NTU Journal for Renewable Energy (2023) Vol. 4 (1): 26-35
DOI: https://doi.org/10.56286/ntujre.v4i1

IRAQI
Academic Scientific Journals

EISSN: 2788-9920
NTU Journal for Renewable Energy
Available online at:
https://journals.ntu.edu.iq/index.php/NTU-JRE

A Simulation Model of a System-based Concentrated Solar Power System (CSP) by Using COMSOL Software

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Article Informations

Received: 15 – 11 - 2022
Accepted: 02 – 01 - 2023
Published: ١٠ – 0٢ - 2023

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Key words:
Solar system, PV system, Concentrated Solar Power System (CSP).

ABSTRACT

Solar energy has piqued people's curiosity since the dawn of civilization, and the technology for harvesting it has advanced at a rapid pace. The development of technology to increase the efficiency of the solar system is of critical relevance due to the energy difficulties that civilization has been facing. Scientists have used the solar concentrated system for several years since it allows for the concentration of solar energy into a concentrate, allowing for a significant increase in energy efficiency. In this paper, a parabolic dish setup is described as a dish-shaped concentrating collector that reflects solar energy onto a receiver located at the focal point. This concentrator is set atop a framework with assumption of that this concentrator obtain the sunlight. Typically, the acquired heat is utilized directly by a heat engine constructed on the receiver that travels with the dish. Typically, the acquired heat is utilized directly with the dish. The suggested dish could achieve very high temperatures and might be utilized in solar reactors to generate high-temperature solar fuels. Consequently, the purpose of this study is to explain the benefits of this technology in a world where fossil fuel usage is a genuine issue that society must address.

1. Introduction

Solar energy is unquestionably the most significant source of energy among the numerous forms of energy (solar, biofuel, geothermal, waves and tidal, winds, and water), since all others rely on it. Solar energy is the continuous emission of energy from the sun at a temperature of roughly 5800 K [1]. Solar photovoltaic systems and solar thermal technologies can both utilize solar irradiance [2]. Solar energy systems get power directly from photovoltaic panels [3], while solar energy collectors must heat a fluid to make heat energy, which could be used as a heat source or in a thermal cycle but could also be used to make energy.

It is possible to increase the energy intensity and, as a consequence, the temperature of the source of the heat by focusing sunbeams[4-6].Because this is a technology that can be used for both electrical and thermal conversions, and because it employs a completely clean and infinite source of energy, it is obvious that this is a solution that can assist to reduce the amount of fossil fuel that is utilized [5-8]. A mirror arrangement is used in all methods of concentrating solar power (CSP) to focus sunlight onto a single target and convert it to heat [9]. It can then be used to generate steam, which can then be used to power a turbine or heat up the manufacturing process. Even when the sun is obscured by clouds, after sunset, or even before sunrise, concentrated solar power plants can continue to generate electricity using devices that store thermal energy [10]. Concentrated solar power is a renewable energy source that can be used in a variety of ways and be deployed quickly due to its ability to store solar energy. Hybrid power plants can be built by combining combined cycle power plants with concentrated solar power (CSP) systems to provide high-value and dispatchable electricity. Embedded thermal-fired power plants, such as those that use coal, fossil fuels, biofuels, or geothermal energy, can also be used as a source of energy. CSP is one type of power block that can be used in these types of plants. CSP plants can even employ fossil fuel as a supplement to their solar production if it is necessary to do so during times of low solar radiation. In this particular circumstance, either a heat source that is fueled by natural gas or a gas steaming boiler/reheater is used [12].

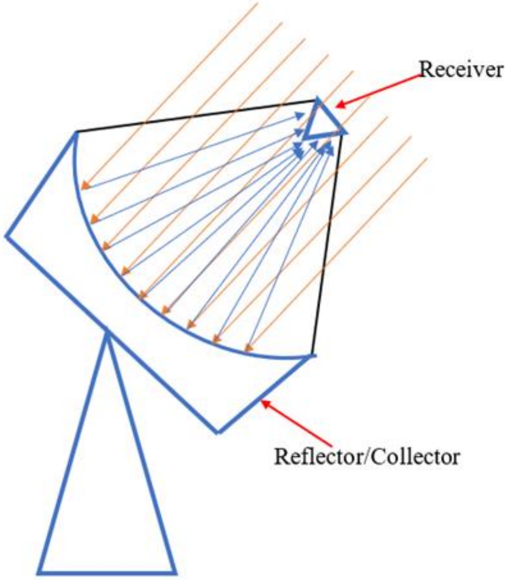

Figure 1: The Schematic of the Proposed Model

As of 2017, there are multiple distinct varieties of CSP technology, with the trough method being the most established and the tower method being the one experiencing the most rapid expansion. There are many other design variations and alternate configurations for each of them, and they are broken down into categories based on whether or not they contain energy storage and what technologies are used to capture solar thermal energy [13]. The categories are as follows: 1) The Parabolic Trough: As the sun's rays reflect off of the curved surface of the mirrors, a reflector with a parabolic shape directs the sun's energy toward a thermal absorber tubing, which runs about one foot above the mirrors [12]. The temperature of the heat transfer fluid, which is typically thermal oil and is running through the pipe at a temperature of 293 degrees Celsius, is increased to 393 degrees Celsius, and the heat energy is then utilized in the solar thermal unit to produce electricity in a traditional steam generator. This type is constructed out of a number of mirrors in the shape of a parabola trough that are arranged in parallel rows [12]. This configuration enables the single-axis trough-shaped reflectors to track the sun from the east in the morning all the way through the day so that it remains focused on the receiver pipes. As of the year 2018, ninety percent of the CSP that was commercially available had been installed. 2) Power tower: In power tower or central receiver systems, sun-tracking reflectors called heliostats concentrate sunlight onto a transmitter that is located at the top of a tower [13]. In the receiver, a heat transfer fluid is brought to a temperature of approximately 600 degrees Celsius, where it is then used to produce steam. This steam is then used to generate electricity in a conventional turbine-generator. 3) The Parabolic Dish: Solar concentrated receiver devices concentrate incident radiation from the sun into a tiny area, so producing tremendous heat that can be converted into either electrical or chemical energy. Solar energy systems frequently use the concentration ratio as a performance indicator. The concentration ratio can be defined as the ratio of solar irradiance on the face of the transmitter or on the focus spot to environmental solar flux [14].

As for modeling of the solar dish, research have been done in different ways. Rashid et. al [15] they discussed the transitioning from solar-only mode to hybrid solar-natural gas mode is quite challenging, especially when the plant is equipped with thermal storage. This study shows that the integration of storage regulates power production by solar energy and natural gas during the day time. It also enables an increase in the solar fraction of the hybrid plant while it causes a small decrease in thermodynamic efficiency. Dobos et al [16] used the System Advisor Model (SAM) which is modeling software for renewable energy systems developed by the National Renewable Energy Laboratory (NREL). SAM combines annual time series power production models with financial models to estimate the levelized cost of energy (LCOE) and other metrics. NREL has undertaken to reformulate the CSP models into a new transient simulation framework written in C++, by NREL. In addition to that, Pelay et. al [17] in their paper present the dynamic modeling & simulation of a concentrating solar power (CSP) plant integrated with a thermochemical energy storage (TCES) system. The results showed that the TCES integration could increase the overall efficiency of the CSP plant by more than 10%. The Turbine integration concept has the best global efficiency (31.39% for summer; 31.96% for winter).

Figure 1 presents the primary idea of the modeling of this paper idea that underpins the paraboloidal dish concentrator that is discussed in this article. A portion of the solar radiation that comes in from the right is reflected by the concentrator. Within the focus plane, the photons concentrate on a very small region that can accommodate a cavity transmitter. This area is known as the focal spot. Medium-to-high temperature applications have emerged as a topic of considerable interest in the field of solar energy in recent years. Following on from what we covered earlier, the paraboloidal dish concentrator gathers energy, which is then transported optically to a central cavity receiver, which performs a function that is analogous to the former. Problems during manufacturing or assembly, as well as less-than-ideal sunlight with a larger angular diameter, could lead to unfavorable effects such as a larger energy spot in the focus region, non-uniform heat flux concentration in the collector, or local heating in the concentrator. These effects could also be caused by sunlight with a larger angular diameter.

2. Model Configuration

Utilizing COMSOL's in-built capabilities, the Ray Optics Module was utilized to design a parabolic solar dish collector with just a focal height of 3 meters. In addition to that, the geometry consists of a teeny small cone in the focus plane that has two diameters. In fact, the induced flux onto that surface is going to be computed, and the concentration ratio is going to be figured out. The form of the cone can be altered to make it possible to calculate the concentration ratios for other cavity designs; however, for the purposes of this study, only the concentration ratio in the focus plane is calculated. It is possible to calculate the concentration ratios for other cavity designs.

3. Modeling and Simulation

When building solar power systems, it is essential to take into consideration all of the system's components, not simply the solar cell process through which the sun's energy is transferred and converted into electricity. The solar components, including their size, need to be accounted for in a comprehensive analysis of the system. Solar irradiance, also known as the focal length and radius of the dish, must be factored into the design in order to account for the fact that any one of these elements has the potential to influence how well the system functions.

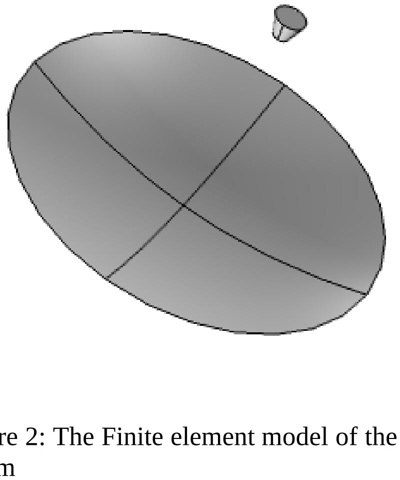

Figure 2: The Finite element model of the proposed system

4. Results and Discussion

We have created a numerical system that simulates a solar heat collection system and we have conducted a number of tests to show the optimal design that can be adopted in such systems. We chose two parameters which are: focal length and solar radiation. In this study, we tested different values for these two variables and studied their effect on the outcomes of the solar system, knowing that changing the focal length would affect the diameter of the dish used. Therefore, any change in the focal length will affect the diameter of the dish that we used in the study, meaning that the two variables are in fact three basic and important variables. The the range of the focal length was set in this study to be [0.5, 1, 2, and 3] while the irradiance values were 700 W/m2 and 1000 W/m2

We tested each focal length with these two irradiance values to test the Ray trajectory and the deposited power as well as the concentration ratios. The three parts are detailed below:

4.1 Ray Trajectories

Figure 3 illustrates the ray trajectories that are produced by the solar dish system. The receiver of the system is responsible for blocking the majority of the beam; as a result, only a very minor fraction of the rays that are traveling may be seen above the focal plane.

It can be seen from the figure that when the focal length is 0.5 meters, the ray trajectories were at the minimum of their values. This indicates that the receiver does not collect an excessive amount of rays, and this value gradually increases until it reaches its maximum value when the focal length is 3 meters.

A simulation was run in which the same range of focal length was used, but this time the sun irradiance was set to be 1000 W/m2 instead of the lower value used in Figure 3. Figure 4 depicts the results that were obtained from the updated simulation using the updated solar irradiance. It is possible to observe that whenever the focal length is longer, the ray trajectories are greater. This is something that may be observed. If we look at the two different figures side by side, we will notice that the outcomes of Figure 4 are superior than the outcomes of Figure 3, which suggests that the magnitude of the ray trajectories increases whenever the irradiance is increased.

4.2 Deposited Power

As we discussed in the section above about selecting the parameters that may affect the study, in this section we chose the same parameters to measure the deposited power on the receiver and the distribution of the heat on the dish surface. Figure 5 depicts the incident heat flux that makes its way to the surface of the collector. From the figure, plot A, we barely can see the flux but if we go ahead to plot B when the focal length became 1 the dotted flux began to appear and in plot C the flus became obvious. All of which are not concentrated in one spot of the dish because of the focal length and for sure the diameter of the dish affects the concentration distribution of the flux inside the dish.

Plot D from the figure when the focal length became 3, the flux concentrated on the receiver. An average value of around 15 W/mm^2 may be found at the plane's focus point, indicating that the heat flow is quite high. The statistical noise is also obvious, as a result of the fact that the incoming heat flux in certain border mesh elements is more than 20 W/mm^2.

This highlights the need of averaging in the azimuthal direction in order to compare the concentration ratio to values that have been

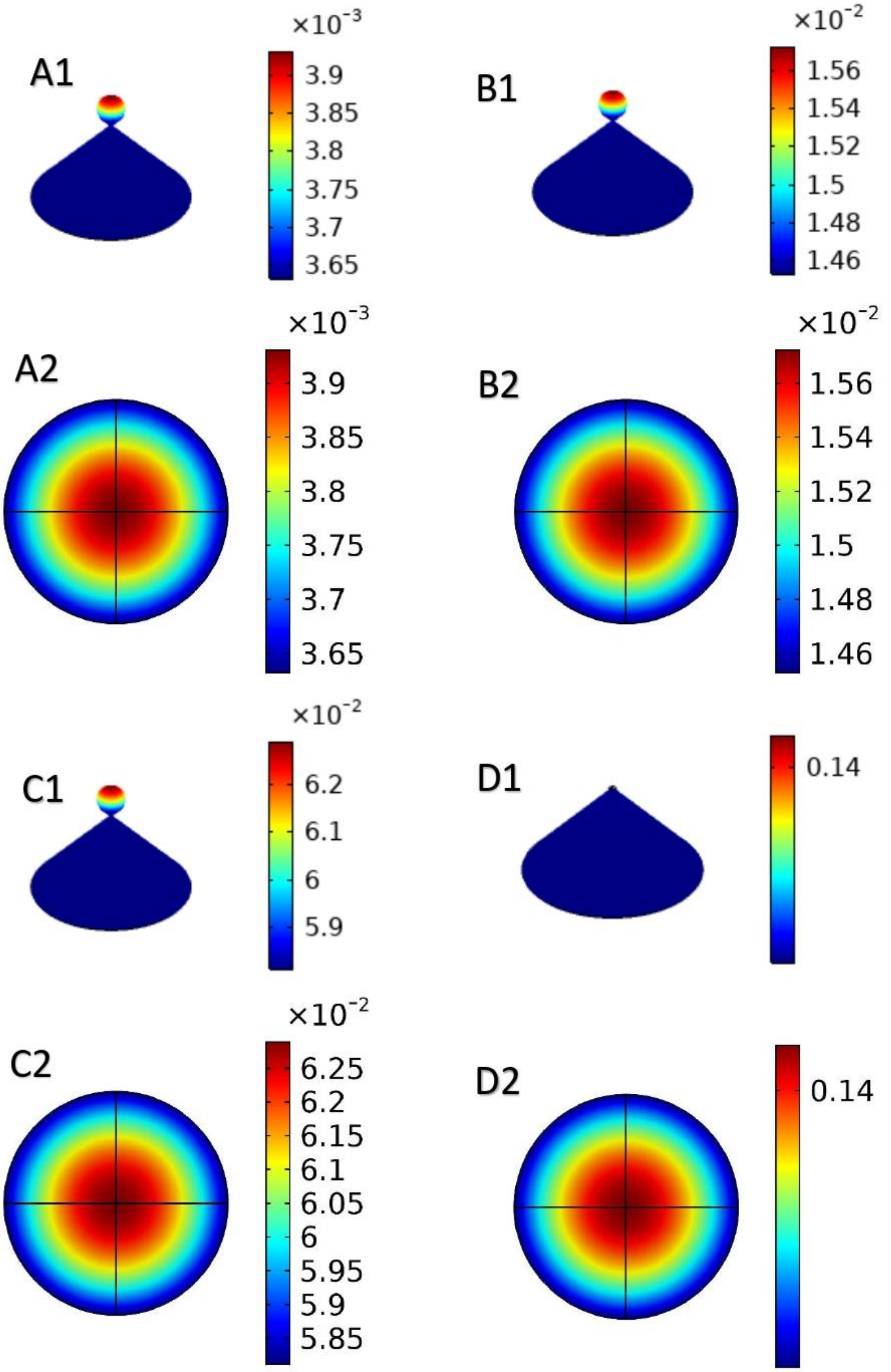

Figure 1: The receiver is struck by the ray trajectories after they have emanated from the illuminating surface when the irradiance is 700 W/m^2: A1 and A2) When the focal length is 0.5m; B1 and B2) When the focal length is 1m; C1 and C2) When the focal length is 2m; D1 and D2) When the focal length is 3m.

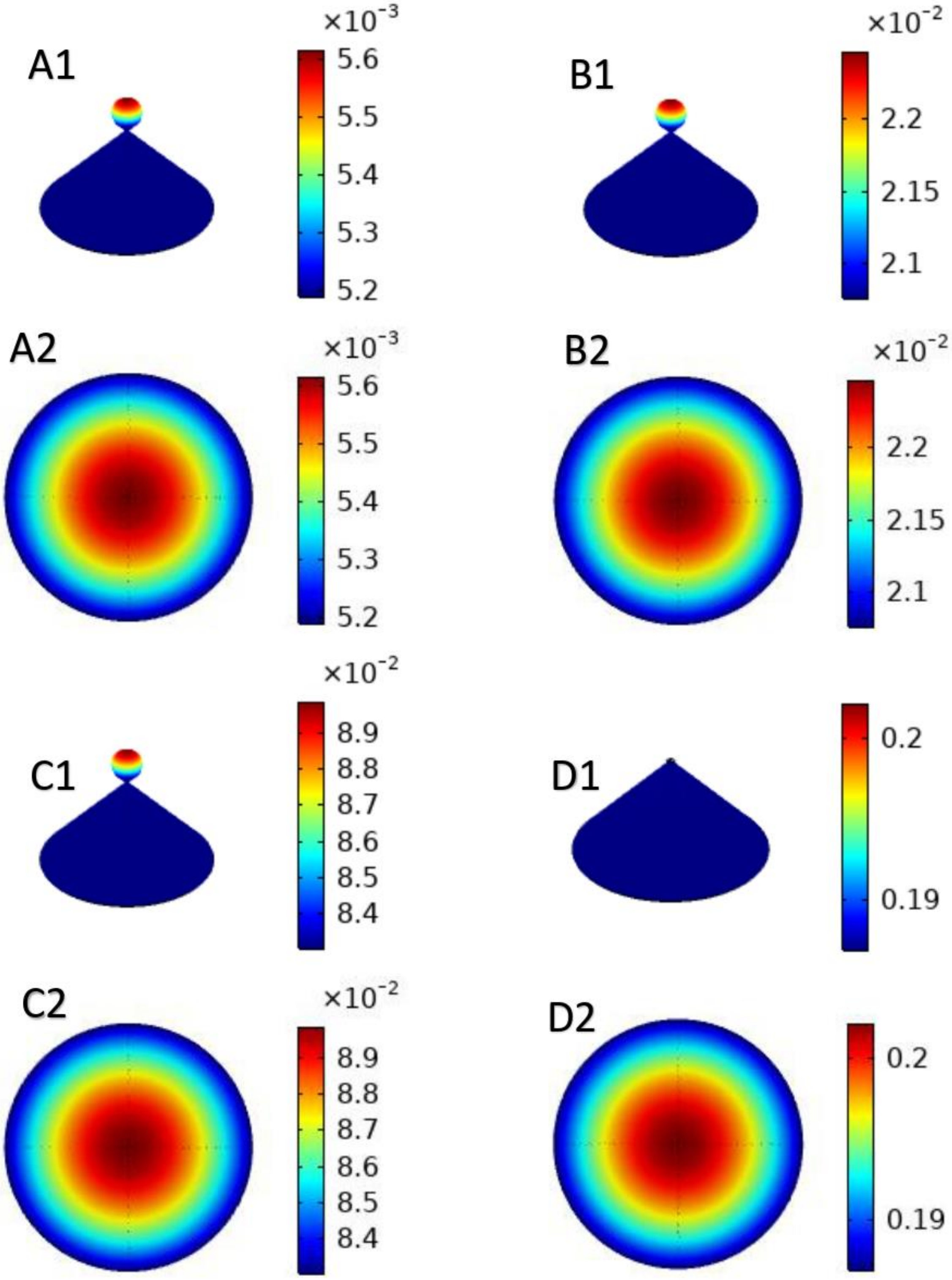

Figure 2: The receiver is struck by the ray trajectories after they have emanated from the illuminating surface when the irradiance is 1000 W/m2: A1 and A2) When the focal length is 0.5m; B1 and B2) When the focal length is 1m; C1 and C2) When the focal length is 2m; D1 and D2) When the focal length is 3m.

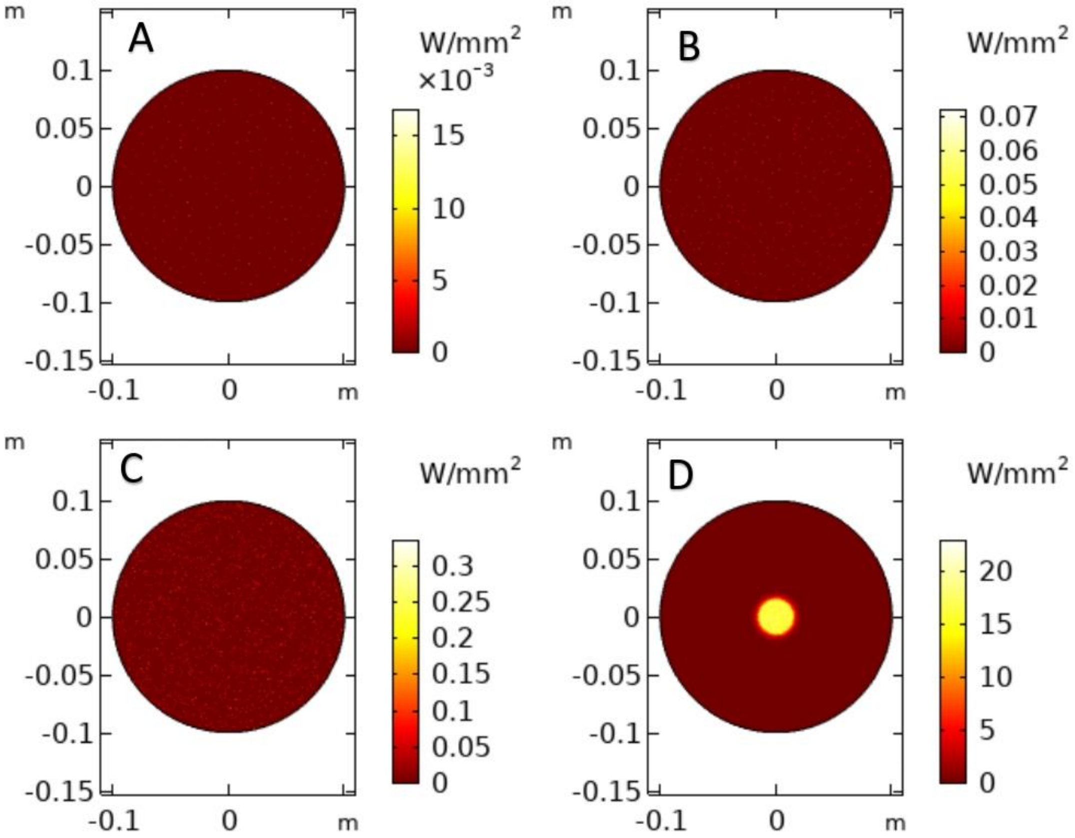

Figure 3: Paraboloidal reflector's incident heat flux on receiver's surface. Also disregarded are solar limb dimming impacts when the irradiance is 700: A) focal length 0.5; B) focal length 1; C) focal length 2; D) focal length 3

The incident heat flux that eventually reaches the surface of the collector is depicted in Figure 6, which shows how it got there. From the figure, which is the same as figure 4, plot A shows that we can hardly see the flux. However, if we move on to plot B, we can see that the dotted flux started to appear when the focal length became 1. Plot C shows that the flux became obvious, and it is important to note that the irradiance was set to 1000 in this instance. Because of the focal length of the dish, none of these factors are concentrated in a single area of the dish. Additionally, the diameter of the dish has an effect on the concentration distribution of the flux that is contained within the dish.

When the focal length was increased to 3, the flux became more focused on the receiver, as seen in plot D of the figure. At the spot where the aircraft focuses its attention, an average value of approximately 22 W/mm2 may be detected; this figure indicates that the flow of heat is very strong. Because the incoming heat flux in some border mesh components is greater than 31 W/mm2, the statistical noise is also very visible. This is the case as a result of the fact that the border mesh elements are very small.

This demonstrates the importance of averaging in the azimuthal direction in order to make a more trustworthy comparison of the concentration ratio to values that have been reported in the past.

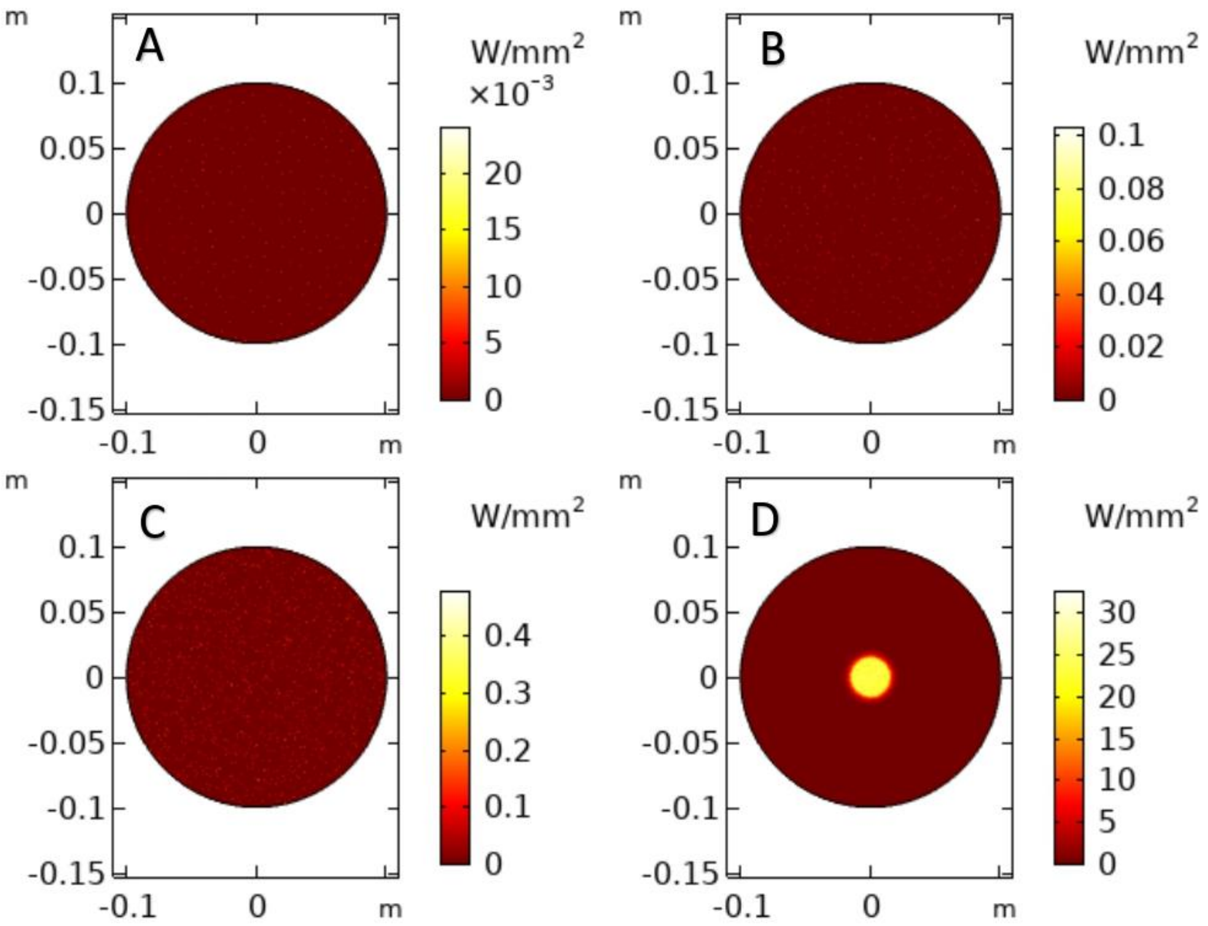

Figure 4: Paraboloidal reflector's incident heat flux on receiver's surface. Also disregarded are solar limb dimming impacts when the irradiance is 1000: A) focal length 0.5; B) focal length 1; C) focal length 2; D) focal length 3

4.3 Concentration ratios

The concentration ratio in the focal plane might contain some quantitative noise as a consequence of the unpredictable nature of the starting ray orientations; nevertheless, this noise does not significantly affect the accuracy of the ratio. The quality of the plots that are produced may be improved by using a few of the smoothing settings that are already integrated into the program. A further strategy for reducing the impact of the statistical noise is to run the simulation with a greater number of rays.

In a manner similar to that which is caused by surface roughness, the effects of sun shape have a tendency to disperse the incoming heat flux throughout a more extensive area in the focal plane. Figures 7-8 illustrate the concentration ratio that should be present in the focus plane for a perfect reflector. Where same rage of focal length and irradiance were used to generate the plots.

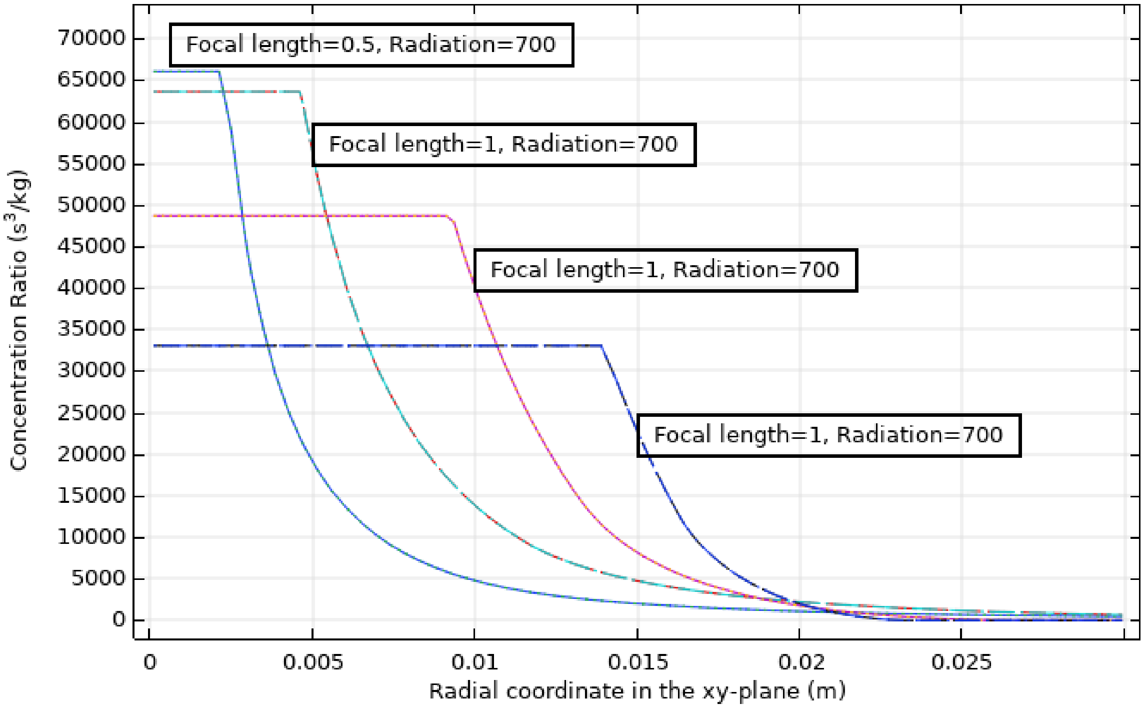

Figure 5: The azimuthally averaged concentration ratio when the irradiance is 700

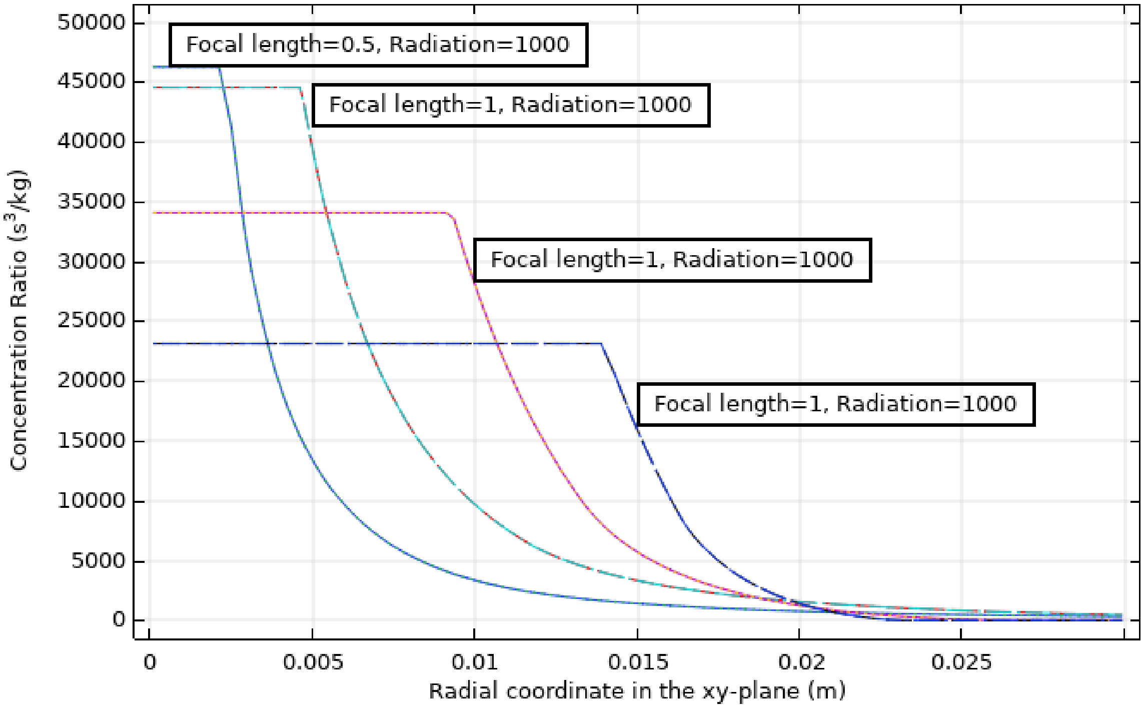

Figure 6: The azimuthally averaged concentration ratio when the irradiance is 1000

5. Conclusions

Solar energy has intrigued humanity since the start of civilization, and its collecting technology has grown quickly. Due to energy problems, improving the solar system's efficiency is crucial. Scientists have employed the solar concentrated system for years because it concentrates sun energy, increasing energy efficiency. A parabolic dish is a dish-shaped concentrated collector that reflects solar energy onto a focal point receiver. These concentrators are mounted on a two-axis sun-tracking structure. The dish's receiver uses the collected heat directly from the sun due to the reflected ray trajectories that hit the dish surfaces and reflect to the receiver. The dish can reach high temperatures and might be used in solar reactors to produce solar fuels. Dishes are seldom used professionally for power generating, but engines are. This paper explains the advantages of this technology in a future where fossil fuel use is a real concern. In this study, a finite element model is used to find a model that may be utilized to gather the maximum amount of heat from the sun. The results of this study are presented in this article. The model was simulated using COMSOL Multiphysics, and the findings indicated that the focal length ought to be at least 3 meters and the irradiance ought to be greater than 700, particularly 1000, for the best flux concentration to be achieved.

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