DEVELOPMENT AND PERFORMANCE ANALYSIS OF FLAT PLATE BASE-THERMAL CELL ABSORBER

BY

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ABSTRACT

This study aims to design, fabricate, and study the performance of a thermal cell absorber attached to a flat plate absorber collector. Flat Plate Solar Collector (FPSC) is widely used in agricultural products for drying applications. An investigation into the effect of design parameters on FPSC has been carried out. Flat Plate Base-Thermal Cell Absorber (FPBTCA) has been designed and fabricated based on the design parameters experiment results which are; absorber base materials (AL), absorber base thickness (0.5 mm), the air gap distance between glass and absorber base (10 mm), the air gap distance between glass 1 and glass 2 (0.4 mm), double glass, glass thickness (2.0 mm), thermal cell thickness (1.0 mm) and material (SS). The experiment was performed using a solar simulator with solar radiation of 700 W/m^2. The solar simulator is used as the artificial sun, which is exposed to solar radiation for 300 seconds and without solar radiation also for 300 seconds. The heat transfer rate of the collector ($\dot{Q}$) and efficiency of the collector shows that stainless steel 1.0 mm with aluminum base absorber has a higher value which is 412 kJ, 18.21 kW, and 47.08 %, respectively. The performance of the outlet temperature in the drying chamber of stainless steel with an aluminum absorber has a higher value of energy gain which is 116.08 J at 300 seconds. Evaluation under outdoor conditions revealed that the FPBTCA has a lower temperature discharge rate as compared to the FPSC. FPBTCA also shows the highest heat absorption ($\dot{Q}$), which is 96079.37 J on 4 March 2021, then FPSC, which is 49187.07 J. The highest efficiency for FPBTCA at 360 minutes is 30.24 %, and for FPSC is 21.81 %. The efficiency of FPBTCA is consistent while the solar radiation is decreased at 120 minutes and 180 minutes. Mathematical modelling analysis proved that the error for energy balance is below 5%. FPBTCA has been introduced to enhance the thermal performance and efficiency of solar thermal collector systems. It also has higher heat storage capabilities during solar radiation drops when the weather is cloudy.

خلاصة البحث

هدفت الدراسة الحالية إلى تصميم وتصنيع ودراسة أداء مُمّتص للخلايا الحرارية والمرتبطة بمجمّع امتصاص لوح شمسي مسطح (FPSC)، حيث أنه يُستخدم على نطاق واسع في المنتجات الزراعية لعمليات التجفيف. وقد أُجري تحقيق لمعرفة تأثير معلمات التصميم المستخدم في البحث الحالي على FPSC والتي كانت؛ المواد الأساسية للامتصاص (AL)، سماكة قاعدة الامتصاص (0.5 مم)، مسافة فجوة الهواء بين الزجاج وقاعدة الامتصاص (10 مم)، مسافة فجوة الهواء بين الزجاج 1 والزجاج 2 (0.4 مم)، الزجاج المزدوج، سماكة الزجاج (2.0 مم)، سماكة الخلية الحرارية (1.0 مم) والمادة (SS)، وتم تصميم وتصنيع ممتص الخلايا الحرارية ذو القاعدة المسطحة (FPBTCA) بناءً على نتائج تجربة معايير التصميم. تم إجراء التجربة باستخدام جهاز محاكاة شمسي بإشعاع 700 واط/م^2، ويتم استخدام جهاز المحاكاة هذا كشمس اصطناعية، حيث تتعرض للإشعاع لمدة 300 ثانية وبدونه أيضاً لنفس المدة. يوضح معدل نقل الحرارة للمُجمّع ($\dot{Q}$) وتبلغ 412 كيلو جول) وكفاءة المجمّع (18.21 كيلو واط) أن الفولاذ المقاوم للصدأ 1.0 مم مع قاعدة الألومنيوم الممتص له قيمة أعلى بنسبة 47.08٪. درجة حرارة المخرج في حجرة التجفيف المصنوعة من الفولاذ المقاوم للصدأ مع ممتص الألمنيوم كانت له قيمة أعلى في اكتساب الطاقة وهي 116.08 جول عند 300 ثانية. أظهر التقييم في الظروف الخارجية أن FPBTCA لديه معدل تدفق أقل للحرارة مقارنة بـ FPSC. أظهر FPBTCA أعلى امتصاص للحرارة ($\dot{Q}$)، وهو 96079.37 جول، ثم FPSC وهو 49187.07 جول. أعلى كفاءة لـ FPBTCA عند 360 دقيقة هي 30.24٪ و FPSC هي 21.81٪. كفاءة FPBTCA ثابتة حينما ينخفض الإشعاع الشمسي عند 120 و 180 دقيقة. أثبت تحليل النمذجة الرياضية أن الخطأ في توازن الطاقة أقل من 5٪. تم إدخال FPBTCA لتحسين الأداء الحراري وكفاءة أنظمة تجميع الطاقة الشمسية الحرارية. كما أن لديها قدرات تخزين أعلى للحرارة أثناء انخفاض الإشعاع الشمسي عندما يكون الطقس غائماً.

APPROVAL PAGE

The thesis of Muhammad Amin Harun has been approved by the following:

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DECLARATION

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

Muhammad Amin Harun

Signature .... Date 09 AUGUST 2023 ....

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

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Affirmed by Muhammad Amin Harun

	09 AUGUST 2023
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Signature	Date

DEDICATION

This thesis is dedicated to my late father and my mother for laying the foundation of what I turned out to be in life.

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LIST OF SYMBOLS

A	Cross sectional area (m^2)
A_c	Surface area of collector (m^2)
A_s	Surface area (m^2)
C_p	Specific heat capacity (kJ/kg.K)
$\dot{E}_{in}$	Rate of energy, inlet (W)
$\dot{E}_{out}$	Rate of energy, outlet (W)
$\dot{E}_{system}$	Change of rate of energy in the system (W)
S_R	Global solar radiation, total (kW/m², W/m²)
h	Convective heat transfer coefficient ($W/m^2.K$)
H	Height (m, mm)
k	Thermal conductivity (W/m.K)
L	Length (m, mm)
S_R	Solar radiation (kW/m², W/m²)
T	Temperature (K)
T_f	Temperature of fluid (K)
$T_{f,i}$	Temperature of fluid, inlet (K)
$T_{f,o}$	Temperature of fluid, outlet (K)
T_{f1}	Temperature of fluid at point 1 (K)
T_{f2}	Temperature of fluid at point 2 (K)
T_i	Temperature, inlet (K)
T_o	Temperature, outlet (K)
t	Thickness (mm)
t	Time (s)
$\dot{Q}_u$	Rate of useful energy gain (W)
V	Air velocity (m/s)
W	Width (mm)
$\dot{m}$	Air mass flow rate (kg/s)
α	Thermal diffusivity (m^2/s)
ε	Emissivity
η	Thermal efficiency

ρ	Air density (kg/m^3)
η	Thermal efficiency
$\tau\alpha$	Transmittance-absorptance product

LIST OF ABBREVIATIONS

BOM	Bills of Materials
CFD	Computational Fluid Dynamic
DAQ	Data acquisition
e.g.	*(exempli gratia)*: for example
FPBTCA	Flat Plate Base-Thermal Cell Absorber
et al.	*(et alia)*: and others
etc	*(et cetera)*: and so forth
fig./ figs.	*figure/ figures*
FPSC	Flat Plate Solar Collector
GMP	Good Manufacturing Practice
i.e.	*(id est)*: that is
ID	Inner diameter
OD	Outer diameter
PV	Photo-voltaic
PVC	Polyvinyl Chloride
SAHP	Solar Assisted Heat Pump
Vol./ Vols.	Volume/ Volumes

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

The solar radiation that reaches the Earth's surface without being diffused is labeled as direct beam solar radiation. The sum of the diffused and direct solar radiation is labeled as global solar radiation. The effective blackbody temperature of the sun is about 5777 K. The central interior region's temperature is varyingly approximated at 8 x 10^6 to 40 x $10^{6,}$ and the density is approximated about 100 times water (Beckman, 2013). Solar energy is known as a renewable energy source (Bahadori & Nwaoha, 2013), and the usage of the energy could be minimized with environmental impacts (Panwar et al., 2011). Solar energy has been used in solar thermal technology such as solar air heating systems, solar water heating systems, photovaltic systems, and thermal systems.

Solar thermal technology can be considered as a reliable technology in the applications related to industry and household due to its abundant sources of energy. Based on history, in 1767, the Swiss scientist Horace Benedict de Saussure was the first man who invented and produced flat plate solar thermal collectors (Huff et al., 1950). The component inside a flat plate solar thermal collector consists of three layers of glass which are used to absorb heat energy from the sun's radiation. Flat plate solar thermal collectors are used because it has advantages such as incurring low cost in manufacturing, economical maintenance (Colangelo et al., 2016), and environmentally friendly.

The principle involved in flat plate solar collectors (FPSC) is to gain as much possible radiation energy from the sun by heat absorption. The absorber for a flat plate solar collector is coated with a flat black coating to increase the rate of energy gained from sunshine. The energy which has been collected is transferred through conduit tubes by working fluids (usually water) which are integrated with a heat absorber plate. On that occasion, the warm water transmits the heat energy through the hot water system at the same time, stores it in the storage system, which is a backup when the sun's radiation is low (John A. Duffie and William A. Beckman, 2006). The performance of solar collectors is analyzed using Thermodynamics analysis.

There is an important issue related to the solar energy system, which is the cost of the system (S. A. Kalogirou, 2008). Basically, it is very expensive to develop solar technology systems. Based on that argument, economic analysis is a very important aspect that should be considered when developing the solar collector. The researcher has been studying the impact of solar water hot systems on the economical and environmental prospects(Ardente et al., 2005; S. A. Kalogirou, 2004; S. A. Kalogirou, 2008; Tsilingiridis, G. et al., 2004).

Malaysia consists of Peninsular Malaysia, Sabah, and Sarawak. The West and east of Malaysia are separated by the South China Sea (Muhammad-Sukki et al., 2011). Malaysia is also a tropical country located at the equator and strategically located. Based on the statistics, Malaysia has received approximately 400–600 MJ/m^2 of monthly solar radiation (Mekhilef et al., 2012). The average daily solar insulation is about 5.5 kWm^2, equivalent to 15 MJ/m (Shafie et al., 2011). Malaysia's climate is suitable for its solar energy usage as a renewable source with 10 hours of predictable daily sunlight (Gomesh et al., 2013).

The purpose of this study is to design a flat plate solar thermal Aluminum absorber (base) collector with an absorber thermal cell. The different absorber thermal cell material is investigated to find the best absorber thermal cell that can be used when designing a new design of Flat Plate Solar Collector (Aluminum and Stainless Steel). The design parameters involved in this experiment are absorber base-collector thickness, absorber collector materials, air gap distance, double glass and glass thickness, thermal cell thickness, and material. The experiment was done indoor and outdoor to determine the experimental data for Flat Plate Solar Collector (FPSC) and Flat Plate Base-Thermal Cell Absorber (FPBTCA). The development of mathematical modelling for the flat plate solar thermal Aluminum absorber (base) collector with absorber thermal cell system will be modelled. Mathematical modelling is performed to compare with the experiment to find the correlation data. The absorber will then be integrated into an open cycle drying chamber with energy storage ability to optimize system performance for the indoor and outdoor experiment. The venue for the indoor experiment was at IIUM campus Kuantan, while for outdoor was at Beserah, Kuantan, and the experiment was conducted to gather the data and to compare it with mathematical modelling.

1.2 RESEARCH PROBLEM

i. Drying chamber system:

The design of flat plate solar collector with different locations of drying chamber has a weakness in the flat plate solar collector's performance. The heat energy is reduced when the heat is transferred from the flat plate absorber collector to the drying chamber (Choudhary et al., 2020; D. Gao et al., 2020; Nabnean et al., 2016). Basically, the current design of a flat plate solar collector is designed with extra insulation, piping, and fitting (Mohamad, 1997). Based on the situation, the performance of a flat plate solar collector is affected when air flow moves from the flat plate solar collector absorber to the drying chamber.

ii. Flat plate solar collector design parameters and materials:

The performance of a flat plate solar collector depends on parameters such as design and components. The parameters were absorber collector thickness, absorber collector materials, air gap distance, double glass, and glass thickness (M. Faizal Fauzan, 2015). Absorber material and design is the most important factor for flat plate solar collector. Therefore, the shape of the absorber collector could affect the efficiency performance of flat plate solar (Essalhi et al., 2018). Basically, the design of the absorber collector could improve heat transfer (Sharol, 2021). Obstacles' presence is an important factor for the improvement of flat plate solar collector performance. Different shapes of obstacles and positions produce different results (A A Razak, 2017; Abene et al., 2004). One of the aspects of enhancing the heat transfer capability in the collector is to increase