HEAT TRANSFER PERFORMANCE OF SINGLE AND HYBRID WATER-BASED NANOFLUIDS (Al_2O_3 AND SiO_2) IN NUCLEATE POOL BOILING

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We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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

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Thesis submitted in fulfilment of the requirements
for the award of the degree of
Master of Science

Faculty of Mechanical and Automotive Engineering Technology

UNIVERSITI MALAYSIA PAHANG

JULY 2020

ACKNOWLEDGEMENTS

First, I would like to thank Allah S.W.T and His messenger, Prophet Muhammad S.A.W for HIS blessing that makes possible for me to finish this research. All the time I spend to discuss ideas and problem occurs were worth effort and time. Next, I sincerely thanks to my supervisor, Dr. Muhamad Zuhairi bin Sulaiman for his invaluable ideas and feedback on my study and research as well as for his endless support and encouragement during my research time. He gave me as much help that I need to complete this research and solve these problems occur together. Finally, I extremely thankful and owes a deep sense of gratitude to all my family, lectures and all my friends for their timely suggestion with kindness, enthusiasm and dynamism for me to be able to do this research. I promise that I will never let your efforts and kindness go to waste. May you be rewarded with endless joy, love and success by The Almighty. Insha'Allah.

ABSTRACT

Enhancement of heat transfer performance in nucleate boiling has become one of the prominent topics due to the demand of high cooling density in industry applications. Recently, various types of nanofluids have been researched in terms of their cooling performance in the multiphase system. For instance, Al_2O_3 nanofluids gave a completely different Heat Transfer Coefficient (HTC) performance compared to SiO_2 nanofluids in various concentration levels. The reasons of the inconsistencies are still elusive. In addition, the HTC performances of those single nanofluids in steady state conditions have not been well reported in literature. The present work aims to evaluate the HTC performance, the steady state conditions, and the relation between surface properties towards the HTC of Al_2O_3 and SiO_2 nanofluids in saturated pool boiling of single and hybrid Al_2O_3/SiO_2 water-based nanofluids. Two types of single nanofluid dispersions (Al_2O_3 and SiO_2) were prepared. Their hybrid nanofluids were mixed in different volume concentration ratios of 0:100, 25:75, 50:50, 75:25, and 100:0 percent to achieve three final concentrations of C = 0.001 vol. %, 0.01 vol. %, 0.025 vol. %. Later, experiments were conducted to obtain the heat transfer coefficients (HTCs) and steady state conditions of the HTC within a prescribed time, as well as evaluation of surface roughness properties. The present work demonstrated the HTC values for single and hybrid nanofluids in a series of time variation of wall superheat, ΔT_w. Next, considering the significance of the clarification of heat transfer steadiness in the system , experiment for the quasi steady state was extended up to 5 hours to reveal the dependencies of HTC over time in single and hybrid nanofluids with low concentration C = 0.001 vol. %. Finally, due to the occurrence of nanoparticle deposition in the present experiment, surface roughness measurements were conducted to investigate the surface structure evolution with respect to the boiling time in nanofluids using SiO_2 and Al_2O_3 nanofluids of low concentration C = 0.001 vol. %. The HTC results were found to enhance considerably for Al_2O_3 and on the contrary, deteriorate for SiO_2 nanofluids. Notably, for the hybrid nanofluids (Al_2O_3/SiO_2: 50/50 vol. %), the HTCs were dramatically enhanced at the initial stage after 5 seconds, whilst slowly deteriorated once the time variation increased up to ΔT_w = 16 °C, especially in a higher ratio of SiO_2 nanofluids. In addition, it should be noted that the HTC performance of hybrid nanofluids was found to be in between those of Al_2O_3 and SiO_2 in the time variation of 1 hour. For the single and hybrid nanofluids in low concentration, SiO_2 nanofluids achieved the steady state conditions after 5 hours at 17 °C except for single Al_2O_3 nanofluids which did not achieve steady state condition even after 5 hours with a slight gradual increase with respect to the time variation of wall superheat (ΔT_w). Meanwhile, the surface roughness of heater surface, Ra values were 1.7995 µm for Al_2O_3 and 1.7507 µm for SiO_2 after boiling in nanofluids. However, the HTC values were different where they increased in Al_2O_3 nanofluids but deteriorated for SiO_2 nanofluids. The surface roughness results of heater surface for both nanofluids were nearly the same but different HTC performances were reported. Therefore, surface roughness was not a significant factor to the HTC performance in the present work.

ABSTRAK

Peningkatan prestasi pemindahan haba dalam pendidihan nukleat telah menjadi salah satu topik penting kerana permintaanya yang tinggi untuk aplikasi industry penyejukan. Terbaru, pelbagai jenis cecair nano telah diteliti dari segi prestasi penyejukannya dalam sistem yang kepelbagaian fasa. Sebagai contoh, cecair nano yang mengandungi Al_2O_3 memberikan prestasi Pekali Permindahan Haba (HTC) yang sanagat berbeza berbanding dengan cecair nano SiO_2 bagi semua tahap kepekatan. Punca ketidaksamaan ini masih belum diketahui secara mendalam. Di samping itu, prestasi HTC cecair nano yang tunggal dalam keadaan stabil tidak pernah dilaporkan secara mendalam berdasarkan kajian-kajian sebelum ini. Kajian ini bertujuan untuk menilai prestasi HTC, kestabilan prestasi HTC, dan hubungan antara sifat permukaan terhadap HTC yang disebabkan oleh cecair dan zarah Al_2O_3 dan SiO_2 bersaiz nano di dalam sistem kolam mendidih berasaskan cecair nano Al_2O_3 / SiO_2 yang tunggal dan gabungan. Dua jenis cecair nano yang tunggal (Al_2O_3 dan SiO_2) telah siap disediakan. Cecair nano hibrid pula dicampur dalam nisbah isipadu kepekatan yang berbeza iaitu 0: 100, 25:75, 50:50, 75:25, dan 100: 0 peratus untuk mencapai tiga kepekatan akhir iaitu C = 0.001 vol. %, 0.01 jilid %, 0.025 jilid %. Kemudian, eksperimen dijalankan untuk mendapatkan pekali pemindahan haba (HTCs) dan kestabilan HTC dalam masa yang ditentukan, serta penilaian terhadap keadaan permukaan pemanas. Kajian ini menunjukkan nilai HTC untuk cecair nano tunggal dan hibrid dalam rangkaian variasi suhu permukaan pemanas, ΔT_w. Seterusnya, eksperimen untuk keadaan separa stabil HTC dilanjutkan hingga 5 jam untuk mendedahkan sifat HTC dari masa ke masa untuk cecair nano tunggal dan hibrid dengan kepekatan rendah C = 0.001 vol. %. Akhirnya, berlaku pemendapan partikel nano di atas permukaan pemanas di dalam eksperimen ini, ketebalan pemendapan pada permukaan pemanas dilakukan untuk mengkaji perubahan struktur permukaan sehubungan dengan masa mendidih dalam cecair nano menggunakan cecair nano SiO_2 dan Al_2O_3 dengan kepekatan rendah C = 0.001 vol. %. Hasilnya, HTC didapati bertambah baik untuk cecair nano Al_2O_3 dan sebaliknya, merosot untuk cecair nano SiO_2, terutama, untuk cecair nano hibrid (Al_2O_3/SiO_2: 50/50 vol.%), HTC meningkat secara dramatic pada peringkat seawal 5 saat, sementara perlahan-lahan merosot setelah suhu yang diambil meningkat hingga ΔT_w = 16 °C, terutama jika cecair hybrid nano yg mempunyai nano partikel SiO_2 yang lebih banyak. Di samping itu, berdsarkan pemerhatian, didapati prestasi HTC cecair nano untuk hibrid didapati berada di paras antara prestasi HTC oleh Al_2O_3 dan SiO_2 untuk lingkungan masa 1 jam. Manakan untuk cecair nano yang tunggal dan hibrid dalam kepekatan rendah, cecair nano SiO_2 mencapai keadaan yang stabil selepas 5 jam pada 17 °C kecuali untuk cecair nano Al_2O_3 yang tunggal gagal untuk mencapai keadaan yang stabil walaupun setelah 5 jam dengan hanya sedikit peningkatan secara beransur-ansur sehubungan dengan masa suhu (ΔT_w). Sementara itu, kekasaran permukaan permukaan pemanas, nilai Ra adalah 1.7995 µm untuk Al_2O_3 dan 1.7507 µm untuk SiO_2 setelah mendidih dalam cecair nano. Walau bagaimanapun, nilai HTC berbeza di mana ia meningkat dalam cecair nano Al_2O_3 tetapi merosot untuk cecair nano SiO_2. Hasil kekasaran permukaan pemanas untuk kedua-dua nanofluid hampir sama tetapi prestasi HTC yang berbeza dilaporkan. Oleh itu, dalam kajian ini, kekasaran permukaan didapati bukan faktor yang utama yang menyumbang kepada kelainan prestasi HTC dalam kajian sekarang.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

μ	Dynamic viscosity of liquid
ρ_l	Density of liquid
ρ_{v}	Density of vapor
r	Enthalpy of evaporation
d	Equilibrium break-off diameter
h_{fg}	Enthalpy of vaporization
ΔT	Excess temperature
g	Gravitational acceleration
q	Heat flux
$\dot{q}$	Heat flux density
λ	Heat conductivity
ρ	Mass density
Pr	Prandtl number of liquids
p	Pressure
p_c	Critical Pressure
C_1	Specific heat of liquid
C_{sf}	Surface liquid factor,
σ	Surface tension liquid vapor interface
T_{s}	Saturation temperature
c'_{p}	Specific heat capacity
a	Thermal diffusivity
ΔT_{w}	Time variation of wall superheat

LIST OF ABBREVIATIONS

Al_2O_3	Alumina oxide
BHTC	Boiling heat transfer coefficient
CHF	Critical heat flux
CNT	Carbon nanotube
Cu	Copper
CuO	Copper oxide
COOH	Carboxylic acid
DLS	Dynamic light scattering
DNA	Deoxyribonucleic acid
EG	Ethylene glycol
EPD	Electrophoretic deposition
AuNP	Gold nanoparticle
HTC	Heat transfer coefficient
Fe_3O_4	Iron oxide
MWCNT	Multiwall carbon nanotube
MgO_2	Magnesium oxide
PTFE	Polytetrafluoroethylene
SiO_2	Silica Oxide
TiO_2	Titanium oxide
USB	Universal Serial Bus
H_2O	Water
ZnO	Zinc oxide

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