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Experimental Analysis of Scheffler Reflector-Based Solar Cooking System: An Application of Sensible and Latent Heat Storage Materials

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ABSTRACT

Solar cooker with different collector like evacuated tubes collector, parabolic trough collector, flat plate collector, and Scheffler reflector collector etc are generally used for the cooking food with SHSMs or PCMs. Present research article, Scheffler reflector with combined heat storage material (one SHSM and one PCM) for late-evening cooking has been experimentally investigated. One material is placed within the inner pot of a solar cooker, while another material is placed outer pot of the solar cooker. Six combinations are formed from various SHSMs (sand, pebbles, and iron pieces) and PCM (acetamide). During the daytime, the solar cooker absorbed and stored heat from the sun, which was transferred to the cooking pot through the heat storage units. The heat required for evening cooking (Rice) has been transferred by the thermal storage system which is kept inside an insulator box. After the experiment, it was observed that food was successfully cooked in pairs of sand-acetamide, acetamide-sand, and acetamide-pebbles and partially cooked in pairs of pebbles-acetamide, iron pieces-acetamide, and acetamide-iron pieces. The water activity test is to be conducted to check the cooking quality of food, and as per the result received from the test, the range of cooking and partially cooking is differentiated between 0.928 and 0.936 and 0.948 and 0.955, respectively. The cooked food's temperature was determined to be between 60 and 63 ^{o}C at 20:00 h. The system's total cost and payback duration were calculated for the economic analysis resulting in 50750 INR and 9.70 years, respectively.

Keywords: Scheffler reflector; solar energy; solar cooking; combined heat storage unit; thermal performance; SHSMs; PCM

INTRODUCTION

Energy serves as the fundamental catalyst for the social, economic, industrial, and technological progress of a nation. Since the dawn of life on Earth, various forms of energy have existed, and humans have continually explored and adapted their applications over time (Panchal et al. 2022; Patel & Patel 2020). It is important to note that cooking occupies a significant portion of the total consumption of energy in developing nations, including both commercial and non-commercial energy sources. Unfortunately, almost 2.4 billion people in India cook food using biomass fuels, including wood, charcoal, dung, and agricultural waste. This causes dangerous smoke to be released into the sky, endangering people's health, and safety, especially women (Murugesan et al. 2023; Aquilanti et al. 2023).

Solar energy, as a renewable and readily available resource, has gained substantial popularity in modern times. Its widespread adoption as an alternative to fossil fuels could provide a tremendous boost to the economy and significantly contribute to global warming mitigation efforts. Solar cooking stands out among the many uses of solar energy as a potentially significant approach to reducing the consumption of conventional fuel. However, the widespread collection and utilization of solar power have faced challenges, making it less convenient compared to other energy sources (Patel & Patel 2022; Modi & Nayi 2020). Indeed, solar energy has unique characteristics that make its collection, conversion, and storage more complex compared to traditional fossil fuels like gasoline and coal. One of the significant challenges with solar energy is its low energy density, as the sun's energy is spread over a large area and is relatively diffuse. This necessitates the use of specialized solar energy harnessing equipment, such as solar panels or solar concentrators, to capture and convert sunlight into usable forms of energy like electricity (Panchal et al. 2018i; Panchal et al. 2018ii).

The efficient use of solar energy requires thermal energy storage. Among the present technologies in use, the latent heat thermal energy storage system is unique because it can store a significant amount of thermal energy in a compact container at a constant temperature (Panchal et al. 2018). Due to these advantageous characteristics, the latent heat TES system finds diverse applications in various industries and solar energy-related fields (Saxena et al. 2023; Mawire et al. 2020, Patel & Patel 2024).

Palanikumar et al. (2021) developed an innovative box-type solar cooker integrating PCM through research and development for solar cooking applications. Three separate studies were carried out by the researchers: one with a solar box cooker containing PCM (waste cooking oil and $C_4H_4O_3$), one with a nanocomposite PCM ($MgAl_2O_4/Ni/Fe_2O_3$-PCM), and one without one. According to the investigation's results, the solar box cooker's overall thermal performance was 24.90-33.90%, 24.77-45.20%, and 31.77-56.21%, respectively, without Nanocomposite – PCM, with PCM, and with Nanocomposite - PCM.

Mekonen Yalelet Getnet et al. (2023) conducted a study in which they developed an indirect solar cooking system featuring a flat plate collector integrated with a phase change material (PCM), and they conducted experimental testing. The purpose of the study was to evaluate the solar cooker's performance both with and without reflectors. To improve the amount of solar energy captured, four plane reflectors were positioned on either side of the collector. The PCM in the thermal storage unit was stearic acid. The findings indicated that when four reflectors were used, there was a daily average increase of 42.3% in reflected solar radiation. Additionally, the study showed that, in comparison to the solar cooker without reflectors (63% and 42%, respectively), the solar cooker with reflectors achieved higher maximum average absorber plate temperature, maximum outlet water temperature, maximum energy efficiency, and energy efficiency (79% and 48%, respectively).

Khalil Abdullah Saleh AL-Nassri et. al. (2023) performed an experimental study that attempted to improve the Scheffler concentrator's and its receiver's performance by adding a conical secondary reflector (CSR). The CSR had been meticulously designed through ray tracing diagram analysis. This enhancement resulted in a significant increase in the receiver surface temperature, averaging approximately 25%, while concurrently reducing the convective heat transfer coefficient by an average of 12-15%. Consequently, this reduction in convective losses at the receiver improved the overall system efficiency by at least 3-5%. Furthermore, the inclusion of the conical secondary reflector had reduced the initial lag period by a minimum of 15 minutes.

Pawar and Tungikar (2022) used a 16 m^2 parabolic Scheffler dish concentrator to examine the thermal performance of a helically coiled conical cavity receiver in the presence of concentrated solar light. The study investigated three different radiation situations and examined several characteristics, such as the total heat transfer coefficient, exergy efficiency, and thermal energy efficiency of the receiver. Water was used as the heat transfer fluid, and testing took place throughout a temperature range of 30 °C to 100 °C at a flow rate of 2.5 L per minute. In the context of the stagnation test, it was noted that the receiver, when subjected to incoming beam radiation of 654 W/m^2, achieved its maximum recorded stagnation temperature of 395 °C. This result highlighted the receiver's capability to produce pressurized steam. The calculation of the overall heat loss coefficient, determined from the stagnation test, yielded a value of 116 W/m^2K.

Anilkumar, Maniyeri and Anish (2022) conducted a study focusing on the utilization of phase change materials (PCMs) for thermal energy storage (TES) in the context of solar cookers (SCs). The research aimed to develop an improved TES unit that integrated PCM as a heat storage medium within the SC's cooking vessel. These TES units were designed to encompass PCM on all sides, including the lid, to enhance heat transfer to the food being cooked. Computational procedures were employed for TES unit design, and MATLAB code streamlined the iterative calculations required for optimization. The study also encompassed the design, construction, and testing of various TES unit geometries using paraffin wax as the PCM. After six hours, the cooking load temperature in all TES unit geometries reached the PCM's melting point. Among the hexagonal, square, and cylindrical designs considered, the cylindrical shape demonstrated the best performance.

Cuce (2018) Utilising experimental methods, the effect of sensible thermal energy storage materials on the thermal performance characteristics of solar box cookers was investigated. Two solar box cookers were built using the same measurements and materials, but one cooker used Bayburt stone as a practical way to store thermal energy. Because it was practical to fabricate and use, the research used a cylindrical box design. Departing from the conventional top lid, this design featured a lid on the side edge, offering thermal advantages by minimizing heat losses. Both cookers underwent testing on a typical late summer day in Bayburt, and the study derived comparative thermal performance data. According to the results, Bayburt stone works well as a sensible thermal energy storage medium in solar box cookers, providing for continuous and effective cooking.

The present literature survey shows that investigation have been reported on solar cookers based on parabolic dish collectors, evacuated tube solar collectors, box type collectors, and parabolic trough collectors with thermal storage units along with phase change materials. On the other hand, very little information has been released on solar cookers using Scheffler dish collectors for cooking in the late evening using a combination of heat storage materials. The objective of the present experimental work is to evaluate the Scheffler dish solar cooker's performance using a combined thermal storage unit (one SHSM and one PCM) at Mehsana, Gujarat, India, at 38° 58' (latitude) North and 72° 36' (longitude) East.

EXPERIMENTAL SETUP

This experiment investigated the performance of a Scheffler reflector-type solar cooker used together with a combined heat storage unit. A schematic diagram of the Scheffler reflector with solar cooker is shown in Figure 1, and Figure 2 depicts the Scheffler reflector and solar cooker experimental setup. The experimental setup consists of the following elements:

1. Scheffler dish type collector
2. Solar cooker
3. Sensible heat storage unit
4. Latent heat storage unit
5. Insulator box
6. Measuring instruments
7.

SCHEFFLER DISH TYPE COLLECTOR

A Scheffler dish-type collector is a device for point-focusing that concentrates solar energy on a receiver. For this application, a 2 m^2 Scheffler reflector is employed to reflect solar lights onto the receiver. Solar rays are reflected by a Scheffler reflector with 150 pieces of solar-grade mirrors.

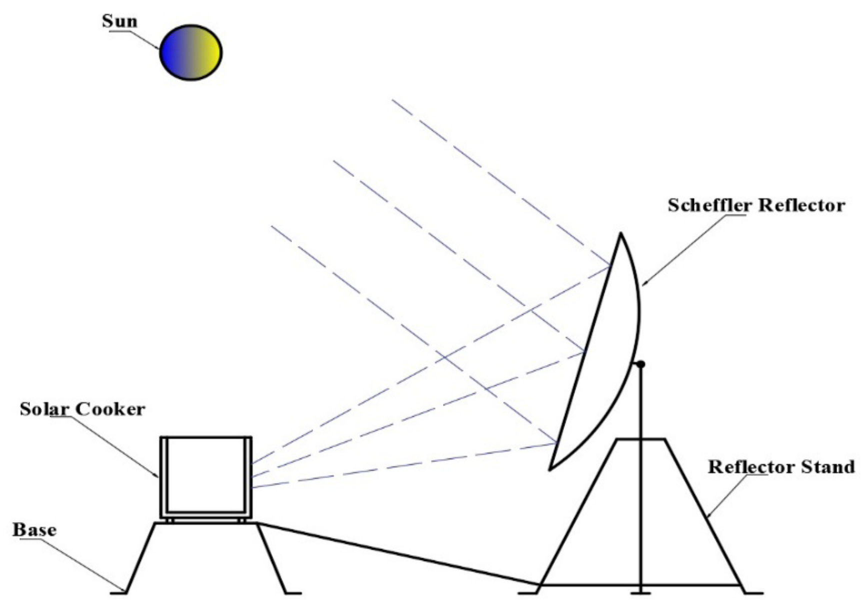


FIGURE 1. Schematic diagram of Scheffler reflector with solar cooker

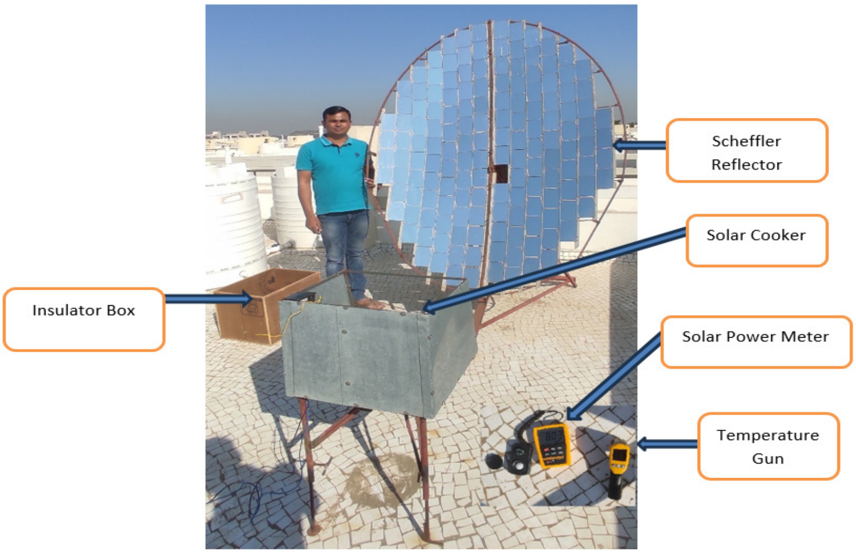


FIGURE 2. Experimental apparatus of Scheffler reflector with solar cooker

TABLE 1. Thermophysical properties of SHSMs

Sr. No.	Materials	Density (kg/m^3)	Thermal conductivity (W/mK)	Specific heat capacity (kJ/kg ^{o}C)
1	Iron Pieces	2100	0.16	0.46
2	Sand	1602	0.71	0.80
3	Pebbles	3300	2.60	0.88

TABLE 2. Thermophysical properties of phase-change material (PCM)

Sr. No.	Materials	Melting Temperature (°C)	Latent heat of fusion (kJ/kg)	Density (kg/m^3)	Specific Heat (kJ/kg °C)
1	Acetamide	79	263	1159	1.94

SOLAR COOKER

In the present experiment, a solar cooker consists of two cylindrical hollow pots made of aluminum material and solar cooker was in the middle of them. The inner pot has a diameter of 0.23 meters, and the outer pot has a diameter of 0.28 meters. The pressure cooker has a capacity of 1.5 liters. The solar cooker has two fill holes and two thermocouple holes at the top surface. Figure 3 shows the solar cooker in three different views: (a) top view of solar cooker; (b) an actual picture of solar cooker; and (c) section view of solar cooker.

SENSIBLE HEAT STORAGE UNIT

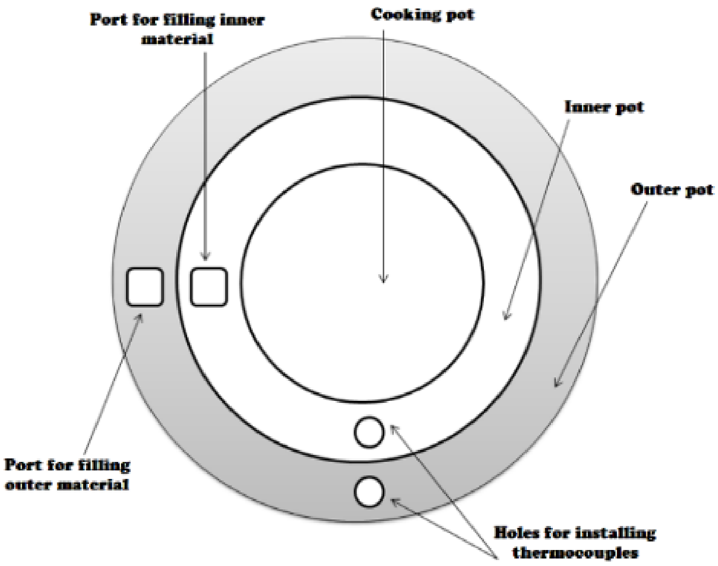
The solar cookers inside have been filled with SHSMs, (sand, pebbles, and iron pieces). SHSMs' thermophysical properties are shown in Table 1. Figure 4 shows (a) sand; (b) pebbles; and (c) iron pieces.

LATENT HEAT STORAGE UNIT

Acetamide is used as a latent heat storage material. Acetamide has been purchased from Global Pharma Chem, Ankleshwar. Thermophysical properties of phase-change material is shown in Table 2. Figure 5 shows acetamide.

INSULATOR BOX

Figure 6 shows (a) a dimension of the insulating box and (b) as an actual picture of the insulating box used for experimental work. Insulation was provided by a plywood material box with dimensions (l × b × h) equal to 0.53 meters, 0.53 meters, and 0.40 meters, respectively, which was filled with wooden sawdust for insulation purposes, and insulation was provided at the bottom and sides of the box.



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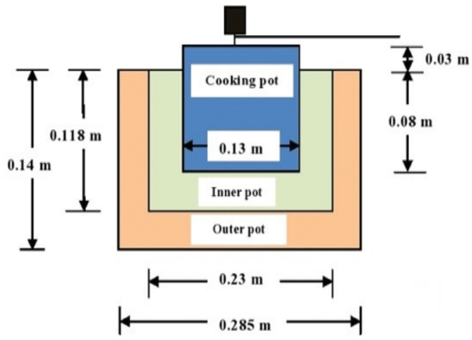
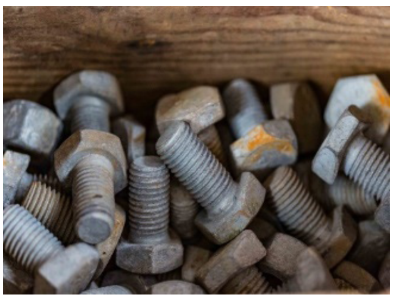


(c)

FIGURE 3. The solar cooker in three different views: (a) top view of solar cooker; (b) an actual picture of solar cooker; and (c) section view of solar cooker

(a)

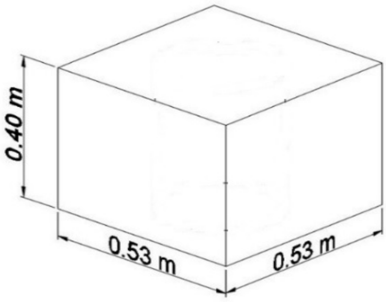
(b)



(c)

FIGURE 4. (a) sand; (b) pebbles; (c) iron pieces

FIGURE 5. Acetamide



(a)

(b)

FIGURE 6. (a) Dimension of the insulating box; (b) actual picture of the insulating box

MEASURING DEVICES & INSTRUMENTS

It is essential to have accurate measurement tools and equipment to conduct effective research work. Various parameters like SHSM temperature, PCM temperature, ambient temperature, and solar intensity readings were taken in the present research work.

A digital temperature indicator, a thermocouple (J-type), and temperature guns have been used to measure the temperatures of SHSM and PCM at cooking medium temperature. The resolution of these instruments is 0.1 ^{o}C.

simplest and elementary form of hygrometer is the sling-type psychrometer. The two thermometers used in a psychrometer included the wet bulb temperature and the dry bulb temperature. A psychrometer with a sling arrangement is used to determine the ambient air's dry bulb temperature.

The amount of solar radiation has been measured with a solar power meter.

Since there are two possible results, charging and discharging, the time between them is monitored every 30 minutes.

METHODOLOGY OF THE SYSTEM

The primary objectives of this study are to assess the combined heat storage system's thermal performance for cooking meals (rice cooking) in the late hours of the evening. As demonstrated in Table 3, six pairs have been produced in the experimental setup through the addition of PCM and SHSMs to the inner and outer pots of the solar cooker. A solar cooker has been placed on the receiver and the system is exposed to sunlight between the hours of 13:00 and 16:00. The Scheffler reflector focuses sunlight towards the solar cooker during the charging process. Materials store available heat. At sixteen hours in the afternoon, the solar cooker is transferred and set on the insulator box. Heat goes into the cooking pot during the discharge process to cook the food and determine which configuration produces the greatest results. Fig. 7 shows the methodology of the system.

SENSIBLE AND LATENT HEAT STORAGE CALCULATIONS

The amount of heat that the sensible heat storage unit has stored can be represented as,

$$Q_{SHSM} = m_{SHSM} \, [\, C_{SHSM} \, (T_{SHSM} - T_a)] \qquad (1)$$

The amount of heat that the PCM unit has stored can be represented as,

$$Q_{PCM} = [C_{PCM}(T_m - T_a) + L + C_{PCM}(T_{PCM} - T_m)] \qquad (2)$$

The solar cooker's total heat stored

$$Q_{Total} = Q_{SHSM} + Q_{PCM} \qquad (3)$$

TABLE 3. Arrangement of various materials in the inner and outer pots of the solar cooker

Exp. No.	Inner material	Outer material
1	Sand	Acetamide
2	Acetamide	Sand
3	Pebbles	Acetamide
4	Acetamide	Pebbles
5	Iron pieces	Acetamide
6	Acetamide	Iron pieces

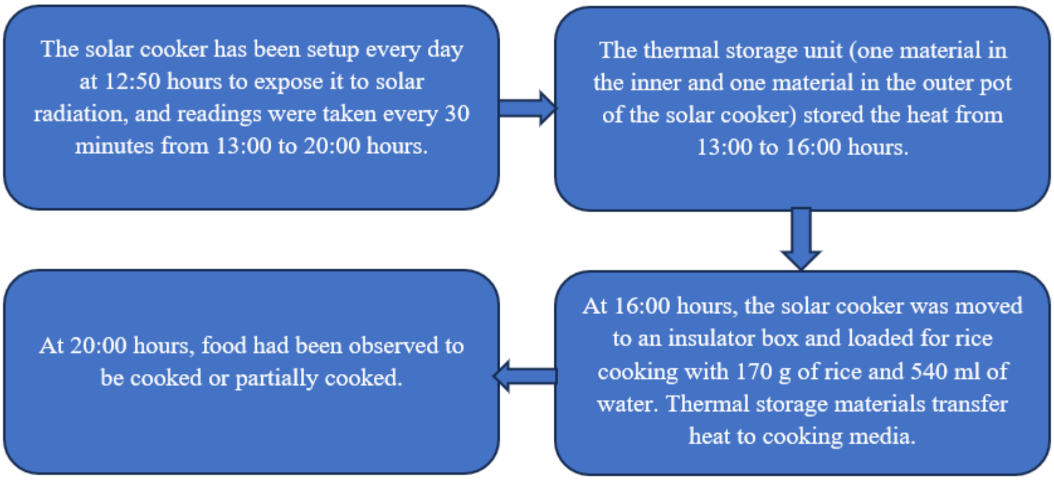


FIGURE 7. Methodology of the system

RESULT AND DISCUSSION

In the current investigation, a solar cooker with integrated heat storage was used to cook in the late evening in Mehsana, Gujarat, India. The experiments were carried out under a clear sky in October 2022. A solar cooker is set up to be exposed to sunlight every day at 12:50 h. Every thirty minutes from 13:00 to 20:00 h., measurements are taken. A similar cooking load of 170 g of rice and 540 ml of water was used to test the six pairs of various combined heat storage materials. The system's outer and inner pots contain one SHSM and one PCM substance each; the better pair is determined through experimentation.

EXPERIMENT 1: SOLAR COOKER WITH INNER MATERIAL (SAND) AND OUTER MATERIAL (ACETAMIDE) (OCTOBER 09, 2022)

On October 9, 2022, an experiment was carried out with acetamide as the outer material and sand as the inner material. The daytime ambient air temperature range has been identified to be 32 to 38 °C, having a maximum intensity of 890 W/m^2 at 13:00 h. Sand reached a maximum temperature of 106 °C, while acetamide reached a maximum temperature of 109 °C. The sand and acetamide were steadily charged until 16:00 h, then started releasing the energy they had stored. At 18:00 h., the food in the pot reached its maximum temperature of 79 °C. The food was observed to be 62 °C at 20:00 h. It was observed that food was cooked.

EXPERIMENT 2: SOLAR COOKER WITH INNER MATERIAL (ACETAMIDE) AND OUTER MATERIAL (SAND) (OCTOBER 15, 2022)

On October 15, 2022, an experiment was carried out with sand as the outer material and acetamide as the inner material. The daytime ambient air temperature range has been identified to be 32 to 38 °C, having a maximum intensity of 877 W/m^2 at 13:00 h. Acetamide reached a maximum temperature of 108 °C, while sand reached a maximum temperature of 112 °C. Figure 8 indicates that the acetamide and sand were steadily charged until 16:00 h., afterwards started releasing the energy they had been stored. At 18:00 h., the food in the pot reached its maximum temperature of 83 °C. The food was observed to be 63 °C at 20:00 h. It was observed that food was cooked.

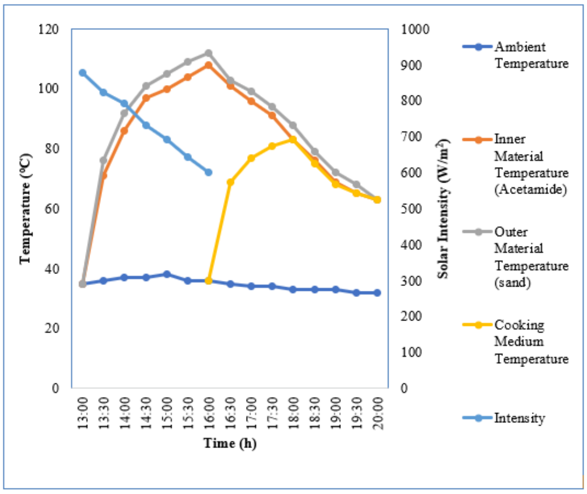


FIGURE 8. Variation of solar intensity and temperature in a solar cooker with an inner material (acetamide) and an outer material (sand) on October 15, 2022

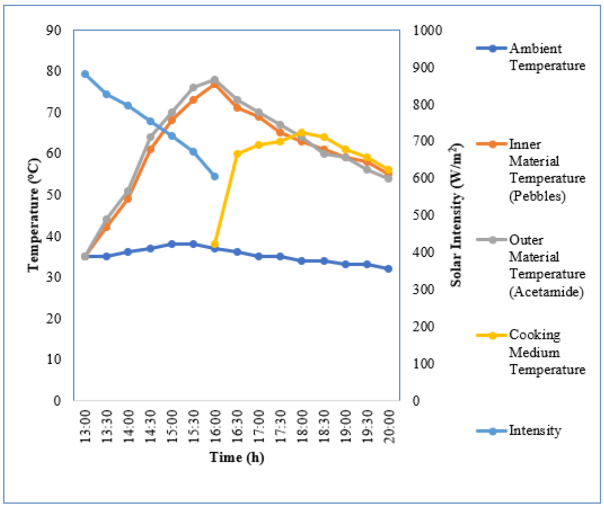


FIGURE 9. Variation of solar intensity and temperature in a solar cooker with inner material (pebbles) and outer material (acetamide) on October 16, 2022

EXPERIMENT 3: SOLAR COOKER WITH INNER MATERIAL (PEBBLES) AND OUTER MATERIAL (ACETAMIDE) (OCTOBER 16, 2022)

On October 16, 2022, an experiment was carried out with acetamide as the outer material and pebbles as the inner material. The daytime ambient air temperature range has been identified to be 32 to 38 °C, having a maximum intensity of 882 W/m^2 at 13:00 h. Pebbles reached a maximum temperature of 77 °C, while acetamide reached a maximum temperature of 78 °C. Figure 9 indicates that the pebbles and acetamide were steadily charged until 16:00 h., afterwards started releasing the energy they had been stored. At 18:00 h., the food in the pot reached its maximum temperature of 65 °C. The food was observed to be 56 °C at 20:00 h. It was observed that food was partially cooked.

EXPERIMENT 4: SOLAR COOKER WITH INNER MATERIAL (ACETAMIDE) AND OUTER MATERIAL (PEBBLES) (OCTOBER 22, 2022)

On October 22, 2022, an experiment was carried out with pebbles as the outer material and acetamide as the inner material. The daytime ambient air temperature range has been identified to be 33 to 38 °C, having a maximum intensity of 908 W/m^2 at 13:00 h. Acetamide reached a maximum temperature of 83 °C, while pebbles reached a maximum temperature of 90 °C. The acetamide and pebbles were steadily charged until 16:00 h., then started releasing the energy they had stored. At 17:00 h., the food in the pot reached its maximum temperature of 70 °C. The food was observed to be 60 °C at 20:00 h. It was observed that food was cooked.

EXPERIMENT 5: SOLAR COOKER WITH INNER MATERIAL (IRON PIECES) AND OUTER MATERIAL (ACETAMIDE) (OCTOBER 23, 2022)

On October 23, 2022, an experiment was carried out with acetamide as the outer material and iron pieces as the inner material. The daytime ambient air temperature range has been identified to be 33 to 39 °C, having a maximum intensity of 907 W/m^2 at 13:00 h. Iron pieces reached a maximum temperature of 83 °C, while acetamide reached a maximum temperature of 78 °C. The iron pieces and acetamide were steadily charged until 16:00 h, then started releasing the energy they had stored. At 18:00 h., the food in the pot reached its maximum temperature of 60 °C. The food was observed to be 51 °C at 20:00 h. It was observed that food was partially cooked.

EXPERIMENT 6: SOLAR COOKER WITH INNER MATERIAL (ACETAMIDE) AND OUTER MATERIAL (IRON PIECES) (OCTOBER 27, 2022)

On October 27, 2022, an experiment was carried out with iron pieces as the outer material and acetamide as the inner material. The daytime ambient air temperature range has been identified to be 31 to 37 °C, having a maximum intensity of 894 W/m^2 at 13:00 h. Acetamide reached a maximum temperature of 78 °C, while iron pieces reached a maximum temperature of 79 °C. Figure 10 indicates that the acetamide and iron pieces were steadily charged until 16:00 h, then started releasing the energy they had stored. At 18:00 h., the food in the pot reached its maximum temperature of 59 °C. The food was observed to be 53 °C at 20:00 h. It was observed that food was partially cooked.

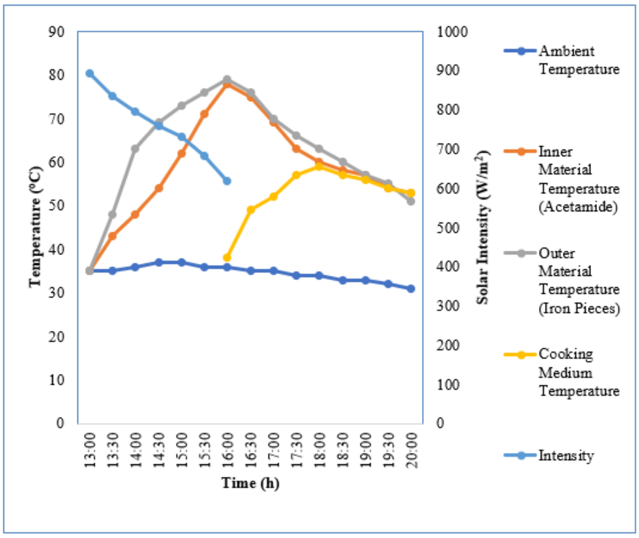


FIGURE 10. Variation of solar intensity and temperature in a solar cooker with inner material (acetamide) and outer material (iron pieces) on October 27, 2022

SUMMARY OF EXPERIMENTAL RESULTS

Out of six pairs of combined heat storage materials as inner and outer materials, food has been partially cooked in pairs of pebbles-acetamide, iron pieces-acetamide, and acetamide-iron pieces.

Food that was partially cooked had been caused by the coarse particles' capacity to serve as an insulator for the transfer of heat. The sizes of the sensible materials are in decreasing order: iron pieces, pebbles, and sand, respectively. Iron pieces have point contact, and gaps between iron pieces are larger than those between pebbles and sand, resulting in an air gap and poor conductivity in partially cooked food. An outside material serves as an insulator and retains heat from the inner material, while the inner material helps with cooking.

Table 4 shows the summary of the experimental results. Experimentally, it shows that food has been cooked when the temperature of the food in the cooking pot is 60 °C or above at 20:00 h; if it is less than 60 °C, it has been partially cooked.

TABLE 4. Summary of experimental results

Exp. No.	Cases (Inner material-outer material)	Maximum Intensity (W/m^2)	Ambient Temperature (°C)	Maximum temperature (Inner material) (°C)	Maximum temperature (Outer material) (°C)	Maximum Food Temperature (°C)	Food temp. at 20:00 h. (°C)	Cooked/Partially Cooked
1	Sand-Acetamide	890	32-38	106	109	79	62	Cooked
2	Acetamide-Sand	877	32-38	108	112	83	63	Cooked
3	Pebbles - Acetamide	882	32-38	77	78	65	56	Partially cooked
4	Acetamide - Pebbles	908	33-38	83	90	70	60	Cooked
5	Iron Pieces - Acetamide	907	33-39	83	78	60	51	Partially cooked
6	Acetamide - Iron Pieces	894	31-37	78	79	59	53	Partially cooked

HEAT STORED BY HEAT STORAGE MATERIALS FOR DIFFERENT EXPERIMENTS

During the charging phase, sensible and latent heat storage materials could have stored in the range of 458 kJ to 1202 kJ of energy. The amount of energy that was stored was maximum when sand was in inner space and acetamide was in outer space, where sand and acetamide stored 784 kJ and 1202 kJ of energy, respectively. Figure 11 shows the energy stored by various heat storage materials. In experiments with pebbles-acetamide, iron pieces-acetamide, and acetamide-iron pieces as an inner and outer pot of solar cooker, food was observed to be partially cooked due to point contact between sensible heat storage materials, resulting in an insufficient amount of heat transfer. As a result, PCM is unable to retain latent heat and does not melt.

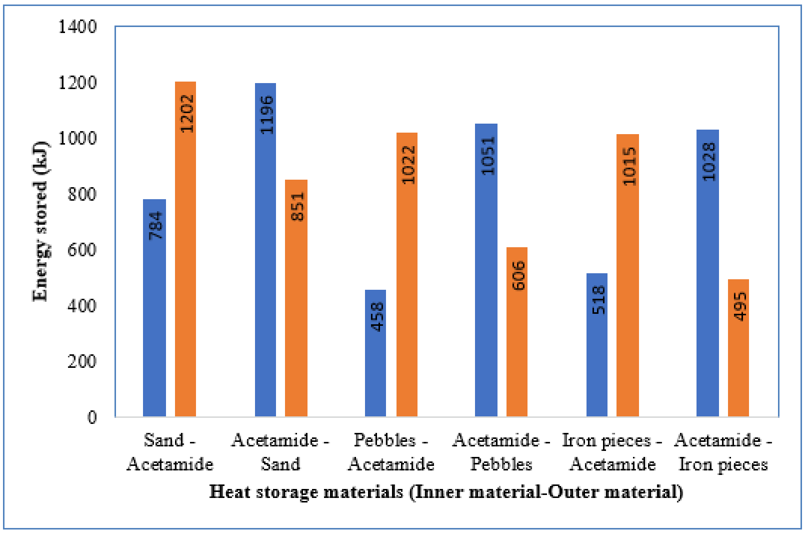


FIGURE 11. Heat storage by different heat storage materials

WATER ACTIVITY TEST

Water activity testing is a method applied to measure the amount of available water in a substance or material. It is a crucial parameter in various fields, such as food science, pharmaceuticals, cosmetics, and microbiology. The water activity, or aw is the ratio of a substance's water vapour pressure to the same temperature as pure water. A water activity meter has been used to measure a substance's water activity. These instruments typically utilize sensors that measure relative humidity in an enclosed chamber or sample. The water activity value has been determined by measuring the sample's equilibrium relative humidity. Water activity is expressed on a scale from 0 to 1, with value near to 0 representing a completely dried material (cooked) and value near to 1 representing pure water (partially cooked), and water activity is the unit less.

The performance of cooking was studied using a water activity meter at the Mansinhbhai Institute of Dairy and Food Technology, Dudhsagar Dairy, Mehsana, Gujarat, India. The water activity of rice in different cases of the experiment is shown in Figure 12. For different cases of experiments, the water activity of rice in different experiments has been recorded to be in the range of 0.928 to 0.955. As per the result received from the test, the range of cooking and partially cooking is differentiated between 0.928 and 0.936 and. 0.948 and 0.955, respectively.

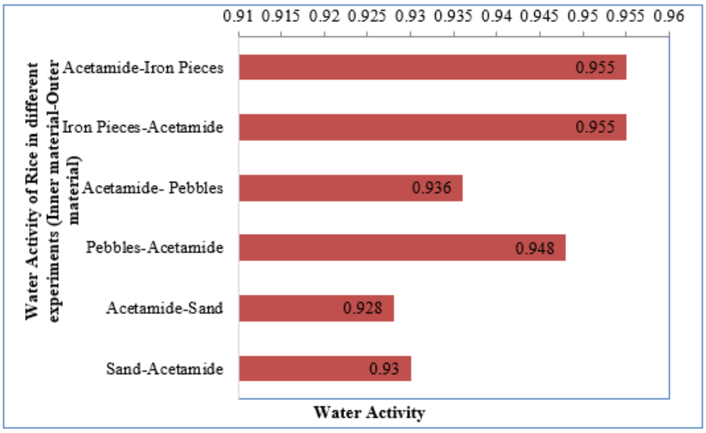


FIGURE 12. Water activity of rice in different experiments

ECONOMIC ANALYSIS

Saxena et al. (2023) used box type solar cooker with sensible heat storage material and resulted thermal efficiency 59.61% and present research work used Scheffler reflector with combined heat storage material and resulted thermal efficiency 37% (inner material acetamide and outer material pebbles).

Any system requires an economic study to determine its economic viability. A novel approach needed to be commercially viable for residential usage. The economic analysis considered the system's payback time, annual cost savings, and total system cost. The system's overall expenditure is shown in Table 5. The total cost was the sum of each type of material used to construct the experimental setup (Dhiman A. & Sachdeva G., 2020; Nerini F. F. et al. 2017; Singh O. K., 2021).

Daily cost savings denote the Indian rupees preserved through utilizing the Scheffler reflector solar-cooking system. After the conventional cooking experiment, the amount of LPG used daily for rice cooking was 250 grammes, saved after the Scheffler reflector solar cooking installation. The cost of LPG per kg was 76.05 INR. India experiences around 275 sunny days annually. The cost saved per day can be determined using the below equation:

Cost saving per day = Amount of LPG saved per day × Cost of LPG per kg

Cost saving per day = 19.01 INR

Annual cost savings refers to the sum of money that has been saved after implementing the Scheffler reflector solar cooking system. It can be determined by using the below equation:

Annual cost saving = Average sunny days in a year × Cost saving per day

Annual cost saving = 5228.43

The below equation used to determine the calculation of the payback period:

Payback period = Total Expenditure / Annual cost of cooking

Payback period = 9.70 years

After calculation, the system's payback period was only 9.70 years.

TABLE 5. Total cost of a system

Sr. No.	Particulars	Cost (INR)
1	Scheffler reflector	45000
2	Acetamide (600 Rs. per kg)	1800 (600 × 3 kg)
3	Solar cooker	2700
4	Paint	200
5	Insulator box	1050
	Total cost	50750

CONCLUSION

The following conclusion can be drawn from the current experimental work:

1. Food successfully cooked in experiments of sand-acetamide, acetamide-sand, acetamide-pebbles, and partially cooked in cases of pebbles-acetamide, iron pieces-acetamide, and acetamide-iron pieces.
2. According to the experiments, the inner materials temperature ranged from 34 °C to 108 °C, while the outside materials temperature ranged from 34 °C to 112 °C. The highest temperature for sand has been shown to be in outer space, whereas the maximum temperature for acetamide was determined to be in inner space.
3. Also, from the experimental data, it has been observed that the food has been cooked when the temperature of the food reached more than or equal to 60 °C at 20:00 hr. Otherwise, it has been partially cooked.
4. During the charging process, 458 kJ to 1202 kJ of energy were stored. The energy stored was maximum in the case of sand, which was in inner space, and acetamide, which was in outer space, where sand (Inner material) and acetamide (Outer material) stored 784 kJ and 1202 kJ of energy, respectively.
5. Food was partially cooked with pebbles-acetamide, iron pieces-acetamide, and acetamide-iron pieces (combined heat storage material). The air gap between the pebbles acts as an insulator against the transfer of heat, which indicates reason. The poor heat transmission rate in the case of iron parts has been triggered by point contact between the components. As a result, PCM cannot sustain latent heat and does not melt.
6. The water activity test is to be conducted to check the cooking quality of food at Mansinhbhai Institute of Dairy & Food Technology, Dudhsagar Dairy, Mehsana, Gujarat, India. As per the result received from the test, the range of cooking and partially cooking is differentiated between 0.928 and 0.936 and 0.948 and 0.955, respectively.
7. For the calculation of total expenditure and payback period, economic analysis is carried out. Economic analysis shows the total expenditure and payback period of the system were 50750 INR and 9.70 years respectively.
8. According to the experiment's results, acetamide as an inner material and sand, pebbles as an outside material for combined heat storage materials perform well, which suggests them as an acceptable option for an energy-storage use in the evening cooking.

FUTURE WORK

1. Computational fluid dynamics (CFD) of the system and comparison with the experimental results are possible for future work.
2. Conduct experiments with other materials that are not used in the present research work.
3. Conduct experiments with other types of solar cooker which are not used in the present research work.
4. To develop a system for reducing the heat losses from the solar cooker using glazing, painting black, etc.

NOMENCLATURE

SHSM:	Sensible heat storage material
PCM:	Phase change material
TES:	Thermal energy storage
Q_{SHSM}:	Heat stored by SHSM, kJ
m_{SHSM}:	Mass of SHSM, kg
C_{SHSM}:	Specific heat of SHSM, kJ/kg °C
T_{SHSM}:	Temperature of SHSM at 16:00 h, °C
Q_{PCM}:	Heat stored by PCM, kJ
C_{PCM}:	Specific heat of PCM, kJ/kg °C
T_m:	Melting temperature of PCM, °C
L:	Latent heat of fusion of PCM, kJ/kg
T_{PCM}:	Temperature of PCM at 16:00 h, °C
Q_{Total}:	Total heat stored, kJ

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DECLARATION OF COMPETING INTEREST

None

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