted in the decrease of specific heat capacity by 12%. However, Vajjha and Das (2009) reported that for aqueous silica nanofluids have an exceptional specific heat capacity far exceeds pure water at temperatures of 70 °C which is considered at high temperature. In a non-aqueous solvent, nanoparticles exhibit enhancements in specific heat capacity of up to 120%, (Shin and Banarjee, 2010).

2.6 Heat Transfer Coefficient

The enhancements in thermal conductivity is not sufficient to determine whether a nanofluid have an overall improvement in terms of heat transport thus the enhancements of the nanofluid in terms of heat transfer coefficient is sought out. The heat transfer test is performed for the first time in the form of heat convection. According to Eastman et al. (1996), an enhancements of approximately 15% of heat transfer coefficient through a sample of 0.9 volume fraction of CuO nanoparticles dispersed in distilled water. The research of Xuan and Li, discovered that nanofluids with water based with Cu nanoparticles have an improvement in the convective heat transfer in the range of fluid flow of Reynold number of 10,000 and 25,000. The Nusselt number of the nanofluids that contains volume fraction of 2% of Cu nanoparticles exhibits and increase in approximately 39%, (Xuan and Li, 2000; Xuan and Roetzel, 2000).

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It is observed that the Nusselt number of nanofluids with water based increases as the volume fraction and the Reynold number increases. The correlation of Dittus-Boelter fails to explain the heat transfer coefficient pattern in nanofluids. However, the enhancements in the viscosity of the nanofluids probably have a negative effect in the heat transfer convection, as discovered by Pak and Cho (1998), a reduction in the heat transfer coefficient through the dispersion of 3% volume fraction of Al_2O_3 and TiO_2 at approximately 12% compared to heat transfer coefficient of distilled water. From the research of Wen, D. and Ding, Y. (2004), they performed a laminar heat transfer experiment through flowing Al_2O_3 nanofluids onto a tube and applying forced convection to the fluid flow and discovered that the nanofluid with a volume fraction of 1.6% exhibits enhancements in terms of heat transfer coefficient by 41%. This pattern is also achieved recently by Mohamad, I. S. et al. (2013), showing an increase in heat transfer coefficient from standard sample through the use of laboratory produced NC300.

CHAPTER III

METHODOLOGY

3.0 INTRODUCTION

The concept of experimental method or methodology is the determination of the components, parameters, method of work, rules and techniques used to conduct a research. The main reason a methodology is done is to ensure the objectives and goals are achieved. In this research, the methodology is planned into two stages in which the first stage discusses on the formulation of the nanofluid samples and its stability while the second stage discusses on the testing of the thermal conductivity, heat capacity and the heat transfer coefficient. In order to synthesize the nanofluid, parameters are selected before conducting the experiments.

A flow diagram is also prepared for to represent the workflow of this research in order to keep the planned task done accordingly as shown in Figure 3.1. In order to achieve a stable nanofluid samples, correct and planned work is needed to ensure enough time and produce results. Four experiment are to be considered in this research which are the formulation of nanofluid samples, stability test, thermal conductivity test, heat capacity test and heat transfer analysis.

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3.1 FLOW CHART OF PSM WORKFLOW

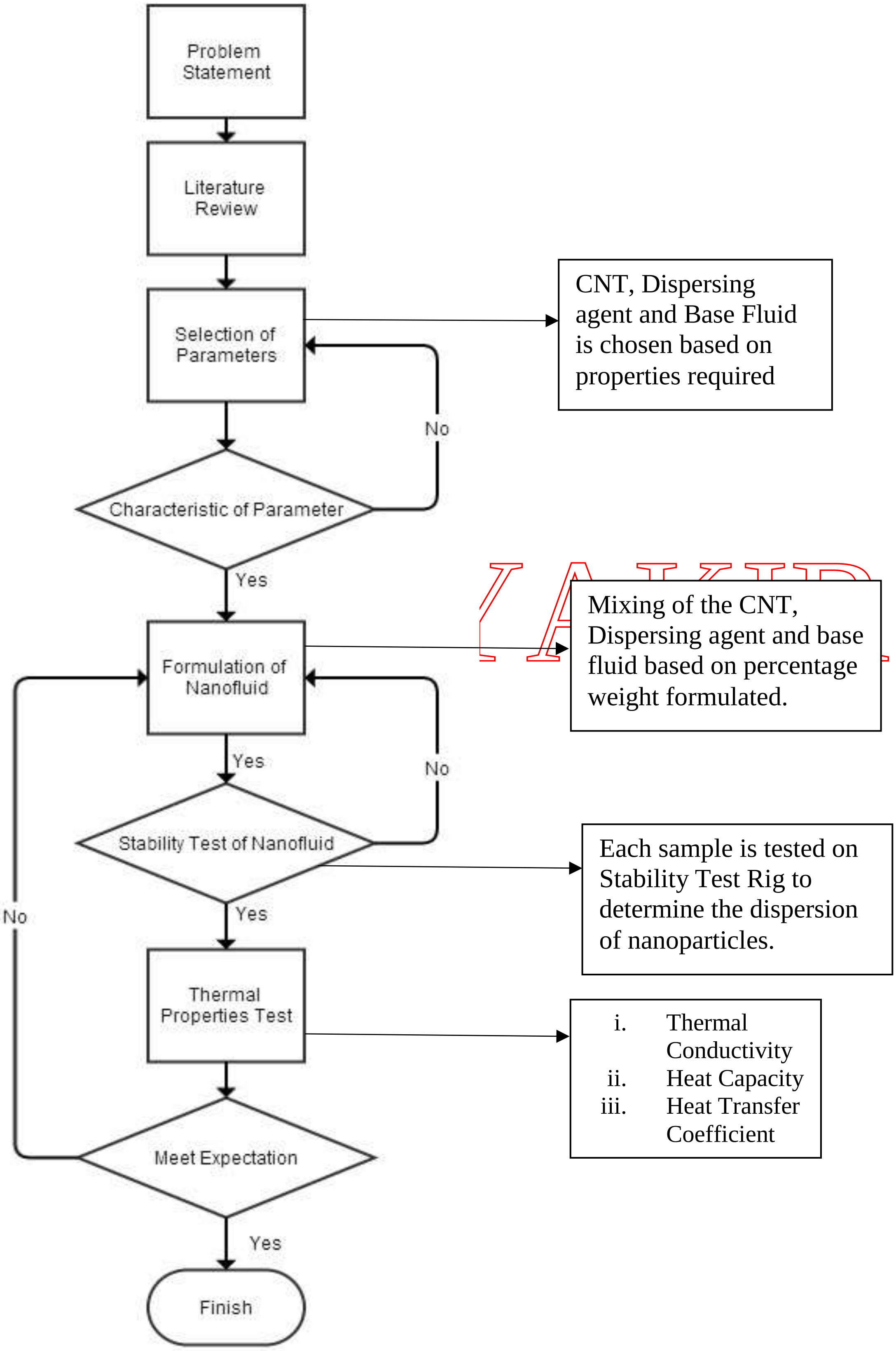

Figure 3.1: Flow chart of work flow of PSM

3.2 PARAMETERS

Four parameters are considered to synthesize the nanofluid which is:

i. Base fluid- Commercial Coolant
ii. CNF - PR24-HHT
iii. Dispersing agent- Poly(Vinyl Pyrrolidone)
iv. Percentage weight of base fluid, CNT, and dispersing agent.

3.2.1 Properties of Base Fluid

A commercial coolant; Toyota Long Life Coolant L215EU is selected as the base fluid of the nanofluid. The coolant is almost pure Ethylene Glycol as the other components is less than 5% from the coolant as shown in Table 3.2, while the properties of the coolant exhibits the standard properties of a radiator coolant as shown in Table 3.1 in which it has a pH value of 7.6.

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Table 3.1: Base fluid properties (Source: Toyota Long Life Coolant Material Safety and Data Sheet)

Parameter	Value
Boiling Point	> 148.889ºC
Melting Point	< -15ºC
Density	1.13 g/cm^3
pH (50v/v%)	7.6
Solubility in Water	Infinite miscibility
Appearance and Color	Clear, slightly viscous, dark red dyed liquid

Table 3.2: Base fluid component (Source: Toyota Long Life Coolant Material Safety and Data Sheet)

Components	**Nominal (%)**
Ethylene Glycol	87-95
Diethylene Glycol	<5
Hydrated inorganic acid, organic acid salts	<5
Water	<5

3.2.2 Properties of CNF

PR24-HHT carbon nanofibre by Pyrograf Products Incorporated is chosen as the CNT for the nanofluid. The as-produced carbon nanofibres of the PR24 type nanoparticle undergoes heat treatment at 3000 °C to produce the HHT grade thus making its purity outstanding and a highly conductive carbon nanofibre with properties as shown in Table 3.3.

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Table 3.3: PR24-HHT Properties (Source: Pyrograf Product Inc.)

Properties	**Value/Description**
CNT Types	Carbon Nanofibre
Density	2.0 g/cm^3
Purity	>98%
Fibre Diameter	100 nm
Moisture	<5%
Surface area	41 m^2/g

3.2.3 Dispersing Agent

Due to the characteristic of the CNT which is hydrophobic, the surface tension of the base fluid needs to be lowered in order for the CNT to be dispersed completely. Thus a dispersing agent Polyvinylpirrolidone (PVP) is chosen to help lowers the surface tension of the base fluid and induces less foam. The density of PVP is 1.6 g/cm^3, Sigma-Aldrich Co. (2013).

3.2.4 Percentage Weight

The total volume for the mixture of the CNT, PVP and base fluid is 100 ml which is equivalent to the container used. The percentage weight is of the CNT and PVP is determined with trial-and-error to find stable mixtures with the low percentage of CNT. Where to determine volume for CNT and PVP, volume of solution used is 100 ml for the percentage weight formula. However, to determine the base fluid volume, the volume of CNT and PVP is subtracted from 100 ml volume of solution. The formulation of the nanofluid samples volume is based on Equation 3.1 as shown in Appendix A.

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$$Volume = \frac{Weight\ percentage}{Density} \qquad \text{(Equation 3.1)}$$

Table 3.4: Example of weight percentage and volume of CNT, PVP and Base Fluid

CNF (%)	CNF Volume (ml)	PVP (%)	PVP Volume (ml)	Base Fluid (ml)
0.4	0.2	0.16	0.1	99.7

3.3 EQUIPMENT

To run the experiments, several equipment are required which are as follows:

a) KD2-Pro Thermal Properties Analyzer
b) Mechanical Homogenizer
c) Ultrasonic Cleaner
d) pH Meter
e) Stability Test Rig
f) Heat Transfer Analyzer Rig

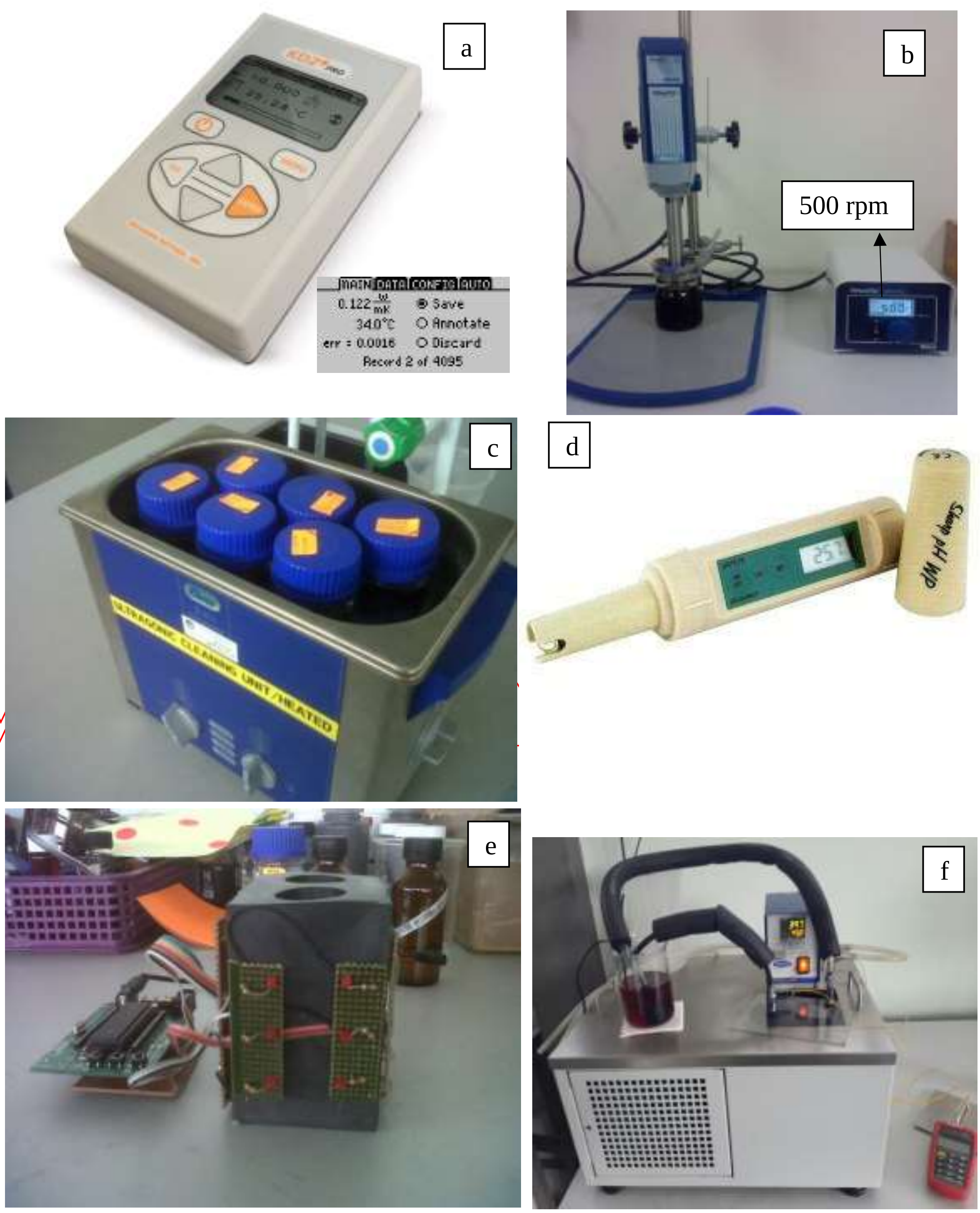

Figure 3.2: (a) KD2-Pro Thermal Properties Analyzer, (b) Mechanical Homogenizer, (c) Ultrasonic, (d) pH meter, (e) Stability Test Rig, (f) Heat Transfer Analyzer Rig

Figure 3.2 shows the equipment used throughout the research where Figure 3.2 (a) is the KD2-Pro handheld device manufactured by Decagon Devices Inc. used to measure thermal properties which is shown in Figure 3.1. It consists of several controllers and sensors that can be inserted to any materials. Single needle sensors measure thermal conductivity and resistivity suitable in fluids while the dual-needle sensor measures thermal conductivity, resistivity, volumetric specific heat capacity and diffusivity which as shown in the screen capture. Figure 3.2 (b) shows the mechanical homogenizer manufactured by LabGenius as it can homogenize solutions with speeds of up to 27000 rpm and used in this research to homogenize nanoparticles inside the base fluid at desired speed. Figure 3.2 (c) shows the Ultrasonic process to nanofluid samples where it can disperse the nanofluid mixture completely using the process of ultrasonication in 60 minutes. Ultrasonic is used to disperse the nanofluid through the use of sonic waves to agitate the particles individually. Figure 3.2 (d) shows the standard pH meter to measure the pH value of the samples to ensure the sample is stable at pH value of 9. Figure 3.2 (e) is the stability test rig developed to test the stability of nanofluid samples. The rig is installed with LED and sensors to detect whether light from the LED can pass through the samples and another set of LED to display the result. Stable samples will dim all LED due to light unable to pass through the samples while for unstable samples is vice versa. Figure 3.2 (f) shows the heat transfer analyzer rig where nanofluid samples is feed through the copper coil and regulated flow through a water bath. This apparatus is used to determine the heat transfer coefficient of nanofluid samples.

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3.4 EXPERIMENTAL PROCEDURE

3.4.1 Nanofluid Synthesis

The synthesizing of the nanofluid and identification of its thermal conductivity, heat capacity and heat transfer capacity efficiency is described in the following procedure:-

i. The parameters are weighed using the analytical balance based on the series of percentage weight of the CNT, PVP, and base fluid prepared earlier.

ii. CNT, PVP and base fluid are mixed together with the prepared ratio of each sample in glass containers. The container is shaken vigorously to ensure rough mixing of the materials.

iii. The mixture is then homogenized using the mechanical homogenizer with the setup speed of 10000 rpm for 60 seconds. Precaution is taken by applying plastic wrap around the container to prevent splashing.

iv. After the homogenizing process, the mixture is then undergoes ultrasonication process using the ultrasonic cleaner with a water bath of 25ºC at the highest frequency for 60 minutes. This process will ensure complete dispersion of the CNT in the base fluid.

v. Then, pH value of the mixture is measured using the pH meter.

vi. The sample is then homogenized once more for 3 minutes at about 1000 rpm.

vii. The mixture is then set aside for 100 hours with periodic tests on its stability using the stability test rig.

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viii. Stable samples that passes the stability test undergoes thermal conductivity test using the KD2-Pro.

ix. Heat capacity and heat transfer efficiency tests is then conducted on stable samples.

3.4.2 Stability Test

Stability test was conducted after the sample is passes the 100 hours of observatory period using the stability test rig as shown in Figure 3.2 (e). The stability test rig utilized light from LED projected to the samples and a set of sensors to detect the light. Light cannot pass samples that are stable thus the LED indicator will not light up while unstable sample is vice versa as shown in Figure 3.3.

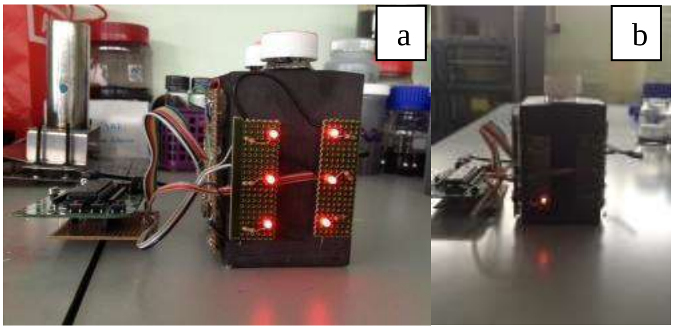

Figure 3.3: (a) Stable sample, (b) Unstable sample

3.4.3 Thermal Conductivity Test

KS-1 sensor was used to measure liquid sample and insulating material with thermal conductivity with value of less than 0.1 W/m.k. The KS-1 sensor is attached to the port on KD2-Pro which is then turned on. Beforehand, the nanofluid sample is transferred to the specimen container with silicone cap to enable the sensor needle stays in place when measuring the thermal conductivity. Measurements is done by switching the mode to Auto in the KD2-Pro and the progress bar at the bottom of the screen shows elapsed of the measurement. The setup for the thermal conductivity test is shown in Figure 3.4.

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Figure 3.4: Thermal conductivity test on sample at room temperature

3.4.4 Heat Capacity

Heat capacity is measured using the calorimeter bomb as shown in Figure 3.5. The sample will be inserted inside the decomposition vessel and the Nanofluids sample is placed into the crucible at 0.5 g and the crucible is inserted to the crucible holder beforehand. A cotton thread is attached earlier to the centre of the ignition wire in a loop and dipped to the sample in the crucible. Then the cover and union nut of the decomposition vessel is attached and oxygen is filled in using the oxygen gas station. Then the ignition adaptor is slide onto the decomposition vessel and the sample is ready to be measured. 2 litres of water is inserted into the storage tank and then the decomposition vessel is placed into the inner vessel of the calorimeter between the three locating bolts. Then inputs such as the weights of the sample and errors are administered to the calorimeter to begin the measuring which then will take about 20 minutes automatically.

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Figure 3.5: Calorimeter bomb with all components

(Source: Calorimeter System C 200 Manual)

3.4.5 Heat Transfer Coefficient

The apparatus of the experiments are set up as shown in Figure 3.2 (f), where the copper coil as shown in Figure 3.6 is soaked into the water bath and the inlet and outlet is attached to the water pump and beaker containing the nanofluid sample through the use of pipes. The water pump is inserted to the beaker of nanofluid sample to pump the sample into the copper coil while the pipe from the outlet expels the fluid sample inside the copper coil into the beaker of nanofluid sample thus ensuring a constant flow of the sample. The water bath is then set to the desired temperature of the experiment on the nanofluid sample. The mechanics of this experiment is to apply the heat convection to the flowing nanofluid inside the copper coil. Graphical presentation of the experimental setup is shown in Appendix D.

Figure 3.6: Copper coil

3.5 SAFETY PRECAUTIONS

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Dispersing agent and CNT are powder particles which can cause irritation if made contact with skin and eye. Gloves and dust respirator or face mask needs to be worn at all times to prevent inhalation and exposure to the particles. In case of spilling of the CNT, immediate removal of the powder is required using vacuum or distilled water. Should the powder came into contact with skin and eyes, rinse with distilled water immediately.

CHAPTER IV

RESULT AND DISCUSSION

4.0 INTRODUCTION

Testing of the nanofluid samples have been carried out and the experimental results are represented in a tabulation of data and graphical charts. Analysis of comparison and observation of the effects of variables on the samples can be done efficiently afterwards.

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4.1 RESULT

4.1.1 Stability Test

Stability test is conducted after 100 hours of observation and the stability of the samples is determined. Twenty-four samples are formulated beforehand and left on laboratory shelf for 100 hour with observatory intervals. The nanofluids are formulated using the PR24-HHT CNF dispersed into Toyota Coolant with dispersing agent of PVP. From Table 4.1, the first five samples follows the standard ratio of nanoparticles and PVP used previous research which is the weight percentage (wt%) of PVP is 40% from the nanoparticles and it is observed to be completely unstable. Then the next ten samples are formulated to determine the stable ratio of PVP ranging from 50% to 200% of wt% from CNF. It is observed that at 180% and 200% of PVP the sample is stable however at 180% the sample exhibits great sedimentation but remains dispersed while the latter shows minute sedimentation and remains dispersed. Thus the PVP ratio of 200% from CNF of wt% is used for the desired range of CNF wt% from 0.1wt% to 1.0wt% which shows great stability.

Sample ID	CNF (wt%)	PVP (wt%)	Base Fluid (ml)	Stability		
				24hr	72hr	100hr
NC001	0.4	0.16	99.70000			
NC002	0.6	0.24	99.55000			
NC003	0.8	0.32	99.40000		Unstable	
NC004	1.0	0.40	99.25000			
NC005	0.1	0.04	99.92500			
NC006	0.1	0.06	99.91250			
NC007	0.1	0.07	99.90625			
NC008	0.1	0.08	99.90000	Stable	Unstable	
NC009	0.1	0.09	99.89375			
NC010	0.1	0.10	99.88750			
NC011	0.1	0.12	99.87500			
NC012	0.1	0.14	99.86250	Stable	Unstable	Unstable
NC013	0.1	0.16	99.85000	Stable	Stable	Unstable
NC014	0.1	0.18	99.83750			
NC015	0.1	0.20	99.82500			
NC016	0.2	0.4	99.65000			
NC017	0.3	0.6	99.47500			
NC018	0.4	0.8	99.30000			
NC019	0.5	1.0	99.12500		Stable	
NC020	0.6	1.2	98.95000			
NC021	0.7	1.4	98.77500			
NC022	0.8	1.6	98.60000			
NC023	0.9	1.8	98.42500			
NC024	1.0	2.0	98.25000			

Table 4.1: Stability of nanofluid sample

4.1.2 Thermal Conductivity Test

The identified stable sample which is NC015 to NC024 is selected to be subjected to thermal conductivity using the KD2-Pro Thermal Properties Analyzer after observation and validation on its stability. Thermal conductivity of the samples are tested under five temperature, which simulates the working condition of a heat exchanger whereby the nanofluid is intended to be used. Table 4.2 presents the thermal conductivity obtained after an extensive time consumption on measuring the thermal conductivity of each sample at temperatures of 3 °C, 6 °C, 25 °C, 45 °C and 60 °C.

Table 4.2: Thermal Conductivity of sample at variable temperatures

Code	CNT %	Thermal Conductivity (W/m.K) at temperature (°C)				
		3	**6**	**25**	**45**	**60**
Standard	0.0	0.255	0.259	0.243	0.263	0.2
NC015	0.1	0.252	0.282	0.266	0.247	0.255
NC016	0.2	0.252	0.287	0.234	0.246	0.227
NC017	0.3	0.254	0.285	0.247	0.283	0.257
NC018	0.4	0.258	0.326	0.229	0.300	0.262
NC019	0.5	0.283	0.366	0.236	0.324	0.316
NC020	0.6	0.250	0.269	0.244	0.303	0.306
NC021	0.7	0.301	0.299	0.297	0.338	0.276
NC022	0.8	0.263	0.305	0.258	0.348	0.330
NC023	0.9	0.325	0.282	0.289	0.350	0.345
NC024	1.0	0.247	0.354	0.243	0.349	0.289

Standard = Coolant only

Table 4.2 is then represented graphically to identify the patterns of the effects of heat to each samples as shown in Figure 4.1.

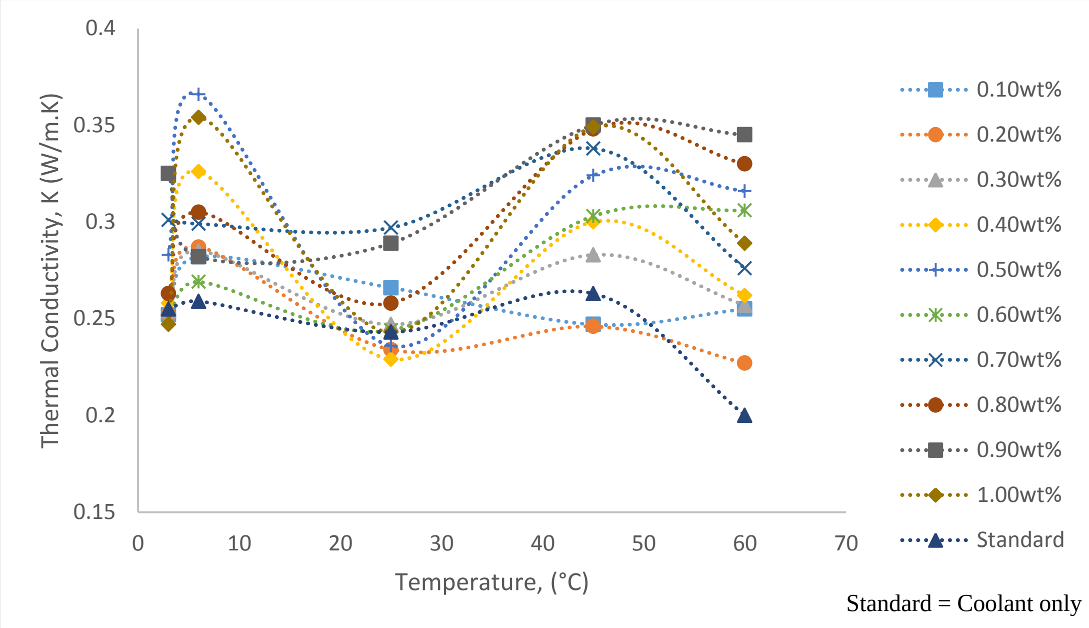

Figure 4.1: Graph of thermal conductivity at variable temperature

From Figure 4.1, it is observed that the standard sample experienced a degradation on its thermal conductivity as the temperature increases. However such is not the case for the nanofluid samples where most of it exhibits enhancements in thermal conductivity as the temperature rises.

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4.1.2.1 Enhancements Analysis

The thermal conductivity of the nanofluid samples is then compared with the thermal conductivity of standard sample by calculating the enhancements of nanofluid through Equation 4.2 which is shown in Appendix A. Table 4.3 shows the enhancements of thermal conductivity of samples.

$$\%\ of\ enhancement = \frac{T.C\ of\ NC023 - T.C\ \ of\ coolant}{T.C\ of\ coolant} \times 100 \qquad \text{(Equation 4.2)}$$

T.C = Thermal Conductivity

Table 4.3: Percentage of thermal conductivity enhancements

Code	CNT %	Percentage of Enhancement (%) at temperature (°C)				
		3	6	25	45	60
NC015	0.1	-1.18	8.88	9.47	-6.08	27.50
NC016	0.2	-1.18	10.81	-3.70	-6.46	13.50
NC017	0.3	-0.39	10.04	1.65	7.60	28.50
NC018	0.4	1.18	25.87	-5.76	14.07	31.00
NC019	0.5	10.98	41.31	-2.88	23.19	58.00
NC020	0.6	-1.96	3.86	0.41	15.21	53.00
NC021	0.7	18.04	15.44	22.22	28.52	38.00
NC022	0.8	3.14	17.76	6.17	32.32	65.00
NC023	0.9	27.45	8.88	18.93	33.08	72.50
NC024	1.0	-3.14	36.68	0	32.70	44.50

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The results obtained is observed to be irregulars in terms of the enhancements and the pattern is further analyzed by representing the enhancements data to graphical charts as shown in Figure 4.2, Figure 4.3, Figure 4.4, Figure 4.5 and Figure 4.6.

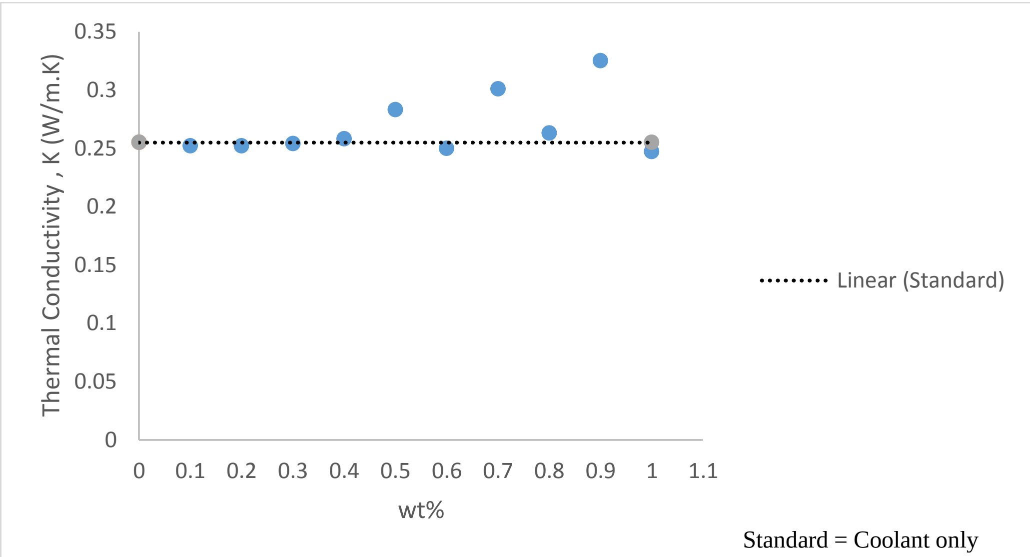

Figure 4.2: Thermal Conductivity at 3 °C

From Figure 4.2, it is observed that at 3 °C most nanofluid samples suffers a reduction in the thermal conductivity except for samples of NC018, NC019, NC021 and NC023 with 0.4wt%, 0.5wt%, 0.7wt% and 0.9wt% of CNF respectively. The highest enhancement of thermal conductivity observed of the samples at 3 °C is at 27.45% from the standard sample, obtained from NC023 with 0.9wt% of CNF. The highest reduction of thermal conductivity is observed on NC022 with -3.14% in enhancement where the sample contain 1.0wt% of CNF.

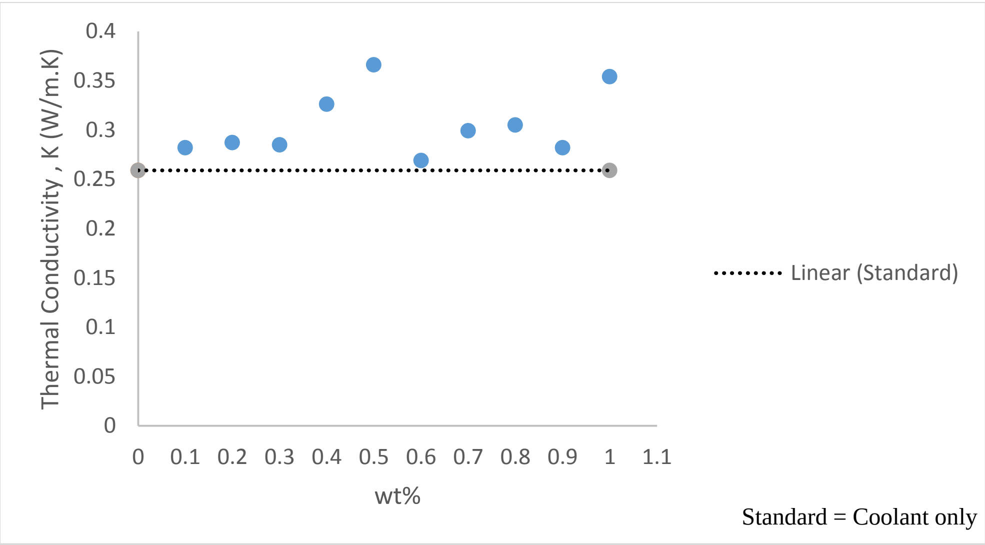

Figure 4.3: Thermal Conductivity at 6 °C

At temperature 6°C, all of the samples exceeds the standard sample in terms of thermal conductivity enhancement. The highest recorded enhancement is at 41.31% obtained from 0.5wt% CNF loading while the lowest is observed at 3.86% obtained from 0.6wt% as shown in Figure 4.3.

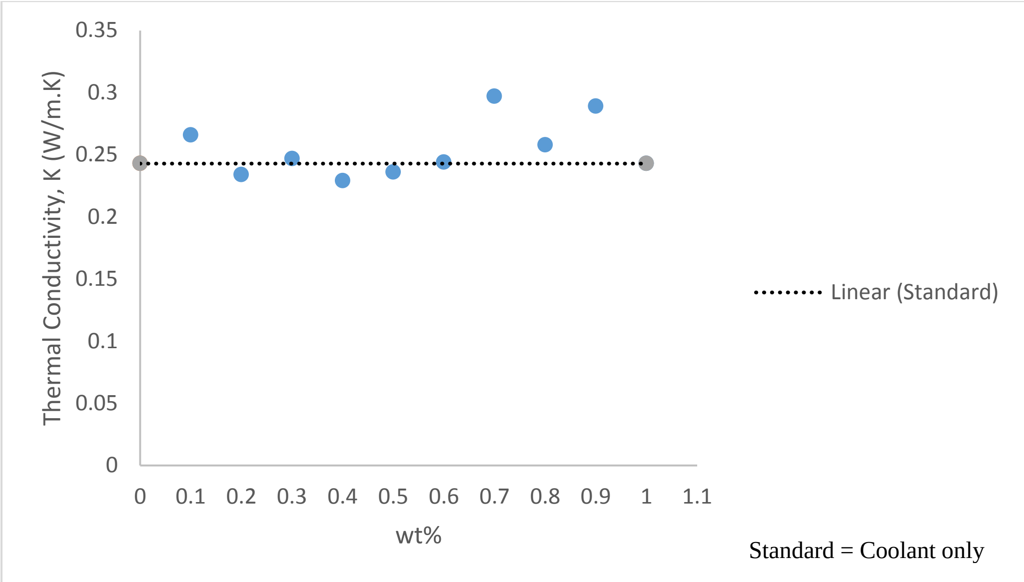

Figure 4.4: Thermal Conductivity at 25 °C

At 25 °C, the enhancements in thermal conductivity of the samples shows a more irregular result as observed in Figure 4.4. Samples that shows increase in enhancements are NC015, NC017, NC021 and NC023 while NC024 shows no enhancements from the standard sample. The highest thermal conductivity enhancements is observed on NC021 containing a 0.7wt% of CNF, at an enhancements of 22.22% while the highest degradation in enhancements is observed on NC020 containing 0.4wt% of CNF, at -5.76%.

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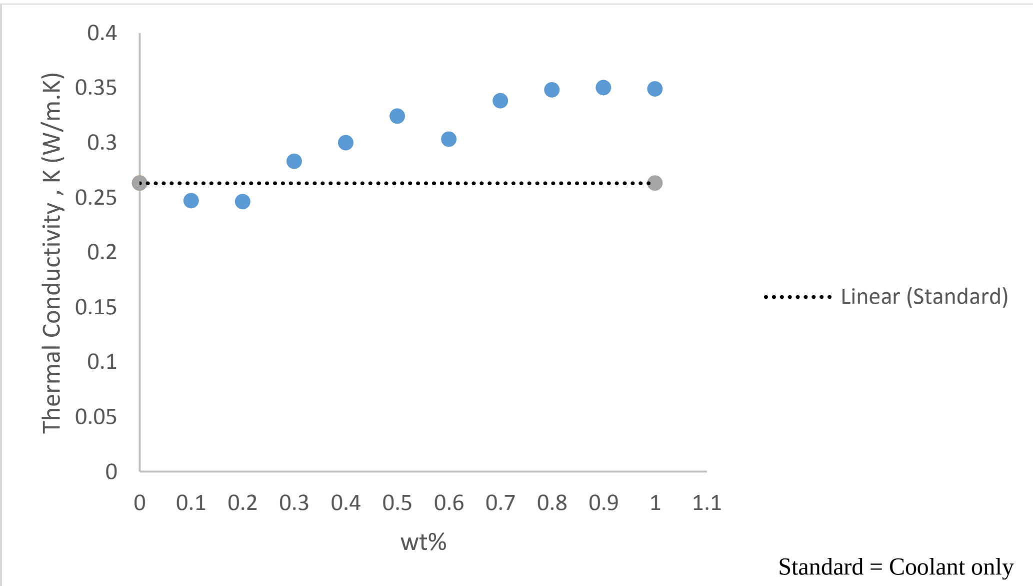

Figure 4.5: Thermal Conductivity at 45 °C

At 45 °C, most of the samples experiences enhancements except for samples at 0.1wt% and 0.2wt% CNF loading experiences reduction of -6.08% and -6.48% respectively. The highest enhancement achieved at 45 °C is at 33.08% obtained from 0.9wt% CNF loading as shown in Figure 4.5.

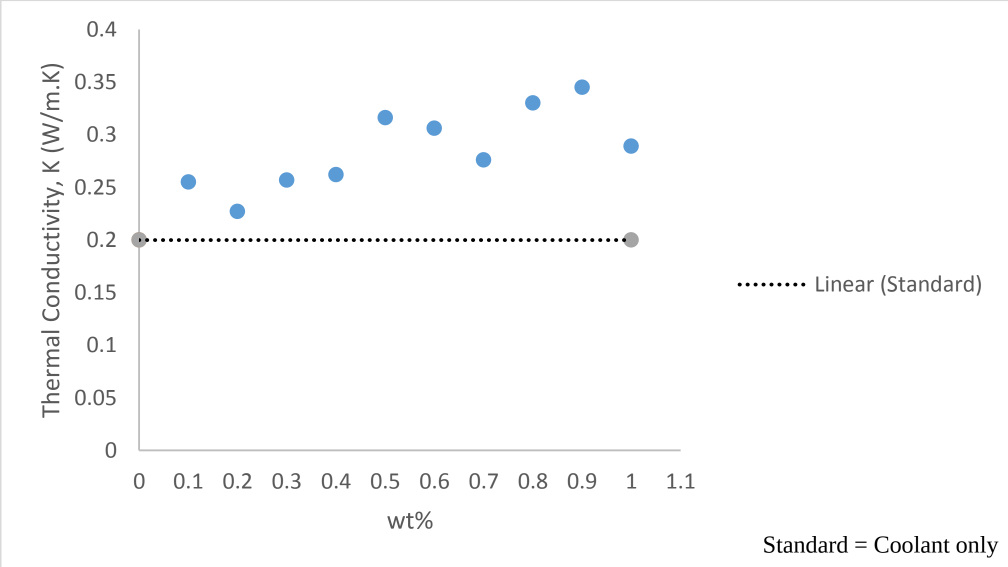

Figure 4.6: Thermal Conductivity at 60 °C

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At 60 °C, the enhancements of the thermal conductivity of all samples experiences great increase as compared to the standard sample which undergoes reduction compared to the temperatures at 3 °C, 6 ˚C, 25 °C and 45 ˚C. The highest thermal conductivity enhancements observed is at 72.5%, obtained from NC023 of 0.9wt% CNF as shown in Figure 4.6. There is no degradation observed for the sample at high temperature which is 60 °C. From the result obtained as shown in Figure 4.2, Figure 4.3, Figure 4.4, Figure 4.5 and Figure 4.6, it is determined that the three best sample in terms of thermal conductivity are NC019, NC021 and NC023 with the respective percentage weight of CNF at 0.5wt%, 0.7wt% and 0.9wt%.

4.1.3 Heat Capacity Test

The selected three nanofluid as well as the standard sample is then subjected to heat capacity test where the measured value is the specific heat capacity of the samples. 0.5 gram of each samples is tested using the calorimeter bomb and the result is shown in Table 4.4. Then the enhancement of the heat capacity of the nanofluid samples is calculated using methods shown in Appendix A and the data obtained in Table 4.4 is presented in graphical chart to further analyze the result.

Table 4.4: Specific heat capacity of sample

Code	CNF (wt%)	Specific Heat Capacity (Cal/g)
Standard	0.0	4063
NC019	0.5	3887
NC021	0.7	3718
NC023	0.9	3661

Standard = Coolant only

The selected nanofluid undergoes significant reduction compared to the specific heat capacity of the standard sample. The samples undergoes increase in reduction as the percentage weight of the samples increases as can be observed from Figure 4.7 where NC019 is reduced by -4.33%, NC021 by -8.49% and NC023 by -9.89%.

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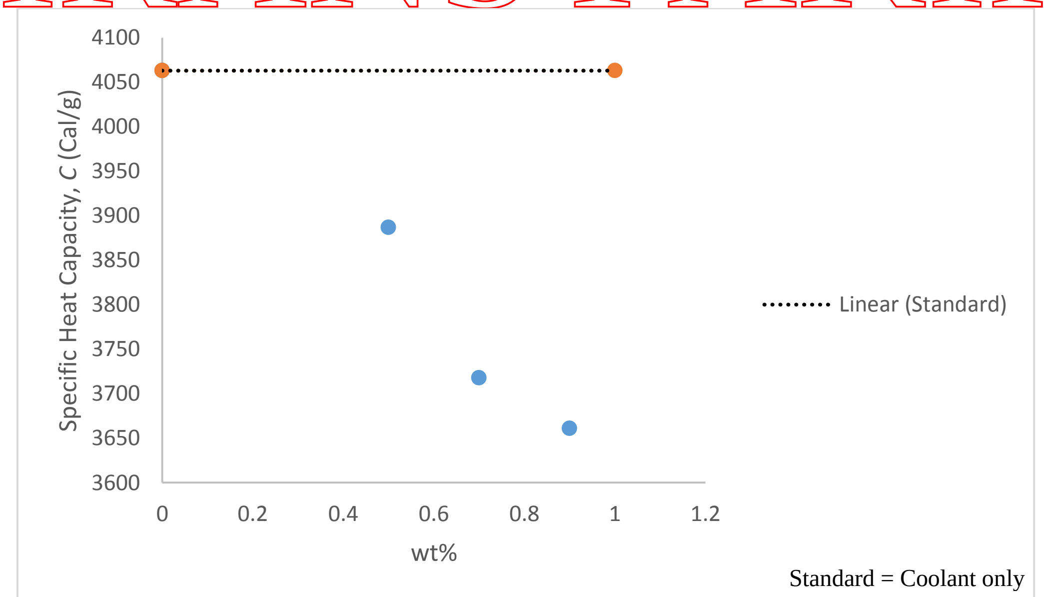

Figure 4.7: Specific heat capacity of selected sample

4.1.4 Heat Transfer Coefficient Test

In order to completely determine whether PR24-HHT nanoparticles improves the thermal properties of a standard coolant, heat transfer analysis is conducted on the three selected samples through heat convection. Temperatures used in this experiment slightly differs in the lower temperature and high temperature compared to the thermal conductivity test due to the constraint of the water bath consuming large time to reduce and increase the temperature of the water. The samples is recorded at 1 minute intervals for 5 minutes of flowing through the experiment set up apparatus which is enough due to constant readings obtained and the samples is subjected to the heat for quite some time to ensure the samples completes the flow cycle of the apparatus. The results obtained can be viewed in Appendix B. Temperature difference of the samples at 6 °C, 25 °C and 45 °C is calculated as shown in Appendix A and then tabulated to Table 4.5 which shows less promising result.

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Table 4.5: Temperature difference of sample at 6°C, 25°C and 45°C

Code	CNT %	Temperature Difference (ΔT) at temperature (°C)		
		6	25	45
Standard	0.0	19.1	0.9	16.8
NC019	0.5	18.6	1.2	17
NC021	0.7	18.2	0.5	16.1
NC023	0.9	19.2	2.3	17.1

Standard = Coolant only

4.1.4.1 Analysis of Enhancement

The enhancements of the temperature difference is then calculated using the methods from Appendix A and then tabulated to Table 4.6. The data obtained in Table 4.6 is then presented in graphical charts to further analyze the enhancements of the heat transfer coefficient of each samples at three different temperatures which is 6 °C, 25 °C and 45 °C.

Table 4.6: Percentage of enhancements of temperature difference

Code	**CNT %**	**Percentage of Enhancement (%) at temperature (°C)**		
		6	**25**	**45**
NC019	0.5	-2.62	33.33	1.19
NC021	0.7	-4.71	-44.44	-4.17
NC023	0.9	0.52	155.56	1.79

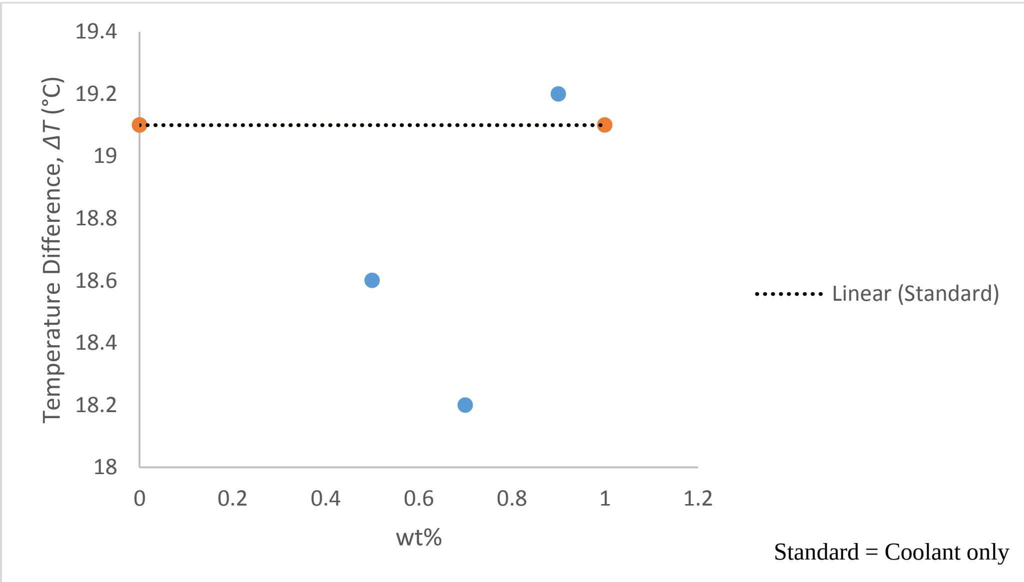

Figure 4.8: Temperature Difference of Samples at 6 °C

At 6 °C, it is observed on Figure 4.8 that only NC023 experiences slight increase in enhancement of the temperature difference from standard sample which is at 0.52% while the NC019 and NC021 suffers a degradation of approximately -2.62% and -4.71% respectively.

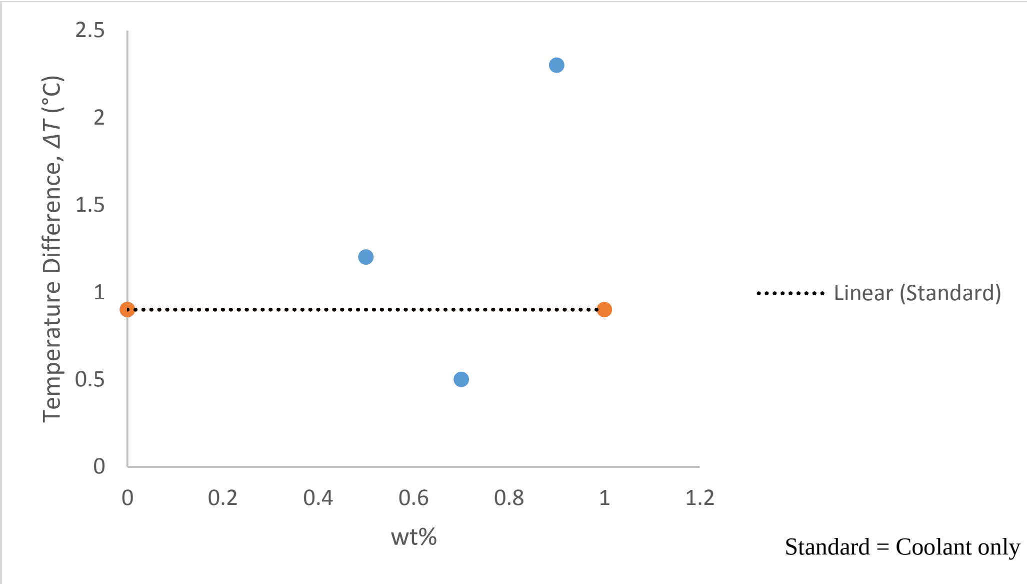

Figure 4.9: Temperature Difference of Samples at 25 °C

At 25 °C, the samples shows a more promising results where two of the samples, NC019 and NC023 experience dramatic increase in enhancements of temperature difference from the standard samples at 33.33% and 155.56% respectively while NC021 suffers great degradation of the temperature difference enhancement as shown in Figure 4.9.

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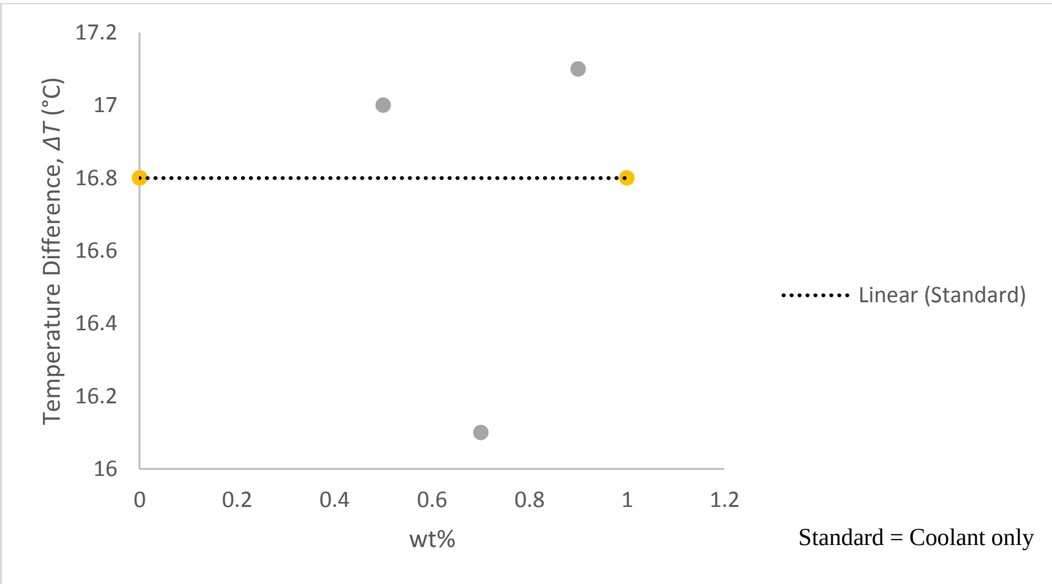

Figure 4.10: Temperature Difference of Samples at 45 °C

At 45 °C, a slight increase in enhancement is observed to the samples of NC019 and NC023 with 1.19% and 1.79% while NC021 suffers a degradation as shown on

Figure 4.10. From Figure 4.8, Figure 4.9 and Figure 4.10, it is determined that only sample NC021 suffers degradation on all temperature while NC023 is the only sample that experiences enhancements from the standard sample thus determining the percentage weight of 0.9wt% CNF with 1.8wt% PVP for the NC023 improves the standard coolant in terms of thermal properties.

4.2 DISCUSSION

4.2.1 Stability Test Analysis

As an approach to determining the factors of stability of the nanofluids, the data obtained is analyzed and previous research is taken into account and it is determined that there are two factors affecting the stability of nanofluids positively which is the dispersing agent and the ultrasonication process. During the formulations of nanofluid samples, the dispersing agent Polyvinylpyrrolidone (PVP) was introduced to the samples ranging from 40% to 200% PVP loading from CNF to ensure the CNF particles remain dispersed for a long periods thus ensuring the stability of the nanofluid. At 40% to 160% PVP loading from CNF is unstable and it is determined that stable samples can be obtained at 200% PVP loading from CNF which is at NC014 to NC024. As the nanofluid is intended to be used in high heat environment, it is utmost important to formulate a highly stable nanofluid as higher temperature increase the probability of particle aggregation and instability of nanofluids, (Prasher et al. 2006). The use of dispersing agent or surfactant helps in reducing the tendency of nanoparticles to agglomerate via distorting the wetting adhesion behaviour, (Nasiri et al. 2010). This is agreeable in this research as the nanofluids becomes more stable with the addition of more PVP into the samples as can be clearly seen in Table 4.1. Ultrasonication process is also important to ensure a stable nanofluids formulated as the increase in sonication time increases the period of stability of the nanofluids as the process need to be carried out intermittently to avoid overheating that can reduce the quality of nanofluid, (Nasiri et al. 2010).

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4.2.2 Thermal Conductivity Analysis

As discussed in the literature review, thermal conductivity is the measurement of the property of a matter to conduct heat and several factors affects the thermal conductivity of nanofluids. As observed from the results of the thermal conductivity measurements of nanofluid samples, it is determined that the factors that are affecting the nanofluids are temperature and the percentage weight of the CNF used.

4.2.2.1 Temperature Effect

As observed in Figure 4.1, Figure 4.2, Figure 4.3, Figure 4.4, Figure 4.5 and Figure 4.6 it is determined that the increment of thermal conductivity mostly occurs at high temperature rather than at lower and room temperature. The standard sample however exhibits reduction as the temperature increases. This pattern can be explained through the existence of Brownian motion of the nanoparticles in the sample as discussed in the literature review, whereas the temperature increases the kinetic energy of the nanoparticles subsequently increases causing more convection effect to be increased and consequently increases its thermal conductivity. Various research also suggested heat as a factor as seen in the research of Mohamad, I. S. et al. (Mohamad, I. S. et al. 2013; Mohamad, I. S. et al. 2012; Mohamad, I. S. et al. 2011) and Murshed et al. (2008), where the enhancement of thermal conductivity increase according to the increment of temperature applied on the nanofluid.

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4.2.2.2 Percentage Weight Effect

From the analysis done in subsection 4.1.2.1, it is found that the percentage weight of the PR24-HHT particles effect the thermal conductivity of samples anomalously supporting various previous research, (Choi, S. and Eastman, J. A. 1995; Choi, S. et al. 1999; Eastman, J A. et al. 2001). As an example of the anomalous effect of the percentage weight of the CNF particles to the thermal conductivity, it is observed in Figure 4.4 that the thermal conductivity of 0.9wt%

sample experienced enhancement of thermal conductivity at 72.5% while at 1.0wt% the sample only experience enhancement of up to 44.5% where one would expect the enhancement to further increase.

4.2.3 Heat Capacity Analysis

As was discovered in previous researches, aqueous nanofluids exhibits reduction in the specific heat capacity value but increases as the nanofluids is subjected to higher temperature as was discussed in the literature review. From the results obtained from the heat capacity test, the specific heat capacity of the nanofluid samples decreases as the percentage weight of CNF increases which supports the behaviour of nanoparticles in aqueous solution in previous research, (Namburu et al. 2007).

4.2.4 Heat Transfer Coefficient Analysis

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The result obtained still suggest that anomalous behaviour is currently in effect on the heat transferred to the nanofluid but nonetheless PR24-HHT improves the heat transfer coefficient of the standard coolant. Several factors can be pointed out on why the PR24-HHT nanoparticles shows improvement in the formulated nanofluid, which is the structure of the nanoparticles and the surface area of the nanoparticles. The enhancement of thermal conductivity correlates with the enhancement of heat transfer coefficient due to the Brownian motion of the nanoparticles with applied heat and increase in percentage weight as was discussed in subsection 2.5 where the increase in heat and volume fraction consequently decreases the viscosity of the base fluid thus inducing the Brownian motion of the nanoparticles to increase and thus increasing the heat convection to the nanoparticles resulting in the increase in thermal conductivity, (Choi, S. and Seok, P. J. 2004).

4.2.4.1 CNF Structure on Heat Transfer

As was discussed in the literature review, the reason a nanofluid dispersed with the PR24-HHT CNF excels in thermal properties lies in its structure where the nanoparticles structure has a long and continuous length of tubes as shown in Figure 4.11 where more heat can be dissipated through the lengthy tube thus enhancing the heat transferred to the fluid dispersed with the nanoparticles. Increase of the tube length results in higher surface area of CNF and higher heat transfer coefficient will be achieved.

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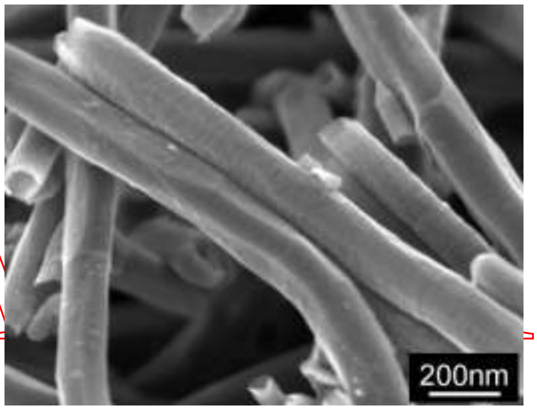

Figure 4.11: SEM image of the structure of PR24-HHT CNF
(Source: Tessonier et al. 2009)

4.2.4.2 Surface Area on Heat Transfer

According to Goldstein et al. (2000), large surface areas of these particles greatly promotes heat transport from the fluid to the particles in places where the fluids is hot and the release of heat from particles to fluid in places where the fluid is cold. As the particles size reduces as in the case of nanoparticles, the surface area per unit volume increases thus the heat is being dependent on the surface area, resulting in the effectiveness of nanoparticles to transfer heat to the base liquid increases, (Hussein et al. 2014). High surface area is observed in PR24-HHT particles as shown in Table 3.3 and as such helps in the enhancements of the heat transfer coefficient.

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

An improvement of the standard coolant in terms of thermal conductivity and heat transfer coefficient has been achieved through the formulation of NC023 of 0.9wt% CNF loading and in addition to its stability from the use of 1.8wt% PVP loading. For thermal conductivity, NC023 exhibits enhancements throughout all five temperatures, which is at 3 °C, 6 °C, 25 °C, 45 °C and 60 °C respectively which can be referred from Figure 4.1. NC023 achieved the highest percentage of enhancement compared to other nanofluid samples formulated, at 3 °C, 45 °C and 60 °C which is at 27.45% (0.325W/m.K), 33.08% (0.349W/m.K) and 72.5% (0.345W/m.k) from the standard sample. It is determined that two factors consequently affects the enhancements of the nanofluid, which is the heat applied and the percentage weight of the CNF used in the nanofluid sample which was discussed in subsection 4.2.2. In terms of heat transfer coefficient, NC023 exhibits enhancements at all three temperatures of 6 °C, 25 °C and 45 °C with the percentage of enhancement of 0.52%, 155.56% and 1.79% respectively. The factors of PR24-HHT nanoparticles to excel in the heat transfer coefficient is due to the factors of the structure and the surface area of the PR24-HHT nanoparticles as well as the Brownian motion of the nanoparticles suspended in the base fluid as was discussed in subsection 4.2.4. However in terms of heat capacity, NC023 experience a degradation from the

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standard sample as well the other nanofluid samples tested, showing support with previous research as was discussed in subsection 2.5 where it is observed that aqueous nanofluids exhibits a degradation in specific heat capacity as the volume fraction increases, whereby in this research percentage weight is utilized. From the analysis of the thermal properties of the stable sample formulated, NC023 is determined to have an improvements in efficiency from the standard coolant and achieving the objectives of this research which is to formulate an efficient nanofluid from the PR24-HHT nanoparticles dispersed into a standard coolant through the introduction of a dispersing agent, PVP to ensure stability of the nanofluid.

5.2 Recommendation

The experimental apparatus of the heat transfer analyzer was designed to be used for water based nanofluid thus it is obsolete in utilizing it for coolant based nanofluid as its viscosity is higher causing difficulties during running the heat transfer analyzer. This is due to the flow rate of the fluid flow is low due to the high viscosity of the fluid, low power of water pump and small diameter of the copper coil. This will result in most likely errors in the experiment thus suggestion for improvement of the future use of the apparatus is to design a new setup suitable for coolant based nanofluid such as a larger diameter of the copper coil and more powerful water pump.

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