Effect of Different Process Parameters on The Heat Transfer of Liquid Coolant in Electronic System

By

Wan Mohd Arif bin W. Ibrahim

(1130410686)

A thesis submitted in fulfilment of the requirements for the degree of Master of Science in Materials Engineering

School of Materials Engineering

UNIVERSITI MALAYSIA PERLIS

2017

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

Author's full name	:	WAN MOHD ARIF BIN W. IBRAHIM
Date of birth	:	01 MAY 1979
Title	:	EFFECT OF DIFFERENT PROCESS PARAMETERS ON THE HEAT TRANSFER OF LIQUID COOLANT IN ELECTRONIC SYSTEM
Academic Session	:	SEM I / 2017

I hereby declare that the thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. This thesis is classified as :

☐	**CONFIDENTIAL**	(Contains confidential information under the Official Secret Act 1972)*
☐	**RESTRICTED**	(Contains restricted information as specified by the organization where research was done)*
☑	**OPEN ACCESS**	I agree that my thesis is to be made immediately available as hard copy or on-line open access (full text)

I, the author, give permission to the UniMAP to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during a period of _____ years, if so requested above).

Certified by:

SIGNATURE	**SIGNATURE OF SUPERVISOR**
790501-11-5105	DR. YEOH CHEOW KEAT
(NEW IC NO. / PASSPORT NO.)	**NAME OF SUPERVISOR**
Date : 18/9/2017	Date : 18-9-2017

NOTES : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentially or restriction.

ACKNOWLEDGEMENT

بسم الله الرحمن الرحيم

In the name of Allah, the most Beneficent, the most Merciful Praise be to Allah who gave me the power, the undying strength and the patience bestowed upon me during the course of this study, blessing and peace be upon our prophet Muhammad.

First of all, I would like to express my sincere gratitude and utmost appreciation to my supervisor, Dr. Yeoh Cheow Keat and my co-supervisors, Assoc. Prof Dr. Khairel Rafezi Ahmad and Prof. Dr. Hj. Zainal Arifin Ahmad from Universiti Sains Malaysia. Their guidance, valuable assistance and support during my research project have helped me accomplish this work successfully – Alhamdulillah.

Special thanks to the management of School of Materials Engineering, Center of Graduate Studies and Universiti Malaysia Perlis for providing me the opportunity to pursue my master study. There are many people who deserve my gratitude since they have been contributing to this thesis. Thanks to my office colleagues, to name few of them, especially Lokman Hakim, Azrem Azmi, Faizul Che Pa, Murizam Darus and Ruhiyuddin Zaki for their help, support and co-operation.

Finally, I would like to acknowledge with gratitude, the support, patient and love of my family – my parents, Wan Ibrahim and Fatimah Omar; and my wife Noorina Hidayu as well as for my princesses Rifaa, Zaara and Keisha. Five years is a lot of times, they all kept me going, and this thesis would not been possible without them.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Al_2O_3	Alumina
$Al(NO_3)_3 . 9H_2O$	Aluminium nitrate nanohydrate
CuO	Copper oxide
CPU	Central Processing Unit
DAQ	Data Acquisition System
IO	Input Output
LCHS	Liquid Cooled Heat Sink
MEMs	Micro-electrochemical system
NaOH	Sodium Hydroxide
SiC	Silicon carbide
TDP	Thermal Design Power
TiO_2	Titanium dioxide
OHP	Oscillating Heat Pipe

LIST OF SYMBOLS

˚C	Celcius
%	Percent
∆T	Temperature difference
A	Heat transfer area
cm^2	centimetre square
h	Heat transfer coefficient
J	Joule
K	Kelvin
mPa.s	Viscosity
M	Molarity
Re	Reynold number
s	Seconds
Q	heat flow,
W	Watt

Kesan Perbezaan Parameter Proses Terhadap Pemindahan Haba Sistem Pendinginan Cecair dalam Sistem Elektronik

ABSTRAK

Sistem pemindahan haba yang berkesan adalah sangat penting untuk meningkatkan prestasi pemindahan haba dalam pengaplikasian teknologi terkini, terutamanya, tren pengecilan saiz sistem elektronik yang menyebabkan peningkatan jumlah haba yang dihasilkan. Dalam keadaan di mana sistem pendinginan udara tidak lagi mampu untuk memindahkan sejumlah haba yang banyak, sistem pendinginan cecair dilihat mampu memberikan kelebihan penyejukan berbanding sistem pendinginan udara disebabkan oleh sifat pemindahan haba yang lebih baik. Tetapi pemilihan bahan pendiginan cecair yang tidak sesuai akan menyebabkan prestasi yang rendah atau memberikan masalah terhadap sistem pendinginan. Kajian ini bertujuan untuk mengkaji kesan perbezaan parameter proses terhadap pemindahan haba bagi sistem pendinginan cecair. Kajian telah dijalankan bagi menentukan prestasi pendinginan oleh air suling, minyak sayuran dan larutan alumina dalam sistem pendiginan unit pemprosesan pusat (CPU) terhadap parameter kuasa masukan dan kadar aliran jisim yang berbeza. Pengoptimuman nilai pH adalah sangat penting kerana ia akan menentukan kestabilan larutan alumina, nilai pH yang optimum iaitu pH 4 diperolehi untuk larutan alumina. Penambahan kepekatan zarah alumina yang rendah ke dalam bendalir asas tidak memberikan kesan ketara terhadap kelikatan larutan alumina. Kuasa masukan merupakan pengaruh langsung kepada suhu akhir blok CPU dan bendalir. Pekali pemindahan haba bendalir bertambah baik serta penurunan yang jelas suhu persimpangan antara komponen yang dipanaskan dan blok pendingin air dapat diperolehi kerana kadar aliran jisim yang lebih tinggi. Larutan alumina menunjukan keupayaan penyingkiran haba yang lebih baik serta menmpunyai nilai pekali pemindahan haba yang lebih tinggi berbanding air suling dan minyak sayuran disebabkan oleh penambahan zarah alumina dalam bendalir tersebut. Keputusan ujikaji menekankan komalaran larutan alumina yang lebih tinggi akan menyumbangkan kepada nilai pekali pemindahan haba yang lebih tinggi. Keupayaan penyingkiran haba oleh 0.1 M, 0.5 M dan 1.0 M larutan alumina adalah lebih tinggi iaitu sebanyak 15.4 %, 32.3 % dan 40.8 % berbanding air suling. Kajian ini mengesyorkan 1.0 M larutan alumina yang stabil boleh digunakan sebagai bahan pendinginan cecair terhadap sistem pendinginan CPU dan juga pengendali ujian komponen dalam industri semikonduktor.

Effect of Different Process Parameters on The Heat Transfer of Liquid Coolant in Electronic System

ABSTRACT

An effective heat transfer system is important for new technologies today to enhance the performance of heat transfer, especially, since the miniaturization of electronic system that resulted in dramatic increase in the amount of heat generated. In the case, where air cooling could not meet requirements, liquid cooling does offer significant cooling advantages over conventional air cooling because of its better thermal transfer property. But unsuitable selection of liquid coolants may result to low performance or problems to the cooling systems. This study investigates the effect of different process parameters on the heat transfer of the liquid cooling. Experimental investigations have been carried out for determining the cooling performance of distilled water, vegetable oil and alumina sols in cooling system of central processing units (CPU) at different parameters of input power and mass flow rate. Optimising the pH values is very crucial because it will determine the stability of alumina sols, an optimal pH value of pH 4 is obtained for the alumina sols. There is no significant effect to the viscosity of the alumina sols because of low concentrations of alumina particles are dispersed in base fluids. Input power is direct influence to the final temperatures of CPU block and fluids. The heat transfer coefficient of the fluids is improved and a clear decrease of the junction temperature between the heated component and the water cooling block due to the higher mass flow rate. Alumina sols show better heat removal capability and higher heat transfer coefficient than distilled water and vegetable oil due to the presence of alumina particles in the fluids. Experimental results emphasize the higher molarity of alumina sols contributes higher heat transfer coefficient. The heat removal capability of 0.1 M, 0.5 M and 1.0 M alumina sols have been found as much as 15.4 %, 32.3 % and 40.8 % higher than distilled water. This study recommend that a stable 1.0M alumina sol may be use as liquid coolant for CPU cooling system as well as in component test handlers in semiconductor industry.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Recent development of microprocessor is getting complex with more sophisticated architecture design, stringent design rules and multi-core package to promise a tremendous performance. But all of these needs to be designed in smaller form factor (yet not to sacrifice the higher IO density) to meet current trend, hence lead to inefficient thermal management due to dramatically increase in power density and heat flux. This research will introduce the use of liquid cooling method to replace the conventional air cooling and heat pipe cooling methods that believed will no longer capable to meet the futuristic thermal needs of the next generation computers or supercomputers.

The development of earlier generation computer has started back in year 1940s, since then, the evolution of the Central Processing Unit (CPU) is heading towards better design in terms of higher clock speed, multi-core design and complex architecture mainly for speedy performance and multitasking operations. But all these criteria's need to be designed in smaller form factor to meet current trend (Viswanath et al., 2000). Over the past few years, with the increase of performance requirements for smaller, more capable and more efficient electronic system, management of generated heat is becoming an even-more important issue (Grujicic et al., 2005; Tong, 2011). Improper heat management on the microprocessor due to ineffective of the thermal energy will lead to poor performance as well as shorten the life cycle and reliability of the electronic devices. A distinct fact can be observed from the evolution of module level heat flux in computers, which shows that the heat flux is dramatically increasing since 1990's. The average module heat flux for IBM RY6 that released in year 1998 is 3 W/cm^2, and in year 2002, Intel released Itanium 2 processor, its average module heat flux is 9 W/cm^2. Comparing to Pentium 4 processor which released in year 2004, its average heat flux is 11 W/cm^2 (Ellsworth & Simons, 2005). This trend leads to higher heat flux that produce from CPU, improper management of the heat generated will lead to the life shortening and weaken the product's reliability.

The current air cooling and heat pipe cooling technology present diminishing returns (Sauciuc et al., 2005), and this is important for the industry to establish the research and development to focus on the future non-air cooling technology which is hoped can be the solution to the futuristic thermal needs of the next generation computers. One of the potential solutions to manage the becoming higher heat flux and heat dissipation is by using liquid cooling method. This liquid cooling method can be applied indirectly (indirect liquid cooling) and directly (direct liquid cooling) to the microelectronic chips.

1.2 Problem Statement

Cooling of electronic devices is one of the main challenges of latest generation technology (Colangelo et al., 2017) such as to maintain the heats in component test handler for semiconductor industry as well as higher thermal design point of latest chipset technology. Hence, liquid cooling system could be a better method for thermal management in electronic system due to its better heat transfer capability (Mochizuki et al., 2011). Liquid cooling systems are not widely used even though it may promise better performance compared to conventional cooling systems. The liquid used for cooling materials in this study are water, vegetable oil and alumina sols. Water is commonly used as liquid cooling because of its good thermal properties (Lin et al., 2014), vegetable oil is selected to understand the effect of high viscosity towards the efficiency of heat transfer and selection of alumina sols because of its thermal performance, better stability and cheaper compare to other additive powders (Colangelo et al., 2017; Lee et al., 2008; Yoo et al., 2007).

Unsuitable selection of liquid coolants may result to low performance or problems to the cooling systems. Unsuitable selection of liquid coolants may result to low performance or problems to the cooling system. A proper selection of the solution will result to better performance and longer the life span of the processor. The instability of the solution may lead to poor heat transfer performance, failure in determine the correct pH and concentration of coolant may resulted to instable solution that lead to low efficiency of thermal management and clog the system. Different solutions may have different optimised parameter, hence process parameters optimising is important to ensure the solution can perform best cooling performance.

1.3 Research Objectives

Experiments are conducted to determine the effect of mass flow rate and different input power to the cooling performance of different liquid cooling inclusive of alumina sol, vegetable oil and water on indirect liquid cooling system of a computer.

1- To study the effect of different liquid cooling materials on the performance of a liquid cooling system.
2- To determine the effects of different pH and concentration on the stability of alumina sol.
3- To optimise the process parameters of a liquid cooling materials.

1.4 Scope of Study

Increasing microprocessor performance has always been accompanied by increasing power and increasing on-chip power density. In addition, local power densities are more difficult to be managed, thus making thermal management become more challenging. Liquid cooling is being research due to the limitation in conventional air cooling in thermal heat transfer and increasing needs of high efficiency cooling system for microprocessor. However, the selection of cooling fluids is very critical to ensure good heat transfer can be achieved in microprocessor. This project will focus on the performance of the heat removal capability of different cooling fluids which are distilled water, vegetable oil and alumina sol. The right selection of cooling fluid will enhance thermal transfer performance.

The project also study on the influence of process parameter such as mass flow rate and input power on liquid cooling for computer. The process parameter needs to be optimized to ensure the best performance in the cooling design. This project focused on the effect of mass flow rate and input power on the heat removal capability of water, vegetable oil and alumina sol. Mass flow rate of each liquid cooling will be measured at different pump speed ranging from 1800 rpm to 3300 rpm. The study will focus on two different input powers which are 29.12 watt and 47.66 watt. The viscosity characteristic of the fluid is also being study to understand the flow behaviour of the transfer fluid.

In the experiment, a model of closed loop liquid cooling system was constructed using commercial liquid cooling parts to run the simulation test. The system consists of liquid tank, tygon tube, radiator, pump, heat sink, copper block and thermocouples. Distilled water, vegetable oil and alumina sol are the types of liquid cooling that being study throughout the simulation test. The different properties of the cooling fluids, flow rate and input power are the process parameters that be observed during the test to understand the cooling performance based on the maximum CPU temperature, heat transfer coefficient of liquid and thermal resistance of the water block.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This section details the available information and theories related to the current trend of heat flux for microprocessor, the current available cooling methods, the future development of cooling methods and relevant fluid behaviour.

2.2 Overview on Electronic Cooling Methods

The reliability of the electronics of a system is a major factor in the overall reliability of the system. Recently, high efficiency cooling systems have been received great attention due to importance of thermal management that able to safely dissipate enormous amounts of heat from a very small area in high performance electronic devices. Meanwhile, miniaturization of electronic system has resulted in dramatic increase in the amount of heat generated per unit volume. The thermal management become a great challenge due to continuously rising of the heat flux from microprocessor according to International Technology Roadmap (Ebadian & Lin, 2011). Electronic packaging devices are continuously demands of high performance with miniaturized packaged designed and low cost (Tong, 2011), this evolution of the microprocessor is one of the most visible and representative facets of the computing revolution (Mahajan et al., 2006). Currently, the development of microprocessor is rapidly developed with smaller form factor and higher input density will lead to higher heat density and enormous power density. Improper managed in heat dissipation of the electronic package can result in microprocessor failure. Figure 2.1 is indicative of the CPU heat flux level predicted into the future. Based on the present trend, heat released by the CPU of a desktop and server computer is 80 – 130 W and of notebook is 25 to 50 W (Duangthongsuk & Wongwises, 2010).

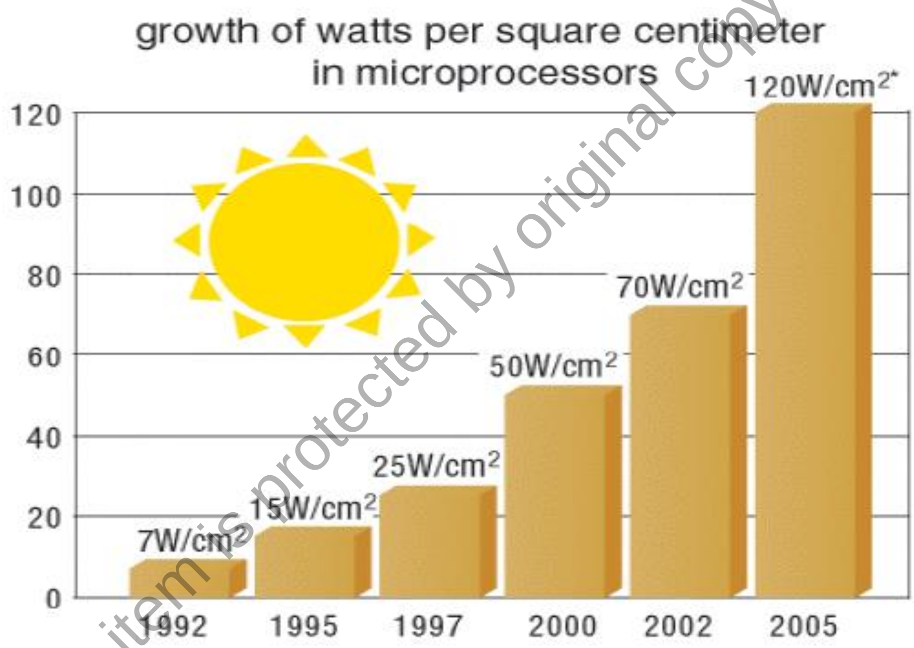

Figure 2.1 : The growth of CPU power density (Davis et al., 2006).

An effective heat transfer system is important for new technologies today to enhance to performance of heat transfer. Technological developments such as microelectronic devices with smaller (sub-100 nm) features and faster (multi-GHz) operating speeds requiring advances in cooling. Especially, for personal computers today have shown a competitive released in more speedy and powerful product and shift to be more compact and smaller in size. Therefore, thermal management becomes a main challenge as the heat flow demands have increased over time.

The flow of heat in a process is shown in Equation 2.1

$$Q = hA \Delta T \tag{2.1}$$

Where, Q is the heat flow, h is the heat transfer coefficient, A is the heat transfer area, and ΔT is the temperature difference that results in heat flow.

The effective heat transfer is direct proportional to the heat transfer coefficient (h), heat transfer area (A) and temperature difference (ΔT). Other than the factor of temperature difference ΔT that can lead to increase heat flow, maximizing the heat transfer area A is a common method to enhance heat transfer performance. In order to optimize the heat transfer, advanced exchangers such as radiators are designed to maximize the heat transfer area, but this method cannot be applied in microprocessor and micro-electromechanical system (MEMs) due to the shrinkage of electronic packaging. Heat transfer improvement can also be achieved by increasing the heat transfer coefficient h with enhancing the properties of the coolant (Ijam & Saidur, 2012). Additives are often added to liquid coolant to improve the heat transfer coefficient.

The primary purpose of electronics thermal control is to prevent the catastrophic failure, which is closely associated with a large temperature rise that may cause a drastic deterioration in semiconductor behaviour, delaminating, fracture and melting of packaging materials (Feroz & Uddin, 2009). This will lead to an immediate and total loss of electronic function and package integrity. The prime failure of electric equipment is always temperature related. Figure 2.2 is shown to reflect a near exponential dependence of the thermal acceleration factor on component temperature. Thus, a rise in temperature from 75 ˚C to 125 ˚C can be expected to result in a five-fold increase in failure rate. Under some conditions, a 10 ˚C to 20 ˚C increase in chip temperature can double the component failure rate (Bar-Cohen et al., 2001).

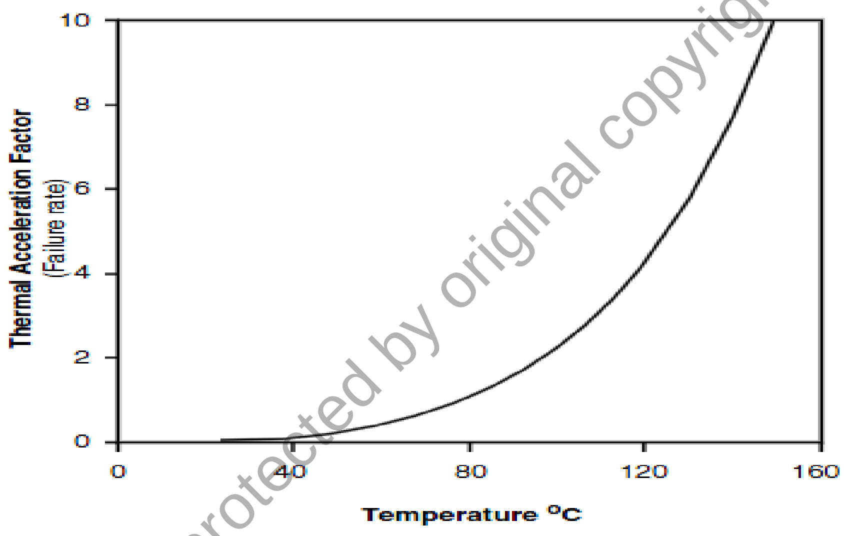

Figure 2.2 : Effect of temperature on failure rate (Bar-Cohen et al., 2001).

The reliability of an electronic system comprising a group of components is most simply stated as the probability, expressed in percent, of operating continuously over a specified period of time with no failures. The failure rate model of CPU may be competitively described by the Arrhenius-type model:

$$\lambda_i = B_i e^{\left(-A_i / \lambda_j(T)\right)} + E_i \tag{2.2}$$

where the coefficients A_i, B_i, *and* E_i are independent of temperature.

Figure 2.3 shows typical junction temperatures for equipment presently operating in a large number of field applications. The 40 °C to 60 °C is the acceptable operating temperatures of range for semiconductor junctions. The reliability below 0°C is uncertain and some semiconductors stop operating, only to return to operation at higher temperatures with no apparent permanent damage. 85 °C is set as the upper limit operating temperature for commercial applications and for military equipment the acceptable upper limit operating temperature is 100 °C to 110 °C semiconductors in power supplies and processors.

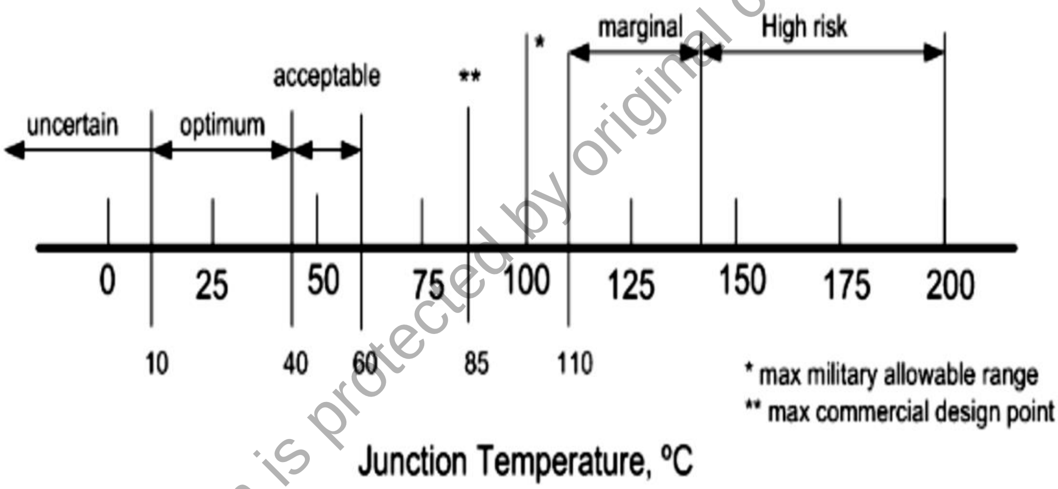

Figure 2.3 : Temperature spectrum of operating junctions (Kaseb, 2011).

The most common cooling method for CPU today is air cooling method because air cooling system is low cost, ready available and transparency to the end user. All IBM computers were cooled solely by forced air due to the introduction of the System/360 Model 91 Processor in 1964 (Ebadian & Lin, 2011). The cooling system which is equipped with heat generating component with heat sinks and fans is named as Air-Cooled Heat Sink. In heat generation module, the heat sink is constructed of a base region that is in contact with the module. The fins push forward from the base serve to