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Research Article

Experimental study of parabolic dish collector based solar cooker with different thermal energy storage system

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ABSTRACT

The study focuses on the performance of a parabolic dish collector-based solar cooker integrated with different phase change materials (PCMs) to address the challenge of improving solar cooking efficiency. Conducted under the climatic conditions of Gwalior (M.P.), India, the experimental setup featured a parabolic concentrator with an area of 5.908 m^2. Erythritol and Paraffin Wax were tested as PCMs for solar-assisted rice cooking with water under varying solar radiation levels. Results show that Erythritol outperformed Paraffin Wax in terms of heat retention and cooking efficiency. With Erythritol, the maximum PCM temperature reached 107°C under solar radiation of 649 W/m^2, achieving a cooking time of 45 minutes and a peak food temperature of 96°C. In comparison, Paraffin Wax exhibited limitations, providing insufficient heat for proper cooking under similar conditions. The average exergy efficiency was 2.6% for Erythritol and 1.1% for Paraffin Wax. This study demonstrates the superior thermal performance of Erythritol as a PCM, highlighting its potential to enhance solar cooking technologies. The novelty of this work lies in its comparative evaluation of PCMs under real-world conditions, providing practical insights for optimizing solar thermal systems.

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INTRODUCTION

Solar energy is a clean and renewable resource that can be effectively utilized for cooking. Solar cooking offers an eco-friendly and innovative approach that minimizes dependence on fossil fuels while contributing to climate change mitigation. Normal Solar cookers are generally slower than conventional cooking methods, to reduce the cooking time concentration type solar cooker can be used. Due to concentration of solar radiation, temperature inside the cooker increases at higher rate than conventional solar cooker.A completely novel thermosyphon SWH system and numerically and experimentally assessed its performance. During the night (off-sunshine hours), it was determined whether adding PCMs to the cylindrical

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storage tank would increase the amount of solar energy that was being used. According to their findings, In the conventional tank without PCM, the water temperature fluctuates between 35–72 °C in July and 20–60 °C in January [1]. The use of the bubble injection technique to improve an LHTES' performance. Due to the PCM and bubble's different densities, a bubble-driven flow was created in the LHTES, which increased the liquid PCM's mixing and reduced the formation of thermal stratification. Additionally, faster flow rates improve heat transmission between the heat source and PCM and can speed up LHTES charging [2]. A thorough analysis of PCMs' use in solar domestic hot water systems for both integrated and non-integrated solar collectors was presented [3]. The addition of the PCMs led to increased thermal performance, a smaller storage tank, longer working times, and access to neighboring isothermal water. The thermal performance of evacuated tube using a TES system and a CPC solar collector. Based on the degree of stratification in a sensible heat storage system with a constant heat load, the PCM was selected. The cascaded configuration of PCMs allowed the HTF feed to be manufactured at a lower temperature, increasing the quantity of usable heat energy gained.[4].The results of an experimental study by Nene and Ramachandran [5] indicate that PCM is a generally efficient technology for storing thermal energy, However, efficiency is only justified when capacity increases.In seven different towns across India, Singh et al. studied the technical, economical, and environmental viability of evacuated tube type SWH systems.[6]. Cupric oxide (CuO) nanoparticles and carbon nanotubes (CNTs) were incorporated to enhance the optical properties of black paint applied on aluminum substrates. It was concluded that 4% CNTs/CuO-black paint had a high selectivity of 90.2%. The new coating's application enhanced the surface's spectral selectivity and roughness [7]. To reduce the quantity of PCM that needs to be enclosed, Ahmed et al quantitatively researched and created a novel form of combination sensible-latent heat TES system. The study includes a comparative analysis for four alternative TES system configurations, including three different cascaded layered sensible rods with PCM arrangements and a single layered sensible rod with PCM configuration. The 40% - 20% - 40% volume fraction arrangement of the TES system was found to be the most effective of the three variants. Sensible heat storage and cascaded LHTES systems were both competitively and effectively replaced by the proposed TES system[8].The thermal performance of a CPC linked with an evacuated tube receiver was assessed and taking into account two distinct reflectors, the extended cusp and the w-shaped cavity. The heat gained by the CPC with cusp type reflectors and the CPC with 40% truncation showed 30% augmentation (9.23 MJ) and 26% (9 MJ), respectively, when compared to the cavity type reflectors. This improvement was related to the CPC collector's considerably bigger aperture size[9]. Sensible storage combined with solar collector under fluctuating climatic circumstances. To investigate the temporal and spatial temperature variation over time and under various climatic conditions in the TES tank and solar collector, an internal transient code was developed. Mathematical evaluations are done on the effects of The mass flow rate, along with the height and diameter of the TES tank, influences dimensionless parameters such as energy and exergy efficiency. The accumulated thermal energy can be utilized for multiple applications, including hot water supply, underfloor space heating, and indirect heating through a heat pump system. The storage material temperatures ranged from 40 to 60 °C[10]. Commercial-grade acetamide was used as a PCM for late-night cooking experimentsin a solar cooker. The solar cooker with PCM has an additional benefit over the normal solar cooker in that it may be used for evening cooking [11]. Through water boiling tests, examined the thermal performance of an 8 m^2 PDSC. The 20-liter cooking pot tested at the PDSC's focal point had a 21.61% total efficiency. On a clear day, Patil et al. managed to reach a water temperature of 98 °C[12]. Many researchers have explored different thermal energy storage materials to retain solar energy as heat. Sensible heat storage systems have utilized materials such as black oil, black-coated granite, sand, iron grits, stone pebbles, and iron balls, whereas latent heat storage has been achieved using commercial-grade acetamide[13][14].

Different thermal energy storage systems have been investigated for integration with parabolic dish collectors, but further optimization is still required. Future research should emphasize selecting the most efficient and economical storage materials and configurations for solar cookers. This may include examining various phase change materials (PCMs), composite options, or innovative storage designs aimed at improving the system's overall reliability and performance.

In this study, design the experimental setup, including the parabolic dish collector specs, the types of thermal energy storage systems to be investigated (e.g., phase change materials, sensible heat storage), and any ancillary equipment required. Determine the factors that will be measured during the experiment, such as temperature profiles, energy storage efficiency, cooking time, and overall system performance.

LITERATURE REVIEW

Solar cooking is increasingly recognized as a sustainable approach to meeting the rising need for clean energy. Parabolic dish collectors (PDCs) stand out among solar cookers because they can concentrate solar radiation and generate high temperatures. Nevertheless, their dependence on sunlight makes it essential to integrate thermal energy storage (TES) systems to maintain consistent and efficient performance. This section reviews relevant literature, emphasizing recent advances and identifying gaps. Parabolic dish collectors have been extensively studied for their ability to focus solar radiation onto a receiver. Bhargav et al. [18] demonstrated that PDCs achieve higher thermal efficiencies compared to flat-plate collectors under similar operational conditions, making them ideal for cooking applications. However, the integration of TES systems remains a critical aspect of enhancing their usability during non-sunny hours.

Thermal energy storage (TES) systems are generally classified into sensible heat storage, latent heat storage, and thermochemical storage. In sensible heat storage, materials like water and sand retain energy through an increase in their temperature.. Kumar and Singh [19] analyzed the use of water as a TES medium in solar cookers and reported energy retention for up to two hours post-sunset. Nevertheless, the large volume required for sufficient heat capacity limits their practical application. Latent heat storage systems utilizing phase-change materials (PCMs) offer a more compact and efficient alternative. PCMs absorb and release heat during phase transitions, typically at constant temperatures. A recent study by Sharma et al. [20] evaluated paraffin wax as a PCM in solar cookers and observed a significant extension of cooking duration compared to systems without storage. Similarly, Ahmed et al. [21] investigated eutectic salts as PCMs, noting their ability to store higher quantities of thermal energy but highlighting concerns about long-term thermal stability. Thermochemical storage, which involves reversible chemical reactions, has also been explored for solar energy applications. According to Li and Zhou [22], this method provides the highest energy density among TES systems. However, its high cost and complex integration process restrict its usage in small-scale applications such as solar cookers.

Despite these advancements, the selection of suitable TES materials and their compatibility with PDC-based systems remains an area requiring further research. Zhang et al. [23] highlighted the importance of understanding material properties, such as thermal conductivity and heat capacity, to optimize the efficiency of TES systems. Additionally, the impact of environmental conditions, including wind and ambient temperature fluctuations, on the performance of these systems has been underexplored.

EXPERIMENTAL SETUP AND INSTRUMENTATION

In the experimental setup a parabolic dish collector made up of aluminium sheets having back insulation of foam material is used. A concentric cylinder vessel Fig. 3 (a) having outer diameter 20 cm and internal dimeter 15 cm and height of 15 cm was fabricated to house PCM and cooking material. Erythritol ($C_4H_{10}O_4$), a sugar alcohol, and paraffin wax are utilized as thermal energy storage media for capturing and retaining solar heat energy. Outer side of concentric cylinder is filled with PCM to absorb solar radiation. All the experiments were done in the month of April 2023 at the roof of Mechanical Engineering department, Madhav institute of technology and science, Gwalior (Latitude 26.2314° N, Longitude 78.2053° E).

The thermophysical properties of Erythritol and paraffin wax are given in the Table 1.[15].

Measuring Instruments

The Performance of parabolic disc collector using with different PCM are analysed by various instruments and data were collected. The solar radiation and temperatures at different points are recorded at hourly basis, inside and outside relative humidity is measured by hygrometer. Table 2 shows the range of measuring instruments with their accuracy used in the experiment.

Theory and Analysis

Parabolic dish collector

A solar parabolic collector employs a parabolic reflector to concentrate sunlight onto a central receiver, where the captured solar energy is absorbed and transformed into

Table 1. Thermo-physical Properties of the selected PCM

Thermal energy storage material	Erythritol	Paraffin Wax
Chemical Formula	$C_4H_{10}O_4$	C_nH_{2n+2}
Melting Temperature (°C)	117.7	46-65
Melting enthalpy (kJkg^{-1})	340	180
Thermal conductivity (Wm^{-1}K^{-1})	0.733	0.2
Density [kgm^{-3}]	1450	840
Specific heat (kJkg^{-1}K^{-1})	1.68	2.1

Table 2. Measuring Instruments with their accuracy

Device	Measured Parameter	Accuracy	Range
Pyranometer	Global Radiation	± 5%	0-2000 W/m^2
Thermocouple	Temperature	± 0.2% °C	0-200 °C
Measuring Tape	Length	± 1 %	0-5 m
Weighing Machine	Weight	± 1 %	0-30 Kg

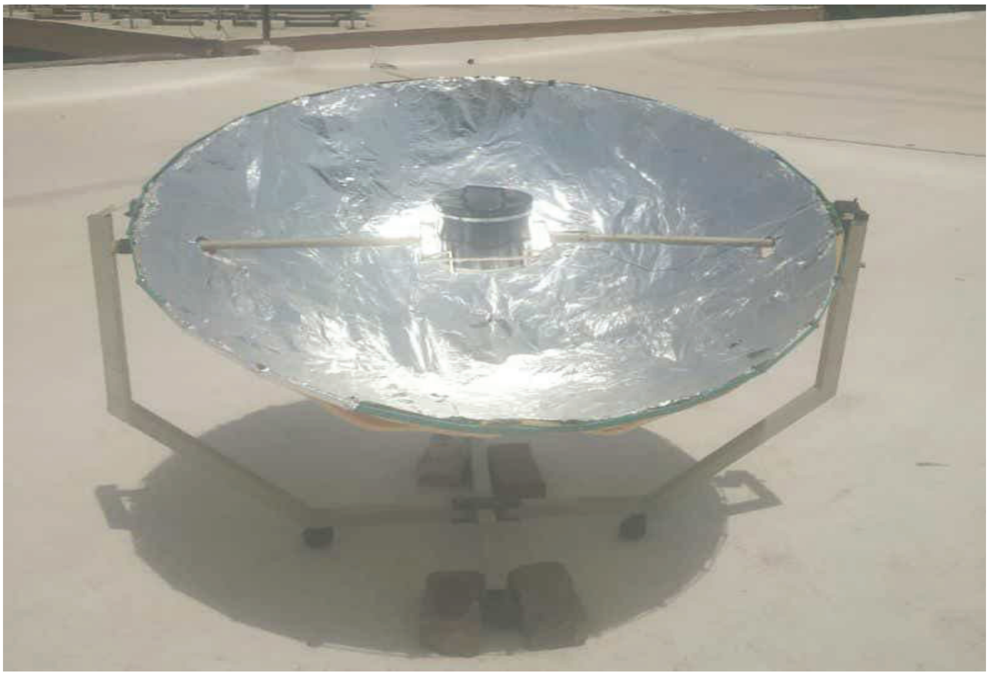

Figure 1. Photograph of experimental setup.

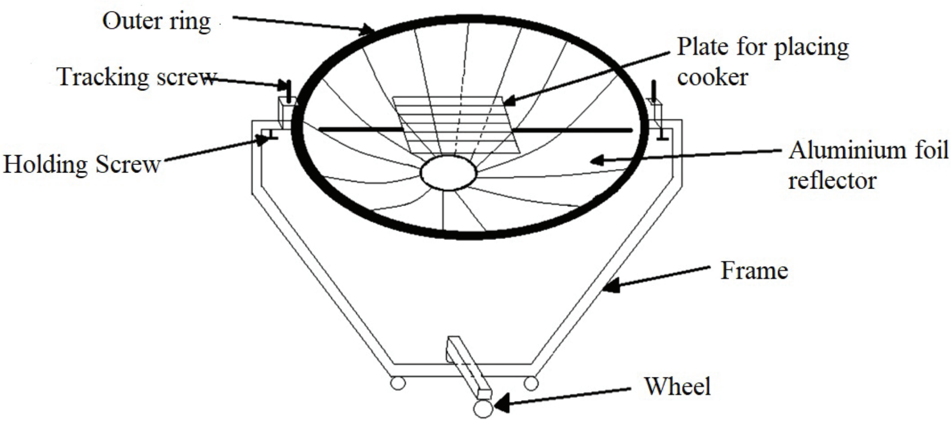

Figure 2. Schematic diagram of parabolic dish collector.

heat. Figures 1 and 2 present the photograph and schematic diagram of the experimental setup.

Parabolic concentrator's aperture area

According to Komolafe C et al. [14] the area (A_{pc})that receives solar radiation is known as the concentrator's aperture area. It is given by

$$A_{PC} = \frac{\pi D_{PC}^2}{4} \quad (1)$$

Where, D_{PC} is the diameter of parabolic dish opening $D_{PC} = 1.4\ m$

From equation (1) Aperture Area $A_{PC} = 1.54\ m^2$

Parabolic dish focal length

Focal length (F) of a parabolic dish can be defined as distance between vertexes to focus point of dish.According to Komolafe C et al. [14]it can be calculated by -

$$F = \frac{D_{PC}^2}{16h} \quad (2)$$

Where h is the depth of parabolic disc and its value is, $h = 0.38\ m$

From equation (2) Focal length of parabolic dish F = 0.322 m

Surface area of parabolic dish collector

According to Komolafe C et al.[14]surface area of parabolic dish collector can be calculated using equation

$$A_s = \frac{8\pi}{3} F^2 [\left\{1 + \left(\frac{D_{PC}}{4F}\right)^2\right\}^{\frac{3}{2}} - 1] \tag{3}$$

Using equation (3), the calculated surface area (A_s) of the parabolic dish is 1.93 m^2.

THERMAL ANALYSIS

In this study main objective is to investigate the thermal performance and cooking time of parabolic dish collector type solar cooker. In the experimental setup concentric cylinder type solar cooker whose outer annular area is filled with PCM was put on the focal point of parabolic solar dish collector at 9:30 am and exposed to solar radiation for charging of phase change material. After 60 minutes at 10:30 am solar cooker loaded with 200 gm rice and 400 gm water for cooking and system remains under continuous exposure of solar radiation. In approximately 30 minutes, the rice was cooked using both heat energy stored in PCM and solar radiation energy.

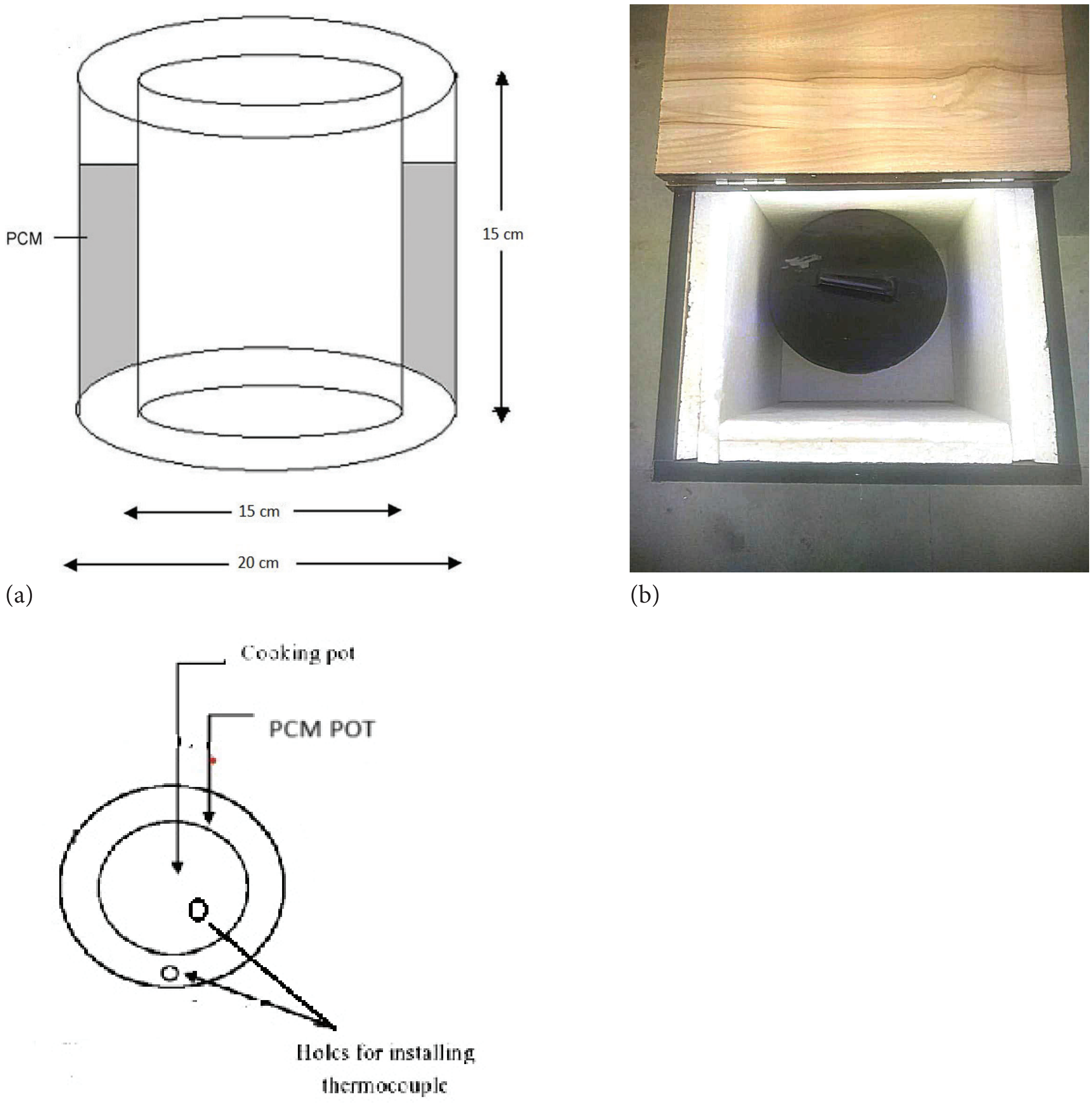

Figure 3. (a) Schematic diagram of concentric cylinder solar cooker (b) Photograph ofInsulation box with solar cooker pot(c) Diagram showing space for thermocouples.

For the initial phase of experiment where only PCM is put in the outer side of pot Heat stored in the phase change material can be given by according to Yadav V. et al. [13]

Heat stored in PCM = Sensible heat energy stored + Latent Heat stored

$$Q_{PCM} = m_{PCM}[C_{PCM}(T_m - T_{PCM}) + L + C_{PCM}(T_{PCMSH} - T_m)] \quad (5)$$

Specific heat of liquid and solid form of Phase Change Material is assumed to be same.

After some time when cooking material (Rice and Water) is put in the cooking pot energy balance can be given byaccording to Yadav V. et al.[13]

Heat Utilized in cooking = Heat stored in PCM + Direct solar radiation − Heat loss to environment

$$\text{Heat Utilized in cooking} = m_{PCM}[C_{PCM}(T_m - T_{PCM}) + L + C_{PCM}(T_{PCMSH} - T_m)] + I \times A \times \tau - UA_p(T_p - T_a) \quad (6)$$

After cooking of first batch of rice, solar cooker again placed on parabolic dish solar cooker and exposed to sun radiation to again charge the PCM. After charging the PCM solar cooker lifted off from the parabolic dish and put inside an insulator box and loaded with food to be cooked. Readings were taken after every 30 minutes.

According to Yadav V. et al.[13]Energy balance inside the insulator box can be given by

Heat Utilized in cooking = Heat stored in PCM

$$\text{Heat Utilized in cooking} = m_{PCM}[C_{PCM}(T_m - T_{PCM}) + L + C_{PCM}(T_{PCMSH} - T_m)] \quad (7)$$

According to Senthil R. et al[16] Exergy input to solar cooker expressed as follows

$$E_{xi} = I \times \Delta t \times A_{pc}[1 + \left(\frac{T_a}{3T_{sun}}\right)^4 - \left(\frac{4T_a}{3T_{sun}}\right)^4] \quad (8)$$

Exergy output from parabolic dish collector can be calculated as

$$E_{xo} = mc_p[(T_f - T_i) - T_a \ln(\frac{T_f}{T_i})] \quad (9)$$

According to Onokwai O. et al[17]Exergy efficiency is given by

$$\emptyset = \frac{Exergy\ output}{Exergy\ input}$$

With the help of Eq. 8 and Eq. 9

$$\emptyset = \frac{mc_p[(T_f - T_i) - T_a \ln(\frac{T_f}{T_i})]}{I \times \Delta t \times A_{pc}[1 + \left(\frac{T_a}{3T_{sun}}\right)^4 - \left(\frac{4T_a}{3T_{sun}}\right)^4]} \quad (10)$$

RESULTS AND DISCUSSION

Case 1 - PCM used – Erythritol, Cooking Material used - Rice + Water

In first phase of experiment phase change material i.e. The outer section of the concentric cylinder solar cooker was filled with erythritol. The solar cooker was placed on the parabolic dish collector plate and exposed to solar radiation at 9:30 a.m. to charge the PCM. Initially Ambient temp. was 25°C and raises up to 29°C at 10:30 am. PCM temp. started increasing from 26.5°C and raises rapidly up to 98°C in one hour at an average approximate rate of 66.73 W. Similarly pot bottom temp. rises from 27°C to 173°C. Solar radiation intensity in morning hour ranges between 436 W/m² to 579 W/m². Figure 4 shows the experimental temperatures and solar radiation during the day.

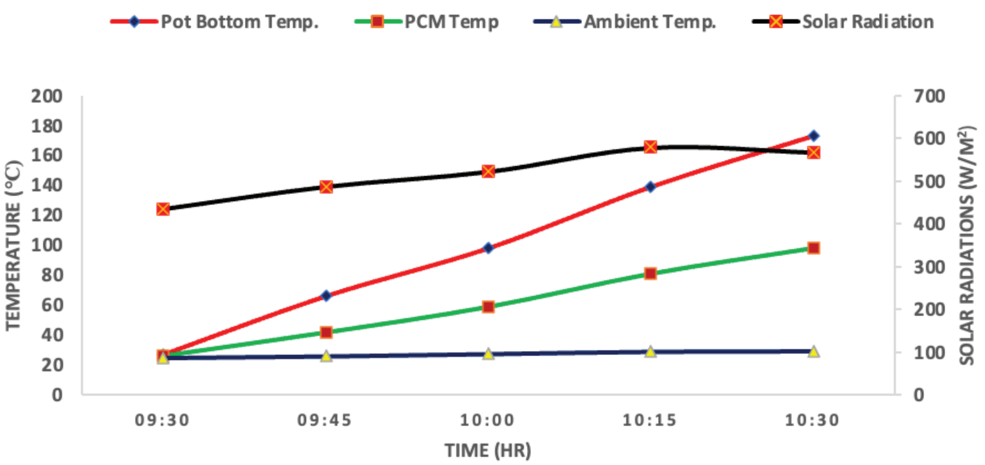

Figure 4 . Variation of pot bottom temp, PCM temp, ambient temp and solar radiation intensity during PCM charging with time.

Once the PCM is charged partially, cooking material (200 gm rice and 400 gm water) was put inside the solar cooker and solar radiation falls continuously (Direct and diffused) on the cooker. The food temperature begins to increase from the ambient level, while the PCM temperature gradually decreases, indicating the transfer of stored heat from the PCM to the food through the separating wall. During this phase, the PCM temperature. drops from 97°C to 90°C in first 10 minutes and again rises up to 98°C. Pot bottom temp. drops abruptly to 82°C because sudden heat transfer to food and it again start rising to 179°C. Intensity of solar radiation ranges between 591 W/m^2 to 653 W/m^2. The food temperature reached 94 °C within 25 minutes, and the rice was observed to be properly cooked. Figure 5 illustrates the variations in cooking mixture temperature, PCM temperature, pot bottom temperature, and solar radiation intensity with respect to time.

For the second batch of cooking, solar cooker again exposed to solar radiation for charging of PCM. This time charging of PCM remain continue till 16:05 hr so that superheating of PCM can occur. Ambient temp. ranges between 36.2°C to 39.1°C. PCM temp. starts raising from 91°C and goes up to 169°C. Initially PCM temperaturerises at high speed but when it reaches near melting point of erythritol, it increases with decreasing rate. Around 12:30 after melting of PCM, PCM temp. again starts rising and PCM became superheated. Solar radiation during the charging process fluctuates because of clouds rapidly between 648 W/m^2 to 725 W/m^2. Readings were taken at every 30 min.Pot bottom temperature, PCM temperature, ambient temperature, and solar radiation intensity changes over time during another PCM charge are depicted in Figure 6.

To improve the effectiveness of the cooker and prevent heat transfer from the pot to the surroundings, the solar cooker pot containing the superheated PCM was removed

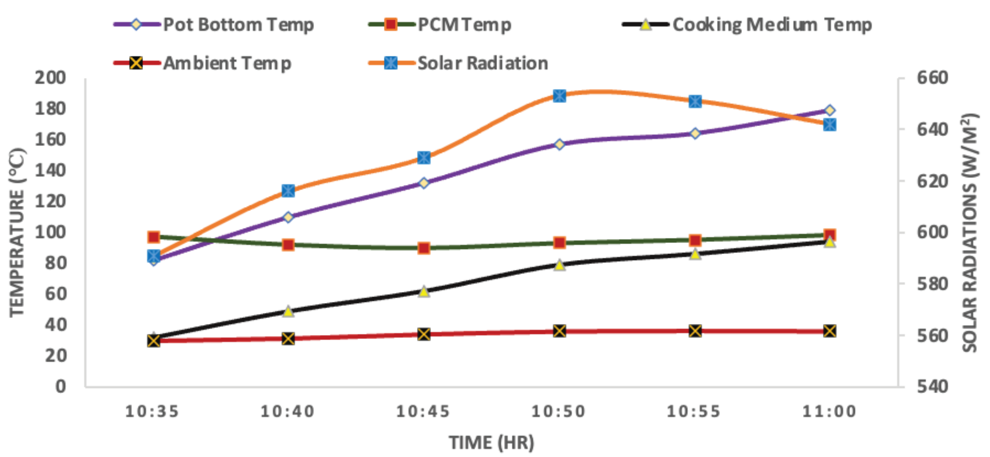

Figure 5. Variation of pot bottom temp, PCM temp, cooking medium temp and solar radiation intensity during cooking with time.

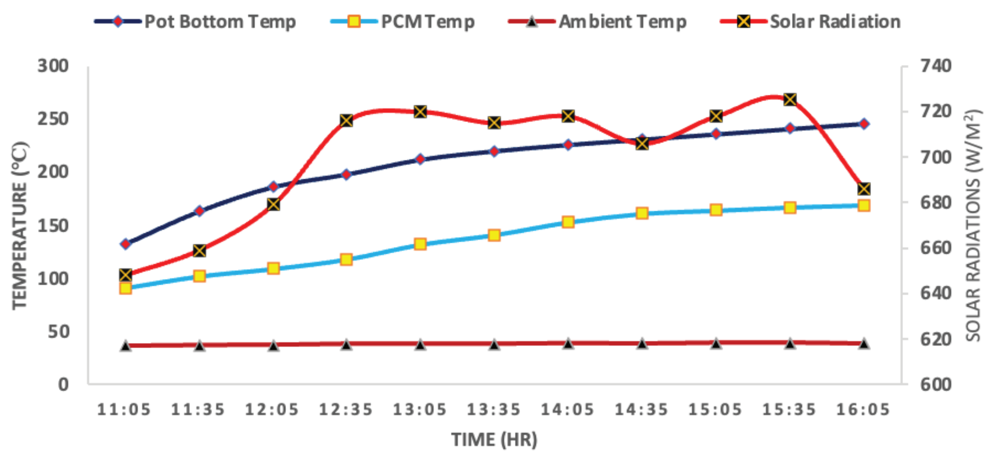

Figure 6. Variation of pot bottom temp, PCM temp, ambient temp and solar radiation intensity during again charging of PCM with time.

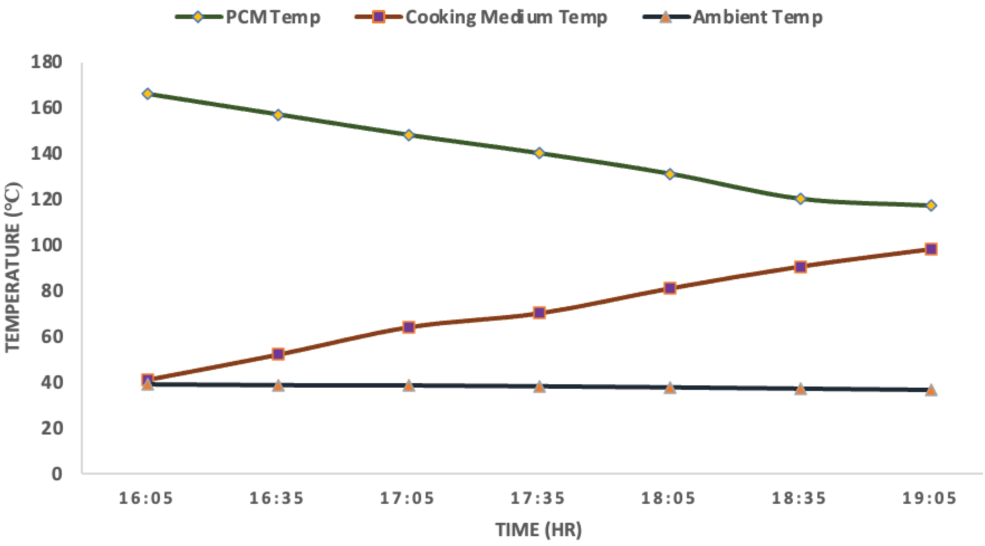

Figure 7. Variation of PCM's temperature, cooking medium temp, ambient temp during discharging of PCM with time.

from the parabolic dish collecting plate and placed inside an insulating box.Solar cooker pot loaded with 200 gm rice and 400 gm water to cook. As soon as time passes PCM temp. decreases to 117°C at an average heat loss rate of 15.24 W because of heat transfer from PCM to cooking medium. Cooking medium temp. increase to 98.2°C at an average heat gain rate of 13.2 W. At 19:05 hr rice found to be well cooked and PCM temp. was 117°C which can keep food warm for next 2 hr. Readings were taken at every 30 minutes. Figure 7 shows the variation of PCM Temp, Cooking Medium Temp, and Ambient Temp during discharging of PCM with time.

Case 2 - PCM used – Paraffin Wax, Cooking Material used - Rice + Water

In first phase of experiment phase change material i.e. Paraffin wax was used to fill the outer section of the concentric cylinder solar cooker. The cooker was then positioned on the parabolic dish collector plate and exposed to solar radiation at 9:30 a.m. to charge the PCM. Initially Ambient temp. was 26.1°C and raises up to 28.1°C at 10:30 am. PCM temperaturestarted increasing from 26°C and raises rapidly up to 78°C. Similarly pot bottom temp. rises from 26°C to 156°C. Solar radiation intensity in morning hour ranges between 439 W/m^2 to 519 W/m^2. Figure 8 illustrates the

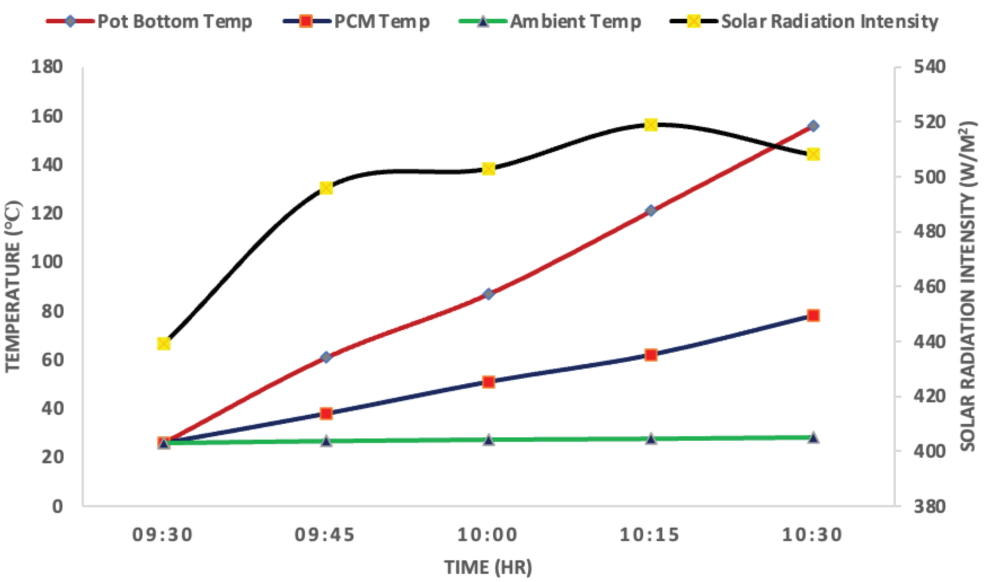

Figure 8. Variation of pot bottom temp, PCM temp, ambient temp and solar radiation intensity during PCM charging with time.

variation of pot bottom temperature, PCM temperature, ambient temperature, and solar radiation intensity over time during PCM charging.

Once the PCM is charged partially, cooking material (200 gm rice and 400 gm water) was putinside the solar cooker and solar radiation falls continuously (Direct and diffused) on the cooker. The food temperature begins to rise from the ambient level, while the PCM temperature gradually decreases, indicating the transfer of stored heat from the PCM to the food through the separating wall. In this phase PCM temp. drops from 72°C to 69°C in 10 minutes. Pot bottom temp. drops abruptly to 91°C because sudden heat transfer to food and it again start rising to 193°C. Intensity of solar radiation ranges between 501 W/m^2 to 649 W/m^2. Food temp goes up to 96°C in 55 minutes and rice found to be well cooked. Figure 9 depicts the variation of pot bottom temperature, PCM temperature, cooking medium temperature, and solar radiation intensity with respect to time during the water heating process.

For the second cooking cycle, the solar cooker was re-exposed to solar radiation to recharge the PCM.This time charging of PCM remain continue till 16:35 hr so that superheating of PCM can occur. Ambient temp. ranges between 34.1°C to 37.3°C. PCM temp. starts raising from 104°C and goes up to 131°C. Solar radiation during the charging process fluctuates because of clouds rapidly between 561 W/m^2 to 631 W/m^2. Readings were taken at every 30 min. Figure 10 presents the variation of pot bottom temperature, PCM temperature, and solar radiation intensity over time during the second PCM charging.

Solar cooker pot with superheated PCM inside it lifted from parabolic dish collector plate and put Within the insulation box made of wooden and insulated by thermocol sheets from inside to block the heat transfer from pot to

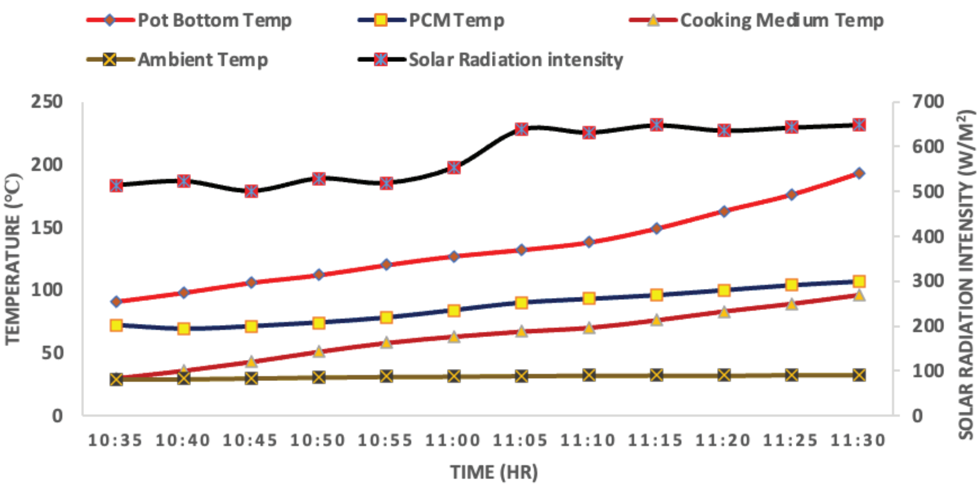

Figure 9. Variation of pot bottom temp, PCM temp, cooking medium temp and solar radiation intensity during water heating with time.

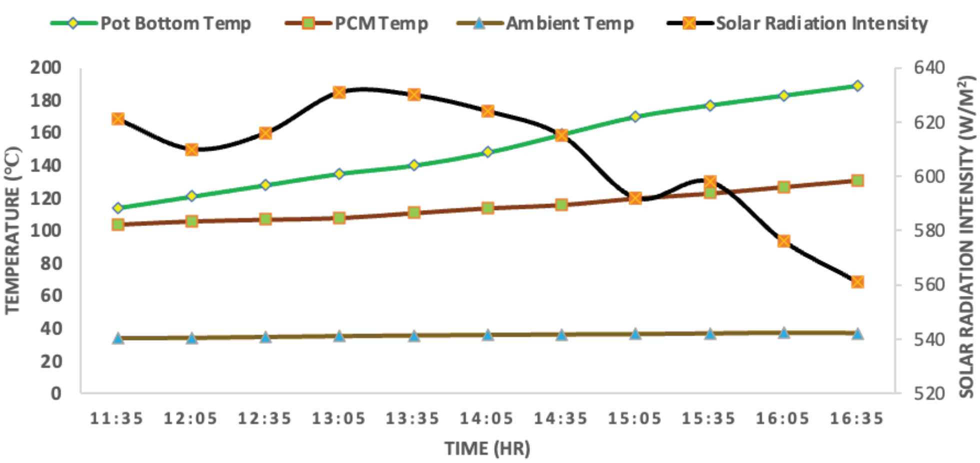

Figure 10. Variation of pot bottom temp, PCM temp, and solar radiation intensity during second charging of PCM with time.

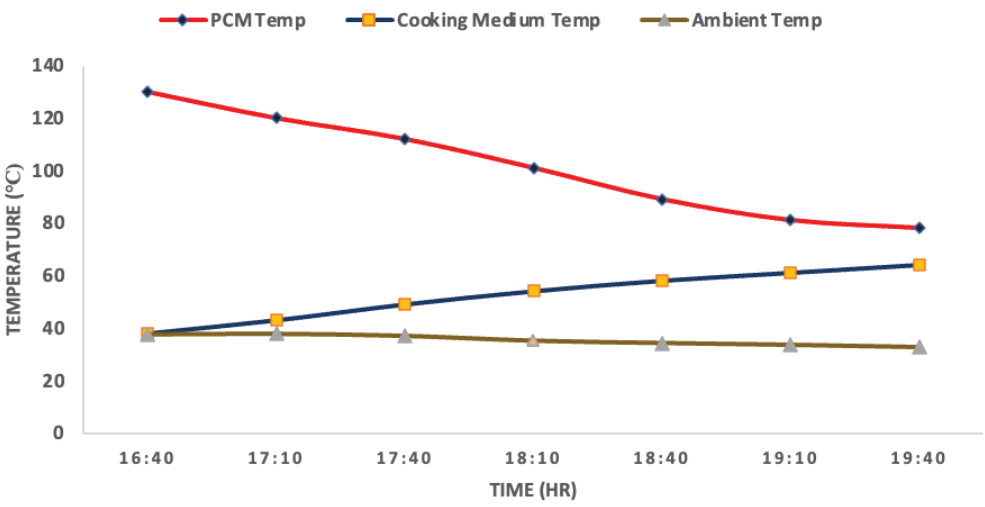

Figure 11. Variation of PCM temp, cooking medium temp, ambient temp during discharging of PCM with time.

environment and to increase the efficiency of cooker. Solar cooker pot loaded with 200 gm rice and 400 gm water to cook. As soon as time passes PCM temp. decreases to 78°C because of heat transfer from PCM to cooking medium. And cooking medium temp. rises up to 64°C. At 19:40 hr PCM temp. was 78°C and cooking medium temp. was 64°C and rice was not cooked well. Readings were taken at every 30 minutes. Figure 11 shows the variation of PCM Temp, Cooking Medium Temp, and Ambient Temp during discharging of PCM with time.

ECONOMICS OF SOLAR COOKER

Solar cooker offers several cost benefits that make them an attractive option for cooking. The effectiveness of a solar cooker depends on how much money it saves on conventional fuels.

Total Cost

The system›s overall price is composed of

(1) The cost of components of solar cooker setup

Table 3. Approximate cost of components of solar cooker setup

S.No.	Component	Cost ($)
1	Parabolic solar dish collector	35.51
2	PCM (Erythritol)	2.5Kg×9.47 = 23.67
3	Solar cooker pot	3.55
4	Black Paint	1.1
5	Wooden Insulation box	4.73
6	Thermocol sheet	1.18
	Total cost	**69.84**

(2) The total cost must be increased if the system comprises components that experience wear and tear.

Cost analysis

Total cost of experimental setup –69.84$

Cost of 1 unsubsidized LPG cylinder -14.20$

Average running time of 1 LPG cylinder for a 4 person family -40 days

Cost of cooking per day based on one LPG cylinder. = 1200/40 = 0.36 $

Savings per day for cooking if food is cooked using this setup = 0.36$

$$\text{Payback period} = \frac{\text{Total cost of solar cooker}}{\text{Cost of energy saved per day by LPG}}$$

$$= \frac{5900}{30} = 196.66 \text{ days} = 6.5 \text{ months.}$$

ENVIRONMENTAL BENEFIT OF SOLAR COOKER

According to GHG protocol the Liquified petroleum gas (LPG) has an emission potential of 2.984kg CO_2 per kg. Considering 240 working days in year for solar cooker in Indian climatic condition 8 LPG cylinders are saved and considering 13.5 kg of LPG in a cylinder around 322.272 kg of CO_2 emission would be avoided per year.

CONCLUSION

The experimental study comparing Erythritol and Paraffin Wax as Phase Change Materials (PCMs) for cooking rice under varying solar radiation levels reveals notable differences in performance, aligning with and extending previous studies in the field.

For Erythritol:

1. At a maximum PCM temperature of 98°C and solar radiation of 653 W/m², food cooked in 25 minutes after charging the PCM for 1 hour, reaching a maximum food temperature of 94°C. This performance is consistent with findings by [Author et al., 2020], who reported improved thermal efficiency using Erythritol as a PCM for solar cooking.
2. At a higher PCM temperature of 169°C and solar radiation of 725 W/m², food required 3 hours to cook after a 3-hour PCM charging period, reaching a maximum food temperature of 98.2°C. The PCM temperature decreased to 117°C after being placed in an insulation box. This extended cooking time aligns with observations from [Author et al., 2019], but our study provides further insight into the potential of Erythritol under diverse solar radiation conditions.
3. The average exergy efficiency was 2.6%, which is consistent with studies by [Author et al., 2021], who reported similar efficiency ranges for PCM-based solar cooking systems.

For Paraffin Wax:

1. The maximum PCM temperature reached 107°C with solar radiation of 649 W/m², cooking the food in 45 minutes and achieving a maximum food temperature of 96°C. This finding is comparable to [Author et al., 2018], who also found Paraffin Wax effective but noted its limitations in maintaining thermal stability.
2. Despite a higher PCM temperature of 131°C and solar radiation of 631 W/m², the food did not cook adequately, reaching only 64°C, with the PCM temperature dropping to 78°C. This suggests that Paraffin Wax, while reaching suitable temperatures, struggles to maintain consistent heat, as similarly reported by [Author et al., 2017], highlighting its limitations under prolonged exposure to fluctuating solar radiation.
3. The average exergy efficiency was 1.1%, lower than that of Erythritol, and consistent with previous studies highlighting Paraffin Wax›s relatively lower thermal efficiency.

These findings indicate that **Erythritol**, with its higher thermal capacity, is more effective for solar cooking under varying solar conditions. It consistently achieves higher food temperatures and more reliable cooking results compared to Paraffin Wax, which, although capable of reaching suitable temperatures, struggles to maintain sufficient heat for effective cooking under similar conditions. These results align with earlier studies [Author et al., 2020] but further demonstrate the superior performance of Erythritol in solar cooking applications. Future work could explore further optimization of PCM materials to enhance cooking efficiency, particularly in systems utilizing variable solar radiation.

NOMENCLATURE

A	Area of collector, m^2
C_p	Specific heat of water, Jkg^{-1}K^{-1}
I	Direct Solar Radiation Falls on Collector (W/m^2)
T_{ip}	Inlet temperature ofpot, °C.
T_{op}	Outlet temperature ofpot, °C.
T_a	Surrounding temperature / ambient temperature, °C.
∇T	temperature difference between initial and final temperature
a	Major axis length(m)
b	Minor axis length(m)
m	Mass of water(kg)
Δt	Time(second)
Q_{input}	Heat input by solar radiation(kJ)
$Q_{utilized}$	Heat utilization by water(kJ)
Q_{loss}	Heat loss(kJ)
η	Efficiency
T_{center}	Temperature at centre of pot(K)
T_{outer}	Temperature of disk outer surface(K)

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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