IMPROVEMENT OF SMALL CHANNEL HEAT TRANSFER CORRELATION USING GENETIC ALGORITHM FOR R290 REFRIGERANT

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DEDICATION

This thesis is dedicated to my nieces and nephews; Natasha, Yasmine, Shafiq, Esmeth, Irdina, Iqbal, Marsya, Adam, Qaseh, Iffat, Iffatul, Ameena, Sofea and Idrees. Family is a gift that can’t be choosen.

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ABSTRACT

The primary issues among the discussions on two-phase flow in small channels are the uncertainties about the contributions of nucleate boiling and forced convective towards the total two-phase heat transfer coefficient, the accuracy of the predicted two-phase heat transfer coefficient which remains unsatisfactory, measured by the mean absolute error (MAE) between the correlation and experimental data, particularly that can accommodate pre-and post-dryout regions, and the limited experimental work for alternative refrigerants for the establishment of related correlations for a specific refrigerant. This thesis presents the results obtained using an optimization approach, Multi-objective Genetic Algorithm (MOGA) to show the conflicting effect of nucleate boiling and forced convective during two-phase flow of the natural refrigerant R290 in a small channel at the saturation temperature of 10˚C under optimized conditions of mass flux, heat flux, channel diameter, and vapor quality. Subsequently, Single Objective Genetic Algorithm (SOGA) was utilized to improve a selected superposition two-phase heat transfer correlation for R290. Experimental data points of R290 from reported experiments in 1.0 to 6.0 mm circular diameters were used to minimize the MAE while searching for the optimum constants and coefficients in the suppression factor (S), and convective factor (F), for the pre-and the post-dryout regions. The newly optimized correlation for R290 has MAE between 17 and 34% for all case studies which involves 40% improvement from the original correlation. Validation was done against a new data set to see the applicability and limitation of the developed correlations. The proposed method is capable of obtaining a precise empirical prediction that fits well with experimental data, as an approach to further improve any existing correlations which can reduce the number of experiments and consequently minimizes associated cost involved. The improved correlation obtained in the present study provides an improved prediction of heat transfer coefficient that in turn leads to accurate design and consequently saves material, refrigerant, and cost for compact heat exchanging devices.

ABSTRAK

Antara isu utama yang dibincangkan bagi aliran dua fasa di dalam salur yang kecil adalah ketidakpastian masih wujud tentang bagaimana pendidihan nukleus dan olakan haba paksa menyumbang kepada jumlah pekali pemindahan haba dua fasa, kejituan ramalan pekali pemindahan haba yang diperolehi masih tidak memuaskan, yang diukur menggunakan Min Ralat Mutlak (MAE) antara kolerasi dan data ujikaji, terutamanya yang dapat memenuhi rantau pra- dan pasca-kering dan kerja ujikaji yang terhad terutama daripada bahan penyejuk alternatif telah menghadkan pembentukan kolerasi pekali pemindahan haba bagi bahan penyejuk tertentu. Tesis ini membentangkan dapatan yang diperolehi daripada kaedah pengoptimuman, Genetik Algoritma pelbagai objektif (MOGA) untuk memperlihatkan kesan berlawanan di antara pendidihan nukleus dan olakan haba paksa terhadap aliran dua fasa bagi bahan penyejuk semulajadi, R290 di dalam salur yang kecil pada suhu tepuan 10˚C di dalam keadaan optimum terhadap fluks jisim, fluks haba, diameter salur dan kualiti wap. Seterusnya, kaedah pengoptimuman menggunakan Genetik Algoritma satu objektif (SOGA) digunakan sebagai kaedah untuk memperbaiki satu korelasi superposisi dua fasa yang terpilih untuk R290. Data ujikaji untuk R290 diperolehi daripada hasil kajian terdahulu berjulat diameter dari 1.0 hingga 6.0 mm yang digunakan untuk meminimakan nilai MAE dalam mencari keadaan optimum bagi pemalar dan pekali faktor penekanan (S) dan faktor perolakan (F), dengan dan tanpa keadaan kering. Kolerasi teroptimum yang baharu bagi R290 mempunyai MAE antara 17% dan 34% untuk kes-kes yang dikaji yang melibatkan 40% penambahbaikan daripada kolerasi asal yang dipilih. Pengesahan dilakukan terhadap data baru yang belum diuji untuk melihat kebolehgunaan dan had batasan kolerasi baru yang dihasilkan. Kaedah yang dicadangkan mampu menghasilkan ramalan empirik yang lebih jitu yang berpadanan dengan data ujikaji, sebagai kaedah untuk memperbaiki kolerasi yang sedia ada yang mana ia dapat mengurangkan bilangan eksperimen dan seterusnya mengurangkan kos yang berkaitan. Kolerasi yang diperbaiki di dalam kajian ini dapat menghasilkan ramalan empirik yang lebih baik bagi pekali pemindahan haba yang seterusnya membawa kepada rekabentuk yang lebih jitu dan seterusnya dapat menjimatkan bahan, bahan penyejuk dan kos bagi alat penukar haba mampat.

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LIST OF ABBREVIATIONS

ANN	-	Artificial neural network
ASHRAE	-	American Society of Heating Refrigeration and Air Conditioning Engineers
CFC	-	Chlorofluorocarbon
CO_2	-	Carbon dioxide
FC77	-	Dielectric fluid fluorinert
GA	-	Genetic algorithm
GWP	-	Global warming potential
HC	-	Hydrocarbon
HCFC	-	Hydrochlorofluorocarbon
HFC	-	Hydrofluorocarbon
HFO	-	Hydrofluoroolefin
LSSVM	-	Least square support vector machine
MAE	-	Mean absolute error
MSE	-	Mean squared error
MOGA	-	Multiobjective genetic algorithm
ODP	-	Ozone depletion potential
R11	-	Trichlorofluoromethane
R12	-	Dichlorodifluoromethane
R22	-	Chlorodifluoromethane
R32	-	Difluoromethane
R113	-	1,1,2-Trichloro-1,2,2-trifluoroethane
R114	-	1,2-Dichlorotetrafluoroethane
R124	-	1-Chloro-1,2,2,2-tetrafluoroethane
R125	-	Pentafluoroethane
R134a	-	1,1,1,2-Tetrafluoroethane
R141b	-	1,1-Dichloro-1-fluoroethane
R142b	-	1-Chloro-1,1-difluoroethane
R143a	-	1,1,1-Trifluoroethane
R152a	-	1,1-Difluoroethane

R170	-	Ethane
R290	-	Propane
R404a	-	R-125/143a/134a (44.0/52.0/4.0)
R407a	-	R-32/125/134a (20.0/40.0/40.0)
R407b	-	R-32/125/134a (10.0/70.0/20.0)
R407c	-	R-32/125/134a (23.0/25.0/52.0)
R410a	-	R-32/125 (50.0/50.0)
R507a	-	R-125/143a (50.0/50.0)
R600	-	Butane
R600a	-	Isobutane
R717	-	Ammonia
R718	-	Water/Steam
R744	-	Carbon dioxide
R1270	-	Propene (Propylene)
R245fa	-	1,1,1,3,3-Pentafluoropropane
R1234yf	-	2,3,3,3-Tetrafluoropropene
GA	-	Genetic Algorithm
PSO	-	Particle Swarm Optimization

LIST OF SYMBOLS

α	-	Optimization variables
b	-	Optimization variables
Bd	-	Bond number
Bo	-	Boiling number
C	-	Chisholm parameter
Ca	-	Capillary number
Co	-	Confinement number
C_o	-	Convection number
C_{ref}	-	Constant in Choi *et al.* (2014) correlation
C_p	-	Specific heat (J/kg)
d_B	-	Bubble departure diameter
D	-	Diameter (m)
D_e	-	Equivalent diameter
D_h	-	Hydraulic diameter
E	-	Enhancement factor
Eo	-	Eotvos number
f	-	Friction factor
F	-	Convective factor
F_f	-	Liquid correction factor
F_M	-	Mixture correction factor
Fa	-	Fang number
Fr	-	Froude number
$F(x)$	-	Fitness
G	-	Mass flux (kg/m^{2}s)
g	-	Gravitational acceleration (m/s^2)
h	-	Heat transfer coefficient (W/m^{2}K)
h_{cb}	-	Convective boiling heat transfer coefficient
h_{Cooper}	-	Cooper’s correlation
h_{DB}	-	Dittus-Boelter’s correlation

h_{exp}	-	Experimental heat transfer coefficient
h_f	-	Liquid heat transfer coefficient
h_{fo}	-	Liquid only heat transfer coefficient
h_g	-	Vapor heat transfer coefficient
h_{nb}	-	Nucleate boiling heat transfer coefficient
h_{SA}	-	Stephan-Abdelsalam's correlation
$h_{optimized}$	-	Optimized heat transfer correlation
h_{pred}	-	Predicted heat transfer coefficient
h_{pool}	-	Pool boiling heat transfer coefficient
h_{tp}	-	Two-phase heat transfer coefficient (W/m^2K)
i_{fg}	-	Enthalpy (J/kg)
k	-	Thermal conductivity (W/mK)
K	-	Mixture correction factor in Zou *et al.* (2010)
L		Channel length
La	-	Laplace number
M	-	Molecular weight
Nu	-	Nusselt number
P	-	Pressure (Pa)
P_H	-	Heated perimeter of channel
P_F	-	Wetted perimeter of channel
Pr	-	Prandtl number
$P(x)$	-	Probability
p_R	-	Reduced pressure ($P/P_{critical}$)
q	-	Heat flux (W/m^2)
Q	-	Heat transfer rate (W)
Re	-	Reynolds number
Re_f	-	Liquid Reynolds number
Re_{fo}	-	Liquid only Reynolds number
Re_g	-	Vapor Reynolds number
Re_{go}	-	Vapor only Reynolds number
S	-	Suppression factor
T_{bub}	-	Bubble temperature (K)

T_i	-	Inner temperature (K)
T_{sat}	-	Saturation temperature (K)
T_w	-	Wall temperature (K)
u	-	Velocity (m/s)
We	-	Webber number
x	-	Vapor quality; design parameter
x_{di}	-	Dryout incipience quality
X	-	Lockhart-Martinelli parameter
X'	-	Children
X_0	-	Population
X_{tt}	-	Turbulent-turbulent condition
X_{vt}	-	Laminar –turbulent condition
X_{tv}	-	Turbulent-laminar condition
X_{vv}	-	Laminar-laminar condition
z	-	Stream-wise coordinate
α	-	Empirical coefficient, probability mask
λ	-	Laplace constant
ρ	-	Density (kg/m^3)
ρ_f	-	Liquid density (kg/m^3)
ρ_g	-	Vapor density (kg/m^3)
μ	-	Dynamic viscosity (Ns/m^2)
μ_f	-	Liquid viscosity (Ns/m^2)
μ_g	-	Vapor viscosity (Ns/m^2)
υ	-	Kinematic viscosity (m^2/s)
$\emptyset$	-	Two-phase multiplier
σ	-	Surface tension (N/m^2), mutation rate
θ	-	Angle
ξ	-	Percentage predicted within ±30%
ΔMAE	-	Reduce MAE

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Improving the performance of heat transfer devices has always been of great interest, towards saving energy, materials and costs. Among the most effective approach used to improve the thermal performance of a heat exchanging device is through the increase in the surface to volume ratio. Figure 1.1 shows the spectrum of surface to volume ratio in heat transfer applications. A heat exchanger having a surface area density on any one side greater than about 700 m^2/m^3 with a diameter between 5 to 6 mm is considered as a compact heat exchanger (Singh *et al.*, 2014). The human lung with 20,000 m^2/m^3 is actually the most compact heat exchanger system to date (Zohuri, 2017).

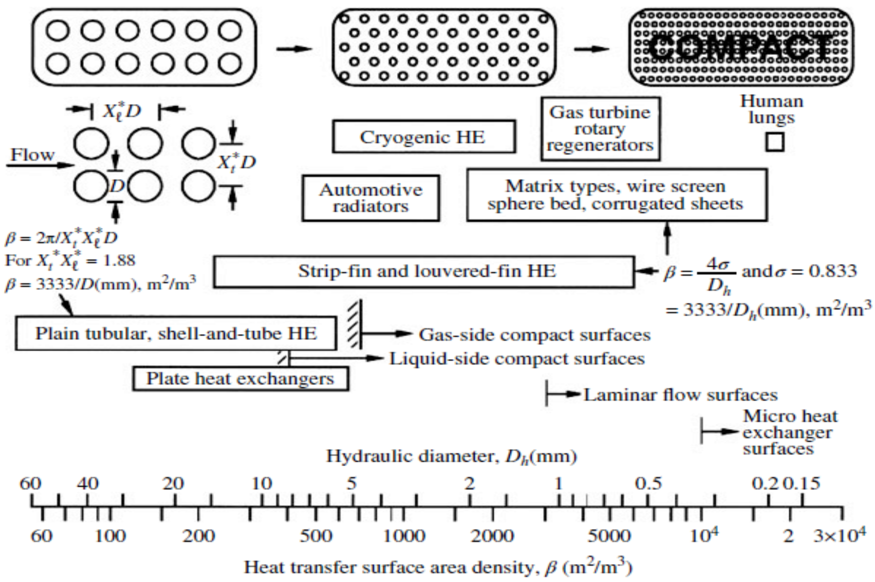

Figure 1.1 A spectrum of heat transfer surface density with channel diameter (Ranganayakulu and Seetharamu, 2018)

Bartel *et al.* (2015) studied the characteristics of a compact heat exchanger for a 600MW nuclear reactor system. The optimum conditions between the heat transfer coefficient, pressure drop and compactness are important in the design of small heat exchanging systems to ensure reliability, easy maintenance and low capital cost, under various constraints allowable. Unfortunately, despite the higher heat transfer achievable, a small heat transfer system experienced a high pressure loss due to friction. The high pressure required a high pumping power. Furthermore, the fabrication of a small system involves a series of channels, which resulted in a high manufacturing cost (Dixit and Ghosh, 2015). Optimization is the process in getting the best solutions under given constraints; high heat transfer, low pressure drop, and low cost. Thus, it is important for the thermal system to be optimized to get the desired heat transfer capacity at its best performance.

Although Mehendale *et al.* (2000) and Kandlikar and Grande (2003) defined the small channel into several categories - mini, micro, meso, nano - nevertheless, ‘conventional’ and ‘small’ channel is generally termed as ‘macrochannel’ and ‘microchannel’ respectively. These terms shall be used in this work. A transition between macro and microchannel is important because many thermal flow properties and behaviour change as the channel diameter decreases. It is reported and agreed well that there is no definite threshold value that can be claimed as a general macro-to-micro transition. It is not always suitable to define a microchannel at a specific hydraulic diameter, although this definition is often used nonetheless (Hesselgreaves *et al.*, 2017). Until now, researchers defined a macro-to-micro transition based on three conditions; channel diameter, bubble confinement and bubble departure diameter.

Since Tuckerman and Pease (1981) had shown that a small channel is capable of producing a higher heat transfer, further development in the compact heat transfer system has been studied in many applications. As an example, the air cooling in electronic devices has reached its cooling limitation due to the high demand and need for better performance. The better solution is by using liquid cooling in the microchannel heat exchanger (Kheirabadi and Groulx, 2016; Sohel Murshed and Nieto de Castro, 2017). Subsequently, two-phase flow has been found to better address very high heat flux removal that could not be handled by a single phase flow, the latent heat being much higher than that of the sensible heat transfer.

1.1.1 Two-phase heat transfer correlation in a microchannel

A single phase flow occurs when the fluid is not changing its phase. It has a limit in temperature rise. A two-phase flow is when the fluid is changing its phase either from liquid-to-gas (evaporation) or from gas-to-liquid (condensation) to accommodate the increasing heat transfer. Two-phase heat transfer has a high latent heat thus having a higher energy efficiency compared to single phase (Li and Wu, 2010a; Xu *et al.*, 2012). The microchannel evaporation single phase flow correlation shows a good agreement with conventional theories when it is in a fully developed, incompressible and laminar flow (Asadi *et al.*, 2014). Therefore, it is generally a practice to test the single phase flow as a validation at the start of two-phase experiments.

Even though two-phase flow has been successfully applied, there exist still challenges in the experimental work. Most of the experimental data heat transfer obtained had been calculated by assuming a linear pressure gradient and the validity is questioned. Mirmanto (2014) showed that at high heat flux, the local pressure distribution was not linear. The calculation by assuming a linear pressure gradient is only recommended at low pressure drop. This causes the deviations in calculation of saturation temperature which further affect the prediction of the heat transfer coefficient.

Two mechanisms of evaporation heat transfer in a channel have been identified through experimental work; nucleate boiling and forced convective process (Riofrío *et al.*, 2016). Nucleate boiling is the phase where there is bubble nucleation growth and forced convective is the moving of heated fluid from the surface. Charnay *et al.* (2015) listed three conditions on how a heat transfer correlation was being developed - nucleate boiling dominance, forced convective dominance and no predominance from both mechanisms. However, this dominant heat transfer mechanism have been conclusively done based on the significant effect of heat flux or mass flux towards the experimental data without adequate physical discussion (Wang and Wang, 2014).

Initial correlations for a microchannel originated from those developed for a macrochannel. Most correlations in a macrochannel are developed under turbulent conditions and dominantly by convective rather than nucleate boiling. Meanwhile, the microchannel involves laminar liquid flow (Ducoulombier *et al.*, 2011). This is caused by different effects of dominant forces. During two-phase flow in a microchannel, the capillary forces become dominant, while buoyancy forces are weaker (Kumar *et al.*, 2017). In practice, the selection of a suitable functional form for a correlation has been done by comparing several correlations from the literature that match the experimental data. The correlation that fits in well with the data was selected as the basis form (Zou *et al.*, 2010; Chen *et al.*, 2015; Kanizawa *et al.*, 2016). Some others, correlated their own correlation through selection of dimensionless parameters that was tested having an influence on the data (Bertsch *et al.*, 2009; Li and Wu, 2010a; Shah, 2017). Either way, new data in heat transfer correlations has to fit into the functional form that they tested with. According to Asadi *et al.* (2014), the data on microchannels was limited with the absence of a theoretical base when choosing a specific correlation. The ability to acknowledge the constants and parameters involved in each prediction method reduces the possibility of high cost and unfitting design of heat transfer equipment (Kandlikar, 1990).

1.1.2 Refrigerant

A refrigerant is a liquid that absorbs heat during an evaporation process. Ether was used during the first breakthrough in refrigeration system on 1834. Later on, natural refrigerants such as ammonia, CO_2 and others were applied until the early 1930s, when the synthetic refrigerant of clorofluorocarbons (CFCs) was invented. CFCs were a favorite and have phased out natural refrigerants due to their excellent performance, are stable and safe to human health. Around 40 years after its first introduction, it was found out that CFCs caused a large ozone depletion (Abas *et al.*, 2018).Consequently, under the Montreal Protocol (1987), CFCs were banned and phased out by 2010. This has shifted the use from CFCs to the widespread of hydroclorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). Nevertheless, both were known as having a high global warming potential (GWP). Therefore, HCFCs and HFCs usage were controlled and scheduled to phase out by 2030 and 2040, respectively. Table 1.1 lists the important timeline related to the introduction and phase-out processes. This situation has put other alternative refrigerants such as hydrofluoroolefins (HFOs) and natural refrigerants as a more environmentally friendly choice. Figure 1.2 shows the alternative refrigerants considered for the CFCs till 2017.

Table 1.1 A brief timeline of refrigerants

Year	**Remarks**
1834	Ether was introduced
1930s – 1950s	Natural refrigerant
1930s	CFCs
1980s	HCFCs and HFCs
1987	Montreal Protocol
	- Banned of CFCs by 2010
1997	Kyoto Protocol
	- Phased out of HCFCs by 2030
2016	Kigali Amendment
	- Phased out of HFCs by 2040

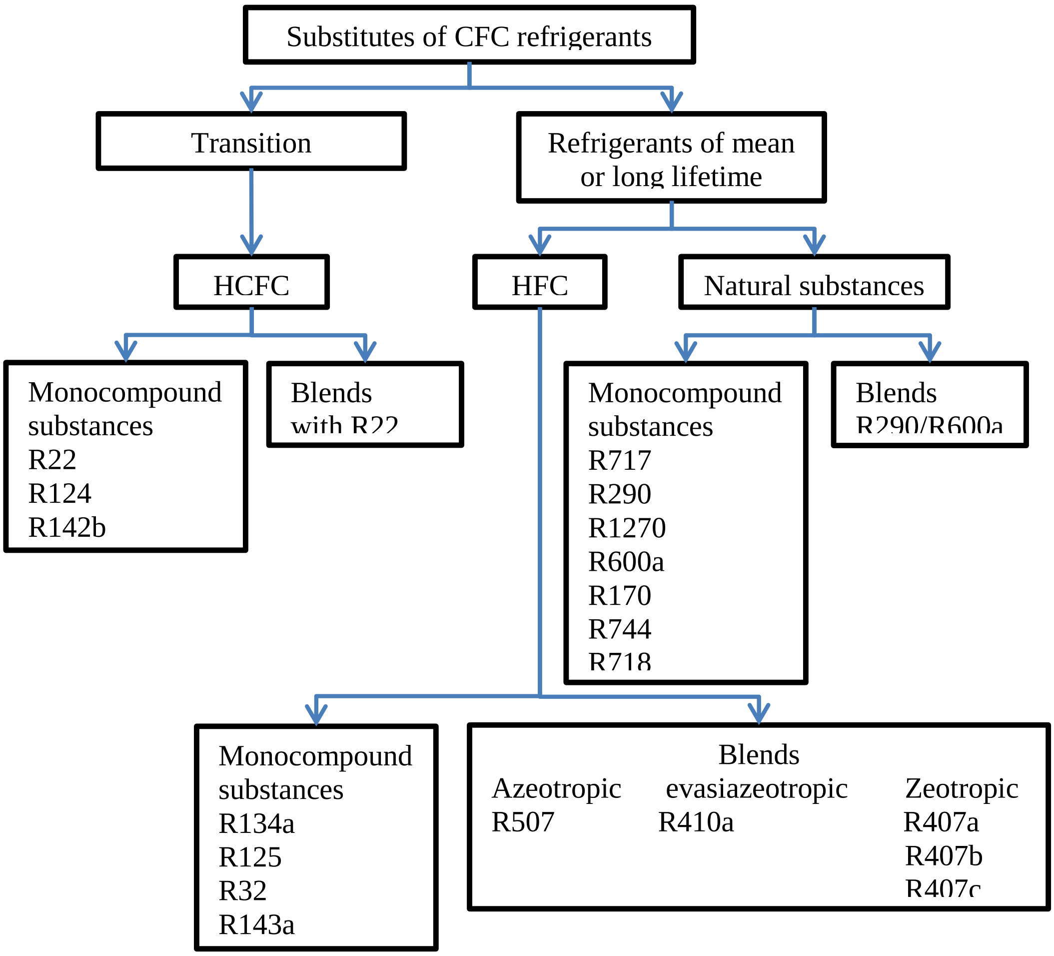

Figure 1.2 Alternative refrigerants for CFCs (Harby, 2017)

Recently, Ciconkov (2018) suggested that natural refrigerants are the most promising long term solutions compared to other options due to their excellent behavior. A natural refrigerant is a substance which occurs naturally, which includes CO_2, ammonia, water, air, and hydrocarbons, also known as the 'Gentle Five'. They have zero ozone depletion potential (ODP) and low GWP. Hydrocarbons (HCs) such as R600 (butane) and R290 (propane) have become a choice in commercial and domestic refrigeration applications. The only disadvantage is their flammability. According to ASHRAE Standard 32, HCs are classified as class A3 which is highly flammable. Thus, it has to be applied with a safety precaution. Due to this, hydrocarbons have been selected as a good choice in the application of compact systems as they can reduce its charge, thus reducing the cost and increasing the design efficiency (Belman-Flores *et al.*, 2015; Choi *et al.*, 2018).

Propane or R290 is recognized as a potential replacement for R22 due to their similar properties and heat characteristics but twice the latent heat of vaporization. Heo *et al.* (2013) listed R290 as the first choice refrigerant in commercial applications. R290 has a GWP of less than 3 and zero ODP. At least one study (Oh *et al.*, 2011) is available in reporting a comparison study in a microchannel between R290 and R22 to show the ratio 0.7:1.0 of their mean heat transfer coefficient. In another study, it was suggested that R290 could achieve between 1.7 to 2.8 $kW/m^2.K$ heat transfer coefficient in an evaporative compact heat exchanger (Thonon, 2008). Several works reported on the advantages of R290 in their refrigeration system. Sánchez *et al.* (2017) showed that it has the highest increased cooling and performance capacity compared to R134a in their refrigeration system. At the same time, it showed increased in power consumption which needed system retrofitting and not suitable as a drop in refrigerant for R134a. Mastrullo *et al.* (2014) proposed the possibility to reduce the refrigerant charge by 30% and reducing energy consumption by 34% in a light commercial freezer when R404a is replaced with R290. Heo *et al.* (2013) showed that R290 charge in a large capacity freezer is 92 g, less than the allowable 150 g (according to International Standard IEC 60335 and European standards EN-378), which is safe to be used in any closed condition without any safety precaution. Due to these advantages and other promising potentials to be explored, R290 has been selected as the refrigerant for the current work.

1.2 Problem Statement

The available two-phase heat transfer correlations consist of dimensionless numbers which are related to various types of dominant forces existing in the heat transfer in a channel. The dimensionless numbers are generally a function of, among others, the channel diameter, heat flux, mass flux and thermodynamic properties under the influence of saturation pressure and temperature. The theory behind these correlations originates from a macrochannel; there are different flow characteristics and effect of forces in a microchannel. To date, it is still questionable that the conventional theory on heat transfer and fluid flow is valid for a two-phase flow in a microchannel due to the difference in nucleate boiling and forced convective mechanism acting in both channel sizes (Karayiannis and Mahmoud, 2017). The contribution of nucleate boiling and forced convective in a microchannel and its reppresentation in heat transfer correlation is still an issue. However, increasing the contributions of each during a heat transfer process is much desired regardless their respective operating conditions.

A heat transfer correlation is generally developed within its experimental parameters range. Certain correlations are developed from several selected refrigerants which have different range of physical and thermodynamic properties, where the relevancy can be argued. Through recent review works, it can be concluded that there are no general predictive methods applicable to all range of data and types of refrigerants (Cheng and Xia, 2017; Fang *et al.*, 2018). The mean average error (MAE) associated with the available correlations for evaporative heat transfer in a small channel is still unsatisfactory. Consequently, more experiments are being done and planned to reduce the MAE. The unavailability of a correlation for a new replacement refrigerant and limited applicability of the existing correlations favors continuous development of the correlation for a specific refrigerant with a more accurate design performance.

A HC such as R290 is a favourite as a replacement to a conventional refrigerant, but there is still inadequate study on individual R290 data especially involving microchannels (Wang *et al.*, 2014; Lillo *et al.*, 2018). Most studies with R290 are partial work where comparisons were done between potential substitute refrigerants (Longo *et al.*, 2017; Sánchez *et al.*, 2017) or as a mixture refrigerant (Zhu *et al.*, 2015; He *et al.*, 2016) with other natural or conventional refrigerants. The development of microchannel systems together with new alternative refrigerants can essentially increases the heat removal performance and addresses the concerns of a sustainable environment.

Although there are several approaches utilized to predict the heat transfer coefficient, these developed correlations (from macro and micro channels) based on past experimental data still disagree (unsatisfactory MAE) with later experimental data obtained even under similar conditions – channel diameter, flow regime, mass flux etc. Most empirical work in heat transfer correlations generally correlated the experimental data using the regression method. New constants and coefficients are produced which resulted in the development of a new correlation (Li and Wu, 2010a). Cheng and Xia (2017) suggested the possibility that an inaccurate regression method led to an unreliable correlation for a new refrigerant with different heat transfer behaviour. An accurate prediction of the heat transfer coefficient in two-phase flow in a microchannel is crucial to avoid under or over design of heat exchanging devices for savings in material and cost.

1.3 Research Question

This study aimed to address the following research questions;

1. Can nucleate boiling and forced convective (both identified to be contributing factors) be optimized simultaneously to enhance the total heat transfer performance in two-phase flow?
2. How can genetic algorithm be applied to develop a correlation for a new experimental data of a specific refrigerant using a functional form of the existing correlation?
3. Can the discrepancies between experimental and existing two-phase heat transfer correlations be minimized under a particular experimental condition?

1.4 Objective

The objective of this research is to propose an approach to modify the two-phase evaporative heat transfer correlation for R290 by using an optimization method in reducing the discrepancies of heat transfer coefficient between predicted and experimental data in a small channel. To fulfil this, the following needs to be completed;

1. Identify the optimal parameters involved in the contribution of nucleate boiling and forced convective heat transfer towards the total two-phase evaporative heat transfer coefficient using Multi-objective genetic algorithm (MOGA).
2. Select a correlation functional form that consists of both the nucleate boiling and forced convective properties to be optimized in order to improve the error between predicted and selected R290 experimental data using Single-objective genetic algorithm (SOGA).
3. Analyse the performance of the modified correlation through prediction, trend and pattern by comparing against available experimental data, other refrigerants and other correlations.

1.5 Scopes

The research study will cover the following scopes;

1. Analysis of the different approaches available in developing the current heat transfer coefficients for evaporation in small channels that have been based on established experimental work.
2. Selection of data is done for R290, collected from available published works which reported the heat transfer coefficient values with the effect of increasing vapor quality. The channel diameter taken is between 1.0 to 6.0

mm. The data is extracted from the graph(s) by using Grabit, an extraction data function developed in MATLAB.

3. The collected R290 data is analysed towards selected generalized correlations; superposition, asymptotic and strictly empirical types. This is to study the behavior of generalized correlations with the new data unknown to them. The selected generalized correlations either have R290 or no R290 data as their developed refrigerants.

4. The collected R290 data is analysed towards two selected superposition correlations which were developed from R290. One of the correlations was developed specifically for R290 and another one consists of R290 along with other refrigerants.

5. Investigating the contributions from nucleate boiling and forced convective heat transfer to the total evaporative heat transfer coefficient for a selected heat transfer coefficient functional form (superposition and asymptotic approach) to identify how both can be maximized simultaneously under parameters of mass flux, heat flux, vapor quality and diameter. The effect of saturation temperature is ignored.

6. The optimization method is used as a novel approach in finding the coefficients and constants of dimensionless parameters in the selected correlation. The error to be calculated in MOGA is Mean Absolute Error (MAE) with the least value given by the optimization result taken as the acceptable result. The genetic algorithm is written in MATLAB environment.

7. Three cases of dryout incipence quality are studied to determine the different condition of dryout vapor quality. The dryout incipence quality is used to determine the condition where the portion of the liquid film starts to experience the dryout and the decreases of heat transfer coefficient. It is used as a threshold to differentiate between pre-and post-dryout data point.

8. The applicability of the proposed method is tested with three different ways; with a new unknown R290 data to the optimized correlations, with a different type of refrigerant (R744) and with a different type of correlation (asymptotic).

1.6 Outline of the thesis

The overall structure of the thesis takes the form of six parts, including this introductory chapter. In Chapter 2, previous pertinent studies on two- phase heat transfer correlations in small channels are discussed which involved channel classification, types of heat transfer correlations and issues related to the subject matter.

Chapter 3 includes the theories of the two-phase heat transfer in a channel and the experimental calculations to get the heat transfer coefficient. The optimization concept and theory of genetic algorithm are presented.

Chapter 4 presents the methodology part which includes the selected data, correlations and algorithm for SOGA and MOGA optimization. It presents the related transfer function, variables and genetic algorithm properties that are used throughout the study.

Chapter 5 presents the discussion on the trend and pattern of nucleate boiling and forced convective contribution toward the selected total two-phase heat transfer correlations under optimized condition gained through MOGA. The parameters of mass flux, heat flux and vapor quality are taken as variables. The chapter also discusses the result on optimized correlation from SOGA in reducing the heat transfer coefficient error between predicted and experimental data. The validation of the optimized correlation is done through comparison between the available experimental data, different refrigerants and different correlations.

Chapter 6 which is the last chapter concludes the research finding and fulfil the objectives mentioned. The recommendations and suggestions for further study on the improvement of related work are proposed.

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