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Dhiman, Abhishek
National Institute of Technology Kurukshetra

Sachdeva, Gulshan
National Institute of Technology Kurukshetra

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Energy and Exergy Analysis of a Pressurized Solar Cooking System Based on a Parabolic Dish Collector

Abhishek Dhiman[1,*], Gulshan Sachdeva[2,]
[1,2]National Institute of Technology Kurukshetra, India

*Author to whom correspondence should be addressed:
E-mail: abhishekdhiman2887@gmail.com

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Abstract: The greenhouse gas emission in atmosphere has been increasing day by day and cooking is one of the primary reasons for this due to the burning of fossile fuels. In the current research article, the thermal performance of solar pressurize cooker has been investigated experimentally. It is an indirect type of cooker setup in which a pressurized cooker and solar collector are placed apart.

Heat transfer fluid is used to transmit heat from a conical receiver to a cooking pot. The cooking potential of the cooker is observed by cooking different edible food at different cooking loads. The cooking is done by circulating heat transfer fluid. Also, energy and exergy analysis have been done for the pressurized cooking used for heating 2 liter of water.

The water in cooking pot took 65 minutes to reach the temperature of 100°C. The maximum energy and exergy efficiency values are found to be 32.62% and 22.11%, respectively, whereas, the average energy and exergy efficiency are determined to be 10.58% and 7.08%, respectively. The temperature of heat transfer fluid reached upto 170°C, and the maximum temperature in cooking pot achieved to 151°C.

It is observed that cooking system can cook different kinds of edible foods of different cooking load. The system is able to cook at medium temperatures for almost six hours. The system has been successfully tested with a maximum cooking load of 3 litres. The system is long-lasting and requires minimal maintenance.

Keywords: Solar cooking, parabolic dish collector, conical receiver, heat transfer fluid, exergy and energy.

1. Introduction

Any nation's progress depends mainly on energy. The availability of energy improves living quality. Energy access is necessary for the long-term survival and welfare of people and society[1)2)]. The globally second-highest energy-using sector is the residential buildings[3)]. The energy used by homes is significantly influenced by cooking, cooling, and water heating methods[4)] . Humans need to eat to survive and meet their daily energy and nutritional demands[5)]. Cooking is the process of applying heat to raw food and can be classified as baking, roasting, boiling, frying, and steaming, depending on the temperature requirements, heat application method, and time. Cooking needs 1.7-2.7 MJ of energy daily per person[6)]. Therefore, at the family level and in institutions, a considerable quantity of fuel is required daily for cooking[7)]. In developing nations, about 40 percent of total energy is used for cooking[8)]. About 52% of the global energy requirement is fulfilled by biomass. In India, the daily average global irradiance ranges from 4 to 7 kWh/m^2 depending on the locations [9)]. Non-conventional energy sources currently provide 14% of the global energy demands, and its future potential is promising[10)]. Solar energy is considered the best alternative among clean energy developments; because it is available in abundance, free of cost, and promotes sustainable development[11)12)]. Earth obtains 3.85×10^{18} MJ of solar energy annually[13)]. The solar cooker is the simplest and most practical way to use solar energy[14)]. In growing nations, wood has been the primary energy resource because it is the cheapest and the easiest option to get the necessary energy. Unfortunately, it results in serious environmental issues like deforestation[15)]. A large number of homes previously using wood have switched to a new energy source i.e. liquefied petroleum gas (LPG)[16)]. In India, 70% of the people reside in villages with a massive requirement for firewood, agricultural wastes, and dung cake[17)18)]. In many rural districts of India, more than 85% of the daily need for fuel is met by bioresources[19)].

Numerous researchers have designed and studied various types of solar cookers. [20)] examined the efficiency of a 0.80m diameter and 0.08m deep parabolic dish concentrator. The investigation employed a cylindrical receiver of 100mm diameter and 200mm length. Synthetic oil, when used as a heat transmission medium, recorded 153°C the highest temperature. Further, energy and exergy efficiency ranged from 2.4% to 29.0% and 0.5% to 1.0%, respectively. [21] examined the efficiency of a solar cooking apparatus based on a PDC and a cavity-type receiver. Heat was stored in an insulated storage tank for night hours. Different types of cooking, like boiling, baking etc., had been done on the solar cooker. Moreover, the device could boil 1 liter of water in 13 minutes only. [22] examined the efficiency of a parabolic trough cooker system numerically. The optical efficiency of the parabolic trough based system was observed from 33% to 53%. Also, theoretical and experimental efficiency were found within the range of 30-50% and 5-38%, respectively. [23] constructed three distinct types of solar cookers: box, panel, and parabolic type. The highest temperature of cookers was observed to be 52.36ºC, 86.5ºC, and 43.5ºC, respectively. Additionally, it was found that the parabolic-type cooker is the least efficient solar cooker and box-type is the most efficient. [24] checked the efficiency of solar cooker using a vacuum tube collector and a parabolic trough collector. The experiment result showed that the temperature in the centre of the pot might reach up to 260°C when sun isolation was 720W/m^2. Also, the temperature of cooking oil reached 200°C within 60 minutes. [25] evaluated the efficiency of a parabolic trough-based indoor solar cooker. The cooking was done inside the kitchen in an indoor solar cooker while the trough collector was placed outside the kitchen, and the oil was used to transfer the energy. The maximum temperature of the oil at the stove and thermal efficiency were observed to be 119°C and 6%, respectively. [26] designed a large frying pan by using a flat mirror for the climatic conditions of East Africa. The pan's diameter was 0.46m, and the bottom of the pan was coated with black absorber paint. To use the setup for the entire year, the mirror had a single mirror adjustment and a seasonal adjustment. The pan temperature and the system's overall efficiency was recorded as 180°C and 60%, respectively. The prototype had a heating capacity of 640W however lost 100W when baking the bread. [27] presented a novel design cooking stove based on Fresnel lenses. Fresnel lenses have been tracked in the sun's direction to reach cooking temperature. It was noted that the cooker achieved a maximum temperature of 300°C, and transmited energy for indoor uses. [28] developed and experimentally investigated a twin-vessel solar cooker for cooking two food items simultaneously. In the experimental setup, pressurized and non-pressurized vessels were connected in series. The energy was transmitted from the receiver to the cooker with the help of HTF using the thermosiphon phenomena. HTF reached the highest temperature of 130.35°C, and the payback period was estimated as 3.89 years. [29] created a unique cooker using a vacuum tube collector. In this paper, the system's optical efficiency was simulated. After the and simulation, the experimental investigation was also done. Moreover, the system's theoretical and experimental maximum temperatures were calculated. The experimental outcome showed the system's highest temperature as 361°C. [30] estimated the effective concentration ratio of concentrated type solar collector. Also, [31] [32] enhanced the efficiency of box-type solar cookers with redesigned pots and tracking type bottom reflector. [33] investigated the efficiency of a solar cooker based on PDC with dual-axis tracking. The temperature inside the pan was observed to be more than 93℃. [34] invented a mini extended solar cooking system weighing only 6.5 kg. A box-style solar cooking system was attached to 5 panels of 15 W to minimize the cooking time. This modified cooking system provided any time cooking facility. The efficiency and the estimated cost of this hybrid solar cooking system were observed to be 38% and $120, respectively. [35] experimentally observed the performance of indoor solar cooker based on parabolic dish. Heat transfer fluid was used to convey energy from receiver to the cooking pot.

Numerous studies have been undertaken on the diverse forms of solar cooking, as evidenced by the reviewed literature. However, the use of solar cookers is limited because the majority of solar cookers can cook food outside. To encourage the residential use of solar cookers, it is important to make solar cooking more practical and user-friendly. Therefore, it is necessary to investigate solar cookers that may be utilized in the kitchen. However, little research has been conducted on indirect cooking for domestic usage. In this work, a solar-powered indirect pressurized indoor cooking system is developed. The main motive of this research is to develop a user-friendly indoor-type pressurized cooking system based on PDC. The PDC is placed 5 m apart from the cooking pot and the energy is transferred by heat transfer fluid (HTF). The HTF is circulated within the insulated steel pipes with the help of a gear pump.

2. Experimental Setup

For the objective of indoor pressurised cooking, a PDC-based experimental apparatus has been developed. This project attempts to design cooker apparatus in which a pressure cooker is installed in the kitchen while the PDC unit remains outside. The pump and HTF are responsible for transporting energy from the PDC to the PCP. The testing equipment is on the roof of the National Institute of Technology Kurukshetra, which is in northern India at 29.96°N latitude and 76.62°E longitude. Fig. 1 shows a photographic view of the experimental setup. The main components of the experimental setup are PDC, conical receiver, connecting pipes, gear pump, and pressurized cooking pot (PCP).

2.1 Parabolic dish concentrator (PDC)

PDC has been utilized to focus sun radiations in order to produce solar energy at a high temperature. It consists of a parabolic reflector, a tracking system, and a stand. A 2.6m^2 parabolic dish is constructed from fiber-reinforced plastic (FRP). Four layers of FRP are utilized to get it manufactured. To concentrate solar radiations, 0.95-reflectivity solar-grade aluminum reflector sheet is selected. To prevent scattered focus, smaller pieces of reflector sheet (10cm x 10cm) are affixed to the FRP dish collector. PDC is tracked by a gearbox with a 40:1 gear ratio. A mild steel support is provided to retain the PDC. The supporting stand is mounted on the roof with a 12mm thick stainless-steel bolt to withstand the adverse weather conditions. Specifications of PDC are listed in table 1.

2.2 Conical receiver

The concentrated heat is collected with the help of a conical tube type receiver. The conical receiver is developed by bending 8 mm-diameter copper tube. The conical receiver's height and diameter are taken same as 200mm. The conical receiver's insulation is done using a 40mm thick layer of glass wool. Also, the receiver is coated with a layer of graphite to maximize the energy absorption. The schematic and photographic views of the conical receiver have been shown in Fig. 2(a) and 2(b), respectively. The geometric concentration ratio (GCR) is the ratio of aperture area of the PDC to the aperture area of the receiver. The GCR is 84 in the present dish. The higher the GCR, higher will be the temperature achived at the focus of PDC.

2.3 Pressurized cooking pot (PCP)

Concentrated solar energy is sent from a solar collector to a transfer unit and then to the cooking pot, where it is used for a variety of cooking. PCP was fabricated by welding an oil jacket at the bottom of a pressure cooker. Baffles are provided inside the oil jacket to ensure proper circulation of HTF to the entire surface. Also, the PCP is insulated using glass wool to minimize the energy loss. In figures 3(a) and 3(b), the schematic and photographic representation of PCP are shown, respectively.

Table 1. Specifications of PDC

Parameters	Value
Diameter	18.28 m
Depth	0.35 m
Aperture Area	2.62 m
Focal Length	0.58 m
Rim Angle	76.14°
GCR	84
Dish Material	FRP
Reflecting Surface	Anodized aluminium sheet
Reflectivity	≥90%

2.4 Energy transfer system (ETS)

In the indirect cooking system, an arrangement is required to transfer energy from PDC to PCP, called the energy transfer system. Heat transfer fluid (HTF) and connecting pipes make up the majority of the ETS, together with a gear pump, and an expansion tank. The different parts of ETS are discussed below:

2.4.1 Connecting Pipes

Well-insulated connecting pipes are used for the flow of HTF from the conical receiver to the PCP. Flexible pipes of stainless steel, having 15.4mm internal diameter, are used as connecting pipes. Insulating the pipes with asbestos tape and polyurethane foam helps to ensure minimum loss of energy. A metallic slip joint nut is used to connect pipes to other components to prevent leakage.

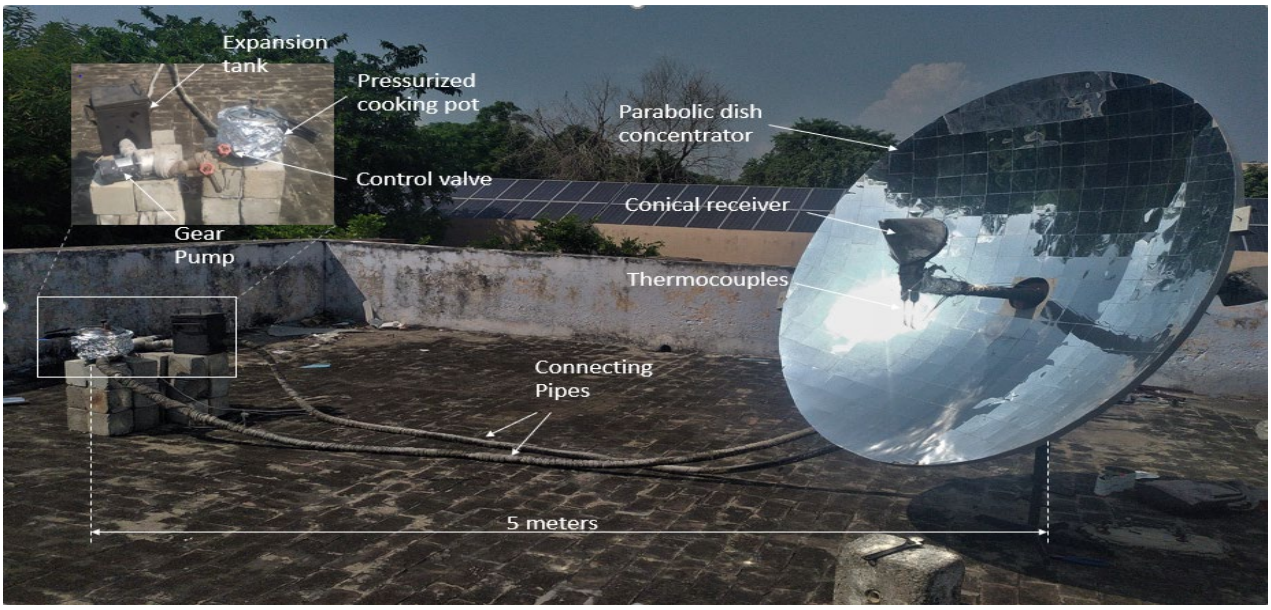
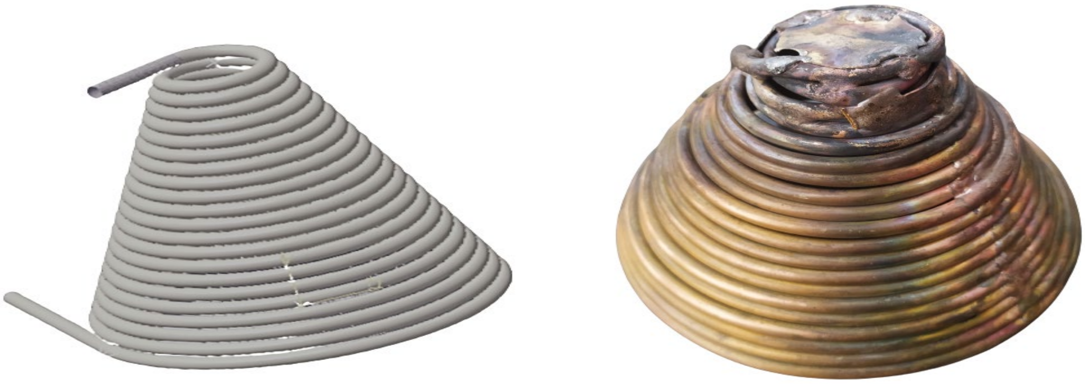
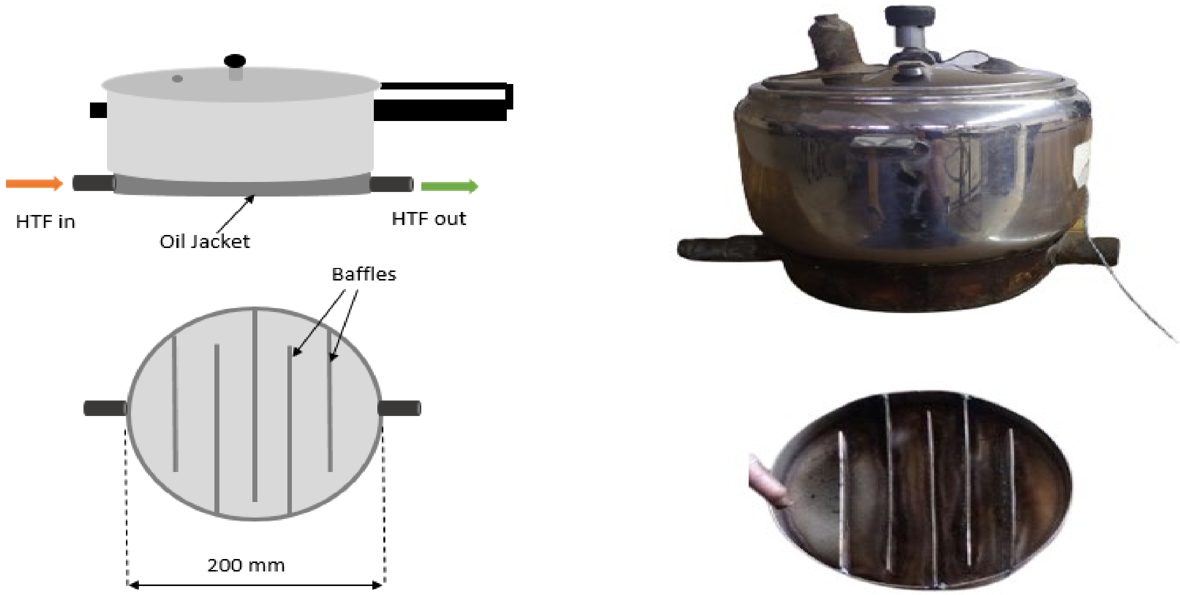


Fig. 1: Photographic representation of the cooking apparatus.



(a) (b)

Fig. 2: (a) Schematic representation of conical receiver (b) Photographic representation of the conical receiver



(a) (b)

Fig. 3: (a) Schematic representation of PCP (b) Photographic representation of PCP.

2.4.2 Gear Pump

A gear pump is required to circulate high temperature viscous fluid in the setup. To circulate HTF, a magnetic drive gear pump has been used. The flow rate of the HTF is controlled by a high-temperature gate valve. The flow rate of the gear pump is adjusted to 1 liter per minute.

2.4.3 Expansion Tank

When PDC is exposed to solar radiation, the volume of HTF increases due to the rise in the temperature of HTF. An insulated expansion tank of dimensions 0.15m×0.15m×30 m, has been used to prevent fluid overflow when the fluid is heated. Expansion tank also ensures that there is no pressure generation in the system. It is fabricated of mild steel, and glass wool is used to prevent the heat loss.

2.4.4 Heat transfer fluid

Because it is chemically stable and safe, Hytherm-600 fluid has been used as HTF to transfer heat from the receiver to the cooking pot. Table 2 lists the physical and chemical properties of HTF.

2.5 Measuring devices:

To figure out how well the system works, different measuring equipment are used. K-type thermocouples connected to a digital display are employed to measure the temperature of HTF at various spots. K-type thermocouples have a least count of 1°C and the range of -200°C to +1,260°C. The weather station of the model number DA9000/DA15K is used ot get the temperature of the atmosphere and sun irradiation. The weather station has been established on the roof of the School of Renewable Energy and Efficiency of National Institute of Technology Kurukshetra, India and is powered by stable energy supply[36]. Fig. 4(a) and 4(b) show the weather station and the temperature indicator, respectively.

For a variety of reasons, uncertainties and errors can happen throughout an experimental analysis. The main reasons for uncertainties and errors are the wrong calibration and environmental conditions. With the proper tools, the current research measures temperature, solar radiation, and wind speed. If all of the uncertainties in the independent variables have the same odds, Eq. (1) is used to figure out the resultant uncertainty[37].

$$W_r = \left[\left(\frac{\partial r}{\partial x_1} W_1\right)^2 + \left(\frac{\partial r}{\partial x_2} W_2\right)^2 + \ldots\ldots\ldots\ldots + \left(\frac{\partial r}{\partial x_n} W\right)^2\right]^{0.5} \quad (1)$$

Table 2. Specifications of Hytherm-600

Properties	Typical Values
Appearance	Clear
Viscosity index	100
Pour Point, ℃	-45
Flash Point, ℃	220
Fire Point,℃	224
Auto-ignition Temperature,℃	426
Specific Heat, (kJ/kg.K)	2.19
Specific gravity	0.825

Table 3. Uncertainty parameters

Parameter	Unit	Uncertainty
Temperature	℃	±0.380
Wind velocity	m/s	±0.170
Solar intensity	w/m^2	±1.414

Where the uncertainties in the independent variables are denoted by W_1, W_2,..., W_n, and the overall uncertainty in the results is denoted by Wr. The function r determines the independent variables x_1, x_2, x_3,..., x_n. Uncertainties associated with different parameters are listed in table 3.

3. System operation

At 8:00 h, cover on the PDC was removed and the collector was exposed to the sun and thus PDC started concentrating solar radiations on the conical receiver. The gear pump motor was then switch on and HTF started circulating throughout the system. The heat building up in the receiver tubes caused the HTF temperature to go up. This high temperature fluid was sent to the cooking vessel by the receiver. High-temperature HTF dissipated its heat to the food and water in the pot, and thereafter the low temperature HTF was transferred from the cooking pot to the receiver as shown in fig. 5. As a result, the receiver continuously provided energy to the cooking pot. The PDC had been tracked to maximise the solar energy absorption during the complete experimentation. The raw food rice, cracked wheat, khichdi, and black gram, were cooked in the pressure cooker at various cooking loads. The cooking periods of various items and the energy transferred from the PDC to the PCP have been calculated in order to assess the performance of the cooking system. The PDC was exposed to solar radiations for every 10 minutes from 08:00 h and 17:00 h. The energy exchange between receiver and PCP is calculated by using type k thermocouples placed at multiple places.

(a) (b)

Fig. 4. (a) Photographic representation of weather station (b) Photographic representation of temperature indicator

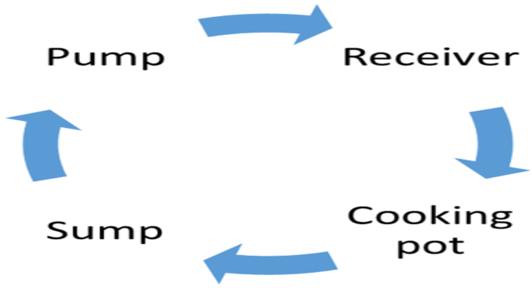


Fig. 5: System of operation

4. Energy and exergy efficiency

In the current experimental analysis, both energy efficiency and exergy efficiency of pressurized solar cooking system (PSCS) are calculated. The system's energy and exergy efficiency are determined when there was 2 liters of water without any food item in the cooking pot. Energy efficiency is the ratio of useful energy to the total energy available at the aperture of the parabolic dish collector.

The total available energy (E_i)

$$E_i = I_n A \tag{2}$$

Energy used for cooking (E_o)

$$E_o = \frac{m_w c_{pw}(t_{wf} - t_{wi})}{\Delta T} \tag{3}$$

Thus, the instantaneous energy efficiency (η) of the PSCS.

$$\eta = \frac{m_w c_{pw}(t_{wf} - t_{wi})}{I_n A \Delta T} \tag{4}$$

Exergy analysis measures how effectively the solar energy is used. A process's exergy efficiency is the ratio of the exergy transfer rate at the output (E_{xo}) to the exergy transfer rate at the driving input (E_{xi}). The current study calculates the exergy input using Petela[38].

$$E_{xi} = I_n \left\{1 + \frac{1}{3}\left(\frac{t_a}{t_s}\right)^4 - \frac{4}{3}\left(\frac{t_a}{t_s}\right)\right\} A \tag{5}$$

The exergy-output rate from the PSCS is calculated using:

$$E_{xo} = \frac{m_w c_{pw}\left\{(t_{wf} - t_{wi}) - t_a \ln\left(\frac{t_{wf}}{t_{wi}}\right)\right\}}{\Delta T} \tag{6}$$

where
time interval (ΔT) is taken as 600s;
constant specific heat for water(c_{pw}) is taken as 4,186 J/kg.K;
Solar radiation temperature (t_s) is taken as 6,000 K.

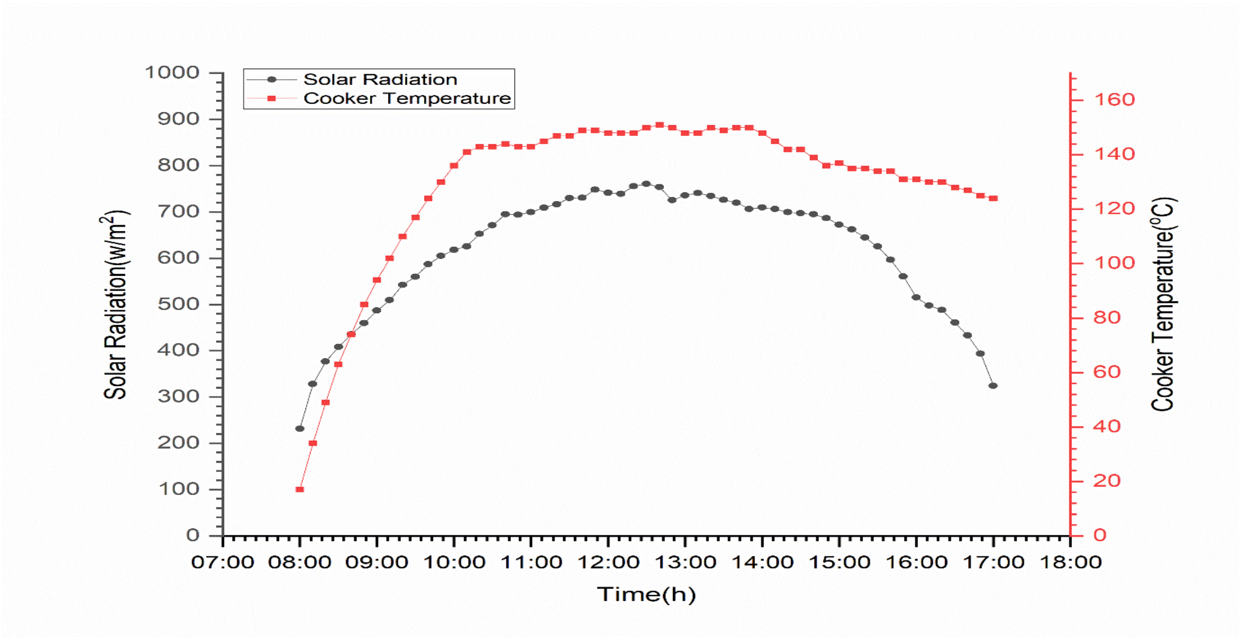


Fig. 6: The temporal variation of the temperature inside PCP and solar intensity.

5. Experimental Results

The prime goal of this current experimental investigation is to analyze the performance of PSCS. Both the energy and the exergy efficiency of the PSCS is calculated. The experimentation was performed on a clear sky day of February 2022. Two liters of water in the pressurized cooker was heated from 8 AM to 5 PM and temperatures at different locations were noted after a fixed interval of 10 minutes. Fig. 6 depicts the temporal variation of the cooker's internal temperature (T_w) and sun intensity. After every 10-minute period, the temperature inside the cooker was recorded. The solar intensity depends on the geographical conditions of the place where the experimentation are conducted. The maximum temperature inside the cooker gone up to 151℃ at 12:40 h. The maximum value of temperature inside the cooker was recorded after 280 minutes of continuous heating, and the cooker takes only 63 minutes to heat 2 liters of water up to 100℃. The surrounding temperature during this experiment changed from 17.3°C to 30.7°C, and the solar intensity varied between 231 to 760 W/m^2.

At 12:30 h, the solar intensity was at its peak value. It is observed that the slope of the temperature v/s time curve is reduced continuously i.e. change in temperature inside the cooker with time got reduced as the temperature increased. This is because there is an increase in heat loss as the temperature of the water inside PSC rises. After some time, the slope became negative i.e., the temperature inside the cooker starts decreasing. The decrease in

Table 4: Time to cook different edible food under different cooking loads

S. No.	Items	Water (liters)	Mass (gms)	Cooking time (minutes)
1.	Rice	1	400	45
		2	800	80
		3	1200	110
2.	Black gram *(urad saabut daal*)	1	250	60
		2	500	90
		3	750	125
3.	Khichdi	1	350	50
		2	650	82
		3	1000	115
4.	Cracked wheat	1	200	50
		2	400	85
		3	600	120

Table 5: Comparative analysis of present study with existing indirect type solar cooker

S. No	Researcher	Type of collector used	Method of energy transfer	Type of cooking	Maximum cooking pot temperature (℃)	Energy efficiency (%)
1.	Harvinder Singh et al.[39]	Evacuated tube collector	-Engine oil -Water	-Boiling	89.1	18.88
2.	S.C. Kaushik and M.K. Gupta[40]	Scheffler Reflector	Secondary Reflector	-Boiling -Pressurized	98.5	27.87
3.	G. Kumaresana et al.[41]	Parabolic Trough	Therminol-55	-Frying	152	10.2
4.	Omendra Kumar Singh[42]	Parabolic Dish	Therminol-55	Boiling	109	21.01
5.	Ranjan Chaudhary and Avadhesh Yadav[28]	Evacuated tube collector	Hytherm-500	-Boiling -Pressurized	104	N.A.
Present Study		Parabolic Dish	Hytherm-600	-Pressurized	151	8.33

temperature happened when the value of heat loss from the cooker became higher than the heat absorbed by the cooker.

Additionally, the performance of the cooking apparatus is evaluated for various cooking ingredients and cooking loads. The time for cooking four items i.e., Rice, Black gram, Khichdi, and Cracked wheat with different cooking loads has been noted. Table 4 shows the time duration to cook four items under three different cooking loads and table 5 shows the comparative analysis of present study with the existing indirect type solar cookers. The cooking is done with 1 L, 2L and 3L of water with suitable amount of edible food as mention in table 4 and fig. 7 represents the cooking time of different edibles with cooking load conditions.

The cooking is started when the temperature of HTF reaches at 100°C. The cooking of every edible food is done after 6 hours of soaking. The energy and exergy input rate are determined using Eqn. (2), (5) and their temporal variation is presented in fig 8. The maximum energy and exergy input rate values are 1721 W and 1606 W, respectively. Additionally, it is reported that the average energy and exergy input rates are 1325 W and 1238 W, respectively. The energy received by the PDC mainly depends on the aperture area of the PDC and the solar intensity.

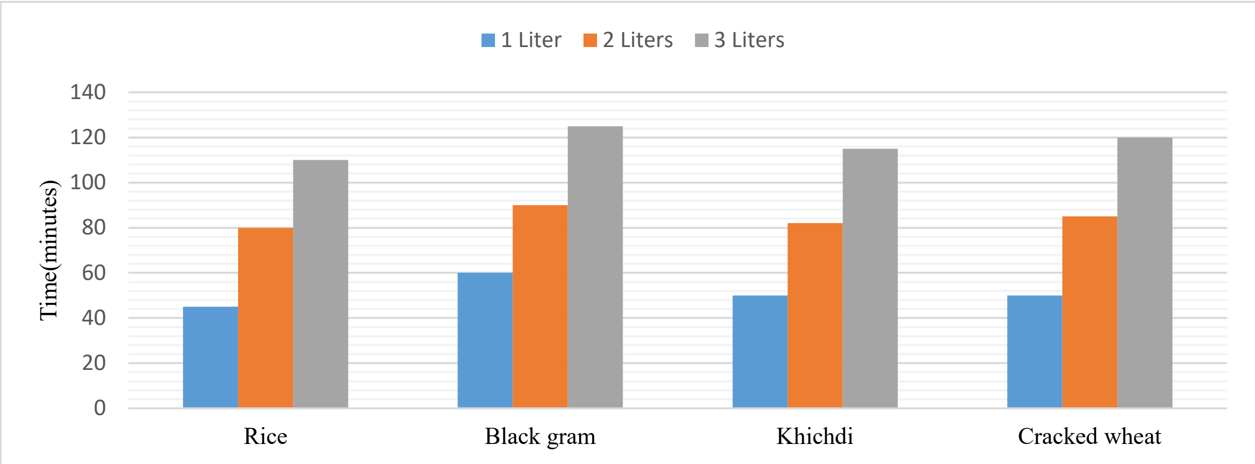


Fig.7: Cooking time of different edibles with various cooking load conditions.

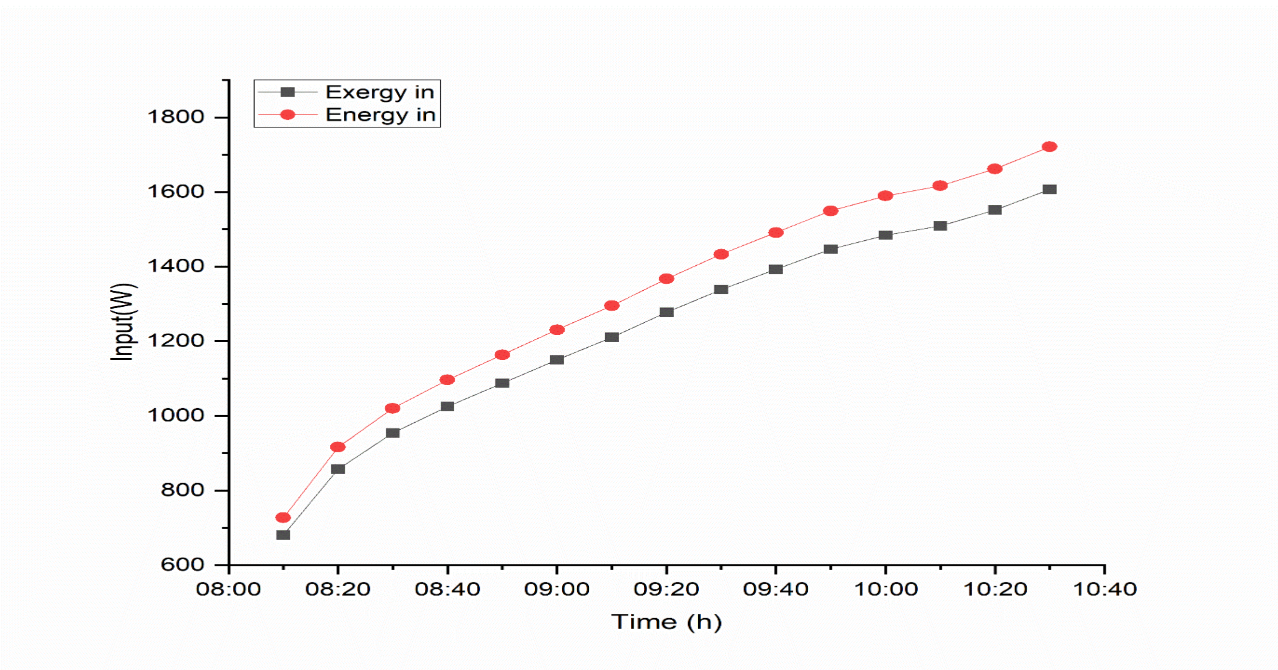


Fig. 8: The temporal variation of energy and exergy input.

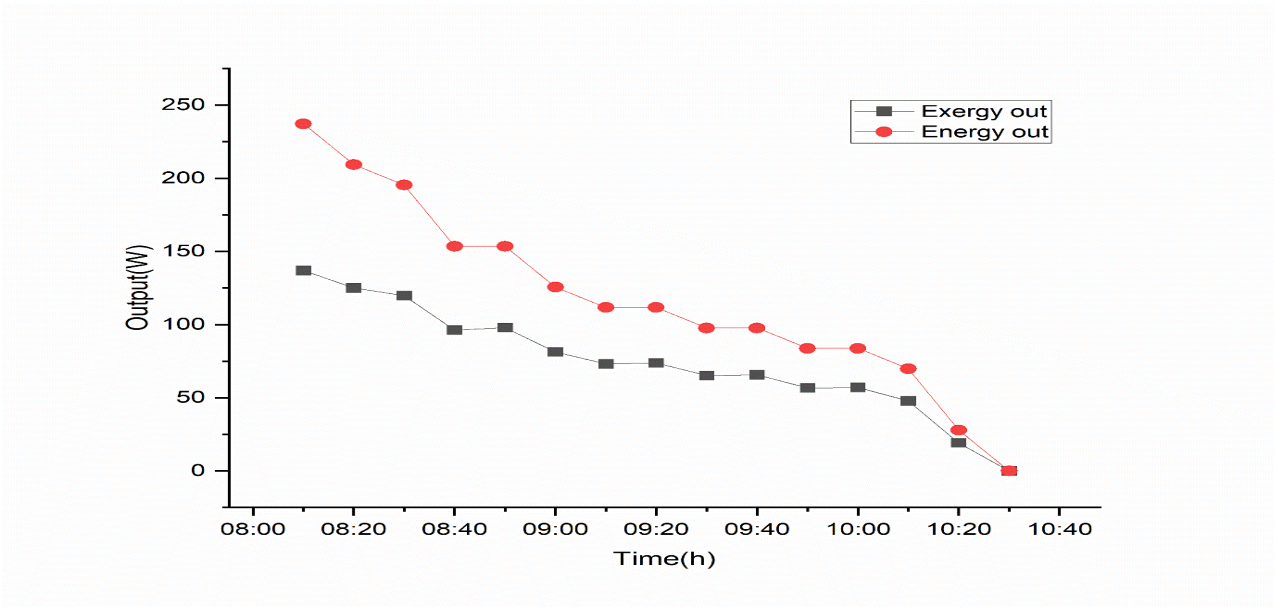


Fig. 9: The temporal variation of energy and exergy output.

The energy and exergy output rate are determined using eqns (3), (6), and its temporal variation is presented in fig 9. It is also observed from the graph that the energy output rate is inversely proportional to the temperature inside the cooker. As the temperature inside the cooker increases, the losses from the cooker also increase, resulting in low energy and exergy output rate. The rate of increase in energy and exergy is higher during the initial hours and it reduces as the cooker's temperature rises. The maximum energy and exergy output rate values are 237W and 136W, respectively. Additionally, it is found that the average energy and exergy output rates are 117W and 74W, respectively. The temporal variation of the instantaneous energy and exergy efficiency is presented in fig 10. The maximum energy and exergy efficiency value are 32.62% and 22.11%, respectively. A large variation in the energy and exergy efficiencies with time has been observed in graph, this is due to increase in HTF temperature. As the HTF temperature increases the convective losses also increases which result in the decrease of efficiencies. It is also reported that the average energy and exergy efficiency is 10.58% and 7.08%, respectively. At higher temperatures, the cooker losses are also high, resulting in low energy and exergy efficiency. A detailed energy distribution is explained in fig. 11. From the figure, it is observed that 8.33% of total energy has been transferred to food, and the remaining energy is lost in the atmosphere due to different types of energy

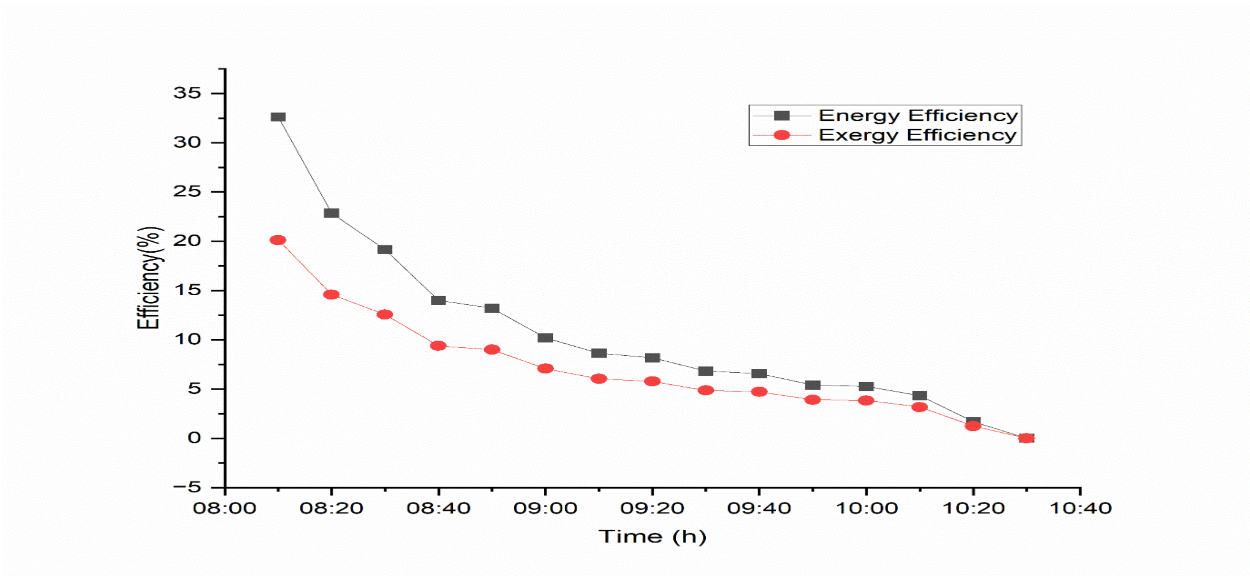


Fig. 10: The temporal variation of energy and exergy efficiency.

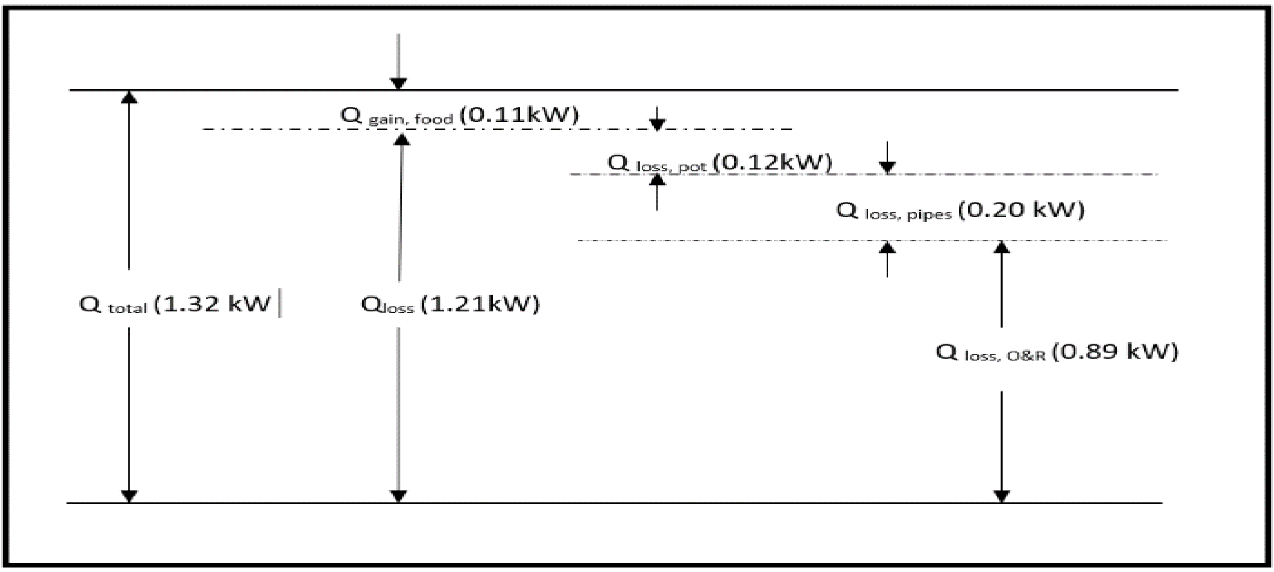


Fig. 11: Distribution of total available energy (Q_{total}).

transfer losses (i.e. $Q_{loss,pot}$, $Q_{loss,pipes}$ and $Q_{loss,O\&R}$). The major loss that occurs in the cooking process is optical and receiver loss ($Q_{loss,O\&R}$), which is about 67.4% of the total energy received by PDC. Significant amount of energy is also lost within pipes in the energy transfer process ($Q_{loss,pipes}$), which is about 15.15% of total available energy. The main cause of the loss of energy from pipes is the convective heat transfer from the surface of pipes to the atmosphere. The efficiency of the cooking pot is observed to be only 45.83%, which means a significant part of the energy is lost due to convective heat transfer from the PCP to the atmosphere.

6. Economic Analysis

Economic analysis of any proposed system is necessary to know the economic feasibility of the system. A newly developed system must be economically feasible for its domestic and industrial use. Economic analysis include the evaluation total cost, annual cost saving and payback period of the system[43]. Table 6 shows the total expenditure of PSCS. Total cost is the sum of different type of material cost, processing cost and labour cost used in the fabrication of PSCS.

Annual cost saving is the amount of money that can be saved after the installation of PSCS. It can be determined by using given equation:

$$Annual\ cost\ saving = Average\ sunny\ days\ in\ a\ year \times Cost\ saving\ per\ day$$

Cost saving per day is the Indian rupees saved that will be saved after the use of PSCS. Cost saving per year can be determined as follow:

$$Cost\ saving\ per\ day = Amount\ of\ LPG\ saved\ per\ day \times Cost\ of\ LPG\ per\ Kg$$

Amount of LPG saved per day is the amount of LPG in Kg that will be saved after the installation of PSCS and it is calculated by eqn. given below:

$$Amount\ of\ LPG\ saved\ per\ day = \frac{Energy\ saved\ per\ day}{Calorific\ value\ of\ LPG \times \eta}$$

Energy saved per day can be calculated using following equation:

$$Energy\ saved\ per\ day = Q_{u,avg} \times h \times 3600\ Joule$$

where,
Q_u is average useful energy gained by food;
h is number of working hours of system;
η is overall efficiency of LPG stove.

After experimental investigation, value of Q_u is calculated as 232 W. It is observed that the system is capable to cook 8 hours in a clear sky day. The overall efficiency of LPG stove (η) is taken as 65%[44]. Cost and calorific value of LPG are taken as Rs 82/- and 46 MJ per Kg, respectively. India is blessed with 275 sunny days in a year.
After calculation the payback period of PSCS is observed to be 4.6 years only.

$$Payback\ period = \frac{Total\ expenditure}{Annual\ cost\ saving}$$

For any cooking system levelized cost of meal (LCM) is an important parameter to analyze economic feasibility of that cooking system. LCM include all type of costs like fuel cost, running cost, depreciation cost for cooking a meal. It can be calculated by using following eq (7)[45].

$$LCM_{total} = LCM_{fuel} + LCM_{stove}$$

$$LCM_{total} = \frac{R_f E_r}{\eta_s} + \frac{\sum_{t=1}^{l} \frac{P_o + M_t}{(1+d)^t}}{\sum_{t=1}^{l} \frac{N_t}{(1+d)^t}} \quad (7)$$

Where,
R_f is fuel cost in INR/MJ.
E_r is energy requirement for cooking a meal in MJ.
η_s is the efficiency of cooker.
P_o is the total expenditure of cooker.
M_t is the yearly running cost of cooker.
d is discount rate (%).
l is the cooker lifetime.
N_t is the number of meals cooked in a year.
To calculate LCM_{total}, in the case of solar cooker R_f and M_t are taken as zero. Also, the lifetime of the present solar cooker is taken as 15 years. Total number of meals cooked in a year is calculated by multiplying average number of sunny days in a year to the number of meals cooked per day. After calculation, the levelized cost of one meal is estimated as 1.15 INR.

Table 6: Total expenditure of PSCS.

S. No	Item/Process	Cost (INR)
1.	Mould preparation	4500
2.	FRP dish	3750
3.	Anodized aluminium sheet	5500
4.	Supporting stand	1500
5.	Tracking mechanism	2200
6.	Receiver	1500
7.	Gear Pump	1800
8.	Flexible steel pipes	2250
9.	Cooking pot	2000
10.	Labour	3500
Total cost		**28500**

7. Conclusions

Energy and exergy analysis of the solar pressurized cooker has been done. Also, the cooker's potential is checked by cooking different edibles with different load conditions. From the experimental study, following results are concluded:

1. Rice, khichdi, black gram, and cracked wheat have been effectively cooked. According to the findings of the studies, the cooking system requires 45 minutes to prepare 400 grammes of rice and just 60 minutes to prepare 250 g of black gram. The average thermal efficiency of the cooking system was found to be 8.33 percent.
2. The highest HTF temperature measured was 170°C, and the highest temperature in the cooking pot was 151°C. Also, it only takes 53 minutes for the temperature of HTF and 65 minutes for the temperature inside the cooking pot to reach 100°C.
3. The system can cook constantly at medium temperatures for almost six hours. The system is successfully tested with a maximum cooking load of 3 litres water with 1.2 kg rice. The system is long-lasting and requires minimal maintenance. In the future, diverse forms of cooking, such as frying and steaming, will utilise the same cooking system.
4. The total capacity of the system is 3.36 MJ per day which is capable to cook 6 meals in a day or it can cook meal of 2-3 person and the levelized cost of each meal is estimated as 1.15 INR.
5. After economic analysis it is found that the total expenditure and payback period of the system is 28500 INR and 4.6 years, respectively.

Nomenclature

PSCS	Pressurized solar cooking system
PDC	Parabolic dish collector
HTF	Heat transfer fluid
ETS	Energy transfer system
FRP	Fiber-reinforced plastic
PCP	Pressurized cooking pot
I_n	Solar Intensity (W/m^2)
m_w	Mass of water (kg)
c_{pw}	Specific heat of water(kJ/kg°C)
t_{wf}	Water temperature at the initial stage(°C)
t_{wi}	Water temperature at the final stage(°C)
ΔT	Time interval(s)
A	Aperture area(m^2)
Q_u	Useful energy

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