UNIVERSITI TEKNIKAL MALAYSIA MELAKA

STUDY ON PERFORMANCE OF COMPACT FINNED HEAT EXCHANGER USINGOPEN-CELL COPPER FOAM

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (REFRIGERATIONAND AIR-CONDITIONING SYSTEMS) WITH HONOURS

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A thesis submitted in fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Refrigeration and Air-Conditioning Systems) with Honours

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2022

DECLARATION

I Declare That This Report Entitled "Study On Performance Of Compact Finned Heat Exchanger Using Open-Cell Copper Foam" Is The Result Of My Own Research Except As Cited In The References.The Project Report Has Not Been Accepted For Any Degree And Is Not Concurrently Submitted In Candidature Of Any Other Degree.

Signature : *MOHAN RAJ*

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Name : Mohan Raj A/L Baskaran

Date : 18 January 2022

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APPROVAL

I Hereby Declare That I Have Checked This Project Report And In My Opinion, This Report Is Adequate In Terms Of Scope And Quality For The Award Of The Bachelor Of Mechanical Engineering Technology (Refrigeration And Air-Conditioning Systems) With Honours.

Signature : *DR. SETYAMARTANA PARMAN*

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Supervisor Name : Dr. Setyamartana Parman

Date : 18 January 2022

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DEDICATION

I would like to dedicate this report for both my parents Baskaran A/L Raju and Parimala A/P Thenamoorthy as they are my lovable courage, inspiration, dedication and strength to complete my project until the end. I also would like to thank to my sisters and friends as they too have helped me in term of financial and motivation during my years of study. Furthermore, I also would like to tell my thanks to my classmates who always supports and updates on the latest updates on the projects.

ABSTRACT

Heat exchangers are widely applied in different fields that can range from heavy industries to small electronic devices. The need for an increase in the effectiveness is of great concern for heat exchanger manufactures to produce better heat exchanger devices. The use of open-cell metal foam in manufacturing heat exchangers is one of the many methods being studied at the moment due to its unique structural and thermal properties. The aim of this thesis is to carry out experimental analysis of the performance of the compact heat exchanger based on open-cell copper foam. To facilitate in this process of performance analysis, an in-house small scale wind tunnel using air as coolant is developed as the test rig. The experiments were conducted on copper foam with porosity, ε of 0.93 and 60 PPI (pores per inch). Different configurations of the compact finned copper foam heat exchanger were tested at varying Reynolds number. The performance of the completed heat exchanger test rig was judged by studying the flow uniformity in the test section area and was found to be satisfactory. The thermal performance of configuration 1 was 2.5 to 5 times better for fixed flow condition and 1.2 to 2.5 times better for fixed pumping power condition as it has twice the heat exchange area than configuration 2. But the pressure drop for configuration 2 was 5 times lower due to the reduced flow resistance courtesy of the air gap in between the finned copper foam. It is recommended that further variation in the configuration is studied in order to further increase the effectiveness of the compact finned metal foam heat exchanger.

ABSTRAK

Penukar haba digunakan secara meluas dalam bidang yang berbeza dan terdiri daripada industri berat ke peranti elektronik kecil. Keperluan untuk meningkatkan keberkesanan adalah kebimbangan yang besar untuk pengilang penukar haba untuk menghasilkan alat penukar haba yang lebih baik. Penggunaan busa logam sel terbuka dalam pembuatan penukar haba adalah salah satu daripada banyak kaedah yang sedang dikaji pada masa ini disebabkan oleh sifat-sifat struktural dan haba yang uniknya. Tujuan tesis ini adalah untuk menjalankan analisis eksperimen untuk prestasi penukar haba padat berdasarkan busa tembaga sel terbuka. Untuk memudahkan dalam proses analisis prestasi ini, sebuah terowong angin kecil dalaman menggunakan udara sebagai penyejuk dibangunkan sebagai pelantar ujian. Eksperimen dilakukan pada busa tembaga dengan porositas, ε 0.93 dan 60 PPI (liang per inci). Penukar haba busa tembaga padat bersirip yang berbeza konfigurasi diuji pada nombor Reynolds yang berbeza-beza. Prestasi rig ujian penukar haba telah dikaji untuk keseragaman alir di kawasan ujian dan didapati memuaskan. Prestasi terma konfigurasi 1 adalah 2.5 hingga 5 kali lebih baik untuk keadaan aliran tetap dan 1.2 hingga 2.5 kali lebih baik untuk keadaan kuasa pam yang tetap kerana ia mempunyai dua kali kawasan pertukaran haba daripada konfigurasi 2. Tetapi penurunan tekanan untuk konfigurasi 2 adalah 5 kali lebih rendah kerana rintangan aliran dikurangkan oleh jurang udara di antara sirip busa tembaga. Adalah disyorkan bahawa variasi lanjut dalam konfigurasi harus dikaji untuk meningkatkan lagi keberkesanan penukar haba busa logam bersirip yang bersaiz padat.

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LIST OF SYMBOLS AND ABBREVIATIONS

PPI	Pores per inch
ε	Porosity
RPM	Rotation per minute
PMMA	Polymethyl Methacrylate
EDM	Electrical discharge machining
TS	Test Section
Re	Reynolds number
ΔP	Pressure drop (Pa)
ρ	Density of fluid (kg/m^3)
V	Average velocity of fluid (m/s)
h	Heat transfer coefficient ($W/m^2.°C$)
Nu	Nusselt number
μ	Dynamic viscosity of fluid (kg/m.s).
A	Convective heat transfer surface area (m^2)
C_p	Specific heat capacity of fluid (J/kg.°C)
$\dot{V}$	Volumetric flow rate of fluid (m^3/s).
$\dot{m}$	Mass flow rate of fluid (kg/s)
k_c	Thermal conductivity of fluid (W/m.°C)
T_w	Average wall temperature (°C)
T_{in}	Average inlet temperature (°C)
T_{out}	Average outlet temperature (°C)
D_h	Hydraulic diameter (m)
W	Pumping power (W)
Q	Total heat transfer rate (W)

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CHAPTER 1

INTRODUCTION

1.1 Background

When a device that is in thermal contact between different mediums of varying temperatures and involved in the operation of heat energy transfer between them, it is commonly referred to as a heat exchanger or heat sink. There is no external heat and work interactions being involved in the processes for most of the time. The most common use for heat exchangers involve heating and cooling processes which may sometimes include the condensing and evaporating of the fluid of interest. Besides that, heat exchangers have also been observed to be used in heat recovery and rejection processes as well. Hence, it is safe to say that heat exchangers are used widely in many engineering systems and products and are a crucial element.

In a majority of the heat exchangers, the transfer of heat occurs through a separating wall in either a continuous manner or just momentarily. Except for a select few, in which there is direct transmission of heat between the fluids.

Since the usage, design method and equipment type vary for the heat exchangers, some classifications are made. Some common classification examples used are as below.

- The type of transfer processes regarding the thermal energy.
- The number of fluids involved in thermal energy transfer.
- The heat transfer mechanism used by the heat exchanger.

Based on their construction type and also the flow arrangements the heat exchangers can be further classified. Besides that, it can also be classified into compact and non- compact heat exchangers based on their volume to effective surface area ratio. Further details on the classifications can be referred in Fig. 1.1. (Shah & Sekulic, 2003)

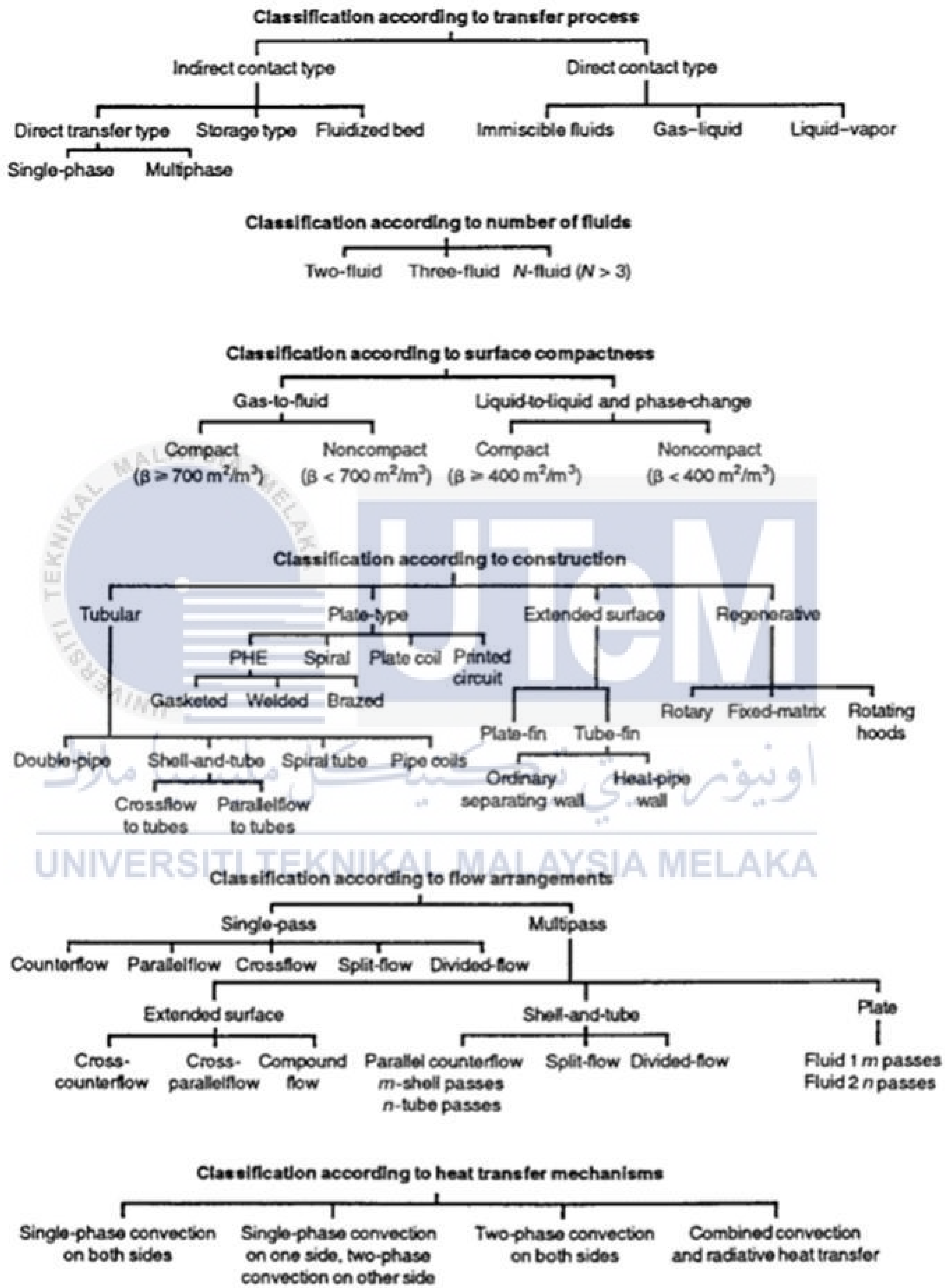

Figure 1.1: Classification of heat exchangers (Shah & Sekulic, 2003)

1.2 Problem Statement

In recent years, major strides have been made in regards to heat exchanger design and manufacturing. This is due to the fact that the optimization of heat exchangers is of paramount importance in regards to saving energy and decreasing the cost. One of the ways to achieve this goal is by enhancing the air-side heat transfer of the heat exchangers in an attempt to improve its thermal effectiveness. (Mobtil, Bougeard, & Russeil, 2018).

The air-side of the heat exchanger is where the thermal resistance is at its highest when it comes to the transfer of heat to the air from the heat exchanger. Fins are usually added here to further enhance the rate of heat transfer. Examples of enhancement techniques developed and being used recently are louvered fins and slit fins with their complex interrupted designs, vortex generators or a combination of both. As new and better designs are being continuously sought after, open-cell metal foam has been singled out as highly potential replacement for the conventional fins due to its unique structural and thermal properties. (Huisseune, De Schampheleire, Ameel, & De Paepe, 2015).

As complex and innumerable in designs it might seem when it comes to optimizing heat exchangers, it can greatly help in reducing the usage of space and also the cost of materials used in fabricating the heat exchangers. Along with that is the improvement in effectiveness of the heat exchangers. By increasing the effectiveness, less power is required to run the heat exchanger and less material is needed to fabricate it, both resulting in significant cost savings. (Catton, 2010).

Hence, it can be seen that the optimization of heat exchangers is essential in current times due to its wide range of application in various fields. One of the ways to achieve this is by reducing the size of the heat exchanger while being able to display a good performance. By doing so, it will result in reduced material usage and cost effectiveness as well as for suitability in small scale applications with minimal compromise in the heat exchanger performance. Thus, the development of a compact heat exchanger is in order, particularly, from open cell metal foam. Researches have suggested that the unique thermal and structural properties of the open-cell metal foam will result in an improved heat exchanger performance.

1.3 Research Objectives

1. To develop an in-house small scale wind tunnel as the test rig to investigate the performance of the compact finned heat exchanger based on open-cell copper foam.

2. To conduct experimental analysis of the performance of the compact heat exchanger based on finned open-cell copper foam with varying configuration.

1.4 Scope of Research

A compact heat exchanger utilizing open cell copper foam fins will be developed and the performance will be tested experimentally along with analysis and discussion of the results. For this experimental analysis, a small scale in–house wind tunnel will be developed to function as the test rig for the process of collecting the experimental results of the compact heat exchanger like the air and wall temperatures as well as the pressure drop across the heat exchanging device. In addition to that, the design of the compact heat exchanger will also be varied by altering the placement of the copper foam fins and aluminium fin. This is done to analyse the difference of the compact heat exchangers performance for varying configurations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review on open-cell metal foam and its applications, performance of open-cell metal foam based heat exchangers, influence on the open-cell metal foam heat exchangers performance due to the parameters and metal foam properties

2.2 Open cell Metal Foam

A part of cellular materials, open-cell metal foam are made of cell structures. This cell structures are made by the conjugation of the solid ligaments resulting in a three- dimensional array of irregular or regular shaped polyhedral cells. Whereas a considerable amount of the open-cell metal foams bulk volume is filled with moving fluid (void volume), typically air. (Beer, Rybár, & Kaľavský, 2019). The open-cell metal foam possesses the properties that are typical of a well- devised heat exchanger (Boomsma, Poulikakos, & Zwick, 2003). It has a relatively low weight and material usage due to its high volumetric porosity as more than 85% of the structure is usually filled with a flowing fluid like air. Besides that, it also has a high specific surface area and in return a high interaction area between the metal struts and the fluid flowing through it. The complex network of the solid ligaments also provides a tortuous flow path which promotes excellent fluid mixing of the coolant flowing through it. In addition, the usage of metal with high thermal conductivity like aluminium or copper to fabricate the open-cell foam structures also helps greatly in increasing the overall effective thermal conductivity (Huisseune, De Schampheleire, Ameel, & De Paepe, 2015). Hence, replacing the conventional fins in heat exchanger with open-cell metal foam can greatly alter its performance by means of improving the convective heat transfer of the dry air flowing over it. (Hu, Weng, Zhuang, Ding, Lai, & Xu, 2016).

The points made about the unique properties of the open-cell metal foam is further referenced by other researches too. Mahjoob and Vafai (2008) state that the conductive heat transfer of the metal struts along with the convective heat transfer from the fluid flowing through it due to the high surface-to-volume ratio helps in enhancing the heat transfer rate. Hamadouche, Nebbali, Benahmed, Kouidri, and Bousri (2016) echo this point by stating that the solid ligaments normal to the fluid flow direction causes disruption on the interacting surfaces and enhances flow mixing, whereas the conductive heat transfer is further improved by the solid ligaments. Xia, Chen, Sun, Li, and Liu (2017) also state that the tortuous flow path of the three-dimensional pore structure along with the increase in effective surface area are responsible for the enhancement of heat transfer in porous foam materials.

The nature of convective and conductive heat transfer in porous foam materials is complicated as a result of their unique structural properties. Hence, there are several parameters involved in the altering of their conductive and convective heat transfer properties. Some examples are porosity, the material used and sintering (Ma et al., 2016). Haack, Butcher, Kim, and Lu (2001) states that interactions between the coolant and metal foam along with the quality of metal-to-foam bond are found to be important in the heat transfer enhancement of metal foam materials.