UNIVERSITI PUTRA MALAYSIA

HEAT TRANSFER AND NANOFLUID FLOW CHARACTERISTICS IN MICROCHANNEL HEAT SINK WITH DIFFERENT SHAPES

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By

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

July 2013

Abstract of thesis presented to the Senate of Universiti Putra Malaysia
In fulfilment of the requirement for the degree of Master Science

HEAT TRANSFER AND NANOFLUID FLOW CHARACTERISTICS IN MICROCHANNEL HEAT SINK WITH DIFFERENT SHAPES

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July 2013

Chairman: Associate Professor Nor Mariah Adam, PhD, PE

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The main aim of this study is to enhance the cooling performance of MCHS by using conventional fluid, nanofluids and different cross-section shapes including hexagon, circular and rhombus MCHS. Microchannel heat sink (MCHS) has the most common and cost-effective hardware employed for the thermal management of Micro-Electro-Mechanical systems (MEMS) devices. The small channels of the Microchannel heat sink hydraulic diameter provided a high heat transfer coefficients. Geometry parameters of the channels like width and height are supposedly to have a significant effect on the laminar heat transfer and liquid flow in MCHS (Gunnasegaran et al. 2009). In this study, a numerical investigation of liquid laminar flow and heat transfer in different cross-section shapes microchannel heat sink using water and different types of nanofluids was studied. The upper wall is heated while the bottom wall and sides are adiabatic. Four types of nanofluids (Al_2O_3, CuO, SiO_2 and ZnO with pure water) with

different nanoparticles volume fraction (1%, 2%, 3% and 4%) and various nanoparticles diameter (25, 40, 55 and 70 nm) were used. In addition, the effect of using different types of base fluid which are ethylene glycol ($C_2H_4(OH)_2$), Engine oil , glycerin ($C_3H_5(OH)_3$) and water in MCHS with the nanofluids was also analyzed. This investigation cover Reynolds number and heat flux ranged from 100 – 1000 and 100 – 1000 kW/m^2, respectively. The three-dimensional (3D) MCHS governing equations for both heat transfer and liquid flow were resolved by using Finite Volume Method (FVM). Model geometries have been drawn and meshed in GAMBIT 2.3 and simulations have been performed in commercial CFD cods FLUENT 13. The results show that the MCHS cooling performance was greatly influenced by the shapes of the channels cross-section and nanofluids. The best heat transfer performance was obtained in the rhombus cross-section MCHS by using Al_2O_3-H_2O nanofluids as a working fluid at 4% particle volume fraction and 25 nm nanoparticles diameter.

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

PEMINDAHAN HABA DAN CIRI ALIRAN BENDALIR NANO DI DALAM SALURAN MIKRO DENGAN BERBAGAI BENTUK SINK HABA

Oleh

ALTAYYEB ABDULLAH KADHIM

Julai 2013

Pengerusi: Profesor Madya Nor Mariah Adam, PhD, PE

Fakulti: Kejuruteraan

Dalam kajian ini, kaedah berangka bagi bendalir aliran laminar dan pemindahan haba di dalam sink haba saluran mikro yang menggunakan berbagai jenis bendalir nano telah dikaji. Sink haba saluran mikro (MCHS) merupakan perkakasan paling lazim dan jimat kos untuk pengurusan haba dalam sistem peranti micro-electro-mekanikal (MEMS). Saluran mikro MCHS mempunyai diameter hidraulik yang kecil dan dapat menyediakan pekali pemindahan haba yang tinggi. Parameter geometri salur sepeti lebar dan ketinggian dikaitkan dapat memberi kesan signifikan terhadap pemindahan haba laminar dan aliran bendalir dalem MCHS. Dinding bahagian atas dipanaskan manakala dinding bahagian bawah dan kedua – dua sisi adalah adiabatik. Empat jenis bendalir nano (Al_2O_3, CuO, SiO_2 dan ZnO bercampur air tulen) dengan pecahan isipadu zarah (1%, 2%, 3% and 4%) dan diameter zarah nano (25, 40, 55 and 70 nm) telah digunakan. Tambahan lagi kesan menggunakan berbagai jenis bendalir asas iaitu ethylene glycol

($C_2H_4(OH)_2$), glycerin ($C_3H_5(OH)_3$), minyak enjin dan air tulen dalam MCHS untuk mendapatkan bendalir nano ulung telah dianalisis. Siasatan ini merangkumi masing-masing nilai nombor Reynolds dan nilai fluks haba dalam julat 100 – 1000 dan 100 – 1000 kW/m^2. Persamaan menakluk MCHS dalam tiga dimensi (3D) untuk kedua-dua pemindahan haba dan aliram bendalir telah diselesaikan menggunakan kaedah Isipadu Terhingga (FVM). Tujuan utama kajian adalah untuk meningkatkan prestasi penyejukan MCHS yang menggunakan bendalir lazim dan bendalir nano dengan berbagai bentuk termasuk heksagon, bulat dan rombus. Model jejaring geometri telah disurih dan dijaringkan menggunakan GAMBIT 2.3 dan simulasi telah dijalankan dengan menggunakan perisian komersil CFD kod FLUENT 13. Keputusan menunjukkan prestasi penyejukan MCHS telah meningkat dengan menggunakan bendalir nano dan parameter geometri untuk bentuk khusus. Prestasi pemindahan haba terbaik telah diperolehi dengan menggunakan bentuk rentang rombus bersamaan bendalir Al_2O_3-H_2O pada 4% isipadu pecahan zarah dengan saiz zarah diameter 25 nm.

ACKNOWLEDGEMENTS

First of all, great thanks to the Most Gracious and Most Merciful, Allah (S.W.T) without His wish and help this work would not have been possible. I also would like to express the most sincere appreciation to those who made this work possible: advisory members, friends and family.

I would like to thank Associate Professor Ir. Dr. Nor Mariah Adam and Associate Professor Dr. Hussein A. Mohammed for providing me with the opportunity to complete my Master studies under their valuable guidance, for the many useful advice and discussions, for their constant encouragement and guidance, and for co-authoring of my publications, where their practical experience and technical knowledge made this research and those publications more interesting and relevant. Also special thanks extended to Supervisory Committee member; Associate Professor Dr Mohd Khairol Anuar bin Mohd Ariffin, I am grateful for his willingness to serve on my supervisory committee, his constant encouragement, helpful advice and many fruitful discussions have been very helpful.

Thanks and acknowledgements are meaningless if not extended to my parents who deserve my deepest appreciation. I am grateful for the countless sacrifices they made to ensure that I could pursue my dreams and for always being there for me. Real and deepest thanks to them (May Allah bless and protect them and may live long and healthy). Lastly but not least I want to thank all my friends for their supporting.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment on the requirement for the degree of Master Science. The members of the supervisory committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institutions.

ALTAYYEB ABDULLAH KADHIM

Date: 9 July 2013

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LIST OF ABBREVIATIONS

A	Channel flow area	m^2
A	Component of vector	
Al_2O_3	Aluminum oxide	
b_{ch}	Half height of the hexagon channel	µm
c_{ch}	Half width of the hexagon channel	µm
CFD	Computational Fluid Dynamics	
C_p	Specific heat	J/kg.K
CuO	Copper oxide	
D_{ch}	Diameter of the circular channel	µm
d_{ch}	Edge length of the hexagonal channel	µm
D_h	Hydraulic diameter	µm
Dp	Diameter of nanofluids particles	Nm
EG	Ethylene Glycol	
F	Friction factor	
FVM	Finite Volume Method	
H	Heat transfer coefficient	$kW/m^2.K$
H_2O	Water	
H_{hs}	Heat sink high	Mm
κ_s	Solid thermal conductivity	W/m.k
κ	Thermal conductivity	W/m.K

L_{ch}	Channel length	µm
L_{hs}	Heat sink length	mm
M	Molecular weight of base fluid	
MCHS	Microchannel heat sink	
N	Avogadro number = $6.022*10^{23}$	mol^{-1}
N	Number of channels	
N	Direction normal to the surface element	
N	Direction normal to the wall or the outlet plane	
P	Channel wet perimeter	mm
P’	Pressure correction	
$\hat{p}$	Dimensionless pressure	
$\overline{P}$	Pumping power	W
P_{ch}	Channel high of the rhombus	µm
P_{in}	Inlet pressure	Kpa
P_{out}	Outlet Pressure	Kpa
Q_{ch}	Channel width of the rhombus	µm
q_w	Heat flux at microchannel heat sink top plat	kW/m^2
R	Radius of channel	μm
Re	Reynolds number	
R_{th}	Thermal resistance	$K/kW/m^2$
S	Distance between two microchannels	µm
SiO_2	Silicon dioxide	

T_f	Temperature of coolant	K
T_{in}	Fluid inlet temperature	K
T_{max}	Maximum temperature	K
T_w	Wall temperature	K
U	Dimensionless velocity in X-coordinate	
U	Fluid velocity	m/s
u_{in}	Inlet fluid velocity	m/s
V	Dimensionless velocity in y-coordinate	
V^{o}	Volume flow rate	
W	Dimensionless velocity in z-coordinate	
W_{hs}	Heat sink width	Mm
x_{ch}	Channel hypotenuse of the rhombus	µm
X,Y,Z	Dimensionless Cartesian coordinates	
ZnO	Zinc oxide	
Δp	Pressure drop	Kpa

Greek Letters

β	Thermal expansion coefficient	K^{-1}
ρ	Density	Kg/m^3
∅	Particle volume fraction	%
Φ	channel angle	
Θ	Dimensionless temperature	

Subscripts

bf	Base fluid
ch	Channel
eff	Effective
f	Pure fluid
h	Hydraulic
hs	Heat sink
in	Inlet
max	Maximum
n_f	Nanofluids
np	Nanoparticles
out	Outlet
s	Sold
th	Thermal
w	Wall

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The expansion of manufacturing of small devises demanded a better understanding of fluid flow and heat transfer in microgeometries. An important part of research have been made on heat transfer and fluid flow, as a new way been paved for research by the introduction of Micro-Electro-Mechanical Systems (MEMS) to establish the continuum is not an option anymore. The various uses of MEMS include the usage in the medical and biomedical fields, in chemical separations, technology field of computer chips and much more. The MEMS are developed not just for scientific research purposes, but also for commercially used applications. The technology in micro machines advancements has allowed the development design of miniature size systems which is used in many confident fields of applications, especially in the fields of electronic-bioengineering and medical sciences. The small scale fluid channels are embedded often in the systems to the surrounding solids with heating sources. A mini-channel (depending on its height) is described at a characteristic dimension of about one mm for a microchannel as the characteristics dimension of a several microns to several hundred microns. MEMS devices performance is related directly to the temperature and it is therefore major concern to maintaining the electronics at acceptable levels of the temperature. The effective cooling techniques have become known as microchannel heat sinks.

The focus point of this research is to size miniaturization and increase the efficiency of the micro-chips which leads with the generation of heat that at the level of 500 kW/m^2. as the temperature removal is a vital issue for security and reliability of the electronic devices (Kumar, 2009). Figure 1.1 illustrates a MCHS which is a multiple microchannels stacked together. Thus, the total contact surface area is increased to enhance heat transfer and so decreasing the total pressure that is dropped with the flow among the many channels. Heat generation is an irreversible process so in order to maintain a continuous operation by extracted heat (Gunnasegaran et al., 2010). The first to place the technology of Micro-channel cooling is Tuckerman and Pease (1981). They managed to circulate water in microchannels that were fabricated in silicon chips. The heat flux flexibly reached 790W/cm^2 without a penalty on phase change in pressure to drop of 1.94 bar. The developed thermal energy during the continuous operation of the electronic chip is dissipated by simple incorporation efficient heat sink on the chips. Previous experience showed that failure of electronic chips was cause due to the rise of temperature in the circuits which accumulated by the generated heat. Therefore, the chips included with micro-channels to heat sink are the ultimate solution in ultra-compact electronic gadgets.

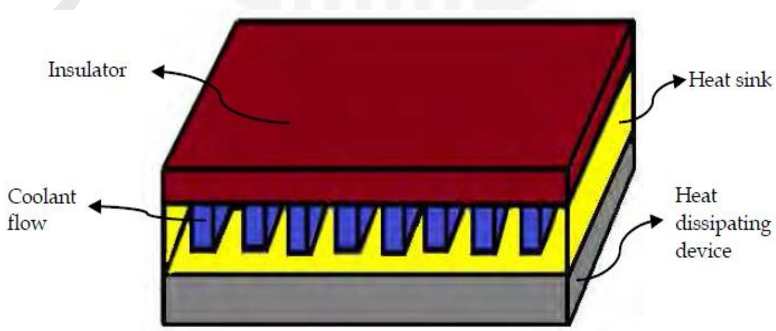

Figure 1.1: Schematic diagram of the MCHS (Gunnasegaran et al., 2010).

In the developed countries, the major priority is to secure clean energy. Energy conversion and transportation that takes place at atomic or molecular levels, with Nano-science and nanotechnology are expectedly playing an important role to revitalize the traditional energy industries and revolutionize the renewable energy industries emergence. Today's various forms of energy that are used more than 70% is produced through or in the form of heat. As many of the systems in the industrial fields, the transfer of heat is either into input energy to operate a system or removed from a heat producing system. Considering the rapid increase in energy demand worldwide, intensifying heat transfer process and reducing energy loss because of ineffective use have become a task of great importance. Heat removal and control are the exacting challenges in some high heat flux systems such as micro/nanoelectronics mechanical systems (MEMS/NEMS), process intensification, nuclear fission, fusion and micro chemical reactions.

The main target of Nanofluids is the enhancement of the thermal conductive abilities of the few of the typical heat transfer fluids, like water, mineral oils and ethylene glycol, as the nanoparticles influence is found to be more than just the profound enhancing of the thermal conductivity effect. The recent researches are concentrated on thermal conductivity, overlooking nanofluids properties alteration specifically the viscosity and surface properties. Nemours inconsistent experiments of nanofluids application under flow conditions with or without phase change have been reported. Therefore, the conclusion that nanofluids do have the potential to becoming the new solution for the

MCHS cooling mechanism for the future that lies ahead the enhancement of heat transfer in the MCHS.

1.2 Problem Statement

Functional component rose rapidly in density and speed in microprocessors use, which in turn led to the significant rise in the generation of heat sink in electronic chips. The heat sink requires the heat fluxes to be dissipated in order to mating the chip temperature at the maximum allowable level. MCHS has a lot of advantage such as compact size, dense package, large amount of heat removal from a small area and larger dense surface area per unit volume. Therefore, many investigations of theoretical and experimental done by several researchers exploring the single phase and two phase microchannel heat transfer in duration of recent decade that would be capable of dissipating high heat flux per unit area. Geometry parameters of the channels like width and height are supposedly to have a significant effect on the laminar heat transfer and liquid flow in MCHS (Gunnasegaran et al. 2009).

There are a few of papers that studied the different shapes of MCHS such as Gunnasegaran et al. (2010) who studied numerically the heat transfer and fluid flow characteristic in the rectangular, trapezoidal and triangular cross-sections shapes MCHS using water as a working fluid. The hydraulic diameters for all shapes of MCHS ranged from 259 μm to 385 µm. The Reynolds number varying between 100 to 1000. It can be noticed from the results that the rectangle cross-section microchannel indicates the lower temperature profile and higher heat transfer coefficient than other shapes. Hexagon, rhombus and circular cross-sections areas are possible to obtain better enhancement than Gunnasegaran at al. (2010), this is due to their lower cross-sections which may reduce the distribution temperature and increase the heat transfer coefficient. Furthermore, Khan et al. (2011) investigated experimentally the performance of the water flow friction factor behavior in a single-phase through circular microchannels. The hydraulic diameter of the microchannel was 279 μm and 45 mm long. Moreover, an investigation carried out by Shams et al. (2009) numerically on the characteristics of fully developed laminar flow and heat transfer in the slip flow regime for rhombus microchannels with the gas working fluid.

Nanofluids, in the recent years focused on cooling in various industrial applications. This new generation of heat transfer fluids consists of suspended nanoparticles, as they possess better stable suspension when compared to sizes of milli-meter to micro-meter (Gunnasegaran et al. 2010). Ho et al. (2010) investigated experimentally the heat transfer performance in rectangular cross-section MCHS. They used water and Al_2O_3 nanoparticles at Reynolds number rated from 100 – 1600. The volume fraction of Al_2O_3 is ranged from 0% to 2%. The hydraulic diameter for the rectangular cross-section is 418 μm.

Extending with the previous part, it can be noticed that limited work has been done with hydraulic diameters ranged from 170 to 300 μm for hexagon, rhombus and circular shaped MCHS using water and nanofluids as a working fluids. The results of the heat transfer enhancement using different MCHS shapes (circular, rhombus and hexagon cross-section MCHS), different type of nanofluids (Al_2O_3, CuO, ZnO and SiO_2 with H_2O), different nanoparticles diameter (25, 40, 55 and70 nm), volume friction of nanoparticles (0%, 1%, 2%, 3% and 4 %), different base fluids (water, glycerin, engine oil and Ethylene Glycol) and Reynolds number vary between 100 to 1000, are examined in this study.

1.3 Aim of the Study

This study mainly focuses on 3D computational simulation of heat transfer and laminar nanofluids flow characteristics in MCHS. In this study, various effects such as geometrical parameters with various shapes, different nanoparticles volume fractions, different nanofluids types, different nanoparticles diameter and nanoparticles in different base fluids will be numerically investigated.

1.4 Objective of the Study

The overall objective of this thesis is heat transfer and nanofluids flow characteristics in microchannel heat sink with different shapes. Based on the problem statement the specific objectives of the present study are as follows:

1. To analyze the heat transfer and liquid flow characteristics in different cross-sections MCHS shapes by using water as working fluid.

2. To optimize the cooling performance of the MCHS using different types of nanofluids such as zinc oxide (ZnO), aluminum oxide (Al_2O_3), copper oxide (CuO) and silicon oxide (SiO_2) with base fluid pure water.

3. To examine the potential influences of different nanoparticles volume fraction (1%, 2%, 3%, and 4%) and different size of nanoparticles diameter (25, 40, 55, and 70 nm) of aluminum oxide (Al_2O_3-H_2O) on heat transfer and liquid flow characteristics in the MCHS.

4. To validate the effect of suspended nanoparticles in different conventional base fluid such as glycerin ($C_3H_5(OH)_3$), engine oil, ethylene glycol ($C_2H_4(OH)_2$) and as well as Al_2O_3 - water on heat transfer and liquid flow characteristics in the MCHS.

1.5 Scope and Limitations

In this thesis, a multidisciplinary optimal design approach is employed to computationally and efficiently optimize the heat transfer capabilities of microchannel heat sink using CFD and numerical optimization. The flow is limited to the laminar flow regime. The thickness of the cross-section for the three different channels (circular, rhombus and hexagon cross-section MCHS) are 200, 250 and 300 μm and the length is fixed as 10 mm for all channels. This study also takes in-depth look at the optimization of heat transfer objective such as temperature profile, heat transfer coefficient, pressure drop, friction factor and thermal resistance by using water and nanofluids as a working fluid.

In this work, hexagon, circular and rhombus cross-section MCHS have the same volume but the hydraulic diameter for circular shape (200,250 and 300 μm) is bigger by 15% than corresponding hexagon and rhombus shapes (170, 216 and 260 μm). The working fluids of the MCHS are water and different types of nanofluids such as Al_2O_3 - H_2O, CuO- H_2O, ZnO- H_2O and SiO_2- H_2O. The Reynolds number is ranged from 100 to 1000. Appendix A shows the top wall temperature of three channels shapes MCHS which are rhombus, hexagon and circular cross-sections for Reynolds number vary between 100 to 2000. It can be observed from the appendix A that the trends of the temperature for the three shapes have reduced and approached to each other until Re = 1000, then the temperature shows stable behavior when the Reynolds number ranged between $1000 \leq Re \leq 2000$. Hence, there is no advantage deliberating of using Reynolds number more than 1000. The Reynolds number also plays an important role in specifying the transition region from laminar to turbulent. Thus, the transition Reynolds number to turbulence was found to be at 1100.

1.6 Application of the Study

MCHS configuration is widely studied on flow and heat transfer in microchannel heat sink for the problems that associate with thermo-fluids area. The reason is that it is used in many industrial applications such as high-energy laser mirrors, microelectronics and diode laser arrays (Phillips, 1988). Coefficient value of heat transfer in MCHS unit greatly depends on the difference of geometrical parameters in MCHS. In this study, increasing the heat transfer coefficient and reduce the temperature were considered. Achievement of an enhanced heat transfer is by the introduction of high thermal conductivity nanoparticles into the base fluid within the channel. This concept is expected when the use of the nanoparticles in nanofluids increases the thermal conductivity and therefore it will substantially improve the characteristics of heat transfer (Eiamsa-ard and Promvonge, 2008).

Ongoing research on nanofluids varieties have found that most the application in commercial and industrial products thermal management. In which recently studies demonstrated the nanofluids ability of the performance to excel and improve for the systems of the real world and devices like the automatic transmission. The development of advanced cooling technology as on the mostly used application used in nanofluids to cool crystal silicon mirrors, vehicle cooling, electronics cooling, transformer cooling, nuclear cooling and space cooling. Nanofluids technology also can help develop better oils and lubrications (Das, 2008). The enhancement of lubricants by the use of nanofluids aid the tribological properties of the lubricants, this is demonstrated in the reduction of friction properties and load carrying capacity between moving mechanical components (Shen, 2008). Formulated Nanofluids in medical applications use are being implicated, that includes cancer therapy. It also can be used in heating buildings and reducing pollution (Kulkarni, 2009). Furthermore, in future the use of nanofluids will be able to maintain a gradient of high temperature in thermoelectric which in turn allow the use of the heat to become utilize energy (Das, 2008). Nanofluids could increase the energy efficiency in building without the need to use a more powerful pump.

1.7 Thesis Outline

Chapter 1 has provided the general background of MCHS, problem statement, aim of study, objective of study, the scope of work and application of study.

Chapter 2 reviews the details of the MCHS. This chapter discussed the microchannel cross sectional shapes and working fluid which are used to investigate the heat transfer and liquid flow characteristics in MCHS. The last part reviews is the fundamentals of the nanofluids such as production of nanofluids, thermophysical properties of nanofluid, industrial application of nanofluids and challenges.

Chapter 3 presented an introduction of numerical methodology of this study and physical model and assumption which is consist of physical model, governing equations, code validation, boundary condition and geometry mesh. CFD and CFD modeling process are also studied. The thermophysical properties of nanofluids using different nanoparticles volume fraction, different nanoparticles diameter and different base fluid are presented. Finally, the finite volume numerical implementation method for solving 3D general convection-diffusion problems and fluid flow computation by SIMPLE algorithm is also briefly described in this chapter.

Chapter 4 presents the result and discussion of the current study. This chapter is divided into four sections. The first three sections are introduction, grid independence test and code validation. The forth section is divided into five sections to show the effect of geometrical parameters with various shapes of MCHS using water, to show the performance of MCHS using different types of nanofluids, different types of nanoparticles volume fractions (ϕ), different nanoparticles diameters (d_p) and different types of base fluids.

Finally, chapter 5 summarizes the conclusions that have arisen from this entire research study and suggestions for future work to improve the current research.

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