THERMAL ANALYSIS OF THERMOSYPHON (HVAC) SYSTEMS USING DIFFERENT REFRIGERANTS

BY

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A thesis submitted in fulfillment of the requirement for the degree of Master of Science (Mechanical Engineering)

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APRIL 2019

ABSTRACT

Most of the comparison studies that carried out on thermosyphon are focused on different parameters and factors that affect the thermosyphon performance thus to identify the most efficient system. Therefore, less attention was given towards comparison of the different structures of thermosyphon. Hence, this research sought to compare and identify the best performing thermosyphon structure among Straight shape, C-shape and Close looped system in terms of thermal performance when subjected to different factors namely fill ratio and inclination angle by using R410A as working fluid. Another primary focus of this research was to address the ability of the best performing thermosyphon structure in real life situation and its ability to reheat the air and prevent excessive dehumidification by using different refrigerants namely R410A, R32 and R134a. The thermal performances of R410A filled thermosyphon subjected to low heat flux from 1200W/m^2 to 5000W/m^2 and evaporator wall temperatures between 20 °C and 50 °C with fill ratios 1.00 and 0.75 and at different inclinations of 45°, 68° and 90° were investigated by using Straight shape, C-shape and Close looped thermosyphon. The performance of the thermosyphon which is determined from its heat transfer capability was found to be dependent on inclination angle and fill ratio. Experimental result shows that heat transfer coefficient increases as the heat input increases, while thermal resistance decreases exponentially with increasing input power for all three structures. Change in fill ratio and inclination angle at various heat input contributed to a better thermosyphon performance. From the investigated experimental set up, heat transfer was highest for fill ratio 1.00 and inclination angle of 68° compared to inclination angles of 45° and 90° for all three investigated structures. Straight shape thermosyphon observed to have better overall heat transfer and smaller thermal resistance compare to C-shape and Close loop thermosyphon due to its geometry which has less resistance for refrigerant circulation in its shape. As straight shape being the best performing structure its ability to reheat the air and prevent excessive dehumidification was investigated by using different refrigerants and fill ratios. From the test, it was observed that fill ratio 1.00 exhibits the largest temperature difference between entering and leaving air compared to other fill ratios of 0.75, 0.50 and 0 for all the refrigerants at same input power. In overall, it was found that R32 refrigerant filled thermosyphon had best performance compared to R134a and R410A refrigerants as it has the smallest difference in temperature between evaporator and condenser section.

خلاصة البحث

تركز معظم دراسات المقارنة التي أجريت على التدوير الحراري (ثيرموسيفون) على معايير وعوامل مختلفة تؤثر على الأداء وبالتالي تحديد النظام الأكثر كفاءة. لذلك ، تم إيلاء اهتمام أقل لمقارنة الهياكل المختلفة للتدوير الحراري. ومن هنا ، سعى هذا البحث إلى مقارنة الشكل المستقيم والشكل C و الشكل المغلق من حيث الأداء الحراري عند التعرض لعوامل مختلفة وهي نسبة الملء وزاوية الميل باستخدام R410A كمائع عامل. تم التركيز بشكل رئيسي آخر في هذا البحث على معالجة قدرة أفضل هيكل تدوير حراري في وضع الحياة الواقعية وقدرته على إعادة تسخين الهواء ومنع إزالة الرطوبة الزائدة باستخدام مبردات مختلفة مثل R410Aو R32 و R134a. الأداء الحراري لـ R410A بالتعرض لتدفق حرارة منخفض من $1200\ W/m^2$ إلى W/m^2 5000 ودرجات حرارة جدار المبخر بين 20 درجة مئوية و 50 درجة مئوية مع نسب تعبئة 1.00 و 0.75 وبدرجات ميل مختلفة من 45 درجة و 68 درجة و 90 درجة باستخدام الشكل المستقيم والشكل C و الشكل المغلق . أداء المدور الحراري الذي يتم تحديده من خلال القدرة على نقل الحرارة يعتمد على زاوية الميل ونسبة التعبئة. تظهر النتيجة التجريبية أن معامل نقل الحرارة يزداد مع زيادة مدخلات الحرارة ، بينما تقل المقاومة الحرارية بشكل كبير مع زيادة مدخلات الحرارة في الهياكل الثلاثة. ساهم التغير في نسبة الملء وزاوية الميل عند إدخال الحرارة المختلفة في تحسين أداء المدور الحراري. من الإعداد التجريبي الذي تم التحقيق فيه ،كان نقل الحرارة أعلى بالنسبة لنسبة الملء 1.00 وزاوية الميل بزاوية 68 درجة مقارنة بزوايا الميل بزاوية 45 درجة و 90 درجة لجميع الهياكل الثلاثة المستقصاة. لوحظ أن الشكل المستقيم يتمتع بنقل حرارة أفضل بشكل عام ومقاومة حرارية أصغر مقارنةً بالشكل C والحلقة المغلقة نظرًا لتمتعة بمقاومة أقل لدوران التبريد في شكله. نظرًا لأن الشكل المستقيم هو أفضل بنية أداء ، فقد تم التحقيق في قدرته على إعادة تسخين الهواء ومنع إزالة الرطوبة الزائدة باستخدام مبردات ونسب تعبئة مختلفة. من الاختبار ، لوحظ أن نسبة الملء 1.00 تظهر أكبر فارق في درجة الحرارة بين دخول الهواء وخروجة مقارنةً بنسب الملء الأخرى البالغة 0.75 و 0.50 و 0 بالنسبة لجميع وحدات التبريد في نفس طاقة الإدخال الحراري. إجمالاً ، وجد أن أداء ثيرموسيفون مبرد بالبرودة R32 كان أفضل أداء مقارنة بتبريد المبردات R134a و R410A حيث أنه كان الفرق أصغر في درجة الحرارة بين قسم المبخر والمكثف.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Mechanical Engineering).

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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ACKNOWLEDGEMENTS

Firstly, it is my utmost pleasure to dedicate this work to my dear parents and my family, who granted me the gift of their unwavering belief in my ability to accomplish this goal: thank you for your support and patience.

I wish to express my appreciation and thanks to those who provided their time, effort and support for this project. To the members of my dissertation committee, thank you for sticking with me.

A special thanks to Professor AKM Mohiuddin for his continuous support, encouragement and leadership, and for that, I will be forever grateful.

Finally, I would like to thank Daikin Malaysia Sdn Bhd and Daikin Research & Development Malaysia Sdn Bhd for support to carry out this research.

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LIST OF SYMBOLS

AR	Aspect Ratio (%)
A_e	Area of Evaporator (m^2)
A_c	Area of Condenser (m^2)
D_i	Inner Diameter (m)
D_o	Outer Diameter (m)
FR	Filling Ratio (%)
h_e	heat transfer coefficient for evaporator ($W/m^2.K$)
h_c	heat transfer coefficient for condenser ($W/m^2.K$)
K	Thermal conductivity (W/mK)
K_s	Thermal conductivity of stainless steel (W/mK)
K_{wall}	Thermal conductivity of wall (W/mK)
Ku	Kutateladze number
L_e	Evaporator length (m)
P	Power (W)
P_{sat}	Saturated Pressure (pa)
Pr_{hw}	Prandtl number of heated water
Q	Maximum heat transferred (W)
Q_{90}	Heat transfer by thermosyphon at 90° (W)
Q_{Avg}	Average heat transfer (W)
q	Heat flux (W/m^2)
$R_{e,wall}$	Thermal Resistance of Outer Wall (°C/W)

R_e Evaporator Thermal Resistance (°C/W)

R_c Condenser Thermal Resistance (°C/W)

R_{ovr} Overall Thermal Resistance (°C/W)

R_{HP} Thermal Resistance of heat pipe (°C/W)

Re_{hw} Reynolds number of heated water

$T_{e,wall}$ Evaporator Wall Temperature (°C)

T_e Evaporator Temperature (°C)

$T_{e,wo}$ Outer wall evaporator Temperature (°C)

T_w Wall Temperature (°C)

T_{ec} Evaporator and condenser Temperature (°C)

T_c Condenser Temperature (°C)

T_v Vapor Temperature (°C)

LIST OF ABBREVIATIONS

CFC	Chlorofluorocarbon
CFD	Computational Fluid Dynamics
CTPCT	Conventional two-phase closed thermosyphon
COP	Coefficient of Performance
FTPCT	Flat two-phase closed thermosyphon
GWP	Global Warming Potential
HCFC	Hydro Fluorocarbon
HVAC	Heat Ventilation Air Conditioning
ISMT	Integrated System of Mechanical Thermosyphon
PCM	Phase Change Material
PHP	Pulsating Heat Pipe
TPCT	Two Phase Closed Thermosyphon
UDF	User Default Function
VOF	Volume of Fluid

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

A thermosyphon is a highly effective heat transfer system. Generally it consists of an evacuated tube that filled with a working fluid at a rated filled ratio to transport heat throughout the system. It divided into three parts an evaporator section, adiabatic section (transport) and condenser section (Faghri, 2014). A thermosyphon may have multiple heat sources or sink with or without adiabatic sections depending on specific applications and design (Faghri, 2014). It works by absorbing latent heat of vaporization from a heat source. As the amount of the heat absorbs increases, the heat vapor produced is transported through the adiabatic section. Due to low density the heat vapor flows upward to the condenser end of the thermosyphon, where it condenses back into liquid state again by releasing the absorbed latent heat to a heat sink. As it condenses and the working fluid takes liquid state, due to increasing in density the liquid then driven back to the evaporator end with aid of gravity. This cycle repeats continuously which results in heat transfer to take place between the evaporator and the condenser end of the thermosyphon. Faghri (2014) described that heat pipes are highly effective passive devices for transmitting heat at high rates over considerable distances with extremely small temperature drops, exceptional flexibility, simple construction, and easy control with no external pumping. In another words heat is transferred as latent heat of evaporation which means the working fluid inside the system is transported continuously by changing phase from liquid to gas. The basic working principle of a thermosyphon illustrated in Figure 1.1.

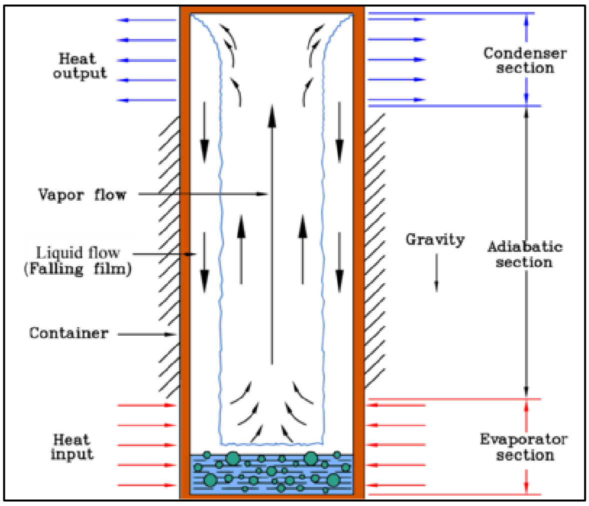

Figure 1.1 Basic Working Principle of a Thermosyphon

Refrigerant are substances which are used for refrigeration. It could be classified into four main categories which are CFC (chlorofluorocarbons), HCFCs (hydro chlorofluorocarbons), HFCs (hydro fluorocarbons) and refrigerant blends (Azeotropic, Zeotropic). Due to the contain of chlorine in CFC and HCFCs it's being slowly phase out by HVAC (Heat Ventilation Air Conditioner) industries as it's contributes to depletion of the ozone layer. Among the currently widely used refrigerants are R22, R-134a, and R407C. In the field of HVAC, newer refrigerants such as R32, R410A and R1234yf are widely publicized as a replacement for R22 and R-134a as this gas contributes less to ozone depletion and lower Global Warming Potential (GWP). Ngoc et al. (2014) study proven that R1234yf is the potential candidate to replace R134a in a refrigerant cycle. Lower GWP will reduce the greenhouse effect hence reducing the global warming effect. Many manufacturers are beginning to look into and develop HVAC equipment using these refrigerants. Although refrigerants like R1234yf has smaller ozone depletion and global warming potential value compare to R32 and R410A, it is not widely used in HVAC industry due to its unstable refrigerant properties. This could be seen from study of Samaneh

Daviran et al. (2017) mentioned that general working pressure of R123yf is lower than that of R134a which results increase in overall COP. But when operating in identical cooling capacity the COP of R1234yf is 1.3-5% lower than that of R134a, thus indicating further research need to be conducted on R1234yf before it is commercial used as replacement refrigerant.

1.2 STATEMENT OF THE PROBLEM

In today's modern world, the earth temperature is rising across the country and air conditioners are working overtime. Due to this they are indirectly injecting additional carbon dioxide into the air, which contributes to global warming. Because of this, new HVAC technologies are being introduced time to time; researchers are seeking more efficient ways to improve the HVAC system to reduce its effects towards global warming and ozone depletion. Researchers have turn their attention to thermosyphon designs to seek such efficient system as they are one of the simplest and effective forms of heat transfer device known to men. Many studies have made on the effects of parameters changes of thermosyphon thus to understand and to identify the most efficient systems. Moreover these parameter changes done by using different types of working fluids and conditions to further understand their effects when it varies. Until today many researches are still focused on the parameters limitations and very few focused on comparing the different structures of the thermosyphons. The aim of this research is to compare and identify the most efficient structure of thermosyphon that are commonly studied and used in HVAC industry. There are three types of commonly studied thermosyphon structure in, which are Straight shape, C-shape and close looped system. These three structures are most commonly used in commercial air conditioning industries that involve refrigeration and fresh air applications.

1.3 RESEARCH OBJECTIVES

The study aimed to achieve the following objectives:

1- To compare heat transfer of Straight shape, C-shape and Close looped thermosyphons at fill ratios of 1.00 and 0.75 and inclination angles of 45°, 68° and 90° by using R410A refrigerant as working fluid.

2- To evaluate the most efficient heat transfer system among different type structures of thermosyphons namely Straight shape, C-shape and Close looped thermosyphon.

3- To validate and compare performance of different refrigerant in real life application unit, namely R134a, R410A and R32 at different fill ratio of 1.00, 0.75 and 0.5.

4- To compare which refrigerant could perform better by reheating the air and prevent excessive dehumidification.

1.4 RESEARCH QUESTIONS

1. What are the currently widely used thermosyphon shapes in the HVAC industry?
2. What is the difference in performance between C-shape, Straight and Loop thermosyphon?
3. Is straight shape thermosyphon better than C-shape and Close Loop thermosyphon?

4. Is usage of thermosyphon one of the most economical ways to control moisture in the air?
5. Is there much application that requires humidity control as their primary requirement?

1.5 RESEARCH HYPOTHESES

Based on the six hypotheses postulating the relationships among fill ratios and inclination angles, which intention to different structures of thermosyphon by investigating it thermal performance are tested in the study. Moreover the ability to prevent excessive dehumidification is also investigated. The hypotheses are as follows:

H1 Higher heat input has positive effect on thermal performance of thermosyphon.

H2 There is optimum operating limit for each system which leads it to perform to its maximum and slowly drops when exceeded.

H3 Higher fill ratio contributes to better thermal performance of thermosyphon.

H4 Different Inclination angle has positive effect on thermal performance of thermosyphon and it slowly drop as it approaches horizontal position.

H5 Thermosyphon structure with less resistance in its geometry will perform the best in terms of overall thermal performance.

H6 Thermosyphon has positive effect on reheating air thus prevent excessive dehumidification.

1.6 SIGNIFICANCE OF THE STUDY

This study will contribute to decision makers to make any intervention based on the findings derived from this investigation to disseminate usage of thermosyphon among dehumidifying applications thus to control the required comfort level.

It stresses out the importance of understanding two of the major factors that affect thermosphon and how each structure performance differs when subjected to these two major factors of fill ratio and inclination angle in terms of thermal performance. By understanding this factors it will be a general guide line in designing a thermosyphon based on required heat load and prevent energy lose. Furthermore, this study is beneficial to specialists that work in applications that require controlling environment at certain temperature and humidity more effectively.

1.7 LIMITATIONS OF THE STUDY

The study sample was limited to two different fill ratios (0.75 and 1.00) and three different inclination angles (45°, 68° and 90°) along with only one refrigerant (R410A) for the experiment part and three different fill ratios (0.50, 0.75 and 1.00) and refrigerants (R32, R410A and R134a) for the application unit. The scope of the study was confined to the three different structures that investigated by using R410A as working fluid.

1.8 CHAPTER SUMMARY

This chapter has presented and discussed the background of the study. It explained why thermosyphon are vital to the HVAC industry and how important its contribution towards global warming and ozone depletion. Additionally, the statement of the problem was discussed, as this study set to compare different structures of