UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF HOT WIRE-LASER BEAM DISPLACEMENT TECHNIQUE FOR DETERMINING THERMAL CONDUCTIVITY AND THERMAL DIFFUSIVITY OF NANOFLUIDS

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BY

FARIS MOHAMMED ALI

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

February 2011

Dedicated to

My dearest Family (Father and Mother)

For their extraordinary love and their endless care

My Brothers and Sister for their supporting, encouragement, and prayer

My darling wife Nabaa for her patience

My Son (Ali)

Thank You

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman : Professor W. Mahmood Mat Yunus, PhD

Faculty: Science

A nanofluid is a fluid containing suspended nanoparticles, with sizes of the order of nanometer. Heat conductors of nanofluid are better than that of base fluid. Therefore, the most important point to know is its thermal conductivity and thermal diffusivity. The focus of this work is on determining the thermal conductivity and thermal diffusivity of nanofluids containing metallic and non metallic nanoparticles. The specific objectives were the determination of the effects of sonication time, volume fraction concentration, particle size, particles materials, and two materials mixture nanoparticles on the thermal conductivity and thermal diffusivity of nanofluids. Thermal conductivity and thermal diffusivity measurements were performed by hot wire-laser beam displacement technique. The hot wire-laser probe beam displacement setup consists of a CW He-Ne laser beam as the probe beam, a thin circular Ni-Cr alloy resistance wire which serves as a heat source, and a position sensitive detector (PSD). The developed coupled transient heat conduction equations of the heating wire and the nanofluid were solved simultaneously by using the Finite Difference Method.

A numerical model, which took the thermal conductivity and thermal diffusivity of the test nanofluids as parameters to calculate the probe beam deflection, was established separately. By comparing the time-varying deflection curve from the numerical model with that recorded in the experiment, the nanofluids thermal conductivity and thermal diffusivity in the model were adjusted to give the best agreement between the model and the experimental results. The nanofluid samples were aluminum (Al) 18 nm, chromium (Cr) 20 nm, and aluminum oxide nanoparticles (Al_2O_3) 11 nm, 25 nm, 50 nm, and 63 nm dispersed in distilled water, ethylene glycol, and ethanol. These nanofluid samples were prepared using the one-step method. The results of the thermal conductivity and thermal diffusivity measurements showed the best interval time of sonicated was 6 hours. The results showed that the thermal conductivity and thermal diffusivity of all samples of nanofluid increased linearly with increases of volume fraction concentration of nanoparticles in base fluid. Where, the thermal conductivity of Al nanofluid suspension in distilled water at volume fraction concentration between 0.42 % to 0.085 was 0.732 W/m.K to 0.648 W/m.K, respectively. The results of the thermal conductivity and thermal diffusivity measurements of Al_2O_3 nanofluids containing different sizes of nanoparticles (11 nm to 63 nm) showed that the smaller nanoparticles yielded lower thermal conductivity and thermal diffusivity. Where the thermal conductivity of Al_2O_3 of particles size 11 nm suspension in distilled water at volume fraction concentration 1.4 % was (0.676 W/m.K) and thermal diffusivity was (1.727×10^{-7} m^2/s), while the thermal conductivity and thermal diffusivity of Al_2O_3 of particle size 63 nm at the same volume fraction concentration was 0.705 W/m.K and 1.793×10^{-7} m^2/s, respectivilly. This means that the thermal conductivity and thermal diffusivity have increased with increase particle size. The result also showed that the thermal conductivity and thermal diffusivity

depended on the material of the nanoparticles, where the thermal conductivity and thermal diffusivity of metallic nanoparticles higher than the nonmetallic nanoparticles. Measurement of thermal conductivity and thermal diffusivity of bimetallic nanofluid was also conducted, and the result showed that the thermophysical properties of two metallic mixture nanofluids improved 15.82 % - 7.94 % for bimetallic in water, 17.44 % - 9.3 % in ethylene glycol, and 19.65 % - 10.4 % in ethanol.

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

PENGEMBANGAN TEKNIK KAWAT BALOK-LASER DISPLACEMENT HOT UNTUK MENENTUKAN KEKONDUKSIAN TERMA DAN KERESAPAN TERMA DARI CECAIR NANO

Oleh

FARIS MOHAMMED ALI

February 2011

Pengerusi: Profesor W. Mahmood Mat Yunus, PhD

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Cecair nano adalah cecair yang mengandungi zarah nano terampai, dengan saiz dalam julat nanometer. Pengalir haba dari cecair nano lebih baik daripada cecair tanpa zarah nano. Oleh kerana itu, yang paling penting untuk diketahui adalah pengaliran terma dan keresapan terma. Fokus dari kajian ini adalah pada pengukuran pengaliran terma dan keresapan terma cecair nano yang mengandungi zarah nano logam dan bukan logam. Matlamat khusus adalah penentuan kesan masa sonikasi, kepekatan pecahan isipadu, saiz zarah, bahan zarah, dan zarah nano dwilogam pada pengaliran terma dan keresapan terma cecair nano. Pengukuran pengaliran terma dan keresapan terma dilakukan dengan teknik sinar laser dawai panas. Penduga sinar laser dawai panas terdiri daripada CW sinar laser He-Ne sebagai penduga sinar, sebuah lingkaran nipis dawai rintangan aloi Ni-Cr yang berfungsi sebagai sumber haba, dan pengesan kedudukan sensitif (PSD). Persamaan pengaliran haba transien berpasang pada dawai pemanas dan cecair nano yang dibangunkan diselesaikan secara serentak dengan menggunakan Kaedah Beza Terhingga, berdasarkan algoritma Crank-Nicolson, untuk

menyelesaikan pengaliran terma dan keresapan terma cecair nano. Model berangka yang mengambil pengaliran terma dan keresapan terma cecair nano ujian sebagai parameter bagi mengira pemesongan penduga sinar didirikan secara berasingan. Dengan membandingkan lengkung pemesongan perubahan masa dari model berangka dengan data dalam eksperimen, pengaliran terma dan keresapan terma cecair nano dalam model disesuaikan untuk memberikan kesepakatan yang terbaik antara model dan keputusan eksperimen. Sampel cecair nano aluminium (Al) 18 nm, Kromium (Cr) 20 nm, dan nanopartikel aluminium oksida (Al2O3) 11 nm, 25 nm, 50 nm, dan 63 nm terdispersi dalam air suling, glikol etilena dan etanol. Sampel cecair nano ini disediakan menggunakan kaedah satu langkah. Pengukuran pengaliran terma dan keresapan terma dilakukan pada suhu bilik. Keputusan pengukuran pengaliran terma dan keresapan terma menunjukkan selang waktu disonikasi terbaik adalah 6 jam berbanding dengan selang waktu yang lain. Keputusan menunjukkan bahawa pengaliran terma dan keresapan terma pada semua sampel cecair nano telah meningkat secara lurus dengan meningkatnya pecahan kepekatan zarah nano dalam bendalir asas. Mana, pengaliran terma cecair nano Al terampai dalam air suling pada kepekatan antara 0.42% dan 0.085 adalah masing-masing 0.732 W/m.K dan 0.648 W/m.K. Selain itu, hasil pengukuran pengaliran terma dan keresapan terma cecair nano Al_2O_3 yang mengandungi saiz zarah nano berbeza (11 nm ke 63 nm) menunjukkan bahawa saiz nano yang lebih kecil menghasilkan pengaliran terma dan keresapan terma yang lebih rendah. Dimana pengaliran terma Al_2O_3 bersaiz zarah 11 nm terampai dalam air suling pada pecahan isipadu kepekatan 1.4% adalah (0.676 W/m.K) dan keresapan terma adalah ($1.727x10^{-7}$ m^2/s), sedangkan pengaliran terma dan keresapan terma Al_2O_3 bersaiz zarah 63 nm pada pecahan isipadu kepekatan yang sama adalah masing-masing 0.705 W/m.K dan $1.793x10^{-7}$ m^2/s. Ini bermakna bahawa

pengaliran terma dan keresapan terma telah meningkat dengan meningkatnya saiz zarah. Selain itu, keputusan menunjukkan bahawa pengaliran terma dan keresapan terma bergantung pada jenis bahan zarah, dimana ia meningkat dengan zarah nano logam lebih dari zarah nano bukan logam. Pengukuran pengaliran terma dan keresapan terma dwilogam cecair nano telah dilakukan, dan hasilnya menunjukkan bahawa sifat fizikal terma cecair nano dua logam campuran telah meningkat 15.82% - 7.94% untuk dwilogam dalam air, 17.44% - 9.3% dalam glikol etilena dan 19.65% - 10.4 % dalam etanol.

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I certify that a Thesis Examination Committee has met on 16 February 2011 to conduct the final examination of Faris Mohammed Ali on his thesis entitled "Development of Hot Wire-Laser Beam Displacement Technique for Determining Thermal Conductivity and Thermal Diffusivity of Nanofluids" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of **Doctor of Philosophy.** 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 UPM or other institution.

FARIS MOHAMME ALI

Date: 16 February 2011

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