DESIGN, FABRICATION AND TESTING OF PARABOLIC DISH SOLAR CONCENTRATOR

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Abstract

The Parabolic Dish Solar Concentrator (PDSC) plays a vital role in harnessing solar energy efficiently. Harnessing solar energy effectively is crucial in the quest for sustainable energy solutions, and the Parabolic Dish Solar Concentrator stands out as a promising and simple technology in this regard. The parabolic dish solar concentrator, with a 1.84-meter aperture diameter, 0.342-meter depth, and 0.619-meter focal length, was designed, fabricated, and tested. Using a concentrating reflector, heat from the sun is focused on a receiver. The main objective of the project is to design, fabricate, and test the Parabolic Dish Solar Concentrator. At the focal point, the collected energy is used for heating water and cooking rice, eggs, and potatoes in the receiver. The receiver arrangement is supported by a four-bar mechanism, ensuring that the sun's rays are always directed toward the receiver at different times of the day. On a sunny, cloud-free day, the maximum temperature recorded was 370°C. The water heating thermal efficiency obtained was 24.67%. The cooking time varies due to the intensity of solar radiation and the time of day. It was observed that during mid-day, the cooking time was shorter because of the higher intensity of solar radiation.

Keywords: Parabolic Dish, Receiver, Solar Concentrator

1. Introduction

The basic principle of solar thermal collection is that when solar radiation is incident on a surface a part of this radiation is absorbed and causes to increase the temperature of the surface. (John, et al., 1991). The global demand for energy, clean energy, is increasing rapidly. Protecting the environment through pollution control, particularly greenhouse gas emissions, has become a significant concern worldwide. The sun is considered the main source of energy. Sun energy is renewable energy, clean, it is available in all parts of the world, and it is not required costly and complicated technology. It can be used to produce a valuable energy source in most parts of the world. Also, countries with insufficient energy can consider the most suitable solution for development and economic growth (Majeed, et al., 2021). The parabolic dish solar concentrator is a progressing and emerging instrument in solar energy with the use of technology, harnessing the power of sunlight through engineering and optical principles.

Its exceptional capacity to focus solar energy into a focal point with previously unheard –of efficiency has drawn considerable research and development. Despite its incredible capabilities, there are still challenges to be addressed in order to fully harness the potential of this technology for widespread use.

Some of the previous work done in the area of solar concentrator shows that the system designed by Javier Diz-Bugarin, employs an offset parabolic concentrator with a dish diameter of 80 cm and a reflective aluminum foil surface, under incident solar radiation of 1000 W/m², the system achieved a power output of 303 W. In comparison, a another system, developed by M. Gwania, G. A. Abubakar, M. Abbas, M. Na Allah, and J. Danyaro, featured a parabolic dish of dimensions 55 x 70 cm, optimized for domestic applications such as frying oil and boiling water. This system achieved a maximum temperature of 180°C for oil heating and 100°C for boiling water on a sunny day.

2. Methods and Materials

The experiment was conducted on the campus premises located at Lamachaur, Pokhara, Nepal, which is situated at 28°12′30″N and 83°59′20″E, at an altitude of 822 m. Data on solar radiation were collected from the Department of Hydrology and Meteorology over a period of about one year, which helped to determine the average solar radiation. The work flow diagram is shown below Figure 1.

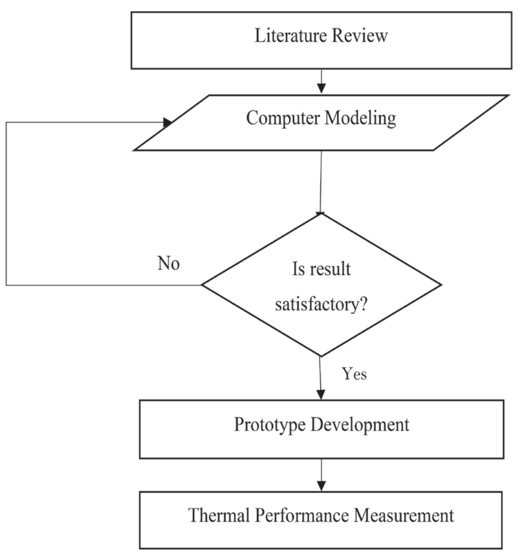

Figure 1: Flow diagram

2.1 Experimental Design:

The parabolic dish was constructed using an old satellite dish. The frame of the dish was cleaned properly for further investigation. First, the frame was tested to check for its parabolic shape, and certain adjustments were made. The focal distance and depth of the dish were calculated. The frame was fastened to the stand base with the help of fasteners. Using the calculated focal length, a steel support was constructed and welded to the stand base, allowing for easy horizontal movement to track the sun from east to west manually.

Considering the diameter of the pot, a receiver was constructed to support the pot and keep it at the focal point. This receiver was fastened to the steel support and arranged with the help of a four-bar mechanism to adjust the reflected rays toward the focal point throughout the day. The frame of the dish was covered with a thin GI sheet to reduce the overall weight of the dish and support the reflecting material. The reflecting material was glued onto the frame. Figure 2 shows the film cutting diagram and sample. Vertical movement was allowed with the help of a mechanism constructed in the workshop.

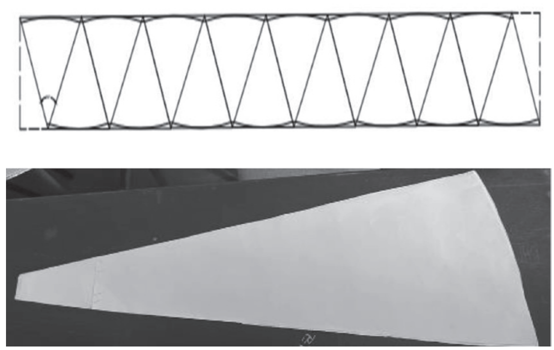

Fig. 2: Cutting Diagram of Vinyl Film, Paper Sample for cutting the reflective film

2.2 Material Selection:

In the development of solar concentrators, careful material selection and geometric optimization play pivotal roles in maximizing system efficiency. Through a comprehensive review of relevant literature, it is well-established that the power output of parabolic dish concentrators is directly proportional to the surface area, which in turn is a function of the dish diameter. In initial trials with smaller dish dimensions, observed a significant reduction in the concentration of sunlight, leading to a lower power output. The reduced surface area limited the amount of incident solar radiation that could be captured and focused onto the receiver. Consequently, the thermal energy available for conversion was insufficient for achieving optimal performance.

To address this limitation, the design was modified by increasing the diameter of the parabolic dish, the receiver and depth of dish. This adjustment was informed by theoretical models and experimental data indicating that larger dish diameters enable greater solar flux concentration, thereby enhancing the overall power output. The increase in dish size also ensures a more uniform distribution of concentrated sunlight onto the receiver, improving the thermal efficiency of the system.

Solar concentrator can be made from a wide range of materials and the process of material selection depends upon its application. The operating environment and the strength required are the major factors that determine the materials.

Reflecting Material Specification:

Reflective Material: vinyl film (also called as window film)

Thickness: 0.1524 mm

Reflective: 88**%**

Thermal Conductivity: 0.17 W/m·k.

2.3 Design Related Terms

2.3.1 Aperture Area:

The area of the concentrator dish (m^2) is the total area of the solar collector surface, and also is the area that receives solar radiation. The area of the concentrator is given by:

$A_a = \pi r_a^2$

2.3.2 Rim Angle:

The rim-angle is the angle measured at the focus from the axis to the rim of the solar parabolic-truncated. The rim angle ($\emptyset_{rim}$) can be calculated by:

$\text{Tan}(\emptyset_{rim}) = r_a / f - h$

Where

r_a = radius of concentrator

h= Depth of concentrator

2.3.3 Receiver area:

It is the area that receives the reflected solar radiation, it can be calculated by using formula:

$A_r = \pi r_r^2$

2.3.4 Concentration Ratio:

The concentration ratio (C) is the ratio of the dish area to the receiver area. It is essential find to design a parabolic dish with a concentration ratio greater than 10.It is calculated using the given formula:

$C = A_a / A_r$

2.3.5 Focal Length:

The solar parabolic dish reflector is used to reflect solar radiation to the receiver, which in turn reflect and focuses the radiations on the focal point. The focal length is the distance from the vertex to the focus. The relation between the diameter of the collector, the depth of the solar dish, and the focal length is shown in Fig. 3:

Focal length (f) = $(r_a)^2/4h$

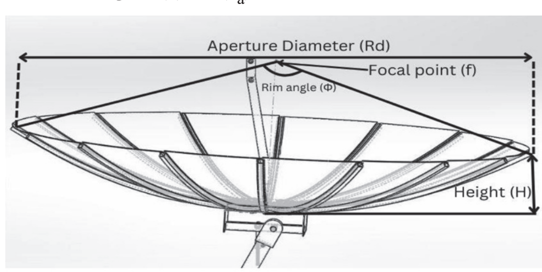

Figure 3: Parabolic Dish Showing Different Parameter (Drawn using Solidworks)

Where, D_a denotes aperture diameter, D_r denotes receiver diameter, f denotes focal length, Q denotes rim angle, and H denotes the vertical length of the curvature.

3. Results and Discussion

Different parameters was calculated analytically in order to determine the thermal performance of the parabolic dish solar concentrator. Parameter like energy input, energy output, power, efficiency etc. were calculated for the evaluation.

Aperture Diameter (D_a) = 184cm.

Receiver Diameter (D_r) = 20 cm.

The depth of concentrator (h) is measured as 34.2cm.

Table 1: Design data of parabolic solar concentrator.

S. N.	Parameters	Formula	Result
1.	Aperture area (Aa)	Aa = $\pi(r_a)$^2	2.659m^2
2.	Receiver area (Ar)	Ar = $\pi(r_r)$^2	0.031m^2
3.	Focal length(f)	f= (r_a)^2/4h	0.619m
4.	Concentration Ratio(C)	C= A_a / A_r	85.774
5.	length of circumference(L)	L=2× π×r_a	5.781m
6.	Rim Angle($\emptyset_{rim}$)	tan($\emptyset_{rim}$)= r_a/(f-h)	73.24º

Table 2: Performance parameter of parabolic dish solar concentrator.

S. N.	Performance parameters	Result
1	Input Energy	1229.203w
2	Output Energy	3,27,600 J
3	Efficiency	24.67%
4	Power	303.33w
5	Average upcoming solar radiation	462.280w/m^2

The thermal efficiency of about 24.67 % was obtained. Many factors are responsible for lower efficiency of the concentrator, some of them are wind, reflectivity of reflective material, time of the day, seasonal variation and so on.

In this study, the water heating efficiency of the parabolic dish solar concentrator obtained was 24.67 %. While water heating efficiency of about 10.75 % was obtained by research article “Design, Construction, and Evaluation of the Performance of Dual-Axis Sun Trucker Parabolic Solar Cooker and Comparison of Cooker”(Tibebu et al., 2021). The different factors like reflective material, solar radiation intensity, size of the parabolic dish etc. affect the efficiency. The reflective material used in the article by (Tibebu et al., 2021) was aluminium foil where as in this project the reflective material used was vinyl film which has greater reflectivity.

3.1 Test Results:

3.1.1 Thermal Performance Result:

The test was done to determine the cooking time for different types of items like water, egg, rice. The test results are given in Table 2.

Table 3: Quantity and time interval of foods cooked by solar concentrator

S. N.	Experiment Day	Cooked Item	Cooking Time Interval	Quantity	Time Taken (Min.)
1	28-Feb-24	Water	12:10 PM - 12:30 PM	500ml	20
2	28-Feb-24	Egg	1:32 PM - 2:00 PM	2 Egg	28
3	28-Feb-24	Egg	2:30 PM - 3:02 PM	3 Egg	32
4	29-Feb-24	Rice	11:58 AM- 12:21 PM	100g	23
5	29-Feb-24	Rice	12:44 PM - 1:20 PM	500g	36
6	1-Mar-24	Water	11:50 AM- 12:08 PM	1000ml	18

Comparing the heating time of water with different energy sources like Solar Concentrator, Gas, Electric Mug, Coil Heater and Fire wood.

Table 4: Cooking Time taken by different energy source

S. N.	Source of Energy	Quantity of water	Initial Temp. (°C)	Final Temp. (°C)	Time Taken
1	Solar Concentrator	1 litre	17	97	19 Min.
2	Gas	1 litre	18	98	7 Min.
3	Electric Mug	1 litre	18	98	3.5 Min.
4	Coil Heater	1 litre	18	98	8.5 Min.
5	Fire Wood	1 litre	18	98	8 Min.

Comparison of Parabolic Dish Solar Concentrator with other energy sources for heating water to 98°C was done. The Solar Concentrator, Gas, Electric Mug, Coil Heater, Fire Wood took 19 min, 7 min, 3.5min, 8.5 min, 8 min respectively to boil water. After analyzing the above data, it was seen that the electric mug heats the water faster than other energy sources but the power of sources also affects the heating time. Although if there is high amount of solar intensity, the cooking time will be reduced. Thus, the Parabolic Dish Solar Concentrator will be best as an alternative source.

3.1.2 Temperature Variation throughout the day:

The temperature distribution of the parabolic dish solar concentrator on March 5th, recorded with a digital thermocouple, highlights key trends over the course of the day. Starting at 100°C at 11:50 AM, the temperature gradually increased, reaching 149°C by 12:15 PM. A sharp rise followed shortly after, with the temperature spiking to 203°C by 12:55 PM and continuing to climb, reaching its peak of 370°C at 1:46 PM.

After this peak, the temperature began to decrease. By 2:27 PM, it had dropped to 140°C. During the afternoon, there were fluctuations, with the temperature briefly rising to 252.1°C at 2:31 PM before gradually cooling down, reaching 66°C by 3:39 PM, and finally ending at 73°C by 3:40 PM. This data shows a rapid increase around midday, peaking early in the afternoon, followed by a gradual decline. The temperature distribution is illustrated in the Figure 4.

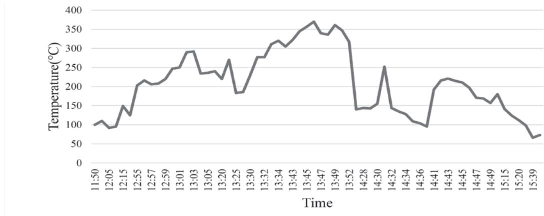

Figure 4: Time vs. Temperature Variation graph

4. Conclusions

In conclusion, an experimental investigation of the thermal performance of a parabolic dish solar concentrator was conducted in the campus premises located at Lamachaur, Pokhara. The experiment exposed that, in February 2024, the Parabolic Dish's thermal efficiency is 24.67%. Following the experiment, 303.33 W of cooking power was obtained. The usage of the parabolic dish solar concentrator to heat water, for boiling eggs and cooking rice was successful. Throughout the day, the manual tracking mechanism made sure the parabolic dish was always pointed toward the sun for maximum energy capture. Overall, this study highlights the value of creativity in resolving environmental problems and shows how parabolic dish solar concentrators may be used as a sustainable energy source.

One of the primary drawbacks of solar energy is its intermittency, as solar power generation is limited to daylight hours. To overcome this, a thermal storage system can be integrated with the parabolic dish concentrator, enabling the stored heat to be used when direct sunlight is unavailable.

Solar concentrators perform optimally when they are aligned precisely with the sun to maximize the capture of incident solar radiation. Traditional manual tracking systems are labor-intensive and often result in suboptimal alignment, leading to reduced energy concentration and efficiency. To address this, an automatic solar tracking system can be implemented, ensuring continuous realignment of the dish to maintain optimal orientation toward the sun throughout the day.

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