AN INVESTIGATION OF HYDRODYNAMICS AND HEAT TRANSFER CORRELATION OF MULTIPLE JET IMPINGEMENT BY USING MAGNESIUM OXIDE-WATER BASED NANOFLUIDS

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A thesis submitted in
fulfillment of the requirement for the award of the
Doctor of Philosophy

Faculty of Mechanical and Manufacturing Engineering
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DECEMBER 2022

For my beloved family

ACKNOWLEDGEMENT

The author would like to express his sincere appreciation to his supervisor, Dr. Hamidon Bin Salleh, for the support given throughout this research.

The author also gratefully acknowledges the financial support which UTHM gives via GPPS, and the funding for the research provided by the Ministry of Higher Education (MoHE) via Grant FRGS VOT 1545. Furthermore, the author is very thankful for the cooperation from the CFD laboratory, Fluid mechanic laboratory, Fabrication lab, and other laboratories involved in this research. Appreciation also goes to everyone involved directly or indirectly towards the compilation of this thesis.

Last but not least, appreciation also goes to the family member since, without their moral and financial support, the author's success is improbable in this research.

ABSTRACT

The research of convection heat transfer using nanofluids mainly in pipe flows. However, there is a lack of fundamental study on the multiple jet impingements using nanofluid. Thus, MgO-H_2O based nanofluid's heat transfer and hydrodynamic characteristic of multiple jet impingement cooling are investigated experimentally and numerically. The jet array consisted of nozzle diameter, *d*, of 1.5 mm arranged in 3x3 rectangular arrays with the jet-to-jet spacing, *s*, from 3.0 to 6.0 mm and nozzle-to-target distance, *H*, from 3.0 to 9.0 mm. The results covered a range of Reynolds numbers based on nozzle diameter, Re_d, from 1000 to 10000, and nanofluids volume fractions, ϕ, from 0% to 0.15%. The effects of Re_d, ϕ, *H*,& *s* are investigated on the average Nusselt number for the impingement surface. The jet arrays were simulated using ANSYS FLUENT software. The present numerical analysis focuses on the jet arrays with *H*=3.0 mm for all jet-to-jet spacing since the flow under this geometry configuration is in submerged conditions, representing the actual system in electronic cooling. Furthermore, the single phase model is adopted to simulate the nanofluids thermal-physical property. The 3D streamlines, velocity contour, and heat transfer coefficient distribution are presented. The experiment results show that depending upon the combination of Re_d, ϕ, *H*,& *s*, the application of nanofluids can achieve a heat transfer enhancement in some cases; conversely, degradation of heat transfer for other combinations may occur. The maximum increase in Nusselt number relative to water is about 19.4% at ϕ=0.15%, Re_d=1001, *s*=4.5 mm, and *H*=3.0 mm. In contrast, the maximum decrease of Nusselt number relative to water is about -6.8% at ϕ=0.10%, Re_d=8493, *s*=6.0 mm, and *H*=3.0 mm. The numerical results can correctly predict the heat transfer trend, but a large discrepancy is observed compared with nanofluid's experimental data, especially at high Re_d, because the single phase model cannot capture the nanoparticle effect. Consequently, a correlation equation is presented combining the impact of the suspended nanoparticles and the flow condition of the multiple jet impingements.

ABSTRAK

Kebanyakan penyelidikan pemindahan haba perolakan menggunakan *nanofluid* hanya fokus kepada aliran paip. Walau bagaimanapun, terdapat kekurangan kajian asas mengenai *multiple jet impingement* menggunakan *nanofluid*. Oleh itu, ciri-ciri pemindahan haba dan hidrodinamik *nanofluid* berasaskan MgO-H_2O *multiple jet impingement* dikaji dengan keadah eksperimen dan berangka. Tatasusunan jet terdiri daripada diameter lubang, *d*, 1.5 mm yang disusun dalam tatasusunan segi empat tepat 3x3 dengan jarak jet-ke-jet, *s*, dari 3.0 hingga 6.0 mm dan jarak lubang ke sasaran, *H*, dari 3.0 hingga 9.0 mm. Hasil kajian meliputi julat *Reynolds number* berdasarkan diameter lubang, Re_d, dari 1000 hingga 10000, dan nisbah isipadu *nanofluid*, ϕ, daripada 0% hingga 0.15%. Kesan Re_d, ϕ, *H*,& *s* terhadap purata *Nusselt number* bagi permukaan perlanggaran telah dikaji. Tatasusunan jet telah disimulasikan menggunakan perisian ANSYS FLUENT. Analisis berangka dalam tesis ini memfokuskan pada tatasusunan jet dengan *H*=3.0 mm untuk semua jarak jet-ke-jet kerana aliran di bawah konfigurasi geometri ini berada dalam keadaan tenggelam dapat mewakili sistem sebenar dalam penyejukan elektronik. Tambahan pula, model fasa tunggal diguna pakai untuk mensimulasikan sifat terma-fizikal *nanofluid*. Garisan aliran *3D*, kontur halaju dan taburan pekali pemindahan haba telah dibentangkan. Keputusan eksperimen menunjukkan bahawa bergantung kepada gabungan Re_d, ϕ, *H*,& *s*, penggunaan *nanofluid* boleh mencapai peningkatan pemindahan haba dalam beberapa kes. Sebaliknya, penurunan pemindahan haba untuk kombinasi lain mungkin berlaku. Peningkatan maksimum dalam *Nussselt number* berbanding air adalah kira-kira 19.4% pada ϕ=0.15%, Re_d=1001, *s*=4.5 mm, dan *H*=3.0 mm. Manakala, penurunan maksimum *Nusselt number* berbanding air adalah kira-kira -6.8% pada ϕ=0.10%, Re_d=8493, *s*=6.0 mm, dan *H*=3.0 mm. Keputusan berangka boleh meramalkan kecenderungan pemindahan haba dengan betul, tetapi percanggahan yang besar diperhatikan berbanding dengan data eksperimen *nanofluid*, terutamanya pada Re_d tinggi, kerana model fasa tunggal tidak dapat meramalkan kesan *nanoparticle*. Dengan ini, persamaan korelasi telah

dibentangkan dengan menggabungkan kesan *nanoparticle* terampai dan keadaan aliran *multiple jet impingement*.

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LIST OF SYMBOLS AND ABBREVIATION

A	-	Major axis length of ellipse
A_D	-	Area of heating surface
A_L	-	Area of wall jet region outside the square module
A_r	-	Relative area of impingement zone surface area to total area
A_l	-	Area of square module formed by the 3x3 impinging jets
Ag	-	Silver
Au	-	Gold
Ave	-	Average
Al_2O_3	-	Aluminium oxide
abt.	-	About
Be	-	Bejam number
b	-	Minor axis length of ellipse
C_f	-	Skin friction factor
C_p	-	Pressure coefficient
C_μ	-	Function of the mean strain and rotation rate
Cp	-	Specific heat
Cu	-	Copper
CuO	-	Copper oxide
Cu_2O	-	Cuprous oxide
CNT	-	Carbon nanotube
CTAB	-	Cetyltrimethylammonium Bromide
Cont.	-	Continue
D	-	Circular impingement hot surface
D_ω	-	Cross-difussion term
DC	-	Direct current
DLS	-	Dynamic light scattering
d	-	Nozzle diameter
d_i	-	Impingement jet diameter before hitting target

d_p	-	Nanoparticle diameter
dia.	-	Diameter
diff.	-	Different
E	-	Energy
EMT	-	Effective medium theory
EDS	-	Energy-dispersive X-ray spectroscopy
EDL	-	Electrical double layer
e_a^{ij}	-	Approximate relative error between grid levels i and j
$\vec{F}$	-	Force body
F_2	-	Blending function in *k*-ω turbulent model
f& *f*	-	Friction factor
G_b	-	Turbulent kinetic energy generated by buoyancy
G_k	-	Turbulent energy generated by mean velocity gradient
G_ω	-	Generation of specific rate of dissipation
GA	-	Gum Arabic
GO	-	Graphene oxide
GCI	-	Grid independent index
$\vec{g}$	-	Gravitational accelerate
H	-	Nozzle to plate distance
HS	-	Hashin& Shtrikman
h	-	Heat transfer coefficient (HTC)
h_i	-	Local HTC
h_L	-	Average HTC on wall jet region outside the square module
h_l	-	Average HTC in square module
h_T	-	Total HTC
h_{ave}	-	Average HTC
k	-	Thermal conductivity
k	-	Turbulent kinetic energy
k_{Al}	-	Thermal conductivity of aluminium alloy
k_f	-	Thermal conductivity of fluid
k_p	-	Thermal conductivity of suspended particle
k_r	-	Relative thermal conductivity
k_{nf}	-	Thermal conductivity of nanofluids

k_{eff}	-	Effective thermal conductiivty
L	-	Effective wall jet length outside square modules
L^*	-	Estimate of the average distance associated with wall jet regions
L_c	-	Charateristic of length
L_e	-	Length of nozzle unit cell for an array
L_H	-	Heater length
L1	-	Wall jet length 1
L2	-	Wall jet length 2
l	-	Length of square modules
l_{ec}	-	Height of ellipse cyclinder
MC	-	Monte Carlo
MJ	-	Multiple jet
MgO	-	Magnesium oxide
MWCNT	-	Multiwall carbon nanotube
m	-	Mass (g)
$\dot{m}$-	-	Mass flow rate (kg/s)
m_f	-	Mass of base fluid
m_p	-	Mass of nanoparticles
max	-	Maximum
N	-	Number of measurement
N_i	-	Mesh number of grid level i
N_{jet}	-	Number of Jet
NF	-	Nanofluids
Nu	-	Nusselt number
Nu_D	-	Average of Nu based on target surface diameter
Nu_L	-	Average of Nu based on effective wall jet length (L)
Nu_{L_H}	-	Average of Nu based on heater length
Nu_d	-	Average of Nu based on nozzle diameter
Nu_i	-	Local Nusselt number
Nu_l	-	Average of Nu based on square module length
Nu_w	-	Nusselt number for water
Nu_{nf}	-	Nusselt number for nanofluid
Nu_{ave}	-	Average of nusselt number
NaOH	-	Sodium hydroxide

P	-	Pressure
PP	-	Pumping power
Po	-	Poiseuille number
Pr	-	Prandtl number
P_{jet}	-	Pressure of Jet
PAO	-	Polyalpha-Olefin
PEC	-	Performance evaluation criterion
PVA	-	Poly Vinyl Alcohol
PVP	-	Polyvinylpyrrolidone
Prep.	-	Preparation
p	-	Apparent order of convergence
Q	-	Volumetric flow rate (LPM)
q	-	Heat flux per unit area
$\bar{q}$	-	Heat flux per unit length
R_{en}	-	Entrance length
R_{th}	-	Thermal Resistance
Re	-	Reynold number
Re_d	-	Re based on nozzle diameter d
Re_L	-	Re based on Effective wall jet length L
$\overline{Re_d}$	-	Average Re based on nozzle diameter d
Re_D	-	Reynold number based on impinging surface diameter D
Re_{di}	-	Re based on diameter jet before hitting target surface d_i
Re_{dh}	-	Re based on hydraulic diameter d_h
Re_δ	-	Re based on nozzle to plate gap distance δ
RNG	-	Renormalization group
ROT	-	Run out table
RSM	-	Reynold stress model
RTD	-	Resistance temperature detectors
r_{ji}	-	Grid refinement ratio for grid level j to grid level i
resp.	-	Respectively
S	-	Entropy generation rate
S_{ij}	-	Components of rate of deformation
S_k,S_ε& S_ε	-	Source term used in k-ε or k-ω turbulent model

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List of published research papers

1) Loong, T. T., & Salleh, H. (2017, August). A review on measurement techniques of apparent thermal conductivity of nanofluids. In IOP Conference Series: Materials Science and Engineering (Vol. 226, No. 1, p. 012146). IOP Publishing.

2) Loong, T. T., Salleh, H., Khalid, A., & Koten, H. (2021). Thermal performance evaluation for different type of metal oxide water based nanofluids. Case Studies in Thermal Engineering, 27, 101288.

VITA

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