THERMAL PERFORMANCES OF HYBRID NANOFLUIDS AS COOLANT IN COMPUTERS USING DESIGN OF EXPERIMENT METHOD

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

According to Gordon Moore's 1965 law, the number of transistors in a dense integrated circuit (IC) doubles approximately every two years, and this correlates with the amount of heat generated by the transistors. Due to the high demand for a better cooling system, one of the solutions to increase the cooling performance of the liquid cooling system is the use of nanofluid or hybrid nanofluid as a coolant in the liquid cooling system. The term "hybrid nanofluid" refers to a fluid containing multiple nanoparticles dispersed in a base fluid. It has excellent thermal properties which can help improve the performance of a conventional coolant. Based on the literature review, a good hybrid nanofluid requires good stability for a period of time and an optimized mixing ratio to ensure a high synergetic effect. However, there were very few studies on the impact of surfactants on thermal conductivity, and the optimization of hybrid nanofluid was limited to the One Factor at a Time method (OFAT). Therefore, this study endeavours to evaluate the stability of the hybrid nanofluid effect on thermal conductivity, to analyse the best mixing ratio of hybrid nanofluid based on thermal conductivity and viscosity using Design of Experiment (DOE), and to analyse the heat transfer performance of hybrid nanofluid in a liquid cooling system for CPU. This study was divided into three experimental works to achieve the aforementioned objectives. Titanium Dioxide (TiO2) and Graphene nanoplatelet (GNP) were mixed in distilled water using Hexadecyltrimethylammonium bromide (CTAB) as surfactant and ultrasonic vibration to increase the dispersion. The DOE analysis was conducted using Design Expert 11, which gives a more comprehensive analysis than OFAT because statistical analysis considers all possible mixing ratios within the range. Then, the best parameter of the hybrid nanofluid was used to prepare as a coolant in the liquid cooling system for the CPU for heat transfer performance analysis. The overall results showed that the prepared hybrid nanofluid was stable for 30 minutes for thermal conductivity and viscosity analysis with a ratio of 1:10 to 3:10 of surfactant to the mass of TiO2. Furthermore, the higher concentration of surfactant, the lower the thermal conductivity reading. Thus, the surfactant ratio of 1:10 is the best surfactant for hybrid nanofluid. For the mixing ratio analysis, three concentrations were used: 0.1vol%, 0.3vol%, and 0.5vol% respectively with mixing ratio and temperature as the factors while thermal conductivity and viscosity as responses. The results revealed the best parameters were 0.3vol% and 1:4 mixing ratio of TiO2-GNP. Subsequently, the best mixing ratio of hybrid nanofluid was used in the liquid cooling system for the CPU. The thermal resistance results showed that the prepared hybrid nanofluid was 2.7% lower than distilled water and the lowest than any other prepared nanofluids in the previous study. In conclusion, this study presents a better insight into the effect of surfactants on thermal conductivity, proposes a method to comprehensively investigate the mixing ratio of hybrid nanofluid as well as the heat transfer enhancement of hybrid nanofluid compared to the conventional coolant.

ABSTRAK

Oleh kerana permintaan yang tinggi untuk sistem penyejukan yang lebih baik, salah satu penyelesaian untuk meningkatkan prestasi penyejukan sistem penyejukan cecair adalah menggunakan cecair nano atau hibrid nano. Berdasarkan tinjauan literatur, cecair nano hibrid yang baik perlu mempunyai kestabilan yang baik untuk satu tempoh dan nisbah pencampuran yang optimum untuk memastikan kesan sinergi yang tinggi. Walau bagaimanapun, terdapat hanya kajian terhad mengenai kesan surfaktan pada kekonduksian terma, dan pengoptimuman cecair nano hibrid dihadkan kepada kaedah Satu Faktor Pada Satu Masa (OFAT). Oleh itu, kajian ini menilai kestabilan kesan cecair nano hibrid pada kekonduksian terma, analisa nisbah terbaik pencampuran cecair nano hibrid berdasarkan kekonduksian terma dan kelikatan, dan menganalisis prestasi pemindahan haba cecair nano hibrid dalam sistem penyejukan cecair untuk CPU. Kajian ini dibahagikan kepada tiga kerja eksperimen untuk mencapai objektif yang dinyatakan di atas. Titanium Dioksida (TiO_2) dan Nanoplatelet Graphene (GNP) dicampur dalam air suling menggunakan Hexadecyltrimethylammonium bromide (CTAB) sebagai surfaktan dan getaran ultrasonik untuk meningkatkan serakan. Strategi eksperimen dan analisis telah dijalankan menggunakan Design Expert 11, yang memberikan analisis yang lebih komprehensif daripada OFAT kerana analisis statistik mempertimbangkan semua kemungkinan nisbah campuran dalam analisa statistik. Kemudian, parameter optimum cecair nano hibrid digunakan untuk menyediakan penyejuk dalam sistem penyejukan cecair untuk CPU untuk analisis prestasi pemindahan haba. Keputusan keseluruhan menunjukkan bahawa cecair nano hibrid yang disediakan adalah stabil selama 30 minit untuk digunakan untuk analisis kekonduksian terma dan kelikatan dengan nisbah 1:10 hingga 3:10 surfaktan berdasarkan jisim TiO_2. Tambahan pula, semakin tinggi kepekatan surfaktan, semakin rendah bacaan kekonduksian terma. Oleh itu, nisbah surfaktan 1:10 adalah surfaktan terbaik untuk cecair nano hibrid. Untuk analisa nisbah pencampuran yang terbaik, tiga kepekatan telah digunakan: 0.1vol%, 0.3vol%, dan 0.5vol% dengan nisbah pencampuran dan suhu sebagai faktor manakala kekonduksian terma dan kelikatan sebagai tindak balas. Keputusan menunjukkan parameter yang terbaik ialah 0.3vol% dan nisbah pencampuran 1:4 TiO2-GNP. Kemudian, cecair nano hibrid terbaik digunakan dalam sistem penyejukan cecair untuk CPU. Keputusan rintangan haba menunjukkan bahawa cecair nano hibrid yang disediakan adalah 2.7% lebih rendah daripada air suling dan paling rendah daripada mana-mana cecair nano yang disediakan dalam kajian terdahulu. Kesimpulannya, kajian ini menunjukkan gambaran yang lebih baik tentang kesan surfaktan ke atas kekonduksian terma, mencadangkan kaedah untuk menyiasat nisbah pencampuran cecair nano hibrid secara menyeluruh, dan peningkatan pemindahan haba cecair nano hibrid berbanding dengan penyejuk konvensional.

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LIST OF ABBREVIATIONS

Adeq Precision	-	Adequate Precision
ANOVA	-	Analysis of Variance
CPU	-	Central Processing Unit
CTAB	-	Hexadecyltrimethylammonium bromide
df	-	Degrees of Freedom
DOE	-	Design of Experiment
GNP	-	Graphene Nanoplatelets
TiO_2	-	Titanium Dioxide

LIST OF SYMBOLS

m	-	Mass
Q	-	Heat Input (W)
R_T	-	Total Thermal Resistance ($^oC/W$)
T_{CPU}	-	Temperature Of CPU
T_1	-	Temperature Of Working Fluid Flow Out From The Liquid Block
T_2	-	Working Fluid Temperature Before Entering The Radiator
T_3	-	Temperature Of Working Fluid Flow Out Of The Radiator.
$T_{ambient}$	-	Ambient Temperature
$\emptyset$	-	Volume Concentration of Hybrid Nanofluid
ρ	-	Density
ΔT	-	Temperature Different (^oC)

CHAPTER 1

INTRODUCTION

1.1 Overview

Electronic equipment, especially the Central Processing Unit (CPU) and Graphic Processing Unit (GPU), creates lots of heat. Excessive heat generated by these units might harm the equipment, resulting in financial losses for the consumer. As a result, a cooling mechanism needs to regulate the heat created by the CPU and GPU. Gordon Moore's 1965 rule states that every two years, the number of transistors in a dense integrated circuit (IC) doubles. Therefore, the amount of heat generated by the transistors also doubles. The increase in the number of transistors over the years is shown in Figure 1.1. As a result, an effective cooling system is critical for controlling the temperature rise caused by these transistors and ensuring the continuation of Moore's law 50 years after its debut. Additionally, Moore's law demonstrates the commitment to developing advanced electronic device technology and the critical nature of cooling system performance to accommodate the advanced technology of electronic devices.

Currently, the industry offers two types of cooling systems: air-cooled and liquid-cooled systems. Most users use an air cooling system since it is inexpensive, simple to operate, and low maintenance. The air cooling mechanism uses fans with varying airflow rates and static pressures. These airflow rates and static pressure values defined the air conditioning system's cooling performance. Additionally, to improve the effectiveness of the air cooling system, the fans are connected to a heat pipe and a heatsink.

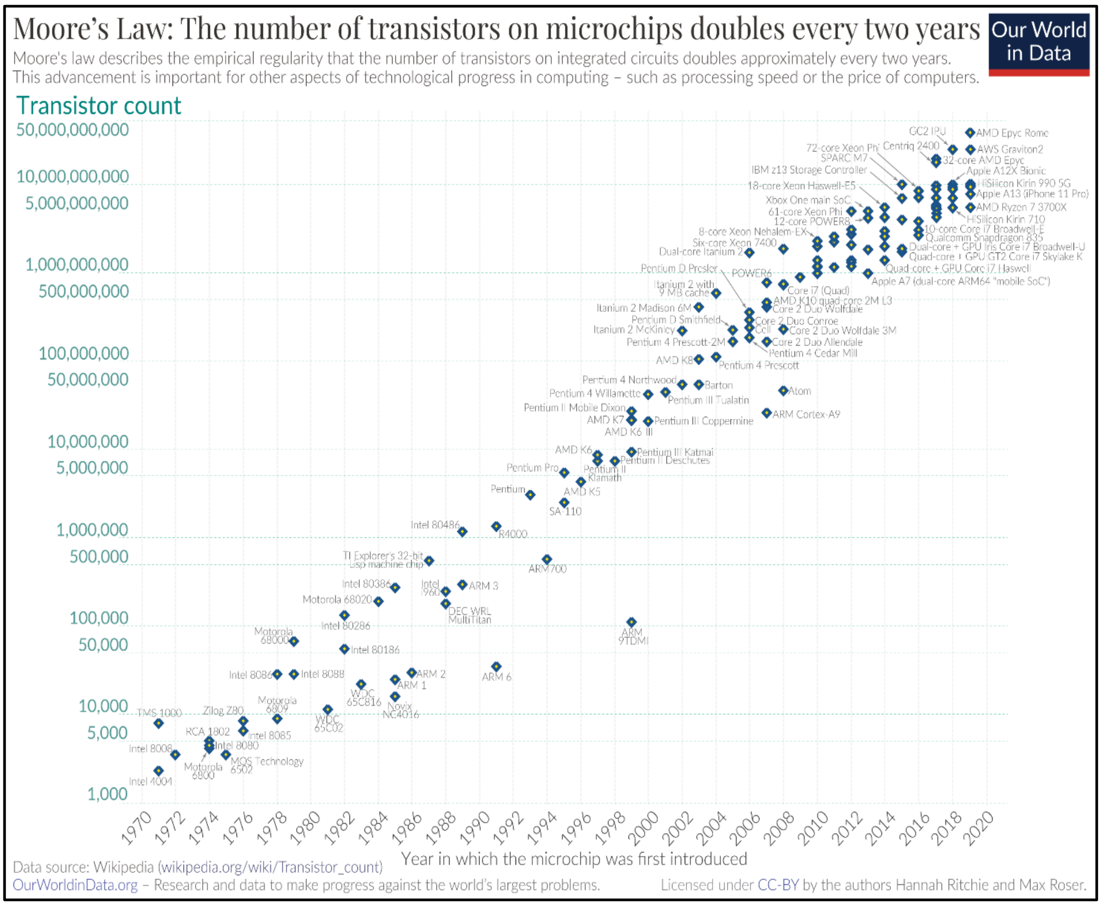

Figure 1.1 Number of transistors increases throughout the years [1]

The cooling system develops further with the introduction of liquid-based cooling. This cooling system is commonly found in high-end computers for gaming or other high-resolution tasks like video editing and simulation. These tasks require a more robust cooling system, as the CPU and GPU temperatures rise faster and faster. A liquid cooling system is made up of a liquid block, a radiator, fans, as well as a pump, and a reservoir. The CPU and GPU are connected to the liquid block's cooling component, which enables more effective heat absorption. Water is the most often utilized working fluid in liquid cooling systems. Due to its increased heat capacity, liquid cooling provides superior cooling performance versus air cooling [2, 3]. Due to this, an experimental investigation conducted by Zhang et al. [4] discovered that the thermal resistance of the liquid cooling system was lower than that of the air cooling system, at 0.35^{o}C/W and 0.52^{o}C/W, respectively.

Due to the growing need for enhanced cooling systems, one strategy for enhancing the cooling performance of a liquid cooling system is to employ nanofluid as the working fluid. The word "nanofluid" refers to a working fluid in which nanoparticles are dispersed in a base fluid. It possesses superior thermal characteristics to a based fluid [5]. Numerous researchers are investigating the possibility of using nanofluid as a coolant in heat transfer applications [6-8]. Nanofluids contain particles ranging in size from 1 to 100 nm. Additionally, nanofluids have piqued the interest of numerous researchers for their potential application as additives to enhance the heat transfer capabilities of base fluids.

Recent advances in nanofluid research have resulted in the development of a hybrid nanofluid containing two distinct nanoparticles suspended in a base fluid. The synergistic effect of two different types of nanoparticles results in significantly improved thermal characteristics of coolant as compared to a water-based fluid [9, 10]. When producing a hybrid nanofluid, there are two critical factors to consider: the mixing ratio and stability. The optimal mixing ratio ensures that the hybrid nanofluid has a synergetic effect, resulting in a coolant with excellent thermal properties. Stable hybrid nanofluid prevents clogging and improves the accuracy of thermal property measurements.

1.2 Problem Statement

Recent improvements in electronic technology have elevated the demand for a more excellent, effective cooling system to cool down the heat generated during the operation of the electronic device. High heat dissipated by high-tech electronic equipment must be cooled or regulated. Without an effective cooling system, the excessive heat generated might harm the components and cause the entire system to malfunction. Furthermore, significant heat output increases the power needed by a cooling device such as a fan for the cooling process. Electronic components such as the CPU should run under 85^{o}C to work effectively and be reliable [11]. As the temperature nears the temperature limit, the computer slows down its core and lowers the voltage, slowing its performance. Apart from that, the computer system shows a

Blue Screen of Death (BSOD) error message. A blue screen of death (BSOD) is an error message that appears on a Windows computer system following a fatal system failure. It occurs when the operating system reaches a point where it is no longer safe to operate. Therefore a better coolant with superior cooling capacity is needed to meet the requirement for an excellent cooling system.

In heat transfer applications, the hybrid nanofluid is one of the most efficient working fluids. Good preparation of hybrid nanofluid could provide higher performance reliability in the heat transfer application. A stable hybrid nanofluid suspension needs to be prepared to maintain the high reliability of hybrid nanofluid. Stability indicates that the nanoparticle does not agglomerate or silt in the base fluid. This occurs when the Van der Waals force of attraction between the nanoparticles is strong. This leads to the quick settling of agglomerated particles (up to micron size), blockage of heat transfer device channels, and an increase in the measurement error for thermal characteristics. Surfactants improve the stability of hybrid nanofluids by reducing the Van der Waals attraction between the nanoparticles. However, too much surfactant decreases the thermal conductivity of hybrid nanofluid due to many surfactants with low thermal properties surrounding the nanoparticles. Therefore less heat is transferred during the heat transfer process. Thus, the appropriate quantity of surfactant is required to maintain the stability of the hybrid nanofluid and prevent it from changing its thermal characteristics.

The mixing ratio of hybrid nanofluid is critical for maintaining the coolant's good thermal characteristics. However, research on optimizing mixing ratios is limited to the One Factor at a Time (OFAT). As a result, not all mixing ratios with enhanced thermal properties were studied. Additionally, the OFAT strategy is insufficient for comprehensively investigating all possible mixing ratios. It increases the number of trials that must to performed, which is impossible. Therefore, a comprehensive study or method is needed to study all possible mixing ratios that give the best thermal properties for a coolant.

1.3 Research Objective

The study aims to develop a hybrid nanofluid coolant with high thermal properties and good stability suitable for a liquid cooling system for the CPU. The research's aims are as follows:

(a) To evaluate the stability of hybrid nanofluid effect on thermal conductivity.

(b) To identify the best mixing ratio of hybrid nanofluid based on the thermal conductivity and viscosity using the Design of Experiment (DOE) method

(c) To analyze the heat transfer performance of hybrid nanofluid in a liquid system for CPU

1.4 Research Significant

Due to surfactants' low thermal conductivity, the results of this research provide a better knowledge of how surfactant stabilization affects the thermal conductivity characteristics of hybrid nanofluids. A good optimization technique is required to determine the amount of surfactant necessary to stabilize the hybrid nanofluid without impairing its thermal conductivity. A suitable hybrid nanofluid for cooling must have a stable dispersion of nanoparticles within the base fluid and superior thermal properties as a coolant.

This study presents a novel technique for studying all possible mixing ratios within a range selected by utilizing the Design of Experiment (DOE) method with the Design Expert 11 software. Earlier research was restricted to mixing ratio optimization using the one factor at a time (OFAT) method. Additional experiments need to conduct for comprehensive analysis which is not practical. Therefore, this software aids in the development of DOE through full factorial design. After collecting data for the trials, choose only significant terms using analysis of variance (ANOVA), and use the equation provided to predict the responses (thermal conductivity or viscosity) in a form of an equation. Higher thermal conductivity gives a better heat transfer rate of the coolant while lower viscosity will lower the risk of channel clogging.

After optimizing the mixing ratio and concentration of hybrid nanofluid, a study of its heat transfer performance in a liquid cooling system for the CPU gives more insight into hybrid nanofluid's cooling performance in contrast to the traditional coolant, which is water. Then, heat transfer performance analysis can be analyzed using thermal resistance analysis.

1.5 Research Scope

Consider the following scopes to meet the objectives:

1. Titanium dioxide (TiO_2) and graphene nanoplatelets (GNP) were employed as the hybrid nanofluid in this investigation. The mixing ratio range used was between 1:9 to 9:1. The findings are compared to those obtained with distilled water, which is the standard working fluid in liquid cooling systems for CPUs.
2. A surfactant called Hexadecyltrimethylammonium bromide (CTAB) is employed to enhance the stability of the prepared hybrid nanofluid. This surfactant was determined to be appropriate for TiO_2-GNP hybrid nanofluids with ethylene glycol as the base fluid in the earlier study. The surfactant's study entails optimization based on thermal conductivity.
3. The mixing ratio of hybrid nanofluid is studied for only 0.1, 0.3, and 0.5vol%. Therefore, this research determined the best mixing ratio for each concentration using the design of experiment method (DOE) with Design Expert 11 software.
4. The heat transfer performance of the hybrid nanofluid is determined using an existing liquid cooling system for the CPU. Multiple thermocouples were included in the liquid cooling system to monitor the temperature during maximum computer performance.

5. Despite the motivation to use statistical analysis for optimization, there is a limitation on the range used in the experiment. Therefore, if the best value is at the limit range, the result is used as the best value.

1.6 Thesis Outline

This thesis is divided into five chapters. Chapter 1 provides an overview of the demand for cooling systems for electronic devices, the many types of computer cooling systems, and hybrid nanofluids. This section also discusses the definition, benefits, and drawbacks of hybrid nanofluids. Finally, Chapter 1 discusses the issue statement, the research scope, the research objectives, and the study's importance.

Chapter 2 discusses the hybrid nanofluid and liquid cooling system in further detail. Additionally, this chapter discusses the creation of stable hybrid nanofluid, the use of hybrid nanofluid in heat transfer applications, the determination of the mixing ratio of hybrid nanofluid, and the heat transfer performance of liquid cooling systems for CPUs.

Chapter 3 elaborates on details of experimental methods to achieve the research objectives. The methodologies discussed in this chapter include the surfactant's effect on the thermal conductivity of a hybrid nanofluid, optimization of hybrid nanofluid mixing ratio with different concentrations, and the liquid cooling system's heat transfer performance for the CPU. Each experiment discusses the material used, preparation method, and experimental setup in detail. This chapter also discusses the significance of these methodologies to achieve the objectives of this research.

Chapter 4 discusses all the results collected from the experimental works and the validation of the data collected. This chapter discusses the effect of surfactants on the stability of hybrid nanofluids and how the amount of surfactant and mixing ratio affect the thermal conductivity of hybrid nanofluids. Furthermore, the discussion of hybrid nanofluid parameter optimization is based on the ANOVA and followed by proposed equations that can be used to determine the other mixing ratio thermal conductivity and viscosity performance. The selection of an optimized parameter of hybrid nanofluid is based on the equations proposed. Then, compare the heat transfer performance of hybrid nanofluid in the liquid cooling system with the heat transfer performance of water.

Chapter 5 summarises the findings of this research in relation to the objectives. Additionally, recommendations for future research on hybrid nanofluids are made.

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