



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

By

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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.

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Symbols

A	Effective heat transfer area, m^2
A_o	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, $J/kg \cdot K$
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
ΔT_p	Temperature gradient of the plate
$T_{p,avg}$	Average temperature of the plate
$T_{p,max}$	Maximum temperature of the plate
$T_{p,min}$	Minimum temperature of the plate

S_k	User define source
S_ε	

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, <i>Pa.s</i>
μ_t	Turbulent viscosity, <i>Pa.s</i>
ρ	Fluid density, <i>kg/m³</i>
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