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A Study of Implementation Fresnel Lens with Tracking Positioning Ability to Achieve Optimum Concentrated Heat on the Solar Heater Element

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Abstract

This study investigates the use of Fresnel lenses with tracking capabilities to enhance the heating efficiency of solar heater elements. The primary objective is to optimize solar energy utilization by maintaining optimal alignment of the lens with the sun. The project involves developing a system that integrates light sensors, servo motors, and an Arduino microcontroller to control the lens's position. Experiments were conducted to measure the temperature increase in a fluid contained within a metal pipe when exposed to concentrated sunlight. The results demonstrated significant improvements in heat concentration, highlighting the effectiveness of this approach. This research underscores the potential of this technology to advance solar power generation and reduce dependence on conventional energy sources.

1. Introduction

Electricity is a fundamental necessity in our modern world, driving technological advancements and economic growth. The rising demand for electricity, coupled with the environmental impact of non-renewable energy sources, underscores the need for sustainable alternatives. Renewable energy sources such as solar, wind, hydropower, and biomass are essential in reducing pollution and conserving natural resources [1].

One innovative approach to harness solar energy is through the use of Fresnel lenses. These lenses concentrate sunlight onto a focal point, generating high temperatures that can be used for various applications, including electricity generation [2]. The Fresnel lens's thin, lightweight construction and its ability to gather light efficiently make it an ideal component for solar thermal power systems.

This project explores the implementation of a tracking Fresnel lens system designed to optimize concentrated solar power for heating a galvanized pipe filled with oil. The oil acts as a thermal conductor, transferring heat to generate steam, which can then be used to produce electricity. The system's tracking ability ensures that the Fresnel lens remains aligned with the sun, maximizing the concentration of light on the pipe throughout the day.

The innovation of using a Fresnel lens with tracking capabilities addresses the limitations of traditional photovoltaic panels. By focusing intense heat on a single point, the system can achieve the high temperatures necessary for efficient steam generation. Additionally, the project aims to enhance the system's reliability and efficiency through continuous alignment with the sun's position. Experiments focus on measuring the temperature increase in a fluid within a metal pipe under concentrated sunlight, demonstrating the potential of this technology to improve solar power generation and contribute to sustainable energy solutions.

1.1 Problem Statement

The increasing global demand for electricity, combined with the negative environmental impacts of non-renewable energy sources, drives the need for alternative, sustainable energy solutions [3]. Photovoltaic panels are commonly used for solar power generation, but they have limitations in efficiency and energy concentration. Therefore, there is a need to explore other methods of harnessing solar energy.

This project investigates the use of a Fresnel lens with tracking capabilities as an alternative to photovoltaic panels. The Fresnel lens is designed to concentrate solar energy onto a single point, generating high temperatures. In this project, a galvanized pipe filled with oil is used to simulate a thermal receiver, where the concentrated light heats the oil, representing the initial stage of heating water to its boiling point.

A significant challenge in this setup is ensuring the Fresnel lens consistently aligns with the sun to maintain optimal light concentration. To address this, the project involves developing a smart tracking system that uses light sensors, servo motors, and an Arduino microcontroller to keep the lens aligned with the sun's position throughout the day. This approach aims to maximize the efficiency of heat generation, providing a viable alternative to photovoltaic panels for solar power generation.

1.2 Objectives and Scope of Project

The primary objective of this project is to design and develop a system that utilizes a Fresnel lens with tracking capabilities to optimize the concentration of solar energy on a heating element. The project focuses on creating a tracking mechanism to ensure the Fresnel lens remains aligned with the sun throughout the day, thereby maximizing light concentration. Additionally, it involves developing a prototype system that integrates the Fresnel lens with light sensors, servo motors, and an Arduino microcontroller to control the alignment and concentration process. The performance of the system will be evaluated by measuring the temperature increase in a fluid within a galvanized pipe, demonstrating the efficiency of heat generation and the potential for steam production. Ultimately, the project aims to provide a sustainable alternative to photovoltaic panels by leveraging concentrated solar power to achieve the high temperatures necessary for electricity production.

The scope of this project encompasses the design, development, and testing of a prototype system that integrates a Fresnel lens with a tracking mechanism for solar energy concentration. It involves designing the hardware and software components necessary for the tracking system, including light sensors, servo motors, and an Arduino microcontroller. The project also includes constructing a prototype that incorporates a Fresnel lens mounted on a tracking platform, with a galvanized pipe serving as the thermal receiver. Experiments will be conducted to measure the effectiveness of the system in concentrating sunlight and generating heat, with an emphasis on maintaining optimal alignment with the sun. The data collected from these experiments will be analyzed to assess the system's efficiency and potential applications in solar thermal power generation. The project will also identify the limitations of the current prototype and propose improvements for future development to enhance the system's reliability and scalability.

2. Methodology

The methodology explains how the Fresnel lens-based solar energy concentration system with tracking capabilities was designed, developed, and evaluated. It covers the entire process from conceptualization and design to development and testing of the prototype. Essential components such as light sensors, servo motors, and an Arduino microcontroller were chosen and integrated to form the tracking system. The construction of the prototype involved using a galvanized pipe filled with oil to simulate heating and steam generation. The experimental setup was designed to measure temperature changes and assess the system's efficiency in concentrating solar energy. Additionally, the methodology includes the software development aspect, focusing on programming the Arduino to manage the tracking and heating processes. This section provides a detailed understanding of the steps taken to achieve the project's goals and evaluate its potential for practical solar thermal applications.

Throughout the development of this project, there are evident of a case study that had been performed before this project was started. First study is a article review “Concentrating Solar Power” by Lee A. Weinstein, James Loomis, Bikram Bhatia, David M. Bierman, Evelyn N. Wang, and Gang Chen discuss the potential of CSP as a renewable energy technology. CSP harnesses solar-thermal conversion to generate electricity, an alternative to the more commonly known photovoltaic cells. While the development of CSP technology began in the 1980s, its growth was limited until recent years when advancements and increased adoption led to a resurgence. The article highlights two CSP plants: a parabolic trough collector plant and a central receiver, also known as a "power tower” [4]. These systems illustrate CSP's efficiency in converting solar energy into electricity, providing a promising solution for sustainable power generation. Figure 1 below show two types of harvesting solar power from the article.

Figure 1 *(a) Parabolic Collector Plant, (b) Central Receiver (Power Tower).*

Another case study that crucially the reason this study be done is "Fixed Mirror Solar Concentrator for Power Generation" by J. R. Schuster, J. L. Russell, Jr., G. H. Eggers, and S. V. Shelton. This article discusses the development of the Fixed Mirror Solar Concentrator (FMSC) system, which aims to efficiently generate electricity by concentrating solar energy. The study highlights three main components: the Solar Field (SF), which uses stationary mirrors to concentrate sunlight onto a focal line; the Thermal Energy Storage (TES), which stores excess thermal energy for use during non-sunny periods; and the Power Block (PB), which converts stored thermal energy into electricity using steam turbines [5]. The innovative design of the FMSC, including the use of a compound parabolic secondary concentrator, enhances the efficiency of solar energy capture and conversion, providing a cost-effective and reliable solution for solar power generation. Figure 2 show 3 main components in generating electricity based from the article.

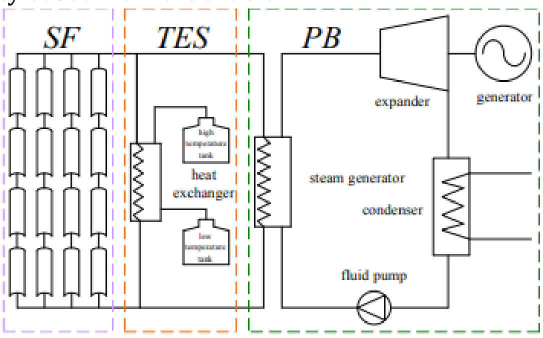
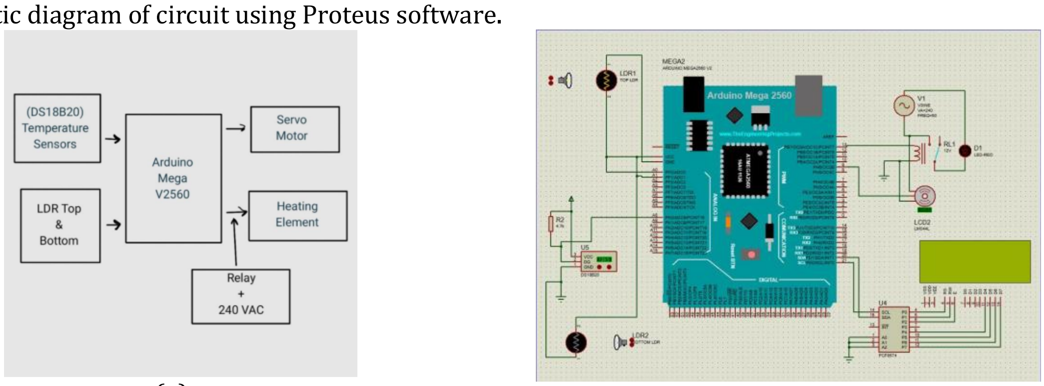


Figure 2 *Schematic of Concentrating Solar Power Station.*

Relation of this case study is at Solar Field (SF) components which is same as my project represent as collector of the sunlight for heat generation. By using Fresnel lens, efficiency of light concentration can be improved to produce heat that been transmitted by conductor to Thermal Energy Storage (TES). Exploration of tracking ability is one of the improvement to optimize sunlight collection throughout the day and emphasize Sun energy harvesting.

2.1 Block Diagram

Implementation of tracking Fresnel lens for concentrated heat for solar thermal power station use Arduino mega as the microcontroller of the system. Sensor as input used is Light-Dependent Resistor (LDR) and temperature sensor for this project. Output use is servomotor, heating element with the support from incoming supply 240VAC from socket and controlled by microprocessor decision. Figure 3 show the block diagram of the system and schematic diagram of circuit using Proteus software.



(a) (b)

Figure 3 Components use for this project *(a) System Block Diagram; (b) Schematic Diagram of Circuit.*

2.2 Flowchart System

Throughout the development of the Fresnel lens with ability to track sunlight there is a system that can track and give signal for Fresnel lens to move its angle to the direction of sunlight. With the help of microprocessor, Arduino that been shown as system block diagram, there are the flow of the system that enhance sunlight collection. Figure 5 show flowchart of tracking Fresnel lens with the functioning of components and the explanation of the system at below of the figure.

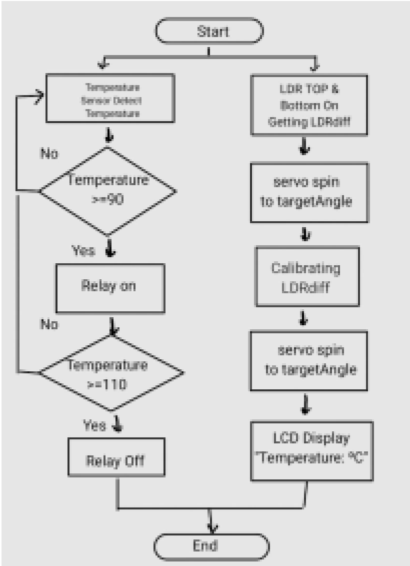
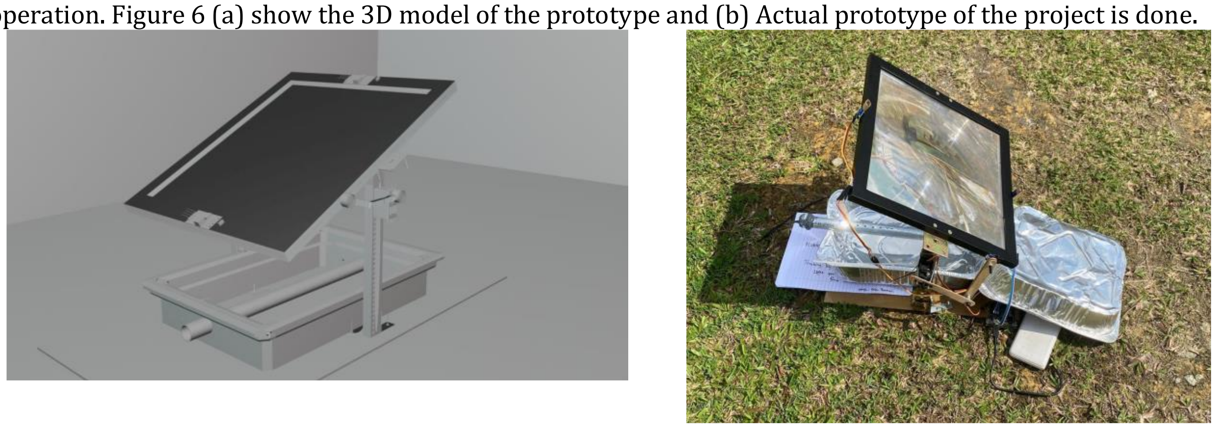


Figure 5 *Flowchart of System.*

The system starts by initializing all components, including the Arduino, LDRs, servo motors, and temperature sensor. It then reads data from the LDRs to determine the direction of sunlight. Based on this data, the system calculates the optimal angle for the Fresnel lens. The servo motors are adjusted to align the lens with the sun, ensuring concentrated sunlight is focused onto the galvanized pipe filled with oil. The system continuously monitors the oil's temperature and, if necessary, activates the heating element to maintain the desired temperature. Real-time temperature and system status are displayed on an LCD. This cycle of reading LDR data, adjusting the lens position, and monitoring temperature is continuously repeated to ensure optimal solar energy concentration and heat generation. The system ends when the process is stopped.

2.3 Hardware Prototype

Hardware prototype of this tracking Fresnel lens is designed in 3D model fist by using Blender Software and the software use to program the Arduino is Arduino IDE. Arduino IDE is a software use to program microprocessor and other components to operate as the flowchart above. Arduino uses C++ programming language for its operation. Figure 6 (a) show the 3D model of the prototype and (b) Actual prototype of the project is done.



(a) (b)

Figure 6 Hardware Development*(a) 3D Model, (b) The prototype of Project.*

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3. Result and Discussion

Aim of this project is to observe and evaluate three key test of Fresnel lens with ability to track sunlight direction. First test is focused on the ability of concentrated light to produce high heat. This test demonstrated that sunlight carries energy and when it been concentrated energy from sunlight converts to produce heat on surface that been pointed. Second testing is on and off relay condition which been use to enhance the rising of the temperature. Relay control the heating element that been set in range of temperature to start operate and to stop from operating. Last test is the calibrating of the LDRs and servo motor to adjust the angle of Fresnel lens to concentrated light in bullet shape and not in crescent shaped.

3.1 Testing 1: Concentrated Light Produce High Heat.

This section discusses the importance of heat in creating a solar thermal power station. The heat is utilized to convert fluid into steam for spinning turbines to generate electricity. The testing involved measuring the temperature increase of oil inside a galvanized iron pipe when exposed to concentrated sunlight. The data collected showed that high-intensity sunlight significantly increased the temperature of both the oil and the iron pipe. Tools such as the SEAWARD Solar Survey 200R irradiance meter that show value of Irradiance and the Kaemeasu Infrared Thermometer that value the temperature were used for data collection. Tables 4.1 to 4.3 present the data of oil and iron pipe temperatures at various times and irradiance levels, illustrating the effectiveness of concentrated light in producing high heat.

Test 1 conducted start from 11 o'clock until 4 o'clock in the evening to get the intensity of sunlight. Table 1 show the data from the testing for day 1 and figure 7 show graph of temperature generated from concentrated light for day 1. Initial temperature of galvanized iron is 36.4(°C) and oil temperature is 38.9(°C) when the irradiance is about 482W/m^2. Highest peak of the temperature is 88 (°C) for oil and 94.5 (°C) for galvanized iron when the irradiance is 944W/m^2.

Table 1 Data of Temperature for Day 1.

Time (Hour)	Irradiance (W/m^2)	Oil Temperature (°C)	Iron Pipe Temperature (°C)
11	482	38.9	36.4
11.3	861	55	59
12	850	60	68
12.3	892	70	75
1	990	67	77
1.3	916	70	82
2	965	79	88.3
2.3	1150	85	105
3	900	87	95
3.3	905	87.6	93
4	944	88	94.5

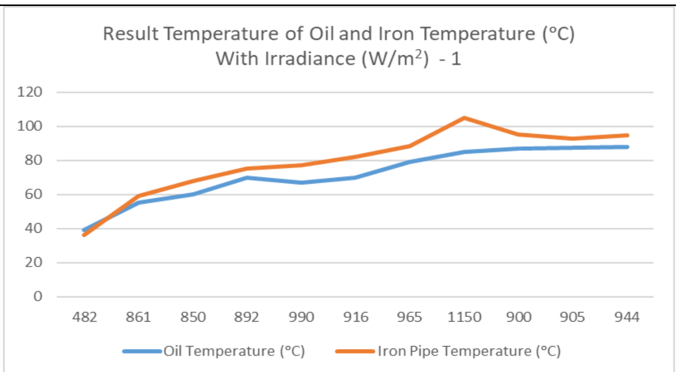

Figure 7 Graph of Temperature for Day 1.

Data for day 2 and 3 are shown in table 2 and table 3 where the graph of temperature-irradiance is figure 8 and figure 9. For table 2 and graph figure 9 data can be seen that temperature start with 33(°C) for oil and 35(°C) when irradiance is at 570W/m^2. Peak temperature for this day 2 of data is 88(°C) for oil and 105(°C) for galvanized iron when irradiance is 1015W/m^2.

Table 2 Data of Temperature for Day 2.

Time (Hour)	Irradiance (W/m^2)	Oil Temperature (°C)	Iron Pipe Temperature (°C)
11	570	33	35
11.3	770	35	36.4
12	930	46.4	47
12.3	850	52	53.5
1	943	56.4	57
1.3	908	59	65
2	945	67	70
2.3	965	78	88
3	1180	87	93
3.3	1015	88	105
4	940	87.6	100.9

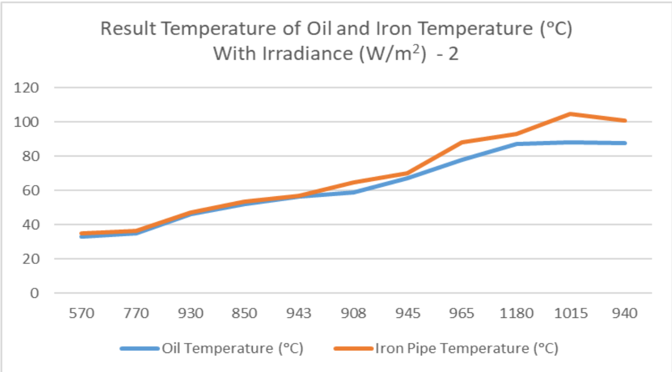

Figure 9 *Graph of Temperature for Day 2*

For table 3 and graph figure 10 data can be seen that temperature start with 32(°C) for oil and 29(°C) when irradiance is at 800W/m2. Peak temperature for this day 3 of data is 93(°C) for oil and 101(°C) for galvanized iron when irradiance is 1100W/m2.

Table 3 Data of Temperature for Day 3

Time (Hour)	Irradiance (W/m^2)	Oil Temperature (°C)	Iron Pipe Temperature (°C)
11	800	32	29
11.3	850	33	35
12	920	44	49
12.3	950	59	65
1	1120	69.4	75
1.3	1050	79	88
2	990	76	90
2.3	1100	93	101
3	980	86	99
3.3	960	88	96
4	870	80	92

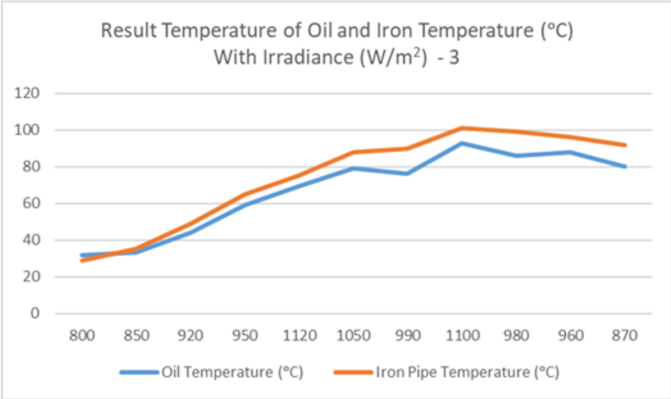

Figure10 *Graph of Temperature for Day 3*

3.2 Testing 2: On and Off Relay Condition.

The second testing phase examined the condition of a relay when switching the heating element on and off. A 60W heating element was connected to the relay, and the temperatures of the oil and iron pipe were recorded with the heating element alternately turned on and off. Revealing the influence of the heating element on temperature rise. The results indicated that the relay's on-and-off condition effectively controlled the temperature, enhancing it above the boiling point of water when necessary. The testing aimed to reduce the reliance on constant electric heating by efficiently utilizing the heating element intermittently.

Table 4 show the data for day 1 when using relay and this test conducted started from 7 am in the morning and end at 5 pm in the evening. Initial temperature starts with 30(°C) for oil and 28(°C) for galvanized iron and relay condition is on because heating element use to rise the temperature until 8.30 am because of that time the sun not shine as 11 am and the ambience is still dewy. Relay off condition when the temperature of oil is 115(°C) and turn back to on when temperature at 80(°C) to make temperature maintain nearly to boiling temperature of water. Analysis is same to the table 5 and 6 represent the day 2 and 3 while figure 11 and 12 represent graph of temperature for day 2 and 3.

Table 4 Data of Temperature for Day 1

Time (Hour)	Irradiance (W/m^2)	Oil Temperature (°C)	Iron Pipe Temperature (°C)	Relay Status
7	350	30	28	ON
7.3	450	70	92	ON
8	660	115	150	ON
8.3	700	85	110	OFF
9	616	82	95	OFF
9.3	442	110	143	ON
10	511	95	172	ON for15min
10.3	611	72	90	OFF
11	702	90	140	ON for 15min
11.3	905	88	105	OFF
12	942	93	117	OFF
12.3	952	95	100	OFF
1	977	100	105	OFF
1.3	992	105	120	OFF
2	1180	110	140	OFF
2.3	1200	112	155	OFF
3	1119	110	143	OFF
3.3	1213	110	160	OFF
4	1080	119.5	125	OFF
4.4	805	107	130	ON for10min
5	720	115	140	ON for 5min

Table 5 Data of Temperature for Day 2

Time (Hour)	Irradiance (W/m^2)	Oil Temperature (°C)	Iron Pipe Temperature (°C)	Relay Status
7	500	30	28	ON
7.3	540	75	99	ON
8	623	115	165	ON
8.3	611	110	145	OFF
9	650	98	123	OFF
9.3	700	115	130	ON for 10min
10	600	103	119	OFF
10.3	792	110	123	OFF
11	802	95	110	OFF
11.3	810	87	97	OFF
12	865	89	99	OFF
12.3	920	103	112	OFF
1	950	102	120	OFF
1.3	1150	110	121	OFF
2	1210	109	135	OFF
2.3	945	100	130	OFF
3	985	104	110	OFF
3.3	1005	110	124	OFF
4	930	98	108	OFF
4.3	900	92	97	OFF
5	804	84	90	OFF

Table 6 Data of Temperature for Day 3

Time (Hour)	Irradiance (W/m^2)	Oil Temperature (°C)	Iron Pipe Temperature (°C)	Relay Status
7	506	30	31	ON
7.3	450	73	100	ON
8	650	88	110	ON
8.3	677	115	126	ON
9	720	115	137	ON for 2min
9.3	767	82	95	OFF
10	850	85	97	OFF
10.3	900	93	103	OFF
11	920	95	107	OFF
11.3	909	98	105	OFF
12	950	95	119	OFF
12.3	1006	99	109	OFF
1	1050	103	115	OFF
1.3	1094	107	121	OFF
2	1150	112	129	OFF
2.3	1133	108	120	OFF
3	1150	110	105	OFF
3.3	1000	97	95	OFF
4	1100	89	143	OFF
4.3	800	115	130	ON for 3min
5	790	88	100	OFF

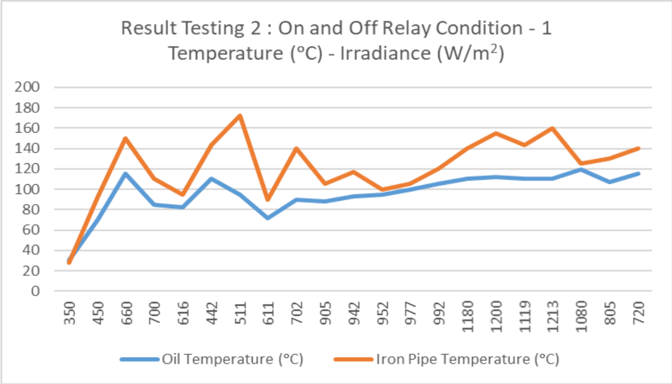

Figure 11 *Graph of Temperature for Day 1*

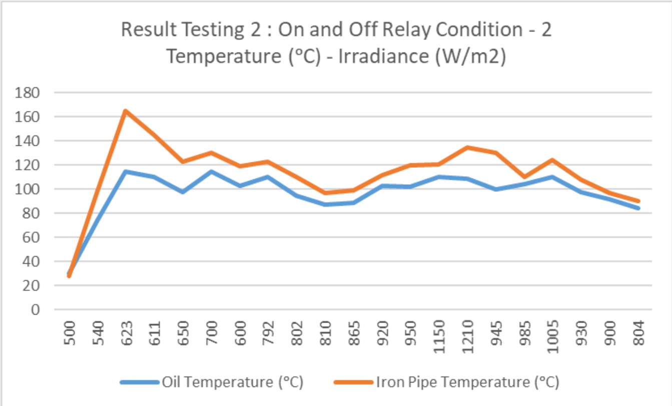

Figure 12 *Graph of Temperature for Day 2.*

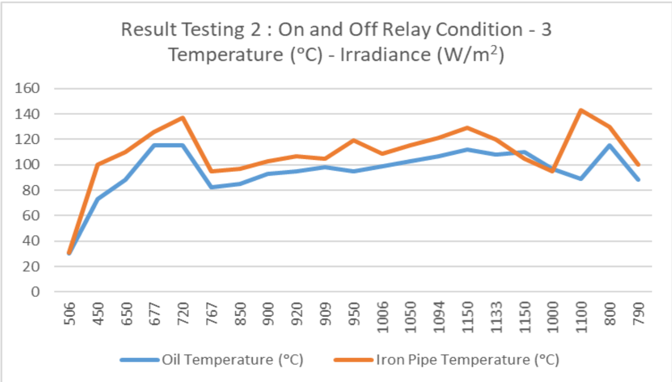

Figure 13 *Graph of Temperature for Day 3.*

3.3 Testing 3: Tracking Ability of Fresnel Lens.

The final testing phase focused on the ability of a Fresnel lens to track a moving light source, which is crucial for maintaining continuous high temperatures. The test setup involved using Light Dependent Resistors (LDRs) and a servo motor to adjust the lens's angle, ensuring it remained aligned with the light source. Conducted in a dark room for accuracy, the test demonstrated the system's capability to dynamically adjust the lens's position based on the light detected by the LDRs. The results confirmed that the Fresnel lens system, controlled by an Arduino, could effectively track the light source, ensuring optimal light concentration and consistent high-temperature readings. This tracking ability is essential for applications requiring precise light or heat detection, such as solar energy collection. Figure 14 (a) When light at the center, (b) When light go to the left, (c) When light go to the right.

(a) (b) (c)

Figure 14 *(a) When light at the centre, (b) When light go to the left, (c) When light go to the right.*

4. Conclusion and Recommendation.

The project successfully developed a smart tracking Fresnel lens system for solar heating, achieving its primary objective. Utilizing light-dependent resistors (LDRs) and servo motors controlled by an Arduino Mega microcontroller, the system accurately tracked the sun's position, ensuring optimal light concentration on the target area. Through meticulous calibration and repeated testing, the system demonstrated reliable and efficient performance. The tracking mechanism maintained the focal point of the Fresnel lens aligned with the sun's movement with high accuracy. Experimental trials validated the system's effectiveness, significantly increasing the temperature of oil in a galvanized iron pipe, indicating clear potential for thermal applications. Challenges such as Arduino library compatibility issues and minor oil leakage were promptly addressed, ensuring overall system efficiency and reliability. Extensive testing under various conditions reinforced the system's practical applicability, marking a significant advancement in solar thermal energy applications.

To further enhance the efficiency and reliability of the solar tracking and concentrating system, several recommendations are proposed. Constructing a dedicated chamber for the concentrated light can achieve very high temperatures and maintain consistent heat throughout the day. This improvement will ensure more stable and efficient thermal energy production by insulating and retaining the heat. Additionally, replacing the galvanized iron pipe with a copper pipe is advised since copper is a superior conductor of heat. Using a copper pipe will enhance heat transfer efficiency, thereby reducing the reliance on electric heating elements. Implementing these recommendations will optimize the system's performance and contribute to more effective and sustainable solar thermal energy applications.

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