NUMERICAL STUDY OF MICROCHANNEL HEAT TRANSFER WITH NANOFLUID BASED TWO-PHASE SLUG FLOW

Siriwardana Sitanange Geethal Chandima Siriwardana

178262G

Thesis submitted in partial fulfilment of the requirements for the degree of

Master of Engineering in ~~Mechanical Engineering~~ Energy Technology.

Department of Mechanical Engineering

University of Moratuwa

Sri Lanka

March 2022

DECLARATION

I declare that this is my own work, and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis/dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

S. S. G. C. SIRIWARDANA

Signature UOM Verified Signature Date: 31-03-2022

The above candidate has carried out research for the Masters thesis under my supervision.

Name of the supervisor: **Dr. P.M.T. BANDARA**

Signature of the supervisor: UOM Verified Signature Date: 16/05/2022

Name of the supervisor: **Dr. R.A.C.P. RANASINGHE**

Signature of the supervisor: UOM Verified Signature Date: 16-05-2022

ABSTRACT

Microfluidics has recently gained research attention for its high-end thermal applications, including micro heat exchangers, Lab on a Chip, micro reactors, and MEMS. It has been proven that the addition of suitable nanoparticles to a fluid can enhance the heat transfer efficiency in microchannels, both in single phase and liquid-liquid two-phase flow. In general, slug flow is said to be the most efficient in heat transfer. However, the investigation performed on liquid-liquid slug flow with added nanoparticles was found to be very limited. Hence, this study numerically investigates the heat transfer characteristics in microchannels with liquid-liquid two-phase fluid flow (water and light mineral oil) with added nano particles (Al_2O_3).

The VOF method and phase field equations were solved using ANSYS Fluent and COMSOL Multiphysics to capture two-phase flow interfaces. Adaptive mesh refinement techniques were employed to reduce computational power while maintaining sharp interfaces between fluid phases. The Eulerian mixture model was used to solve the cases containing nanoparticles. Numerical results were validated against published experimental data reported by [1] and [2].

Simulations were conducted for a 3000 micron long microchannel with a diameter of 100 microns for fluid velocity, ranging from 0.1 m/s to 0.5 m/s. First, 1 kW/cm^2 of heat flux is introduced to the channel wall after 1000 microns to mimic the microchip heat generation, also allowing flow to be developed.

Results have shown that using nanoparticles in either phase significantly increases heat transmission. This can be amplified even more when used in the secondary phase, by 58 percent compared with liquid-liquid two phase slug flow. This was accomplished with a nanoparticle fraction of 0.05 v/v in the secondary fluid phase. The addition of nanoparticles to the primary fluid increased heat transfer by 34%. The findings of this study can be used to improve MEMS and micro-to-macro systems that move heat.

THIS PAGE IS INTENTIONALLY LEFT BLANK

DEDICATION

පිදුම

දරුවන්ගේ නිදහස් අධ්‍යාපනය වෙනුවෙන් බදු ගෙවනා

සුවහසක් ශ්‍රී ලාංකික ජනයාට

මෙය පිදුම් දෙමි.

I dedicate this to the

thousands of Sri Lankans who paid and are paying taxes for the free education of the children

Geethal Chandima Siriwardana

ACKNOWLEDGEMENTS

I would like to express my heartiest gratitude to all the lectures of the Department of Mechanical Engineering, University of Moratuwa and the Department of Mechanical Engineering, University of Sri Jayewardenepura for their valuable advice, guidance, and commitment to the MEng in Energy Technology program. Secondly, I would like to express my heartiest appreciation to my supervisors, Dr P M T Bandara and Dr R A C P Ranasinghe, for their advice, patience, and aspiration to complete this report. I would like to express my sincere gratitude to our Course Coordinator of this MEng in Energy Technology program and all group members of MEng in Energy Technology 2018, who gave me the fullest support in my studies in this academic program. Finally, my sincere thanks go to family members who wished, supported, and spared me at their level best for this study.

Geethal, Chandima Siriwardana

2022-02-04

THIS PAGE IS INTENTIONALLY LEFT BLANK

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Roman Symbols

A	Correlation constant for chemical compound
B	regression coefficients for chemical Compound
Ca	Capillary Number.
Co	Confinement number
c_p	Specific heat
C_{ps}	Heat capacity of saturated liquid
D	Diameter of the microchannel
d	Nanoparticle diameter
d_a	Diameter of the aggregate
d_f	Fractal dimension of the aggregates
D_h	Hydraulic Diameter
Di	Internal diameter
Do	Outer diameter
e	Internal energy
e_{Di}	absolute error of the parameter Di
F	Body force
g	Gravitational acceleration
G_z	Graetz number
k	Thermal conductivity of the fluid
K^*	Geometry dependent constants
Kn	Knudsen Number

L	Characteristics channel dimension
L_c	Microchannel length
L_{HT}	Heated length of the microchannel
L_{hyd}	Entry Length of a flow
M	Constant depends on the geometry of the channel
m	The fraction of the cross-sectional area of the tube covered with liquid.
M^*	Dimensionless quantity initiated by the author
n	Constant exponent component
Nu	Nusselt number
p	Pressure
pi	Primary fluid
Pr	Prandtl number
q	Heat flux
Q	Flow rate
r	Distance from the axis
R	Radius of the circular pipe
Re	Reynolds Number
se	Secondary fluid
T	Temperature
$T_{(r)}$	Fluid temperature at a distance of r
T_h	Dimensionless heated perimeter
T_m	Bulk mean fluid temperature
T_w	Wall temperature

u	Flow velocity
$U(r)$	Velocity component in the fully developed laminar flow
U_{avg}	Average velocity
U_B	Bubble Velocity
U_s	Slug Velocity

Greek symbols

ΔP	Pressure drop
μ	Dynamic viscosity
μ_r	Relative Viscosity
λ	Mean free path length
ρ	Local density
ρ_l	density of the liquid
ρ_v	density of the vapor
σ	surface tension
σ_i	interfacial tension between two fluids
τ	Stress tensor
Φ	nanoparticle volume fractions
σ_{l-g}	surface tension between liquid and gas
σ_{s-g}	surface tension between solid and gas
σ_{l-s}	surface tension between solid and liquid
θ_E	Young's equilibrium contact angle

Acronyms

CFD	Computation Fluid Dynamics
CHF	Critical Heat Flux
CNT	Carbon Nanotubes
EDL	Electric Double Layer
EG-T	Glycol/Water-Toluene
EG-W	Ethylene Glycol and Water
EHF	Extreme High Heat Flux
HHF	High Heat Flux
LoC	Lab On a Chip
LVG	Longitudinal Vortex Generators
MCU	Micro Controller Unit
MEMS	Micro Electromechanical Systems
O/A	Organic to Aqueous Volumetric
PDE	Partial Differential Equations
SF	Stagnant Film
UHF	Ultra High Heat Flux
W-T	Water-Toluene
MWCNT	Multi-Walled Carbon Nanotubes