STUDY OF COMPUTATIONAL FLUID DYNAMICS ON PHOTOVOLTAIC THERMAL SOLAR WATER COLLECTOR

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A report submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering with Honours

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I declare that this project report entitled "Study of Computational Fluid Dynamics on Photovoltaic Thermal Solar Water Collector" is the result of my own work except as cited in the references.

Signature : …………………………………….

Name : …………………………………….

Date : ……………………………………..

SUPERVISOR'S DECLARATION

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Honours.

Signature	:...
Supervisor's Name	:...
Date	:...

DEDICATION

To my beloved mother and father

ABSTRACT

The purpose of this research is to investigate the performance of photovoltaic thermal collector with different design of absorber tube in steady state condition. ANSYS Fluent software was used to carry out computational fluid dynamics (CFD) simulation. In this study, water was selected as the heat transfer fluid. The geometric model was drawn in CATIA V5R20 and imported into ANSYS software to generate mesh model. In setup of simulation, the viscous model, radiation model and material properties were constructed. Flow of heat transfer fluid was laminar flow. In radiation model, surface to surface (S2S) model was used. The photovoltaic panel used in this research was silicon based photovoltaic cell. Validation was carried out by referring to the previous work. In the comparison between author simulation results and previous simulation results, the root mean square error was 2.52 °C. On the other hand, the root mean square error was 1.29°C in comparison between current simulation results and previous experimental results. The root mean square error between previous research simulation and previous experimental results is 2.08°C. The influences of mass flow rate and solar irradiance intensity on performance PVT was determined. Spiral absorber PVT has the highest total efficiency at most of the mass flow rate among the three design of absorber and followed by vertical serpentine absorber and then horizontal serpentine absorber.

ABSTRAK

Tujuan penyelidikan ini adalah untuk mengkaji prestasi pengumpul haba photovoltaic dengan reka bentuk tiub penyerap yang berbeza dalam keadaan mantap. Perisian ANSYS Fluent telah digunakan untuk menjalankan simulasi cecair dinamik (CFD). Dalam kajian ini, air dipilih sebagai cecair pemindahan haba. Model geometri telah dilukis dalam CATIA V5R20 dan diimport ke perisian ANSYS untuk menghasilkan model mesh. Dalam "setup", model aliran, model radiasi dan sifat bahan telah dibina. Aliran cecair pemindahan haba adalah aliran laminar. Dalam model radiasi, model permukaan ke permukaan (S2S) telah digunakan. Panel photovoltaic yang digunakan dalam penyelidikan ini adalah sel photovoltaic silikon. Pengesahan telah dilakukan dengan merujuk kepada penyelidikan sebelumnya. Dalam perbandingan antara keputusan simulasi semasa dan keputusan simulasi sebelumnya, perbezaan peratusan tertinggi ialah 9.33%. Sebaliknya, ralat peratusan tertinggi ialah 6.89% berbanding keputusan simulasi semasa dan keputusan eksperimen terdahulu. Pengaruh kadar aliran jisim dan keamatan sinar matahari terhadap prestasi PVT ditentukan. PVT penyerap lingkaran mempunyai kecekapan keseluruhan yang tertinggi dalam kebanyakan kadar aliran jisim di antara tiga reka bentuk penyerap, dan diikuti oleh penyerap serpent menegak dan penyerap serpent mendatar.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to my supervisor Dr. Mohd Afzanizam Bin Mohd Rosli from Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka for his guidance, advice, as well as support provided to me throughout this research.

Beside my supervisor, I would also love to express my gratitude to Dr Tee Boon Tuan and Dr Fudhail Bin Abdul Munir that have provided me with solutions and advices at difficult times faced throughout this research.

I would also like to thank my fellows who willing spend their precious time to teach me step by step of the procedure of simulation software patiently and share the knowledge with me.

Last but not least, I would like to thank my family members that have been always supporting me spiritually throughout my life.

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CAD	Computer-Aided Design
CdTe	Cadmium Telluride
CFD	Computational Fluid Dynamic
CIGS	Copper Indium Gallium Selenide
CPVT	Concentrated Photovoltaic Thermal
c-Si	Monocrystalline Silicon
HTF	Heat Transfer Fluid
pc-Si	Polycrystalline Silicon
PV	Photovoltaic
PVT	Photovoltaic Thermal
PVT/a	Photovoltaic Thermal Air
PVT/w	Photovoltaic Thermal water

LIST OF SYMBOLS

α	-	Absorptance
β_{ref}	-	Temperature coefficient
η_{Total}	-	Total efficiency
η_{pv}	-	Electrical efficiency / photovoltaic cell efficiency
η_{ref}	-	Reference efficiency
η_{th}	-	Thermal efficiency
τ	-	Transmittance
A	-	Area
F_R	-	Heat removal factor
h	-	Heat transfer coefficient
I	-	Intensity of irradiance
$\dot{m}$	-	Mass flow rate
Q_i	-	Heat gain
Q_o	-	Heat loss
Q_u	-	Useful energy
q	-	Heat flux
T_a	-	Ambient temperature
T_c	-	Photovoltaic Cell temperature
T_{col}	-	Collector temperature
T_i	-	Inlet temperature
T_o	-	Outlet temperature
T_{ref}	-	Reference temperature
U_L	-	Overall heat transfer coefficient
v	-	Velocity
V	-	Volume

LIST OF PUBLICATIONS

Joon Ping, Y., Afzanizam, M., Rosli, M., & Saruni, M. A. (2018). Preliminary study of computational fluid dynamics on photovoltaic thermal solar air collector. *Proceedings of Mechanical Engineering Research Day*, (May), 175–177.

Joon Ping, Y., Afzanizam, M., Rosli, M., & Saruni, M. A. (n.d.). Simulation Study of Computational Fluid Dynamics on Photovoltaic Thermal Water Collector with Different Designs of Absorber Tube. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*. Submitted on 31st May 2018.

CHAPTER 1

INTRODUCTION

1.1 Background

The research on renewable energy has been going on for decades and solar energy is one of the most researched field since it is clean and easily obtainable and almost inexhaustible for another 5 billion years. Solar energy should be used to substitute the energy obtained from burning fossil fuels to reduce the environmental pollution and global warming.

Currently, the harvesting of solar energy is divided into two main categories, which is by using the photovoltaics (PV) system or the solar thermal system. The difference between those two is that PV system uses solar energy to generate electrical energy while solar thermal system is for generating thermal energy. With the combination of both systems, photovoltaic thermal (PVT) system is introduced. This system able to generate electric energy while converting the heat lost to the surrounding into thermal energy, this may cool down the PV system to provide a better efficiency. The PVT system can also improve the appearance of roofs and requires a lower cost compared to installing PV system and solar thermal collector separately (Khelifa et al., 2016). The PVT system can be further classified into two category which is glazed PVT collector and unglazed PVT collector. Generally, the glazed PVT collector will produce more heat energy but is lower in electrical efficiency. On the other hand, unglazed PVT collector will yield less thermal energy but generate more electric energy (Kim & Kim, 2012).

The study of fluid dynamics is also critical during this research as it allows better understanding and design of the system. With the help of Computational Fluid Dynamics (CFD), numerical analysis and data structure was used to simulate the design and perform lengthy calculations. Since all experiments were done inside a virtual flow laboratory, by simply changing the variables, the characteristic changes of the fluid can be visualized. Therefore, optimization can be made to improve the designed model. Simulation using CFD can obtain results without carry out costly and time-consuming real experiment.

1.2 Problem Statement

Global warming is one of the most serious issues that the world facing today. The main cause of global warming is the emission of greenhouse gases from burning fossil fuel to provide electric energy. Moreover, these non-renewable resources are finite, and it will eventually run out. Renewable energy, for instance, solar energy, wind energy and hydropower are better choices to replace the non-renewable energy.

Photovoltaic thermal hybrid solar collector is a system which can convert solar radiation into heat and electric energy simultaneously by using solar collector and photovoltaic panel. However, at high temperature, the performance of photovoltaic panels will be reduced but while at low temperature, the solar collector will underperform. The purpose of this project is to achieve optimum performance on photovoltaic panel and thermal collector. With the aid of CFD, the results can be predicted without using the actual PVT. If the results are not desired, no resources will be wasted, and improvement can be made based on the results. According to Kim & Kim (2012), the average thermal and electrical efficiency of glazed PVT collector is 48.4% and unglazed PVT collector has 35.8%. The efficiency of both unglazed PVT and glazed PVT are less than 50%. This means that there are more than 50% of energy is lost.

1.3 Objectives

The objectives of this project are:

1. To design new absorber tube of flat plate photovoltaic thermal hybrid solar collector.
2. To determine the overall performance of PVT.
3. To determine the relationship of heat transfer fluid mass flow rate and solar irradiance intensity against performance of PVT.

1.4 Scopes

The scopes of this project are:

1. Simulation will be conducted on glazed photovoltaic thermal collector.
2. The serpentine and spiral design of absorber tube will be used in photovoltaic thermal collector.
3. Absorber tube with one inlet and one outlet will be used in simulation.
4. Length of absorber tube will be fixed at 4.8m.
5. Simulation will be performed under steady state.
6. Bottom of absorber tube is assumed as adiabatic, hence insulation is not included in simulation.

CHAPTER 2

LITERATURE REVIEW

2.1 Photovoltaic Cell

Photovoltaic cell, also known as solar cell convert the light received to electrical energy, this process is known as photovoltaic effect. The photovoltaic cell is treated semiconductor in positive side (P-type) and negative side (N-type). When photon or light strike on photovoltaic cell, electron from N-type will be dislodged. As the dislodged electron move to P-type, flow of electric current is formed.

Figure 2.1 Types of Silicon Photovoltaic Panels

Mostly of the photovoltaic cells are made up of crystalline silicon which are monocrystalline silicon (c-Si) and polycrystalline silicon (pc-Si). Figure 2.1 shows c-Si, pc-Si and amorphous photovoltaic panels. Monocrystalline photovoltaic cells are the most efficient among all type of the commercial photovoltaic cells. Monocrystalline is in shape of hexagon which is black in colour, therefore it can fit well in photovoltaic panel and increase the light absorption. Because of its high efficiency, the space required to yield a certain amount of power output is relatively lesser. It also has the greater durability and perform better in low light but it is more expensive than other photovoltaic cells. Efficiency range of monocrystalline photovoltaic cell is between 15% and 29%. Polycrystalline photovoltaic cell is blue colour because of the anti-reflective layer which used to ensure the maximum adsorption of light. It has the efficiency of 13-15%. Amorphous silicon photovoltaic cell is a non-crystalline silicon and is a type of the thin film PV. Its efficiency is far lesser than crystalline silicon photovoltaic cell, only from 5 to 8%. Besides amorphous photovoltaic cell, the other types of thin film photovoltaic cell are cadmium telluride (CdTe) and copper indium gallium selenide (CIGS). As ease of manufacturing and abundant of cadmium telluride photovoltaic cell, now it is the second most utilized material in manufacturing of photovoltaic panel, followed by silicon. However, their efficiency is relatively lower than crystalline silicon photovoltaic cell. Table 2.1 indicates the efficiency of different types of photovoltaic cell in normal and laboratory condition.

Table 2.1 Efficiency of Different Type of Photovoltaic Cell (Stylianou, 2016)

Technology	Mono c-Si	Poly c-Si	GaAs	a-Si thin film	CIS/CIGS thin film	CdTe thin film	Organic	Dye-sensitized	Multi-junction
Generation	1st	1st	1st	2nd	2nd	2nd	3rd	3rd	3rd
Commercial cell efficiency (%)	15-29	13-15	N/A	5-8	7-11	8-11	3-4	1-5	25-30
Best laboratory cell efficiency (%)	25	20.4	26.4	13.4	20.4	19.6	11.1	11.4	37.9

The electrical efficiency of photovoltaic cells is strongly affected by operating temperature and irradiance or light intensity. According to Skoplaki & Palyvos (2009) and Daghigh, Ibrahim, Jin, Ruslan, & Sopian (2011), the electrical efficiency decreases linearly with operating temperature and irradiance. Experimental study has been conducted to determine the effect of light intensity on performance of photovoltaic cell (Khan, Singh, &

Husain, 2010). The study shows that the performance of photovoltaic cell is decreases with illumination intensity. However, the rate of decrease is lower at higher illumination intensity.

2.2 Solar Thermal Collector

The solar thermal collector is a device that utilizes solar radiation to heat air or water for space heating and domestic water heating purposes. There are many different types of solar thermal collector. The flat-plate collector is the most common solar thermal collector.

The main components of flat plate collector comprised of glazing cover, absorber plate, tubes, and insulation. The glazing cover is transparent and is normally made up of glass or plastic. The glazing cover helps to minimize the convection and radiation heat loss and protect the thermal collector from harsh weather. The surface of absorber plate is treated with black colour coating for maximizing the heat absorption. Absorber tubes act as channel for heat transfer fluid (HTF) to pass through the solar thermal collector. Absorber tube and absorber plate are welded together to allow heat transfer between fluid and absorber. While the bottom and sides of flat plate collector is cover by insulated casing to prevent heat loss. Absorber tubes in harp and serpentine design is the common design in the commercial solar collectors.

A flat plate collector without glazing cover is known as unglazed solar thermal collector whereas flat plate collector with glazing cover is known as a glazed solar collector. Cross-section of glazed and unglazed PVT collector is shown in Figure 2.2 and Figure 2.3 respectively. Unglazed solar collector costs less compared to glazed solar collector but it has poor performance in cold or windy weather. According to Kim & Kim (2012), several experiments were carried out to compare the performance of unglazed PVT collector and glazed PVT collector and conclude that the unglazed PVT collector has the better electrical efficiency whereas glazed PVT collector has the better thermal efficiency. However, the total efficiency of glazed PVT collectors is still higher, it has efficiency of 48.4%, while unglazed PVT collector has only 35.8%.

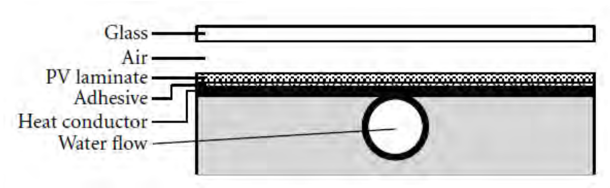

Figure 2.2 Cross-section of Glazed PVT (Kim & Kim, 2012)

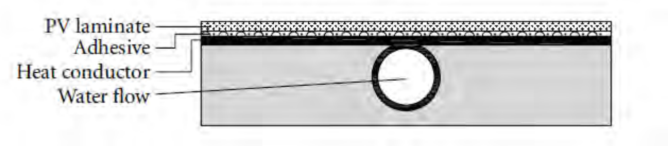

Figure 2.3 Cross-section of Unglazed PVT (Kim & Kim, 2012)

2.2.1 Energy Analysis of Solar Thermal Collector

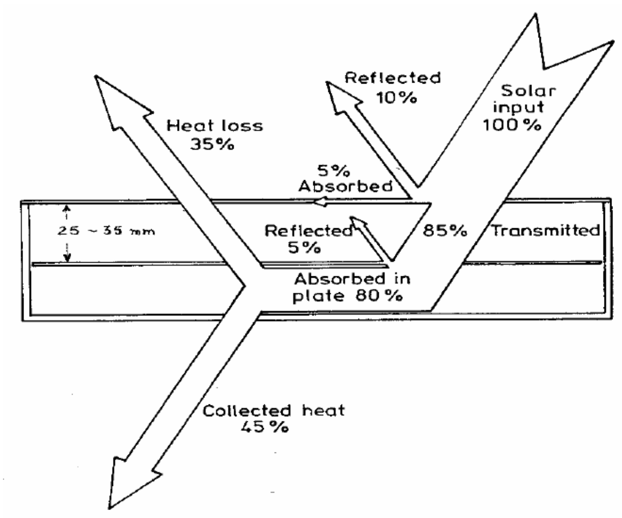

Figure 2.4 Heat Flow through Solar Thermal Collector

Figure 2.4 illustrate schematic diagram of heat flow through flat plate solar collector.