NUMERICAL PREDICTION OF LAMINAR NANOFLUID FLOW IN RECTANGULAR MICROCHANNEL

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Dedicated to my late father

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ABSTRACT

Numerical simulation of laminar nanofluid flow in Three-dimensional (3D) straight rectangular microchannel heat sink is carried out. In this study the behavior and effect of using pure water and Fe_3O_4-H_2O as working fluids in the microchannel are examined. Fe_3O_4-H_2O with volume fraction range of 0.4% - 0.8% are used in this simulation to evaluate the cooling performance of microchannel heat sink. Fluent, a Computational Fluid Dynamic (CFD) is used as the solver of simulation. A rectangular microchannel with hydraulic diameter of 86 µm and length of 10mm under the boundary condition of constant heat flux and uniform inlet velocity is set on this analysis. The Results of present work show that using Fe_3O_4-H_2O as coolant resulted in to higher efficiency of heat transfer in microchannel heat sink in comparison to Pure water. However, using Fe_3O_4-H_2O with 0.8% volume fraction provide a high heat transfer enhancement of 30% as compared to 0.4% and 0.6% volume fractions of the same Fe_3O_4-H_2O. Numerical results show that increasing the thermal conductivity of working fluid can enhanced heat transfer. Therefore, it is equally important to note that the presence of nanoparticles could enhance the cooling of MCHS. Meanwhile, higher Nusselt number is found as fluid enters the channel inlet. This could be anticipated as a result of the development of thermal entry region at the channel and the values of Nusselt number tend to stabilize after fully develop region has been achieved.

ABSTRAK

Kajian simulasi berkaitan pengaliran aliran nano (lamina) berdimensi segi empat tepat menerusi penyerap haba saluran mikro dalam Tiga Dimensi (3D) dilakukan. Perubahan dan kesan ketika pengunaan air tulen (suling) dan Fe_3O_4-H_2O (bendalir kerja) di dalam saluran mikro ini akan dikaji.Simulasi ini akan mengkaji pretasi penyejukan penyerap haba saluran mikro dengan mengunakan Fe_3O4-H_2O pada julat yang kecil,iaitu diantara 0.4% - 0.8%. Perisian Fluent, Computational Fluid Dynamic (CFD) akan digunakan untuk menjalankan simulasi ini. Analisis ini akan dilakukan pada saluran mikro segi empat tepat dengan dimensi, 86 µm diameter hidraulik dan 10mm panjang pada keadaan sempadan fluks haba yang berterusan dengan halaju seragam. Hasil daripada kajian terkini berkaitan penyerap haba saluran menunjukan pengunaan Fe_3O_4-H_2O sebagai penyejuk akan memberi kesan kecekapan yang lebih tinggi berbanding air tulen (suling) dari segi pemindahan haba.Walau bagaimanapun, pengunaan Fe_3O_4-H_2O 0.8% pecahan isipadu akan memberi peningkatan pemindahan haba yang tinggi iaitu sebanyak 30% berbanding 0.4% dan 0.6% pada pecahan jumlah yang sama. Keputusan berangka menunjukkan bahawa peningkatan kekonduksian haba bendalir kerja boleh menigkatkan pemindahan haba. Oleh itu, adalah mustahak untuk mengambil kira kehadiran partikel-partikel nano yang boleh meningkatkan penyejukan MCHS. Sementara itu, bilangan Nusselt yang lebih tinggi telah ditemui ketika bendalir mengalir pada saluran masuk terusan. Ini dapat dijangkakan akibat

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LIST OF ABREVIATIONS

3D	Three Dimensional
Fe_3O_2-H_2O	Ferrofluid
H_2O	Pure water
CAD	Computer Aided Design
CFD	Computational Fluid Dynamic
EG	Ethylene glycol
EO	Engine oil
FVM	Finite Volume Method
GAMBIT	Geometry and Mesh Building Intelligent Toolkit
IC	Integrated Circuit
MCHS	Microchannel heat sinks
VEROS	vacuum evaporation onto a Running oil substrate
VSLI	very large scale integrated

LIST OF SYMBOLS

A	Area
C_p	Specific heat capacity
Dh	Hydraulic Diameter
h	Heat transfer coefficient
H	Height of the microchannel heat sink
H_{ch}	Height of the channel
H_{w1}	Height from bottom surface
H_{w2}	Height from the top Surface
L	Hydraulic length
K	Thermal conductivity
k_{bf}	Thermal conductivity of base fluid
k_p	Thermal conductivity of solid nanoparticle
k_s	Solid thermal conductivity
Nu	Nusselt Number
q"	Heat Flux
Re	Reynolds Number
T	Temperature
T_{in}	Inlet temperature
V (u,v,w)	Velocity
W	Microchannel heat sink width
W_{ch}	Channel width
$W_{w1/w2}$	Channel thicknes
Φ	Volume fraction of nanoparticles

Greek Symbols

ρ	Density
μ	Kinematic Viscosity
ϕ	Particle volume fraction

Subscripts

b_f	Base fluid
f	Fluid
in	Inlet
nf	Nanofluid
s	Solid nanoparticle

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The severe need by user for greater IC speeds, functionality and minimization has fuelled an extraordinary acceleration in chip power dissipation. Amongst all the problems facing by the chip and computer designers is none other than more burning than the soaring levels of power flowing through the integrated circuits. Thermal demands are continuously on the rise. Increasing process speeds (up to 2.5 GHz), decreasing product sizes and styling requirements cause higher and higher heat loads on the products and consequently thermal management is becoming a critical bottleneck to system performance. The National Electronic Technology Roadmap, 1997 has acknowledge the expectation that the Moore' law improvements in the semiconductor technology will continue into the second decade of the 21st century [1]. Due to these enhancements, the chip level heat fluxes have gone up tremendously.

The heat dissipated by silicon chips has increased from 10-15 W/cm^2 in the year 2000 to 100 W/cm^2 in the year 2006. High heat fluxes of the order of 10^2-10^3 W/cm^2 are also found in opto-electronic equipment, high performance super computers, power devices, electric vehicles and advanced military avionics[2]. As now the thermal design power of the last versions of processors for high performance calculation is about 100-130 W/cm^2.

These significant developments of power of microprocessors and other electronic components by simultaneous reduction of their surface area contribute to critically high the heat flux generation. An increase in the heating density of these components has been a serious problem affecting the performances and reliability of the electrical devices. The advance cooling technology using microchannels were proposed by [3] for cooling very large scale integrated (VLSI) circuitry. The concept of microchannel heat sink applied in cooling system is important due to high-density electronics packaging requires new advancement in thermal management.

Cooling becomes one of the top technical challenges facing high-tech industries. Since conventional methods of cooling such as forced convection air cooling fails to dissipate away the astronomical volumetric heats from the very small surfaces of electronic chips and circuits, new solution need to be present to overcome these matter. The small physical size of electronic equipment and limitations of air cooling systems have caused an increase of interest in high-performance liquid cooling systems. A liquid coolant is pumped through the microchannels of the hea sink so as to extract the heat from the source such as electronic chip on which it I mounted. In most cases, water is used as a coolant. But water is well known as hea transfer fluids which have low thermal conductivity that greatly limits the hea exchange efficiency. Other base fluids like engine oil and ethylene glycol also have low thermal conductivity.

Promising result was obtained if using nanofluids as a coolant. Nanofluidscan be used to improve heat transfer and energy efficiency by addition of solid phase into the base fluid. Nanofluids can be considered to be next generation heat transfer fluids as they offer exciting new possibilities to enhance heat transfer compared to pure liquids. Nanofluids are expected to have superior properties compared to conventional heat transfer fluid.

1.2 Problem Statement

The used of nanofluids as a coolant for microchannel heat sink on semiconductor and electrical field is found out more effective and researches on this application are increase from time to time. Before nanofluids was first discovered, most of the researches focus on conventional methods of cooling such as forced convection air-cooling and using fin to dissipate away the excessive heats from the microchannel heat sink. Most of the researches focused on the material properties of microchannel heat sink can enhance the heat transfer. There are a few journals and papers discuss about heat transfer mechanism and research on material properties of the microchannel using Fe_3O_4-H_2O. This study will focus on heat transfer enhancement Using Fe_3O_4-H_2O in Microchannel.

1.3 Objectives of the Study

Before the research is carried out the objectives of the study has to be defined. However the main objectives regarding this simulation study are:

1. To study the fluid behaviour along the rectangular microchannel
2. To analyse the heat transfer performance in microchannel using Fe_3O_4-H_2O

1.4 Scope of the Project

To achieve the stated Objectives above the scope of this study are liminted to the following:

1. The mode of heat transfer is internal forced convection

2. The working fluids in microchannel heat sink consist of pure water and Fe_3O_4. Using volume fractions 0.4% - 8%
3. Fluid flow and heat transfer are in steady state.
4. Fluid is in single phase and incompressible flows are investigated.
5. The microchannel is in constant diameter, constant shape design and constant heat flux applied.
6. The study covered laminar flow only.
7. The simulation is conducted using FLUENT.

REFERENCES

1. Bar-Cohen, Y., et al. *Electroactive polymer (EAP) actuators for planetary applications*. in *1999 Symposium on Smart Structures and Materials*. 1999. International Society for Optics and Photonics.
2. Mudawar, I., *Assessment of high-heat-flux thermal management schemes.* Components and Packaging Technologies, IEEE Transactions on, 2001. 24(2): p. 122-141.
3. Tuckerman, D.B., *Heat-transfer microstructures for integrated circuits*. 1984, DTIC Document.
4. Choi, S.U. and J. Eastman, *Enhancing thermal conductivity of fluids with nanoparticles*. 1995, Argonne National Lab., IL (United States).
5. Parida, P.R., *Experimental investigation of heat transfer rate in micro-channels*. 2007, Faculty of the Louisiana State University and Agricultural & Mechanical College In Partial fulfillment of the Requirements for the degree Master of Science in Mechanical Engineering In The Department of Mechanical Engineering by Pritish Ranjan Parida B. Tech., Indian Institute of Technology.
6. Gunnasegaran, P., et al., *Heat transfer enhancement in microchannel heat sink using nanofluids.* Fluid Dynamics, Computational Modeling and Applications, InTech, China, 2012: p. 287-326.
7. Kandlikar, S.G. and M.E. Steinke. *Examples of microchannel mass transfer processes in biological systems*. in *ASME 2003 1st International Conference on Microchannels and Minichannels*. 2003. American Society of Mechanical Engineers.
8. Toh, K., X. Chen, and J. Chai, *Numerical computation of fluid flow and heat transfer in microchannels.* International Journal of Heat and Mass Transfer, 2002. 45(26): p. 5133-5141.

9. Peng, X. and G. Peterson, *The effect of thermofluid and geometrical parameters on convection of liquids through rectangular microchannels.* International Journal of Heat and Mass Transfer, 1995. 38(4): p. 755-758.
10. Qu, W. and I. Mudawar, *Analysis of three-dimensional heat transfer in micro-channel heat sinks.* International Journal of heat and mass transfer, 2002. 45(19): p. 3973-3985.
11. Kawano, K., et al., *Development of micro channel heat exchanging.* JSME International Journal Series B, 2001. 44: p. 592-598.
12. Wong, W.H., *Numerical simulation of a microchannel for microelectronic cooling.* Jurnal Teknologi A, 2007(46A): p. 1-16.
13. Chein, R. and J. Chuang, *Experimental microchannel heat sink performance studies using nanofluids.* International Journal of Thermal Sciences, 2007. 46(1): p. 57-66.
14. Lee, J. and I. Mudawar, *Assessment of the effectiveness of nanofluids for single-phase and two-phase heat transfer in micro-channels.* International Journal of Heat and Mass Transfer, 2007. 50(3): p. 452-463.
15. Mohammed, H., P. Gunnasegaran, and N. Shuaib, *The impact of various nanofluid types on triangular microchannels heat sink cooling performance.* International Communications in Heat and Mass Transfer, 2011. 38(6): p. 767-773.
16. Fani, B., A. Abbassi, and M. Kalteh, *Effect of nanoparticles size on thermal performance of nanofluid in a trapezoidal microchannel-heat-sink.* International Communications in Heat and Mass Transfer, 2013. 45: p. 155-161.
17. Tsai, T.-H. and R. Chein, *Performance analysis of nanofluid-cooled microchannel heat sinks.* International Journal of Heat and Fluid Flow, 2007. 28(5): p. 1013-1026.
18. Bhattacharya, P., A. Samanta, and S. Chakraborty, *Numerical study of conjugate heat transfer in rectangular microchannel heat sink with Al2O3/H2O nanofluid.* Heat and mass transfer, 2009. 45(10): p. 1323-1333.
19. Li, Q., et al., *Experimental investigation on flow and convective heat transfer feature of a nanofluid for aerospace thermal management.* Yuhang Xuebao/ Journal of Astronautics(China), 2005. 26(4): p. 391-394.

20. Zeinali Heris, S., S.G. Etemad, and M. Nasr Esfahany, *Experimental investigation of oxide nanofluids laminar flow convective heat transfer.* International Communications in Heat and Mass Transfer, 2006. 33(4): p. 529-535.

21. Das, S.K., et al., *Temperature dependence of thermal conductivity enhancement for nanofluids.* Journal of Heat Transfer, 2003. 125(4): p. 567-574.

22. Faulkner, D.J., et al. *Enhanced heat transfer through the use of nanofluids in forced convection*. in *ASME 2004 International Mechanical Engineering Congress and Exposition*. 2004. American Society of Mechanical Engineers.

23. Murugesan, C. and S. Sivan, *Limits for thermal conductivity of nanofluids.* Thermal Science, 2010. 14(1): p. 65-71.

24. Wang, X.-Q. and A.S. Mujumdar, *Heat transfer characteristics of nanofluids: a review.* International journal of thermal sciences, 2007. 46(1): p. 1-19.

25. Qingzhong, X., *Effective-Medium Theory for Two-Phase Random Composites with and Interfacial Shell.,* 2000. 16(4).

26. Wang, X., X. Xu, and S.U. S. Choi, *Thermal conductivity of nanoparticle-fluid mixture.* Journal of thermophysics and heat transfer, 1999. 13(4): p. 474-480.

27. Xie, H., et al., *Thermal conductivity enhancement of suspensions containing nanosized alumina particles.* Journal of Applied Physics, 2002. 91(7): p. 4568-4572.

28. Xuan, Y. and Q. Li, *Investigation on convective heat transfer and flow features of nanofluids.* Journal of Heat transfer, 2003. 125(1): p. 151-155.

29. Lee, S., et al., *Measuring thermal conductivity of fluids containing oxide nanoparticles.* Journal of Heat Transfer, 1999. 121(2): p. 280-289.

30. Syam Sundar, L., M.K. Singh, and A. Sousa, *Investigation of thermal conductivity and viscosity of Magnetic nanofluid for heat transfer applications.* International Communications in Heat and Mass Transfer, 2013. 44: p. 7-14.

31. Hosseini, M. and S. Ghader, *A model for temperature and particle volume fraction effect on nanofluid viscosity.* Journal of Molecular Liquids, 2010. 153(2-3): p. 139-145.

32. J.M. Li, Z.L.L., B.X. Wang, *Experimental viscosity measurements for copper oxide nanoparticle suspensions.* Tsinghua Science technology, 2003. 7: p. 3.
33. Wang, X., X. Xu, and S.U.S. Choi, *Thermal conductivity of nanoparticle-fluid mixture.* Journal of thermophysics and heat transfer, 1999. 13(4): p. 474-480.
34. Kumar, P.M., J. Kumar, and S. Suresh, *Review on nanofluid theoretical viscosity models.* IJEIR, 2012. 1(2): p. 128-134.
35. S.K. Das, N.P., P.Thiesen, W. Roetzel, *Temperature dependence of thermal conductivity enhancement for nanofluids.* ASME Trans.J. Heat transfer, 2003. 25: p. 7.
36. Lee, S., et al., *Measuring Thermal Conductivity of Fluids Containing Oxide Nanoparticles.* Journal of Heat Transfer, 1999. 121(2): p. 280-288.
37. Koo, J. and C. Kleinstreuer, *Impact analysis of nanoparticle motion mechanisms on the thermal conductivity of nanofluids.* International Communications in Heat and Mass Transfer, 2005. 32(9): p. 1111-1118.
38. N.Putra, W.R., S.K. Das, *Natural convection of nanofluids.* heat mass transfer, 2003. 39: p. 84.
39. Chon, C.H., et al., *Empirical correlation finding the role of temperature and particle size for nanofluid (Al 2O 3) thermal conductivity enhancement.* Applied Physics Letters, 2005. 87(15): p. 1-3.
40. Godson, L., et al., *Enhancement of heat transfer using nanofluids-An overview.* Renewable and Sustainable Energy Reviews, 2010. 14(2): p. 629-641.
41. Zhou, S.Q. and R. Ni, *Measurement of the specific heat capacity of water-based Al2 O3 nanofluid.* Applied Physics Letters, 2008. 92(9).
42. Xuan, Y. and Q. Li, *Heat transfer enhancement of nanofluids.* International Journal of heat and fluid flow, 2000. 21(1): p. 58-64.
43. Liu, Y., et al., *Training radial basis function networks with particle swarms*, in *Advances in Neural Networks–ISNN 2004*. 2004, Springer. p. 317-322.
44. Zeinali Heris, S., M. Nasr Esfahany, and S.G. Etemad, *Experimental investigation of convective heat transfer of Aluminium water nanofluid in circular tube.* International Journal of Heat and Fluid Flow, 2007. 28(2): p. 203-210.

45. Chein, R. and G. Huang, *Analysis of microchannel heat sink performance using nanofluids.* Applied Thermal Engineering, 2005. 25(17): p. 3104-3114.
46. Ho, C.-J., L. Wei, and Z. Li, *An experimental investigation of forced convective cooling performance of a microchannel heat sink with Aluminium water nanofluid.* Applied Thermal Engineering, 2010. 30(2): p. 96-103.
47. Jang, S.P. and S.U. Choi, *Cooling performance of a microchannel heat sink with nanofluids.* Applied Thermal Engineering, 2006. 26(17): p. 2457-2463.
48. Li, J. and C. Kleinstreuer, *Thermal performance of nanofluid flow in microchannels.* International Journal of Heat and Fluid Flow, 2008. 29(4): p. 1221-1232.