CHARACTERISTIC STUDY OF FRESNEL LENS PERFORMANCE FOR SOLAR CONCENTRATION APPLICATION

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THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR DEGREE OF BACHELOR OF MECHANICAL ENGINEERING

FACULTY OF ENGINEERING
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2022

DECLARATION

I hereby declare that this project entitled "Characteristics Study of Fresnel Lens for Solar Concentration Application" that is submitted to Universiti Malaysia Sabah is original and it is submitted as partial fulfilment of the requirement for the degree of Bachelor of Mechanical Engineering. I also declared that the material in this thesis is entirely mine except for the quotations, equations, summaries, references have been duty acknowledged.

1st July 2022

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CERTIFICATION

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ABSTRACT

Solar energy has been a field or well-known topics that take place in the industry as it is very related to the environmentally friendly source of energy as well as today's energy demand. Solar concentrators, particularly Fresnel lenses, have been used in industry to adapt solar energy application and production. In this project, the performance of the Fresnel lens in solar concentration application is studied by designing an experiment for the performance characterization of Fresnel Lens, characterization of Fresnel lens geometrical and profile as well as the to correlate the operation parameters which are the lens angles and exposure area with the performance characteristics of heat energy and concentration ratio. With that, the geometrical and profile characterization is conducted by microscopic observation method as well as the focal length assessment. From that, obtained that the thickness, groove length and focal length of the lens is 1.82 mm, 0.24 mm and 300 mm respectively. Next, experimental work also designed with the variation of lens angle in the transversal and incidence orientation also the exposure area. It resulted in the obtained of optimum Fresnel lens setting as solar concentrator at 90° of transversal angle, 5° of incidence angle and 0.045 m^2 of lens exposure area. In general, the lens positioning is very important in installing high-output solar concentration system. It is due to the sun's positing and declination. Therefore, it is very important to study the performance characterization of the Fresnel Lens as solar concentrator as it can help in optimum and high efficiency solar concentrator installation using the Fresnel Lens as well as fulfilling the today's energy demand.

ABSTRAK

Tenaga suria telah menjadi bidang atau topik terkenal yang berlaku dalam industri kerana ia sangat berkaitan dengan sumber tenaga mesra alam serta permintaan tenaga masa kini. Penumpuan solar berkaitan kanta Fresnel telah digunakan dalam industri untuk menyesuaikan aplikasi dan pengeluaran tenaga suria. Dalam projek ini, prestasi kanta Fresnel dalam aplikasi untuk menumpukan suria dikaji dengan mereka bentuk eksperimen untuk penilaian prestasi Kanta Fresnel, penilaian geometri dan profil kanta Fresnel serta untuk menghubungkaitkan parameter operasi iaitu sudut kanta dan kawasan pendedahan dengan ciri prestasi tenaga haba dan nisbah penumpuan tenaga. Oleh itu, penilaian geometri dan profil dijalankan dengan kaedah pemerhatian mikroskopik serta penilaian jarak fokus. Justeru, ketebalan, panjang alur dan panjang fokus kanta dapat diperolehi pada 1.82 mm, 0.24 mm dan 300 mm masing-masing. Seterusnya, kerja eksperimen turut direka bentuk dengan variasi sudut kanta dalam orientasi transversal dan insidens serta kawasan pendedahan. Ia menghasilkan tetapan kanta Fresnel optimum sebagai penumpu suria pada 90° sudut melintang, 5° sudut tuju dan 0.045 m^2 kawasan pendedahan kanta. Secara amnya, kedudukan kanta adalah sangat penting dalam memasang sistem penumpuan suria keluaran tinggi. Hal ini disebabkan oleh kedudukan dan deklinasi matahari. Oleh itu, adalah sangat penting untuk mengkaji pencirian prestasi Kanta Fresnel sebagai penumpu suria kerana ia boleh membantu dalam pemasangan penumpu suria yang optimum dan kecekapan tinggi menggunakan Kanta Fresnel serta memenuhi permintaan tenaga masa kini.

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θ_T	-	Transversal angle
θ_i	-	Incidence Angle
A	-	Exposure Area
Q	-	Concentrated Heat Energy on Receiver
$\dot{Q}_r$	-	Radiative Heat Transfer
σ	-	Stefan-Boltzmann constant (5.6703×10^{-8} $wm^{-2}K^{-4}$)
e	-	Emissivity coefficient
r_c	-	Concentration Ratio

CHAPTER 1

INTRODUCTION

1.1 Overview

Energy is very critical and important for humanity's survival and growth which contributed to everything that happened around human. Recently, the impact of conventional energy has been taken into serious consideration. It is because the conventional energy affected the environment. With that, development of renewable and new energy drew a lot of people's attentions especially in the sectors of development and technology as the result of the drying up of terrestrial fossil fuels due to the production of conventional energy. One of renewable and declared as environmentally friendly energy is solar energy as it will become undoubtedly a key element of the future energy system. However, identifying viable applications that use solar energy as a heat source is difficult because to the lower energy density and seasonality, as well as geographical dependency. As a consequence, it is required and feasible to investigate high-efficiency solar energy concentration technology.

Solar concentrator is a technology that used to collects light energy from the Sun across a broad area and concentrates it on a smaller region. In solar concentration concept, energy is focused on a smaller area so, concentrators may offer greater temperatures than flat plate collectors. In addition, there are two types of solar concentrators: solar thermal conversion systems and direct conversion systems. The sunlight is gathered and transformed into thermal energy and other usable forms of energy in a solar thermal conversion system, whereas the sunlight is

immediately converted into electrical energy in a direct conversion system. Concentrated solar technology is also one of great interest because it is an efficient and adequate way to meet the ever-growing demand for solar electricity on a global scale (Ghodbane, M., 2020). It allows for very practical temperatures suitable for use in many domestic and industrial fields, where concentrated solar technology is of great interest because it is an efficient and adequate way to meet the ever-growing demand for solar electricity on a global scale. Overall, the solar concentrators collect beam radiation using a flawlessly reflecting surface and a tracking mechanism, then refract it through prisms or lenses or numerous reflections on mirrors to a reduced surface receiver. In the field of solar concentrator energy technology, Fresnel lenses have recently been one of the finest alternatives to benefits as it has small volume, light weight mass manufacturing at cheap cost, and has the ability to efficiently improve energy density as Fresnel lens is actually a lens that has series of concentric grooves that act as an individual refractor. It is similar to other lens that can capture light and refract it.

However, Fresnel lenses has a flat surface which is different from concave and convex lenses. This technology basically is named after Augustin-Jean Fresnel, a French physicist who created the Fresnel objective for lighthouses in the eighteenth century (Silvi, C., 2009). His concept was to grind a typical convex lens onto a multi-section lens to create a cheaper and lighter lens that could accurately guide light rays in a particular direction. The Fresnel lens, which divides a parabolic mirror into a series of reflecting mirrors to focus collimated rays on a focal point or line, depending on whether the reflectors are circular or linear, was the inspiration for the LFR technology. Previously, Martinez Antón, J. C. *et al* (2011) investigated the performance of Fresnel lens as solar concentrator for flux transfer. The investigation enables for a rapid and direct assessment of overall optical efficiency while also providing a map of the lens' efficiency point by point, revealing lens flaws and faults in detail. The results of the lenses investigated lead to the conclusion that when the working aperture of a lens is increased, flux performance degrades considerably. Small surface angle faults in the lens have a larger influence in the paraxial working area than chromatic aberration.

Therefore, this project study the performance characterization of Fresnel Lens as solar concentrator. This project involves on investigating the effect of angle such as longitudinal, transversal and incident angle to the performance of the Fresnel lens. The performance characterization of the lens is identified by the power output in the production of energy from solar radiant. With that, this project will obtain optimum angle of installing the Fresnel Lens in solar concentration field. This is very important to improvise the current production of energy through the renewable energy of solar by concentrating it efficiently. On the other hand, this project is proposed with the method of experimental study with the guidance of background study to do the parameter design and numerical modelling for the usage of experimental work. Besides, the study of the lens geometrical characteristic also taken into consideration in this project. Thus, the optimum characteristic of angles for the Fresnel lens for the solar concentration application were characterized by the output produced.

1.2 Problem Statement

Recently, solar energy has been a field or well-known topics that take place in the industry as it is very related to the environmentally friendly source of energy. This scenario also occurred in this country; Malaysia as the Malaysian government is eager to expand solar energy as one of the country's major energy sources. According to the 9th Malaysia Plan (9MP), a significant amount of money has been allocated for the installation of solar PV systems. Despite the government's efforts, solar energy accounts for less than 1% of Malaysia's energy demand. The high initial cost and extended payback period are two of the most significant disadvantages of solar technology. According to current installation prices for a basic solar PV system, the PV module accounts for around 60% of the overall cost. This issue led to the more rooms for research and development in the energy production from solar energy including the solar concentration aspects. It is because the solar concentration technology and installation is one of the aspects that contribute to the production of energy especially in large amount and efficient as well as cost-friendly.

Solar concentrators especially Fresnel Lens that has been used in the industry to adapt the solar energy application and production in this country. It is because the lower energy density and seasonality, as well as geographical dependency are

the natural scenario that happened in this country as Malaysia experiences hot and humid weather with a generous amount of rainfall all year round due to its geographic location. It receives an abundant amount of solar radiation throughout the year, with most places having daily solar radiation mean of 4.7–6.5 kWh/m^2. With this case, it is very important to take advantage of this tropical climate of Malaysia to expand and develop more initiatives to increase the solar energy production by using the feasible high-efficiency solar energy concentration technology especially with the application of Fresnel Lens.

1.3 Research Objectives

The main objective of this research project is to study the performance characterization of the Fresnel Lens as solar concentrator. The project main objective is specified to following specific aims,

i. To design an experiment for the performance characterization of Fresnel Lens as solar concentrator.
ii. To characterize Fresnel lens geometrical and profile.
iii. To correlate the operation parameters (lens angles and coverage area) with the performance characteristics (heat energy and concentration ratio)

1.4 Scope of Works

The research on study of performance characterization Fresnel Lens as solar concentrator is proposed by using the following scope of works in order to achieve the aims.

a. Geometrical Characterization

Fresnel Lens as solar concentrator is a device that used to concentrate solar radiant into one focal point. The Fresnel lens also has a lot of type and various geometrical specifications. Thus, it is very critical to characterize the geometrical specification to be used in the approach of performance characterization of optimum angle.

b. Experiment

The experiment is conducted in order to do the approach of studying the performance characterization. The designed parameters which are transversal angle, incidence

angle and coverage area will be adjusted and the optimum angle that produced high heat energy or maximum concentration ratio of the lenses are investigated in this method.

1.5 Research Methodology

The research is planned to be conducted by following to the specific and arranged methodology. This methodology is very important in order to ensure the project is done in correct approaches. Thus, the research methodology to achieve the objectives of the project are shown as follows

a. Literature Review

The understanding and background study of the topics related to the renewable energy, solar concentrated and Fresnel Lens is obtaining by conducting the literature review. The literature review method is done by reviewing the existing or previous research papers and projects. All the related theory provided in the research papers or journals as well as any offline and online source materials is taken onto consideration for the review.

b. Experimental Assessment

This method is very important as this is the core of the research and study. It is because operation parameter will be adjusted in this method to investigate the optimum angle that produce high ratio of solar concentration. Therefore, the performance characteristic will be able to be identified in this method.

c. Result Verification and Validation

This method will approach the result obtained from the experimental assessment as in this method the critical analysis will be done. This method also will allow to the identification of correlation between the theory studied and the practical investigation done. This method also will conclude which operational characteristics is the optimum one to produce high ratio of concentration for solar concentrator technology.

d. Documentation

This method will allow the documentation of all the background study, theoretical and experimental investigation as well as the finding and conclusion of the study. It is very essential to document as it can be used for academically reference in the future.

This research will be conducted by following the flowchart as shown in Figure 1.1 below in order to ensure the research can be done smoothly and achieving the main objective of this project.

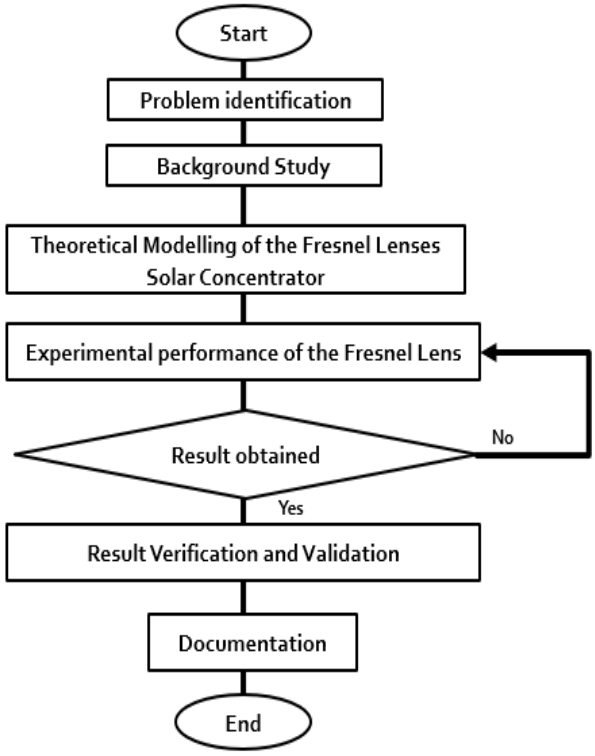


Figure 1.1: Project Methodology Flowchart

1.6 Thesis Organization

The thesis is organised as follows:

Chapter 1 introduced the project in studying the Fresnel lens solar concentration system performance. This chapter listed the main objectives of the study, followed by the methodology, flowchart as well as the scope of works involved in this study of performance characteristics of Fresnel lens as solar concentrators.

Chapter 2 is a compilation of project topic related literature reviews. This chapter discussed recent developments and research conducted by researchers from a variety of disciplines, working principles and mathematical equations related to the Fresnel lens solar concentration. This chapter also includes summaries of the literature review to highlight the main findings.

Chapter 3 elaborated the Fresnel lens geometrical and profile characterization works. This chapter also included the theory for mathematical modelling the Fresnel lens construction. Aside from that, all of the specification and instruments used for the geometrical characterization also included in this chapter.

Chapter 4 elaborated the project instrumentation and experiment jig. It is provided the information regarding the experimental setup and procedures as well as the observation of the investigation works.

In Chapter 5, the results of the performance evaluation and assessment that obtained from the previous chapters are gathered and compared to be validated and discussed. This section also provided the heat gain and concentration ratio analysis of the concentration system using the Fresnel lens.

Chapter 6 is concluding the projects findings, where it explained the achievement of project objectives. This section also proposed the improvements and recommendation for the related topic future works.

1.7 Summary

This project conducted an undergraduate student with the supervision of a Senior Lecturer from University Malaysia Sabah. This project entitled characteristic study of Fresnel lens performance for solar concentration which can be utilize as the Fresnel lens has a lot of benefits including cost effective and convenient access especially in renewable energy industry.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Solar concentrators are one of the devices that can enhance the production of solar energy. With the application of Fresnel lens as solar concentrator which is known for its economical and efficient behaviours, the solar concentration can be improved. It is because the beam of solar energy incident over a large surface can be concentrated onto a smaller surface as it depends on the focal length of the concentration lens. With that, this chapter presented the reviews on history, application, mathematical modelling and previous study related to the Fresnel lens as solar concentrator as well as the radiation of solar throughout a period of time for the purpose of research's guidelines and information.

2.2 Fresnel Lens as Solar Concentrator

Fresnel lenses are used as solar concentrators because they give high optical efficiency while being light in weight and inexpensive. Though Fresnel lens concentrators have been used in solar energy concentration systems since the 1960s, due to the potential and benefits, development of Fresnel lenses in commercial solar energy concentration is currently ongoing.

2.2.1 Principle of Fresnel Lens

Solar concentrators devices specifically Fresnel Lens basically working by focusing the sun ray. In the concentrating of the ray, the high temperature also will be yielded from the intensity of the sun ray which will resulted in heat generation and can be converted into another form of energy such as mechanical energy. Figure 2.1 below illustrated the differences between conventional lens and Fresnel lens.

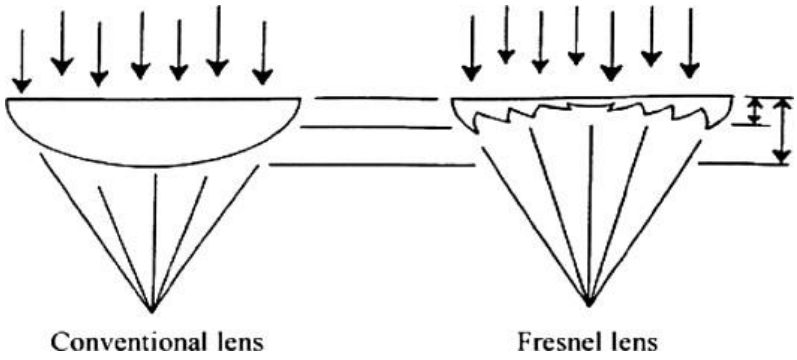
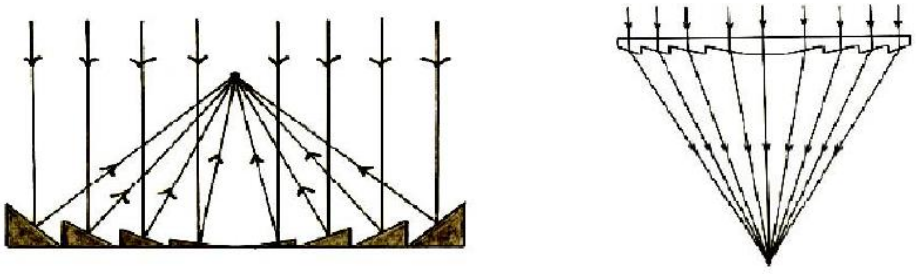


Figure 2.1: Differences between conventional lens and Fresnel lens.

Source: Xie, W. T. *et al.*, (2011)

A Fresnel lens is a lens with a series of concentric grooves that each operate as a separate refractor. It works in the same way as other lenses that can collect and refract light. In contrast to concave and convex lenses, Fresnel lenses have a flat surface. Fresnel lens is also capable to reflect, refract as well as reflect-reflect in order to be used as solar concentrator. It is because it can be divided into two types which are reflective Fresnel lens and refractive Fresnel lens. The schematic draws in Figure 2.2 below illustrated the difference between reflective and refractive Fresnel lens present in the market and industry.



(a) Reflective Fresnel lens (b) Relective lens

Figure 2.2: Type of Fresnel Lens

Source: Aniesh, B. & Lionel, B. (2017)

Fresnel lenses are adaptable in terms of optical design and can provide uniform flux density on the absorber or receiver. The two types of Fresnel lens commonly can be distinguished by the application as refractive lenses are mostly employed in photovoltaic applications, while reflecting mirrors are used in photothermic applications. With that, Fresnel lens also can be categorized into non-imaging and imaging lens. The difference between these two categories is the image of the source can be portrayed or shaped on the receiver for imaging lens, meanwhile there is no image of the source can be found on the receiver for non-imaging Fresnel lens. Solar concentration by using Fresnel lens is strongly related to the sun ray, intensity as well as position. It is because the sunlight must be projected directly to the lens in order to maximize the refraction of the sunlight.

2.2.2 History of Development

A Fresnel lens is a kind of composite compact lens invented for the use in lighthouses by the French scientist named Augustin-Jean Fresnel. The design permitted the fabrication of lenses with huge apertures and short focal lengths without the bulk and volume of material required by a typical lens. With that, these lenses addressed a requirement for lighthouses that could beam further and through thick layers of fog. It helped achieve that by catching all the light coming from a lamp, then amplifying and guiding it in one direction. A Fresnel lens also may be substantially thinner than a corresponding conventional lens, and may even assume the form of a flat sheet under some cases. It is also gathered more oblique light from a light source, allowing the light from a lighthouse equipped with one to be visible from a wider distance.

In the 1950s, an appropriate polymer such as polymethylmethacrylate (PMMA) were available and it leads to the first attempts to utilize Fresnel lenses for solar energy collecting were made. PMMA is material that known for its ultra violet (UV) resistant which is thermally stable up to 80°C. It is also having a unique transmissivity that fits the solar spectrum as well as refractive index of 1.49, which is extremely near to that of glass (Xie *et al.*, 2011) As a result, the majority of Fresnel lens designers for concentrated solar energy applications choose for PMMA because of its outstanding optical quality paired with less expensive production processes.