Faculty of Mechanical Engineering

THERMOPHYSICAL PROPERTIES OF CNF-BASED NANOCOOLANT AS A HEAT TRANSFER MEDIA

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Mechanical Engineering

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DECLARATION

I declare that this thesis entitled “Thermophysical Properties of CNF-based Nanocoolant as A Heat Transfer Media” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : .....

Date : .....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature : .....

Supervisor Name : .....

Date : .....

DEDICATION

To Allah s.w.t, Alhamdulillah for your blessings.

To my beloved family and friends,

Thank you for your love, care and support.

May Allah grant us a forever Jannah.

To supervisor,

Thank you for your unlimited patience, heaps of tolerance and inspirational personality.

Working with you was a privileged.

ABSTRACT

High heat flux removal is one of the major challenges in designing for the future electronic devices. The trend to address these high heat fluxes is to introduce microchannel arrays directly in the heat generating by the electronic component. Commonly, water is suggested to be used as a single-phase coolant in combination with the microchannel heat sinks for cooling of electronics applications. However, one of the major problems faced by the existing coolants is the limited amount of heat that can be absorbed by the fluids. An innovative way to overcome this limitation is by utilizing a nanocoolant as the heat transfer medium in a cooling application. This research was aimed at formulating an efficient nanocoolant from PR-24 HHT carbon nanofibers (CNF) in a base fluid consisting of deionized water (DI) and ethylene glycol (EG). The dispersion of nanofibers was enhanced by the presence of polyvinylpyrrolidone (PVP) as the stabilizing agent through two-step preparation process. The experiment was conducted by setting the variable weight percentage of CNF from 0.1wt% to 1.0wt%, with the base fluid ratio range from 100:0 (DI:EG) to 0:100 (DI:EG). The characterization testing was performed to study the surface species of the nanofiber using nitrogen gas adsorption technique, fourier transform infrared spectroscopy (FTIR) and field emission scanning electron microscopy (FESEM). The detailed study of the thermophysical properties such as thermal conductivity, viscosity, and specific heat capacity of stable CNF-based nanocoolant was also been investigated at three different temperatures (6°C, 25°C and 40°C). The maximum thermal conductivity enhancement of 29.95% was noticed for the nanocoolant with 0.6wt% at 0:100 (DI:EG). The rheological analysis showed that when the temperature increases, the viscosity diminishes. Whereas, due to a lower specific heat of the CNF, the specific heat of the nanocoolant decreased in proportion with the CNF concentration. Experimental investigations into the forced convective heat transfer performance of the CNF-based nanocoolant in a laminar flow through a mini heat transfer test rig showed that the presence of nanoparticles enhanced the heat transfer coefficient as opposed to the original base fluid. The highest heat transfer coefficient was reported with 30:70 (DI:EG) by the 0.7wt% nanocoolant at 40°C with the value of 265.28 x 10^3 W/m^2.K. The enhancement of the heat transfer coefficient was due to the higher thermal conductivity value. The Nusselt number was also calculated and presented in this research. Overall, this study shows that the CNF-based nanocoolant has a huge potential to replace existing coolants in electronic cooling applications. Thus, in order to commercialize nanocoolant in practice, more fundamental studies are needed to understand the crucial parameters that affect their thermal characteristics.

ABSTRAK

Penyingkiran fluks haba yang tinggi adalah salah satu cabaran utama dalam mereka bentuk peranti elektronik masa hadapan. Trend untuk menangani fluks haba yang tinggi ini adalah dengan memperkenalkan saluran mikro secara langsung ke komponen elektronik yang menghasilkan haba. Umumnya, air dicadangkan untuk digunakan sebagai pendingin fasa tunggal dengan kombinasi sinki haba mikro untuk aplikasi penyejukan elektronik. Walau bagaimanapun, salah satu masalah utama yang dihadapi oleh pendingin sedia ada ini ialah jumlah haba yang terhad yang boleh diserap oleh cecair tersebut. Salah satu cara yang inovatif untuk mengatasi masalah ini adalah dengan menggunakan cecair pendingin nano sebagai media pemindahan haba dalam aplikasi penyejukan. Justeru, kajian ini berobjektif untuk mengformulasikan cecair nano dari PR-24 HHT karbon nanofiber dengan penggunaan cecair asas etilena glikol dan air ternyahion serta polivinilpirolidon sebagai ejen dispersi. Eksperimen ini dijalankan dengan menetapkan pembolehubah peratusan berat CNF dari 0.1wt% hingga 1.0wt% dengan peratusan nisbah cecair asas bermula dari 100:0 (DI:EG) hingga 0:100 (DI:EG). Ujian pencirian telah dilakukan untuk mengkaji spesies permukaan nanofiber menggunakan teknik penjerapan gas nitrogen, spektroskopi perubahan inframerah fourier (FTIR) dan mikroskop elektron pengimbas (FESEM). Kajian terperinci tentang sifat-sifat terma-fizikal seperti kekonduksian termal, kelikatan, dan kapasiti haba spesifik pendingin nano berasaskan karbon nanofiber yang stabil juga telah disiasat pada tiga suhu berbeza (6°C, 25°C dan 40°C). Peningkatan kekonduksian termal maksimum telah dicatatkan sebanyak 29.95% oleh pendingin nano dengan peratusan berat 0.6wt% pada nisbah 0:100(DI:EG). Analisis rheologi menunjukkan bahawa apabila suhu meningkat, kelikatan berkurang. Selain itu, haba spesifik yang lebih rendah oleh karbon nanofiber telah menyebabkan kapasiti haba spesifik pendingin nano menurun berkadaran dengan kepekatan karbon nanofiber. Penyiasatan eksperimen ke atas prestasi pemindahan haba konvektif pendingin nano berasaskan karbon nanofiber dalam aliran laminar melalui ujian pemindahan haba mini, hasil menunjukkan bahawa kehadiran nanopartikel telah meningkatkan pekali pemindahan haba berbanding dengan cecair asas. Pekali pemindahan haba tertinggi dilaporkan pada nisbah 30:70 (DI:EG) oleh 0.7wt% pendingin nano pada suhu 40°C dengan nilai 265.28 x 10^3 W/m^2.K. Peningkatan pekali pemindahan haba adalah disebabkan oleh nilai kekonduksian termal yang lebih tinggi. Nombor Nusselt juga dikira dan dibentangkan dalam kajian ini. Keseluruhannya, kajian ini menunjukkan bahawa pendingin nano berasaskan karbon nanofiber berpotensi besar untuk menggantikan pendingin sedia ada dalam aplikasi penyejukan elektronik. Oleh itu, untuk mengkomersialkan pendingin nano, lebih banyak kajian fundamental diperlukan untuk memahami parameter penting yang mempengaruhi ciri-ciri termal cecair ini.

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LIST OF ABBREVIATIONS AND SYMBOLS

CNF	-	Carbon nanofibers
CNT	-	Carbon nanotube
CF	-	Carbon fiber
EG	-	Ethylene glycol
DI	-	Deionized water
PVP	-	Polyvinylpyrrolidone
Cu	-	Copper
CuO	-	Copper oxide
Al_2O_3	-	Aluminium oxide
$CuSO_4.5H_2O$	-	Copper (II) sulfate pentahydrate
$NaH_2PO_2.H_2O$	-	Sodium hypophosphite monohydrate
NaH_2PO_2	-	Sodium hypophosphite
$CuSO_4$	-	Copper (II) sulfate
Cu_2O	-	Copper (I) oxide
TiO_2	-	Titanium dioxide
LaB_6	-	Lanthanum hexaboride
SiO_2	-	Silicon dioxide
SiC	-	Silicon carbide
PVA	-	Polyvinyl alcohol
SDS	-	Sodium dedocyl sulphate

DTAB	-	Dodecyltrimethylammonium bromide
VEROS	-	Vacuum evaporation onto a running oil substrate
SANSS	-	Submerged arc nanoparticles synthesis system
HVAC	-	Heating, ventilation and air conditioning
PCM	-	Phase change materials
OHP	-	Oscillating heat pipe
HPLC	-	High performance liquid chromatography
CPU	-	Central processing unit
SWCNT	-	Single-walled carbon nanotubes
MWCNT	-	Multi-walled carbon nanotubes
CVD	-	Chemical vapor deposition
SCCNT	-	Stacked-cup carbon nanotubes
AC	-	Activated carbons
FESEM	-	Field emission scanning electron microscopy
TEM	-	Transmission electron microscope
FTIR	-	Fourier transform infrared
EDS	-	Energy-dispersive spectrometer
EBSD	-	Electron backscatter diffraction
BET	-	Brunauer emmet teller
DFT	-	Density functional theory
IUPAC	-	International union of pure and applied chemistry
ASHRAE	-	American society of heating, refrigerating and air-conditioning engineers
ASTM	-	American society for testing and materials
IEEE	-	Institute of electrical and electronics engineers

Q	-	Flow of heat
h	-	Coefficient of heat transfer
A	-	Heat transfer area
ΔT	-	Temperature different
m	-	Mass of water bath
C_p	-	Specific heat of the water bath
K	-	Temperature difference in the water bath
Nu	-	Nusselt number
D	-	Copper pipe diameter
k	-	Thermal conductivity

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