Solar Cooker for Night Cooking: Design, Fabrication and Performance Analysis

Dharmananda Barik [1*], Nabnit Panigrahi [2]
[1*]Assistant Professor, Department of Mechanical Engineering, Nalanda Institute of Technology, Bhubaneswar, Odisha, India
[2]Associate Professor, Department of Mechanical Engineering, Nalanda Institute of Technology, Bhubaneswar, Odisha, India
*Corresponding author e-mail: dharmanandabarik@thenalanda.com

Abstract: At the home and commercial levels, solar cooking and water heating are commonly regarded as clean and environmentally friendly energy applications. According to research on the various collector designs, box type cookers are superior from a cost standpoint, and compound parabolic collectors (CPC) are superior when cooking time is taken into account. So, it was intended to develop, produce, and study a specific kind of cooker that does not require tracking and can maximise solar energy all day long. According to the analytical and experimental findings, the energy generated is significantly more than what is needed to cook 500 g of rice. Due to variations in analytical and measured solar radiation level, there is a substantial disparity between analytical and experimental values of oil temperature. For six days straight, the CPC-based solar cooker setup is put to the test. The highest oil temperature recorded is 110 C. The oil temperature dropped by about 35 during non-sunny hours. The technology couldn't operate at its full potential because of the bad weather and built-in restrictions. It has been found that a rise in oil temperature during the afternoon is adequate to cook rice, and a rise in oil temperature during the late evening is sufficient to preheat food.

Keywords: *Compound Parabolic Collector, Oil Storage Tank, Energy Content, Cooking Time*

Introduction:

The primary energy source comes from fossil fuels. The balance between the supply and demand of energy appears to be deteriorating in the upcoming years as a result of the restricted availability or gradual depletion of various sources. In addition, fossil fuels are naturally polluting. Using renewable resources to their fullest extent is necessary to maintain a balance between the supply and demand of energy and to provide a clean, environmentally friendly source of electricity.

In contrast to the global per capita yearly average of 2600 kWh and 6200 kWh in the European Union, the average annual home power consumption in India in 2009 was 96 kWh in rural regions and 288 kWh in urban areas for those with access to electricity. Despite being the world's fourth-largest energy consumer behind the United States, China, and Russia, India today faces a severe deficit of electrical generation capacity..

Renewable energy accounts for approximately 12% of a total 200 GW of power generation capacity installed in India.Demand for power in India has been increasing due to the rising population, growing economy, and changing lifestyles.Despite substantial capacity additions, the power sector is still in shortage of energy.Peak demand shortage averages around 12%.

Solar cookers:

A solar cooker, or solar oven, is a device which uses the energy of direct sunlight to heat, cook or pasteurize food or drink. Over the past many decades, a number of designs of solar cooker have been developed. The majority of solar cookers presently in use are relatively cheap, low-tech devices. Although solar cookers have been available for many years, there is continuing interest in their performance optimization.

The two box-type cooker designs have undergone testing. The second type has a painted black with coal basis while the first type has a painted black base. Two operational modes were used to assess these designs: fixed location and tracking system. When the sun was at its strongest during the day, the cooker's thermal efficiencies ranged from 25.2% to a dramatic peak of 53.8%, with an average overall efficiency of roughly 32.3%. The thermal efficiency of the black coal-fired cooker, built on a sun tracking system, ranged from 28% to 62.1%, with an average total efficiency of roughly 43.8%. [1]. The research work presents a hybrid solution to problems presented by box-type solar ovens in night and cloudy conditions. The developed hybrid solar oven is supplied with both electric and solar energy and can be used in early morning hours, on cloudy days, or when solar radiation decreases or disappears. The experimental results demonstrate that these ovens are suitable for home use in dry climates [2 the need for frequent tracking, and standing in the sun while cooking. A cylindrical solar cooker with two axes sun tracking system has been designed and tested during different days. It showed that the cylindrical solar cooker system with two axes tracking can increase water temperature up to 90°C [3]. The design development and performance

characteristics of direct steam generation by non-tracking solar paraboloidal dish concentrating system has been studied. The performance of the concentrator is experimentally investigated with the water circulated as heat transfer fluid. The system is fabricated with high reflectivity aluminium foil sheet. The test results gave steam temperature of 215°C with conversion efficiency of 60-70% [4].An experimental set up consisting of an array of photovoltaic panels, microprocessor based tracking System, cylindrical parabolic collector, insulated oil storage container and insulated pipe was taken up for techno-economic assessment of solar steam cooking system. An assessment of viability of such system is discussed and the payback period found to be 26months [5].

The other research work proposes a hybrid solar cooking system where the solar energy is brought to the kitchen. The energy source is a combination of the solar thermal energy and the Liquefied Petroleum Gas (LPG) that is in common use in kitchens. There are three parameters that are controlled in order to maximize the energy transfer from the collector to the load viz. the fluid flow rate from collector to buffer, fluid flow rate from buffer to load and the diameter of the pipes. The entire system is modeled using the bond graph approach with seamless integration of the power flow in these domains. The modeled system is simulated and the results are validated experimentally [6]. The inventor reviews relevant issues on solar cooking in order to define and evaluate an innovative layout of a portable solar in the heated oil coming from the self-circulating loop. The salts provide latent heat to the heat storage (melting temperature: 215 to 225°C). The absorber is originally insulated with an air layer; an cooker of the standard concentrating parabolic type that incorporates a daily thermal storage utensil. This utensil is formed by two conventional coaxial cylindrical cooking pots, an internal one and a larger external one. The void space between the two coaxial pots is filled with a phase change material (PCM) forming an intermediate jacket. The numerical model is used to study its transient behavior for the climatic conditions and validated with experimental data. The results indicate that cooking the lunch for a family is possible simultaneously with heat storage along the day. Keeping afterwards the utensil inside an insulating box indoors allows cooking the dinner with the retained heat and also the next day breakfast. This expands the applicability of solar cooking and sustains the possibility of all the day around cooking using solar energy with a low inventory cost [7]. Another research work includes a self-circulating loop coupled with a heat storage and a solar parabolic trough. The loop is filled with thermal oil (Duratherm 630). Based on experimental results of the charging of a heat storage, a numerical upscaling of the system is made using Matlab. By numerically improving the coating of the absorber, modifying the pipe diameters and optimizing the size and the content of the storage, an optimal system can be virtually designed. The storage is originally based on aluminum cylinders filled with nitrate salts immersed evacuated tube is then numerically tested. The vacuum provides a much better insulation: it allows then a greater potential for heat storage. However, overheating of the oil in the absorber is an issue and the design of the pipes needs then to be modified (increase of diameter). A new heat storage based on tin is virtually designed, with larger heat storage potential. The diameters of the pipes are slightly increased again to speed up the flow and reduce overheating [8]. It has been concluded from the detailed literature review that the information pertaining to the application and analysis of low cost non-tracking type compound parabolic collector (CPC) trough for solar cooking is limited. Hence there is a need to get this topic into limelight.

Design considerations:

The prime intention was to fabricate a CPC solar cooking system which can harness maximum solar radiation throughout the day. Hence it had been decided to incorporate 3 troughs with different orientations without tracking. The various parameters to be considered in the design and performance analysis are discussed here.

A. *Energy requirement for cooking*

It has been observed that to cook 500gm of rice, approximately 0.28 kWh of energy is required [9].
The width (W) of the CPC can be calculated as:

$$C = (\mathrm{W} - D_o)/\pi D_i \qquad (1)$$

Absorbed solar flux is given by:

$$S = [I_b R_b + (I_d/C)]_c \alpha \qquad (2)$$

Where, 'R_b' is the tilt factor for beam radiation,

The intensity of radiation (at Manipal on 15th February) and the absorbed flux have been calculated analytically (as shown in Table 1) by referring to the specifications mentioned in Table 2. This is to ensure the effective working of the solar cooker.
Useful heat gain by the system is:

$$Q_u = F_R \mathrm{W}[S - (U_L/C)(T_{hi} - T_a)]\mathrm{t} \qquad (3)$$

$$= m(T_{ho} - T_{hi}) \qquad (4)$$

***Table 1**: Solar radiation analysis with time*

S.No.	Time interval (t) (h)	Beam radiation (I_b)(W/m^2)	Diffused radiation (I_d)(W/m^2)	Absorbed flux (S)(W/m^2)
1	10 - 11	751.87	102.48	499.84
2	11- 12	861.92	104.59	547.27
3	12- 13	899.45	105.22	567.34
4	13-14	861.92	104.59	547.27
5	14-15	751.87	102.48	499.84

***Table 2**: Specification of CPC [10]*

S. No.	Description	Value
1	OD of the evacuated tube (D_o)	58 mm
2	ID of the evacuated tube (D_i)	48 mm
3	Length of the tube (L)	1800 mm
4	Transmissivity of cover material (τ)	1(no cover)
5	Reflectivity of Aluminium Foil (ρ_c)	0.6
6	Absorptivity of the inner tube (α)	0.9
7	Collector heat removal factor (F_R)	0.95
8	Overall heat loss coefficient (U_L)	7.5
9	Concentration ratio (C)	1.6

Where, 'm' is the mass of oil in the container in kg, 'T_a','T_{hi}' and 'T_{ho}' are the surrounding temperature, oil inlet and outlet temperature respectively.

Initially a CPC trough was designed, fabricated and fitted with an evacuated tube and container. The used engine oil (ρ = 850 kg/m^3 and Cp = 2395 J/kgK) of 5 litres was taken to evaluate the analytical (referring Eq. 4) and experimental final temperature as shown in Figure 1. The analytical (assuming adiabatic vessel) and experimental energy content of oil (effectively 1.75

Modelling of CPC trough

By considering the above design parameters, CPC modelling is done using CATIA V5 R18 software. Steps involved in modelling the CPC trough are as follows:

(i) An involute of a circle having same diameter as that of evacuated tube i.e. 58mm is drawn.
(ii) Using concentration ratio value of 1.6, acceptance angle is calculated to be 40˚ approximately. The involute profile is trimmed to the required acceptance angle of 40˚.
(iii) Two parabolas are now drawn taking the diametrical ends of the evacuated tube as the respective foci of the parabolas.
(iv) Parabolas are adjusted to maintain the width of the CPC trough at around 300mm as calculated during the design considerations.
(v) In the 'Sheet Metal Design' Workbench, the CPC profile is extruded after giving the required sheet thickness as shown in Figure 2.
(vi) The side covers with a hole of 58mm are then made in 'Part Design' workbench.

Fabrication details:

The various components to be fabricated are discussed here:

A. *CPC trough*

Galvanized Iron (GI) has been selected as the most economical material for the CPC Trough. Moreover, GI Sheets can be bended and welded easily. To further enhance the reflectivity of CPC, it has been

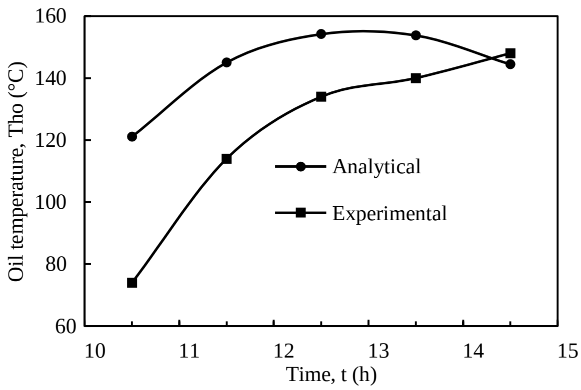


***Figure 1** Variation of oil temperature with time*

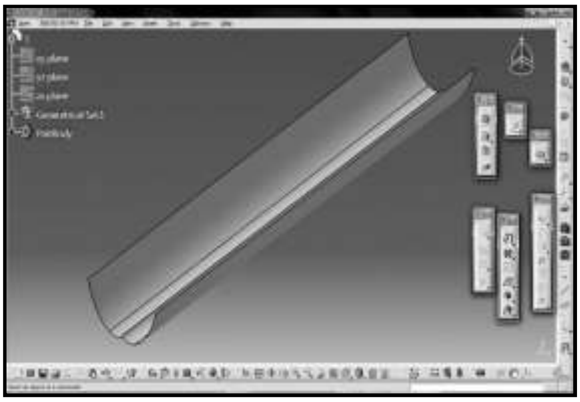


***Figure 2**: 3D drawing of CPC trough*

decided to stick aluminium foils along the entire trough The surface area of the designed CPC is calculated to be 1m^2. The fabrication steps involved are as follows:

(i) The contour of the CPC profile is cut from an 18 gauge GI sheet.
(ii) A 24 gauge GI sheet of length 1700mm is cut and the desired contour/profile is obtained along the entire length.
(iii) Hole of 60mm diameter is punched in both the side covers.
(iv) The two side covers are than welded to the CPC trough.
(v) Aluminium Foil is now stuck to the CPC to increase the reflectivity.

B. *Oil storage tank*

The fabrication procedure for the oil storage tank is explained below:

(i) Three holes of diameter 52 mm (size of GI pipe) and a small hole to insert vacuum valve are made on to an outer container.
(ii) Three holes of 52 mm diameter are also made in middle container and after inserting GI pipes into it, these are welded together with outer container as shown in Figure 3.
(iii) A lid of diameter same as that of middle container is taken and a hole of 186 mm is made to fix the inner container (to hold the cooker). To

pour oil and to check the oil temperature provision is made within the lid.

(iv) The inner container is brazed to the lid and later the lid is brazed to middle container as shown in Figure 4.

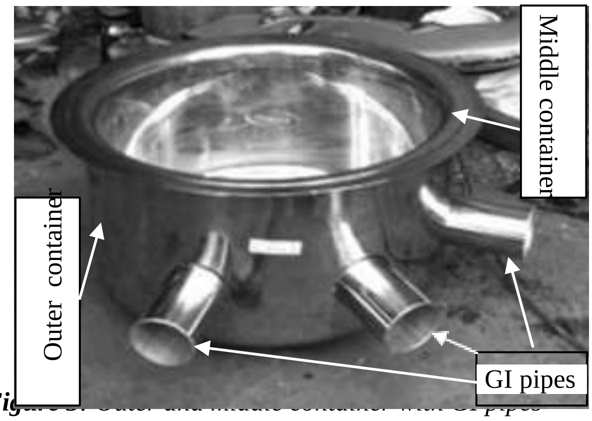
(v) M-Seal is applied at the brazed portions in order to completely seal the joint. The portion above the lid is covered with thermocol to minimize the heat loss as shown in Figure 5.

(vi) The space between the outer and the middle container is evacuated using a vacuum pump and the valve is completely tightened.

The passage between inner and middle container is filled with engine oil. A little amount of oil is also put in inner container to maintain better thermal contact with cooker. The gap between middle and outer container is evacuated to minimize heat loss from hot oil to surrounding.

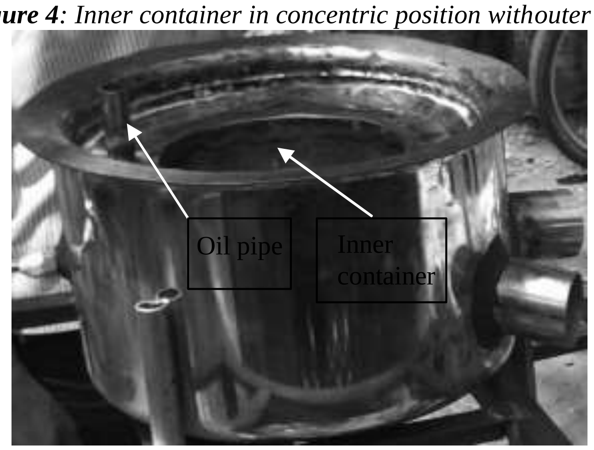
C. CPC system

Three troughs with evacuated tube are assembled as a single unit using metal frame. The provision has been made for both system as well as trough orientation. Three GI pipes protruded from oil storage tank are connected to evacuated tubes by Neoprene hose pipes as shown in Figure 6. The complete CPC system is shown in Figure 7.



Fi

***Figure 4**: Inner container in concentric position withouter*



container

Experimental set up:

The experimental set up (Figure 8 and Figure 9) consists of a solar radiation recorder and thermometer to measure oil temperature. The system was kept facing south and both solar radiation and thermometer readings were taken for many days before putting the cooker into it.

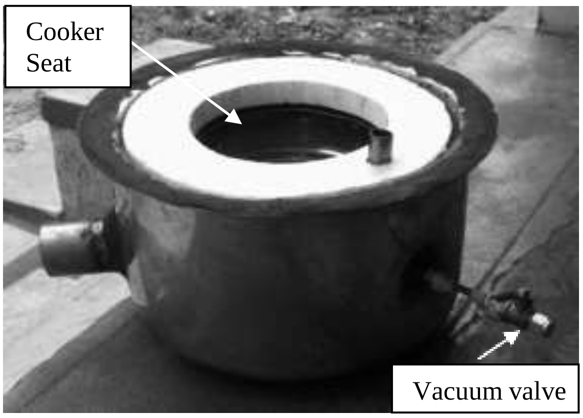


***Figure 5**: Oil storage tank with vacuum valve*

***Figure 6**: Oil storage tank connected to CPC*

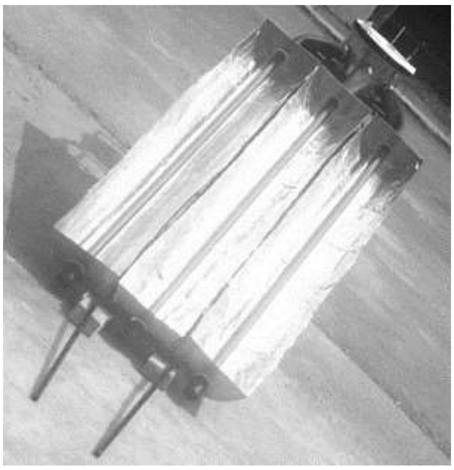


***Figure 7**: CPC system*

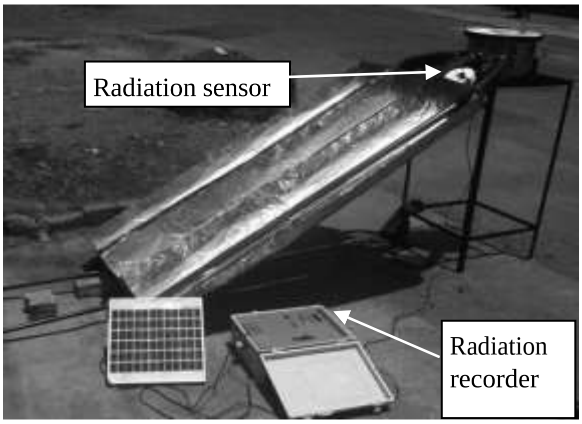


***Figure 8**: CPC system with solar radiation recorder*

***Figure 9**: CPC system with solar cooker*

Results and Discussion:

The set up was tested with solar cooker and the highest temperature of oil recorded was 110˚C and it was dropped to 75˚C during 1930 hours as shown in Figure 10. It has been found out that the time required for cooking 500 gm of rice was less than an hour during afternoon period. Whereas the temperature available wasn't enough to cook rice during late evening. But this temperature is sufficient to warm up the food. This inefficient nature of the system have been diagnosed as follows:

(i) The complete experimentation period was partially cloudy.

(ii) Since the evacuation process wasn't perfect, the outer container surface temperature was high.

(iii) Since the pipe size is bigger, the conduction heat loss from pipe wall to container wall was considerable.

(iv) Heat loss from the outer surface of hose pipe and outer container as they weren't insulated.

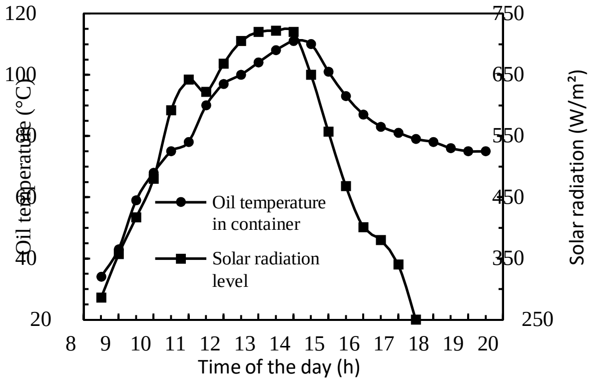


***Figure 10**: Variation of solar radiation and oil temperature with time*

Conclusion:

(i) On the basis of the analytical and experimental analysis, the following findings are made:

(ii) I Due to variations in analytical and measured solar radiation level, there is a notable disparity between experimental and analytical values of oil temperature.

(iii) The CPC's construction and design are sufficient to meet the demand for cooking energy.

(iv) The current cutting-edge non-tracking CPC system is capable of absorbing the most solar energy possible throughout the day.

(v) The CPC system can be redesigned to increase the amount of stored energy.

(vi) Notwithstanding the large initial investment, such systems can be promoted because of their clean and environmentally friendly character.

References:

[1] Viral K Pandya, 2011, "Assessment of Thermal Performance of Box Type Solar Cookers under Gujarat Climate Condition in Mid Summer", International Journal of engineering Research and Applications, 1(4), pp. 1313–1316.

[2] Arturo F Buigues Nollens, Esteban O Rojos and Marcelo O Fariello, 2012, "Use of a Hybrid Solar Oven for Houses in Dry Climates: An Experimental Study of Thermal Performance", International Journal of Renewable Energy Research, 2(4), pp. 767-772.

[3] Essam Abdallah, Mohammed Al_Soud, Ali Akaylehand Salah Abdallah, 2010, "Cylindrical Solar Cooker with Automatic Two Axes Sun Tracking System", Jordan Journal of Mechanical and Industrial Engineering, 4(4), pp. 477-486.

[4] Meenakshisundaram, Arulkumaran and William Christraj, 2012,"Experimental Analysis of Non Tracking Solar Parabolic Dish Concentrating System for Steam Generation", EJ Engineering Journal, 16(2), pp. 53-60.

[5] M R Patil and P S Patil, 2012, "Techno- economic assessment of solar steam cooking system", World Journal of Science and Technology, 2(4), pp.12-14.

[6] U R Prasanna and L Umanand, 2011, "Modeling and design of a solar thermal system for hybrid cooking application, Applied Energy, 88, pp. 1740–1755.

[7] Antonio Lecuona, José-Ignacio Nogueira, Rubén Ventas, María-del-Carmen Rodríguez-Hidalgo and Mathieu Legrand, 2013, "Solar cooker of the portable parabolic type incorporating heat storagebased on PCM", Applied Energy, Vol. 111, November, pp. 1136 –1146.

[8] Maxime Mussard and Ole Jørgen Nydal, 2013, "Charging of a heat storage coupled with a low-cost small-scale solar parabolic trough for cooking purposes", Solar Energy, 95, pp. 144-154.

[9] Poritosh Roy, Daisuke Nei1, Takahiro Orikasa,, Hiroshi Okadome, Manasikan Thammawong, Nobutaka Nakamura and Takeo Shiina, 2010, "Cooking properties of different forms of rice cooked with an automatic induction heating system rice cooker", Asian Journal of Food and Agro-Industry, 3(04), pp. 373-388.

[10] S P Sukhatme and J K Nayak, 2008, "Solar Energy: Principles of Thermal Collection and Storage", 3rd ed., Tata McGraw-Hill Education, India.