Thermal Performance Analysis of Conventional and Enhanced Corrugated and Flat Plate Heat Exchangers

By

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Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

University of Technology Sydney

School of Mechanical and Mechatronic Engineering

November 2020

CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Salman Al zahrani, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in Mechanical Engineering at the University of Technology Sydney. This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program.

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Date: 11.11.2020

Keywords

Plate Heat Exchanger; Corrugated Plate Heat Exchanger; Flat Plate Heat Exchanger; Novel Design; Chevron Angle; CFD; Corrugation; Thermo-Hydraulic Characteristics; Overall Thermal Performance; Numerical Modelling; Turbulent; Laminar; Heat Transfer; Nusselt Number; Single-Phase; Reynolds Number; Basic Design; Heat Transfer Enhancement; Heat Exchanger; Flow Maldistribution; Pressure Drop; JF Factor; Flow Resistance; Flow Velocity; Modified Plate; Passive Technique; Compact; Conventional Plate Heat Exchanger.

Dedication

This thesis is dedicated to my deceased father, **Ahmed**, who passed away just one year before I started my PhD journey, to the one I love the most, my mother **Alia** with eternal appreciation, to my brothers and sisters, to my wife **Asrar** and to my children **Battal, Jassar,** and **Alia.**

Abstract

Plate heat exchangers (PHEs) have been extensively adopted for a large number of industrial applications, particularly systems that require high thermal efficiencies such as aerospace and heat recovery applications. Several studies have been performed on PHEs to disclose the impact of different geometrical parameters on heat transfer characteristics. However, the demand for energy is continuously increasing, and there is continuous development in industrial processes that require newly developed compact heat exchangers (HEs). Therefore, this thesis aims to introduce enhanced corrugated and flat PHEs. Passive enhancement techniques are adopted. Computational fluid dynamics (CFD) has been utilised to verify the superiority of the proposed enhanced PHEs. All turbulence models have been tested, and realizable $k - \varepsilon$ with scalable approach for wall treatment is found the best model that could provide the most accurate data. All PHEs that have been studied in the present thesis have identical geometrical and physical parameters. Full CAD approach is used, and all geometrical parameters are considered i.e. port effect and sinusoidal corrugations shape. The numerical approach has been extensively validated with benchmark studies from the literature, and an experiment is conducted for further validation. All studies are performed for water-water, 1-1 pass, U type, and counter-current flow arrangements. To assess the thermal performance of the enhanced PHEs, the findings have been compared with those of the conventional PHEs. Nusselt number (Nu), and fanning friction factor (*f*) are utilized as indicators of enhancement in the convective heat transfer and pressure drop, respectively. Moreover, turbulence kinetic energy, turbulence intensity, JF factor, intensity of flow maldistribution along with other parameters, are also employed to compare the thermal performance of the enhanced PHEs against the conventional ones. Generally, the thermal performance of the proposed corrugated and flat PHEs unequivocally outperforms that of the conventional PHEs. For instance, the enhancement in Nu data of the modified PHEs are up to 75%, 70%, 30%, and 175% with respect to the conventional PHEs. Hence the selection of the enhanced PHEs must be carefully performed, e.g. based on allowable pressure drop. Overall, these enhanced PHEs could pave the way for more compact HEs to be built and incorporated in applications that require more compact and durable HEs. They could be potential replacements of their counterparts of PHEs. In all studies, heat transfer correlations have been developed to assist the designers in predicting the HEs' thermal performance and to estimate the required heat transfer surface area.

Acknowledgements

I would like to express my heartfelt thanks to my principal supervisor and mentor, Dr Suvash C. Saha, for his unlimited support and guidance. He has always been the best example for me of how a professional researcher should be. Since the first day of my PhD journey, he has been a kind mentor, constructive, and with an encouraging attitude.

I would also like to express my sincere gratitude to my co-supervisor, Dr Mohammed S. Islam, for his endless support and guidance. I know a mere "thank you" is not enough to be said to those who have always been there to guide, inspire and assist me. However, it will always remind me that I am indebted to them.

My gratitude also goes to my sponsor Al Baha University for their financial support. I would also like to acknowledge professional editor, Diane Kolomeitz, for copyediting and proofreading services according to the guidelines laid out in the university-endorsed national 'Guidelines for editing research theses'.

I would like to stress how indebted I am to all of the UTS members, and to the members of my group in particular. Also, my gratitude goes to UTS interactive high performance computing members, for their technical services.

List of Publications

Journal Papers:

1. **S. Al-Zahrani**, M.S. Islam, F. Xu, S.C. Saha, Thermal performance investigation in a novel corrugated plate heat exchanger, **International Journal of Heat and Mass Transfer**, 148 (2020) 119095, [Q1], IF: 4.947
2. **S. Al-Zahrani**, M.S. Islam, S.C. Saha, Comparison of flow resistance and port maldistribution between novel and conventional plate heat exchangers, **International Communication in Heat and Mass Transfer**, 123 (2021) 105200, [Q1], IF: 3.971
3. **S. Al-Zahrani**, M.S. Islam, S.C. Saha, Heat transfer enhancement investigation in a novel flat plate heat exchanger. **International Journal of Thermal Sciences**, 161 (2021) 106763, [Q1], IF: 3.476
4. **S. Al-Zahrani**, M.S. Islam, S.C. Saha, Heat transfer augmentation in retrofitted corrugated plate heat exchanger, **International Journal of Heat and Mass Transfer**, 161 (2020) 120226, [Q1], IF: 4.947
5. **S. Al-Zahrani**, M.S. Islam, S.C. Saha, Heat transfer enhancement of modified flat plate heat exchanger, **Applied Thermal Engineering**, 186 (2021) 116533, [Q1], IF: 4.725

Peer Review Conference Paper:

S. Al-Zahrani, M.S. Islam, S.C. Saha, A thermo-hydraulic characteristics investigation in corrugated plate heat exchanger, Energy Procedia. 160 (2019) 597–605 .

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Symbols

A	Effective heat transfer area, m^2
$A_\circ$	Channel flow heat transfer area, m^2
A_h	Heat transfer area of the process fluid, m^2
A_P	Cross-sectional area of the inlet port, m^2
b	Corrugation depth, m
C_p	Specific heat, $J/kg.k$
d_e	Equivalent diameter, $d_e = 2b, m$
f	Fanning friction factor
h	Convective heat transfer coefficient, W/m^2K
G	Mass flux, kg/m^2s
L_h	Horizontal length from port to port, m
L_p	Plate's channel effective length, m
L_v	Vertical length from port to port, m
L_w	Flow channel width, m
$\dot{m}$	Mass flow rate, kg/s
N	Number of channels
Q	Heat transfer rate, W
P_m	Overall pressure drop, Pa
T	Temperature, K
t	Plate thickness, m
ΔTp	Temperature gradient of the plate
Tp,avg	Average temperature of the plate
Tp,max	Maximum temperature of the plate
Tp,min	Minimum temperature of the plate

S_k

S_ε User define source

Dimensionless quantities

j Colburn factor, $j = \frac{Nu}{RePr^{1/3}}$

JF JF factor

Nu Nusselt number

Pr Prandtl number

P_{mal} Flow maldistribution intensity

Re Reynolds number

Re_{cr} Critical Reynolds number

Abbreviation

CPHE Corrugated plate heat exchanger

FPHE Flat plate heat exchanger

HE Heat exchanger

HVAC Heating, ventilation, and air conditioning

NTU Number of transfer units

PHE All types of plate heat exchanger

PHE^1 Basic plate heat exchanger

PHE^2 The modified plate heat exchanger

Greek letters

β Chevron angle, °

μ Dynamic viscosity, $Pa.s$

μ_t Turbulent viscosity, $Pa.s$

ρ Fluid density, kg/m^3

E Effectiveness

Subscripts

avg	Average
b	Bulk fluid temperature
c	Cold stream
h	Hot stream
HTC	Heat transfer characteristics
i	Inlet condition
min	Minimum
max	Maximum
m	Measured
O	Outlet condition
w	Wall
mal	Maldistribution
i, j, k	Unit vectors for 3-space coordinates