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Thermal Performance Analysis Of A Hybrid Box Type Solar Cooker Using Finned Cooking Pot

Saibikash Prusty[1], Brundaban Sahoo[2],
[1,2]Assistant Professor
[1,2]Department of Mechanical Engineering,:
[1, 2]CVRP, CGU, Bhubaneswar
Odisha, India

Abstract: Solar energy is very large, in exhaustible source of energy. The use of renewable energy is receiving growing interest worldwide. Cooking is the measure necessity for people all over the world. This paper presents the fabrication details and on-field experimental studies of a novel hybrid box type solar cookers, suitable for cooking requirements of small family. The objective of the study is to enhance the heat transfer rate and to reduce the cooking timings by consumption of minimum heat energy. Small size, high thermal performance, light weight, low-cost and short payback periods are some important features of these cookers. The values of some essential thermal performance parameters, first figure of merit (F1), second figure of merit (F2) and standard cooking power suggested by Bureau of Indian Standards and International Standard for box-type solar cookers, have been evaluated by experimental studies. A comparative analysis of the thermal performances of the hybrid solar cookers, developed by many authors, has also been presented here with proper analysis. Main objective of experiment is to enhance the heat transfer rate and to reduce the cooking timing by consumption of minimum energy. Small size, high thermal performance, light weight, low cost are the important features of the cooker. It can be use any time day and night with electrical back up.

Index Terms - Hybrid solar cooker, Heat transfer, Heat loss, Electrical back-up, Figure of merit, Thermal performance, copper and aluminium finned cooking pot.

I. Introduction

Solar energy is the energy derived from the sun in the form of solar radiation. The sun produces energy through a process of nuclear fusion which takes place in its core. In this process energy is released when four hydrogen nuclei (protons) are fused to form a helium atom. The energy emitted during this process is released into the adjoining space in the form of solar radiation. Only a small part of this energy actually reaches the earth's atmosphere, but this fraction is very significant. It's true that solar energy is considered one of the most useful developments from science and technology, especially because it's free and provides clean and ecologically safe energy. A whopping 3.85 million EJ worth of solar energy is asteady supplied to the earth every year. To meet the global energy needs, there's an increasing demand to comply with the solar power cuts of pollution and use solar energy as an alternative energy source. Alongside being one of the most utilized sources of renewable energy, the sun is also an inexhaustible source. Earth alone receives approximately 1.8x10^14 MW of solar power which is exponentially larger than the current energy consumption across the globe. With that being said, harnessed solar energy has the potential to sustain the ever-increasing global energy requirements worldwide.

This contributes to solar energy being one of the most appealing alternatives energy sources. Besides its scope, there are two other factors in favor of solar energy. First, unlike fossil fuels or nuclear energy, it is an environmentally clean source of energy. Second it is free and available in adequate quantities in almost all parts of the world where people live. The energy from the sun can be used directly and indirectly. The direct means include thermal and photovoltaic conversion, while the indirect means include the use of hydroelectric power, the winds, biomass, wave energy, temperature differences in the ocean and marine currents. The sun is a large sphere of very hot gases, the heat being generated by various kinds of fusion reactions. Its diameter is 1.39× 10^6 km, while that of the earth is 1.27× 10^4 km. the mean distances between the two is 1.496× 10^8 km. although the sun is large, it subtends an angle of only 32 minutes at the earth's surfaces. This is because it is also at a very large distance. Thus, the beam radiation received from the sun on the earth is almost parallel. The brightness of the sun varies from its centre to its edge. The sun being at a very large distance from the earth solar rays subtend an angle of only 32 minutes on flux received from the sun before entering the earth's atmosphere, is a constant quantity. The solar constant (I_{sc}) is the energy from the sun received on a unit area perpendicular to solar rays at the mean distance from the sun outside the atmosphere. Solar radiation propagating in straight line and received at the earth surface without change of direction, in line with the sun is called beam or direct radiation. The radiation received on a terrestrial surface (scattered by aerosols and dust) from all parts of the sky dome, is known as diffused radiation. It does not have a unique direction. The sum of beam and diffused radiation is called global radiation. When measure at a location on the earth surface it is called solar insolation at the place. When measured on a horizontal surface it is called global radiation. Sun at zenith is the position of the sun directly overhead. The rate of incident energy per unit area of a surface is termed irradiance. Solar time is a reckoning of the passage of time based on the sun's position in the sky .solar noon the sun is at the highest position in the sky .the sun traverses each degree of longitude in 4 minutes. Among the thermal applications of solar energy, solar cooking is considered as one of the simplest, the most viable and attractive options. There is no gainsaying the fact that, conventional sources of energy for domestic cooking like liquefied petroleum gas otherwise called natural gas, kerosene and electricity are characterized by irregular availability, increasing costs and some are mostly not environmentally friendly. Solar energy is one of the main alternative renewable sources of energy crucial to our search for domestic fuel replacements. It is the cleanest, it is free from environmental hazards and it is readily available. Increase in the awareness of the global need for alternative energy source has led to proliferation of research and development in solar cooking. Solar cooking offers a simple, effective, low cost and practical method of utilization solar energy for meeting a considerable demand for cooking energy and, hence, protecting the environment. Considerable efforts have gone into the development and performance testing of a variety of solar cooking and their suitability for cooking different food. The solar cookers if available can offer a partial solution to multitude of cooking problems face by people of low income. Solar cooking offers an effective method of utilizing solar energy for cook different food item. So there is no use of conventional fuel and hence, protecting the environment. Considerable efforts have gone into the development and performance testing of a variety of solar cookers and their suitability for cooking different foods. A solar cooker or solar oven is a device which utilizes solar energy to cook .Solar cookers also enable some significant processes such as pasteurization and sterilization. Solar cookers have a long history dating back almost to the eighteenth century when Nicholas- de-Saussure built first ever fabricated solar box-cooker.

II. LITRATURE SURVEY

Saxena et al [1] Studied Experimentally Performance characteristics of a new hybrid solar cooker with air duct. It can be concluded that this is the first kind of SBC which can perform on forced convection with the help of a specially designed duct integrated with a 200W halogen lamp and a low power fan. Cuce [2] A comparative experimental investigation and thermodynamic analysis of a Box type solar cookers with sensible thermal energy storage medium. According to the results, energy efficiency of Bayburt stone cooker is determined to be in the range of 35.3–21.7% while it is found to be 27.6–16.9% for conventional solar cooker. Nahar et al [3] Studied Experimentally a solar cooker used in agro based industries. Performance of a community solar cooker having absorber area 3.2 m^2 has been described. The cooker is based on hot box principle having a single reflector. Coccia et al [4] Experimental validation of a high-temperature solar box cooker with a solar salt- based thermal storage unit. In this study, a solar box cooker equipped with a thermal storage unit (TSU) based on a solar-salt-mixture. Cuce et al [5] Review on solar cookers historic overview of solar cooking technology, detailed description of various types of solar cookers, geometry parameters affecting performance of solar cookers such as booster mirrors, glazing, absorber plate, cooking pots, heat storage materials and insulation. Moreover, thermodynamic assessment of solar cooking systems and qualitative evaluation of thermal output offered by solar cookers are analysed in detail. Chaudhari et al [6] Studied Experimentally Hybrid Solar Box Type Dryer cum Cooker of Chilly Drying for Domestic Usage. Joshi et al [7] A Review on Experimental analysis of effect of cooker base coating material on the performance of solar cooker. A Small Scale Box type solar cooker (SSB) weighing 4.8 kg is modified into a novel photovoltaic and thermal hybrid solar cooker named as Small Scale Box type Hybrid solar cooker (SSBH) weighing 6.5 kg. Mahavar et al [8] this paper presents the design development and, thermal and cooking performance studies of a novel solar cooker. During testing, the highest plate stagnation temperature, under no-load condition, approached 144°C. Verdugo [9] Experimental analysis and simulation of the performance of a box-type solar cooker. A heat transfer model was proposed to describe the performance of a box-type solar cooker based on the solar radiation and the external temperature. Mirdha et al [10] theoretically investigated various designs of solar cookers with a view to optimize their thermal performances with respect to north and south facing booster mirrors have been analysed theoretically. Starting from a conventional box type cooker, various combinations of booster mirrors have been studied to arrive at a final design, aimed at providing a cooker, which can be fixed on a south facing window (for countries of northern hemisphere, mainly situated near the tropic of Cancer). Saravanan et al [11] analysed the exergy and energy assessment of double exposure solar cooker (DESC). Cooking test of food stuffs was done with vessels viz., copper, aluminium, stainless steel and ceramic pots. Saxena et al [12] carried out the study of implementation issue of box type solar cookers in India. a literature survey on various aspects of solar cooker were discussed including its basic mechanism, construction, the developments of cooking sector financial evaluation, the assumption, validity and main reason for not opting solar cooker in India. Geddam et al [13] Analyzed experimentation of the solar box type cooker with finned cooking vessel showed consistent reduction in cooking time which is due to increase of the heat transfer surface area by fins attached to the external surface of the cooking vessel. The food cooked in solar cooker can be kept hot for 3–4 h with the help of PCM medium. Mithun et al [14] Experimental analysis of effect of cooker base coating material on the performance of solar cooker It is observed that system producing steam for solar heating of water will be very useful in the industrial and commercial sectors this system can help to reduce the load and the fossil fuel energy used to steam generation also with the help of black coating. Mahavar et al [15] Developed analytical model for electric back-up power estimation of solar box type cookers this back-up (which is named as required electric back-up 570 power 'Prb') can be determined using comprehensive equations introduced in the paper for any SBC in different cooking and weather conditions. Misra et al [16] Analyzed performance enhancement of box-type solar cooker is observed. The experimental results show that the forced convection-based environment improves the thermal performance of box-type solar cooker. Forced convection-based cooker is able to cook food at much faster rates compared with natural convection-based cooker. The solar cooker performance has been rated using the first figure of merit (F1) on the no-load test and the second figure of merit (F2) on the sensible heat tests. The cooking time was considerably reduced by 30.6%. Nahar [18] studied the design and development of a large size non-tracking solar cooker. It has been found that stagnation temperatures were 118.5 centigrade and 108 centigrade in large size non-tracking solar cooker and hot box solar cooker respectively. B. Joshi et al [19] Photovoltaic and Thermal Hybridized Solar Cooker the objective of the present research work is to design user friendly solar cooker which can be commercialized too. This cooker is designed, developed, and tested in laboratory. It is observed that the designed cooker needs the boosting of only 30 watt power which is generated by a small solar panel connected with it. Heater connected with it can be powered by a solar panel of 75 watt. This boosting can reduce the cooking time. Different recipes were prepared to test its actual performance. Prasanna et al [20] modelling and design of a solar thermal system for hybrid cooking application. The energy for cooking accounts for 36% of the total primary energy consumption. The energy source is a combination of the solar thermal energy and the Liquefied Petroleum Gas (LPG) that is in common use in kitchens. The entire system is modelled using the bond graph approach with seamless integration of the power flow in these domains. A method to estimate different parameters of the practical cooking system is also explained. Design and life cycle costing of the system is also discussed. The modelled system is simulated and the results are validated experimentally. Shyam S et al [21] Design, construction and study of a hybrid solar food processor. Effective thermal efficiency of food processor was found in the range of 23–32% depending on the mode of use. It has been used for cooking, heating/pasteurizing water (to inactivate microbes) and distillation of small quantity of water (to remove different minerals) and drying domestic products (fruits, vegetables and condiments/herbs, etc.). Aramesh et al [22] Review of Recent Advances in Solar Cooking Technology. One of the primary factors affecting the amount of worldwide energy consumption and greenhouse gas emissions is cooking. Solar cooking is an appropriate solution because it is both inexpensive and expandable. To illustrate modern advancements and the current status of solar cooking technology, this paper presents a review of recent experimental and analytical socioeconomic studies on solar cookers. Sharma et al [23] analysed the thermal performance of a box-type solar cooker to propose a simple test procedure to determine different parameters using the experimentally obtained F2 data for different load of water; discussed the thermal test procedure to determine the design parameters, which can be used to predict the heating characteristic curves (or thermal performance) of a box-type solar cooker. The close agreements between the predicted and experimental heating characteristic curves as well as F2 revealed that the proposed methodology is capable of predicting the thermal behaviour of the solar cooker. T. C. Thulasi Das et al [24] Presented experimental studies carried out to obtain the heat-transfer coefficients, required for simulation. Based on the model proposed in the companion Part 1 a method is outlined for simulation of the solar box-cookers loaded with one, two, or four vessels. The relative importance of various heat exchange rates in the cooker was examined.

Motivation for the Present Research

Cooking is an integral part of each and every human being as food is one of the basic necessities for living. Commonly used sources of energy for cooking are fire wood, crop residue, cow dung, kerosene, electricity; liquefied petroleum gas (LPG), biogas etc. Half of the world’s population is exposed to indoor air pollution, mainly the result of burning solid fuels for cooking and heating. Wood cut for cooking purpose contributes to the 16 million hectares (above 4% of total area of India) of forest destroyed annually.

Whereas many people face acute fuel wood shortages, human and environmental ecology could be improved by introducing alternatives to cooking with wood, few of the people who most need them can afford currently available solar cookers, much of the potential design space remains unexplored.in the case of box type solar cooker having natural convection-based cooker are take more time for cooking at about 90 min to 120 min. it was not suitable for outdoor cooking purposes so, reducing the cooking time are needed for promoting the use of solar cooker.

The Solar cookers are needed due to

1. High cost or Unavailability of commercial fuels – Kerosene, Coal, cooking gas and Electricity.
2. Deforestation caused by increasing firewood consumption.
3. Use of dung and agricultural waste as fuels instead of for soil enrichment.

III. CONSTRUCTION

A box-type solar cooker consists of an outer box, inner cooking box, the simple or double glass lid, thermal insulator, mirror and cooking containers. The inner cooking box is made of Aluminium sheet that absorbs solar radiation, it is coated with black paint so as to easily absorb solar radiation and transfer the heat to the cooking pots. A glass lid covers the inner box. The space between the outer box and inner tray including bottom of the tray is packed with insulating material to reduce heat losses from the cooker. Mirrors are used in a solar cooker to increase the radiation input on the absorbing space. Sunlight falling on the mirror gets reflected from it and enters into the tray through the glass lid .This radiation is in addition to the radiation entering the box directly and helps to quicken the cooking process by raising the inside temperature of the cooker. The cooking containers are painted black on the outer surface so that they also absorb solar radiation directly. The upper surface of the absorber plate is painted with dull black coating thus increasing its capability of absorbing incident solar radiation.

Different components used for the construction of solar cooker are

1. Absorber plate.
2. A glass sheet.
3. Insulation.
4. Casing.
5. Reflector.
6. Utensil.
7. Thermocouple thermometer
8. Switches.
9. Aluminium Finned cooking pot.
10. Copper finned cooking pot.

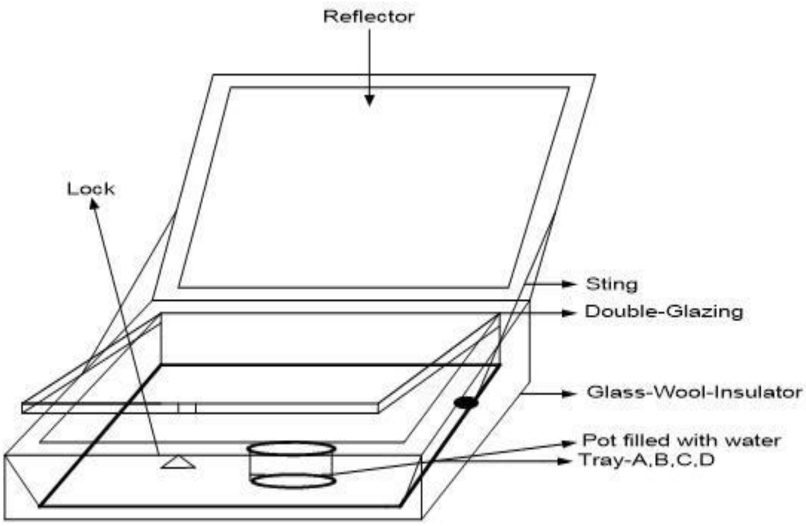


Figure 1: (sketch of Box type solar cooker.)

Absorber plate

Absorber tray of a solar cooker is a crucial component since it absorbs the useful energy from sun to be able to succeed cooking process. In order to maximize the illumination intensity falling on the absorber tray and enhance the heat transfer from the absorber tray to the food in cooking vessels, absorber tray is a key item which allows various modifications. Thick aluminium plate was used as the absorber plate. This was painted matt black to improve its absorptivity. Aluminium satisfies the absorber plate desirable characteristics of good thermal conductivity and high resistance to corrosion. The upper surface of the absorber plate is painted with dull black coating thus increasing its capability of absorbing incident solar radiation. In box-type solar cooker a trapezoidal shaped absorber tray is used because absorption of a higher fraction of incident solar radiation falling on the aperture at larger incidence angles, due to a more exposed surface area. It is required less absorber material and lower fabrication cost.

Figure 2: (Image of absorber plate)

Figure 3: (Image of insulation)

A glass sheet

Glass cover is considered as a flat plate at a lower temperature than hot plate but above atmospheric temperature. The glazing material was commercially available 0.003 m (3mm) and 0.002 m (2mm) thick tempered glass. Glass satisfies the cover desirable properties of high optical transmittance, low reflectivity, low transmittance to heat and low absorptance of solar radiation. It served as the door to the casing and was supported by wooden frame. It was built such that there was no space between door and the box (casing), to prevent conventional heat loss. The glass door designed for double layer was properly constructed with about 15mm air space between them. . At top portion plane glass is provided to allow entry of solar radiation and minimize convective heat losses.

Insulation

Glass wool was used for insulation. It has low thermal conductivity, it is stable at the operating temperature regimes and is cheap and readily available. The gap between the absorber plate and the outer box is filled with glass wool to provide thermal insulation which are maximize heat gain and minimize heat loss. All materials with low thermal conductivity may be used as an insulation material in solar cookers Figure 3.

Casing

Commercially available 1.8 cm thick plywood was used for the casing. Plywood is cheap, readily available, and easy to handle during construction and has low weight and rigidity.

Reflector

A plane mirror is quite significant for a solar cooker since it allows higher illumination intensity falling on the transmitting surface of the cooker hence higher working temperatures which enhance the efficiency. It has the desired property of high optical reflectivity.

Plate heater

These were fixed on the underside of the aluminium tray to provide uniform heating through a servo stabilized electric power supply. The four inclined sides of the tray (120° to horizontal) were also individually heated by set of four identical plate heaters of total capacity 100 W.

The tray was heated by five plate type electric heaters (each 0.380 m long) of total capacity 250 W.

Utensil

The cooking containers are painted black on the outer surface so that they also absorb solar radiation directly. Any type of cooking vessel can be used in solar cookers but generally rectangular and cylindrical shaped cooking vessels made of aluminium and copper are recommended for the experiment. Cooking pots are used in order to receive the absorbed energy and transfer it to the food.

Thermocouple Thermometer

Four thermocouple were used in solar cooker to measure the temperatures at different locations of the cooker; namely, water in utensils; absorber plate; inner surface of the lower glass; and outer surface of the upper glass. It is a device by which four thermocouple connected with thermometer to major the four temperature for thermal performance analysis.

Figure 4 ;(Image of thermocouple thermometer)

Fin material

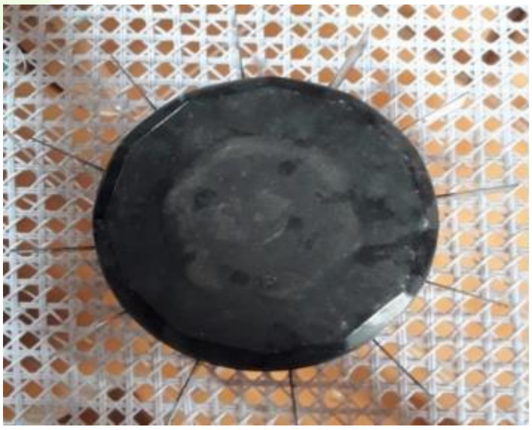


Figure 5: (Image of aluminium finned cooking pot with black painted pot)

Both copper and aluminium material of rectangular fin is used in this experiment for the thermal performance analysis of the solar cooker. Fins are surfaces that extend from an object to increase the rate of heat transfer to or from the environment by increasing convection. The amount of conduction, convection, or radiation of an object determines the amount of heat it transfers. Increasing the temperature gradient between the object and the environment, increasing the convection heat transfer coefficient, or increasing the surface area of the object increases the heat transfer. Sometimes it is not feasible or economical to change the first two options. Thus, adding a fin to an object, increases the surface area and can sometimes be an economical solution to heat transfer problems.

Principle of Solar Cooking

Most solar cookers convert sunlight to heat energy that is utilized for cooking. The ability of a solar cooker to collect sunlight is directly related to the projected area of collector perpendicular to the incident solar beam radiation. The geometric concentration ratio is defined as

$$CR = \frac{At}{Arc}$$

Where A_t is the total collector area and A_{rc} is the area of the receiver/absorber surface.

Figure 6 :(Image of copper cooking pot)

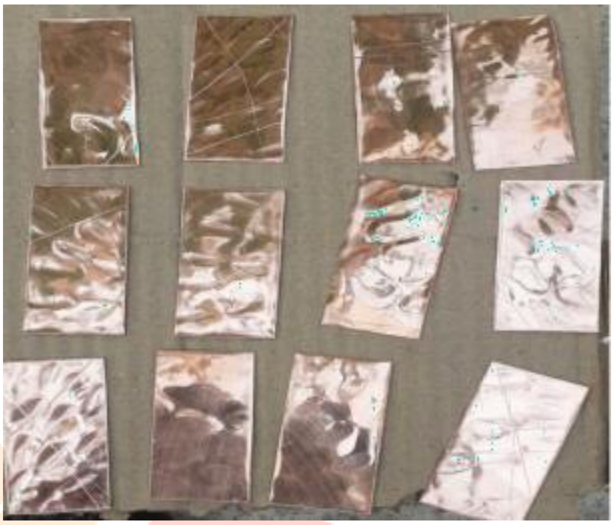


Figure 7: (Image of copper fins which to be set on copper pot)

Figure 8: (Box type solar cooker with fan in cooking space)

Table 1: Dimension of Materials

Parameters	Details
Casing Dimensions Thickness Material	 600× 600 ×165 mm 1.8cm Ply wood
Absorber plate Dimensions Shape Material Coating	 380 ×380 mm (bottom surface) 495× 495 mm (top surface) Angle of inclination:120degree Trapezoidal Aluminium Black matt paint
Thickness of Glass covers Inner glass cover Outer glass cover Spacing between glaze Material	 3mm 2mm 15mm Glass
Insulation Thickness Material	 50 mm(bottom) Glass wool
Fin Thickness Material Shape	 5 cm × 2.5 cm Copper and Aluminium Rectangular

IV. WORKING PRINCIPLE

It is well known fact that a black colour surface absorbs more heat than a white surface. So the inner wall and bottom of metallic box to be used for making solar cooker are painted black to increase absorb the insulation and get heated. This box is covered by a thick transparent sheet of glass. When the box with glass cover is placed in the sun light the glass cover allows the infrared rays present in sunlight to pass into the box. Most of these infrared rays are then absorbed by black surface of the box and the box become hot but after some time when the black surface become hot it start radiating out heat in the form of infrared rays .but the glass sheet cover placed over the box does not allow the heat radiated by the black surface to go out from the box. In this way the glass cover enables the cooker to entrap the heat inside it. Usually a plane mirror reflector is also attached on the top of the box. The plane mirror reflector increases the efficiency of solar cooker by reflecting more and more sunlight inside the box. Those food material which require gentle heating. In natural environment box-type solar cookers, the heat absorbed by the blackened absorber plate is transferred to the air in the cooking space by setting up the natural convection currents and then it is transferred to the water inside the utensil by conduction and convection. Since the air in the cooking space gets heated by the absorber plate by natural means, it offers a low value of convective heat transfer coefficient and also low cooking environment temperature.

V. EXPERIMENTAL SETUP

A commercially available double-glazed box type solar cooker with fan has been used for the experiment. The experimental test set-up. The dull black painted aluminium trapezoidal shaped tray with an aperture of 0.245 m^2 was fitted inside the cooker. The cookers consist of trapezoidal-shaped absorber plate of size 0.380×0.380 m and 0.495m × 0.495m at bottom and top, respectively, with a depth of 0.095m, made up of 1mm thick aluminium sheet. The upper surface of the absorber plate is painted with dull black coating, thus increasing its capability of absorbing incident solar radiation. The rear side of the absorber plate was wrapped with aluminium foil. The sides and bottom of the absorber plate are encased in an outer box made of plywood. The gap between the absorber plate and the outer box is filled with glass wool to provide thermal insulation for minimize the thermal losses. The dimensions of the outer box are 60m × 60m × 0.165m. The cooking space is provided glass having a thickness of 3mm and 2mm with a spacing of 15mm in between, hinged to one side of the outer box at the top. A plane glass mirror is encased in a plywood frame, is fitted to serve as a reflector. This serves as a cover for the double glass glazing when the cooker is not in use. The cooking utensils made of aluminium and copper are cylindrical in shape and have flat base. The utensils are provided with tight rubber gasket-fitted lids, making them perfectly air tight and leak proof. So the utensils can be slightly pressurized. The outer surfaces of the vessels are also painted with dull black paint. Solar cooker consists of a 12V DC fan to provide forced convective environment, powered by an electric supply. All the temperatures were measured by thermocouple thermometer. Calibrated thermocouples were fixed at different locations on the absorber plate as well as in the centre of the inner glass cover. Another thermocouple was embedded in the centre of the outer glass cover (by cutting a fine groove). The ambient air temperature was also measured through a separate thermocouple along with these observations. Forced airflow inside the glass cover of the cooker was produced by a 12v fan. Different wind speeds were produced by controlling the air supply on the suction side of the fan.

Experimental Procedures

The cookers were tested simultaneously following a standard procedure as recommended by ASAE. The test was conducted with measurements of temperature using thermocouple and sensor. The main procedures during testing were:

1. We will start around 9 to 10 AM and were stopped before 4:00 PM.
2. The cookers were kept under shading before the start of the tests and brought to receive solar radiation simultaneously.
3. Tracking of the cookers was done every fifteen minutes.
4. Thermocouples were attached to the centre of the bottom absorber plate during the stagnation test and were immersed into water during the boiling test.
5. Four thermocouple were attached with four location of the solar cooker and another end were connected with the eight switch when press the switch which indicate the temperature in the corresponding location of the cooker.
6. 1.5 liter of cold water was used at each start of the boiling test.
7. Solar radiation measurement was taken from a pyranometer in the nearby campus metrological station.
8. Wind speed measurement was taken. Any influence of wind speed is measured with the help of anemometer.

Figure 9: (Experimental set up of a box-type solar cooker)

VI. RESULTS AND DISCUSSION

Thermal performance test

Experiments were conducted in outdoors to evaluate the performance of solar cooking systems. The experiments were conducted between 10:00am and 16:00pm solar time. Temperature measurements were taken with Thermocouple thermometer. The solar cookers were not opened during the course of the test. The cookers were tracked at an interval of 15 min in order to collect the maximum amount of insolation. The tracking was done by rotating the cookers azimuthally in such a way that the azimuth of the mirror normal and the sun are equal and the reflected rays from the mirror illuminate the entire cooker aperture and the aperture alone.

Dt-04/01/2020

Initial temperature=22.5°C

TABLE-2 (With load condition, without finned cooking pot)

Time	Absorber plate temperature(T1)	Aluminum pot temp(T2)	Glazing surface temperature(T3)	Ambient temperature(T4)
11.30am	49°C	35°C	33°C	30°C
11.45am	59°C	49°C	39°C	31°C
12.00am	67°C	55°C	40°C	33°C
12.15am	71°C	61°C	41°C	32°C
12.30am	78°C	68°C	45°C	35°C
12.45am	80°C	70°C	47°C	32°C
13.00pm	85°C	79°C	46°C	31°C

Stagnation temperature (No Load) Test

To determine the first figure of merit F_1, both the solar cookers without reflector and pots were exposed to solar radiation at about 11 a.m. allowing plate temperature to rise gradually. Global, plate temperature, and ambient temperature were recorded at an interval of 15 min simultaneously till the stagnation condition was achieved. A typical thermal performance analysis is presented in figure-11, figure-12 obtained under stagnation test conditions.

Cloudy day

Local temperature on 6/02/2020

Initial temperature=22.5

No load condition

Table-3 (No load condition, without finned cooking pot)

Time	Absorber plate temperature(T1)	Aluminum pot temp(T2)	Glazing surface temperature(T3)	Ambient temperature(T4)
11.15am	26.1°C	26.5°C	24°C	22.5°C
11.30am	48.3°C	47.6°C	31.2°C	26.5°C
11.45am	62.9°C	63.5°C	35.7°C	29°C
12.00am	76.5°C	80.8°C	42.4°C	29.5°C
12.15am	75°C	78°C	43°C	30.4°C

Table-4(No load condition, without finned cooking pot)

Local temperature of 10/02/2020

Time	Absorber plate temperature(T1)	Aluminum pot temp(T2)	Glazing surface temperature(T3)	Ambient temperature(T4)
10.45am	22.6°C	22.7°C	22°C	22.5°C
11.00am	57°C	30°C	34.1°C	26.5°C
11.15am	70°C	53°C	43.4°C	29°C
11.30am	96.2°C	67.7°C	49°C	29.5°C
11.45am	105°C	81°C	56°C	30.4°C
12.00am	106°C	88.8°C	55.6°C	75°C
12.15am	94°C	91.3°C	51.7°C	75°C
12.30am	81°C	87°C	47°C	75°C

Water heating test

In the water heating test, the solar cookers with reflectors were loaded with 1.5 kg of water at the same initial temperature. During each test, the cooking pots were placed at the centre of the absorber plate. The following data were taken at a regular interval of 15 min: water temperature in pot, the ambient temperature, absorber plate temperature, temperature of air inside the cooker, and the temperature of inner and outer glass surfaces. During the experiments, the cookers were manually aligned at an interval of 15 min, or when shadows appear on the absorber plate, in order to track the sun. Figure-13, figure-14 presents the temperature–time history of the water in cooking utensils under the test conditions.

Table-5(With load condition, with finned cooking pot)

Local temperature on 11/02/20

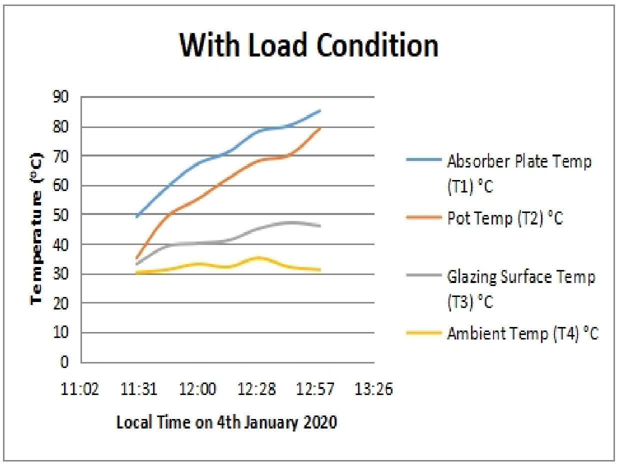
Time	Absorber plate temperature(T1)	With fin Aluminium pot temp(T2)	Glazing surface temperature(T3)	Ambient temperature(T4)
10.10am	23°C	25°C	20°C	32°C
10.25am	65°C	32°C	38°C	25°C
11.40am	81°C	50°C	51°C	26°C
10.55am	94°C	68°C	61°C	32°C
11.10am	98°C	78°C	63°C	31°C
11.25am	101.6°C	88°C	66°C	32°C
11.40am	112°C	92°C	65°C	32°C
11.55am	120°C	94°C	75°C	33°C
12.10am	121°C	94.3°C	76°C	30°C

Table-6(with load, with aluminium pot, with aluminium finned cooking pot, With copper pot)

Local temperature on 16/03/2020

Time	With Fin Aluminium Pot Temp (T1) °C	Without Fin Aluminium Pot Temp (T2) °C	Without Fin Copper Pot Temp (T3) °C	Absorber Plate Temp (T4) °C	Ambient Temp (T5) °C
10.00am	33.5	30.7	31.5	30.2	30
10.15am	77	72	74	56	30.2
10.30am	85	79.8	82.5	63	31
10.45am	86	80	83	66	31
11.00am	94	82	85	69	32
11.15am	87	75	82.5	67.5	31
11.30am	106.2	76.8	90	71.4	32
11.45am	112.5	76.1	93.5	73	31
12.00am	108.6	73.3	68.9	72.3	31

GRAPHICAL TEMPERATURE ANALYSIS OF THE SOLAR COOKER -



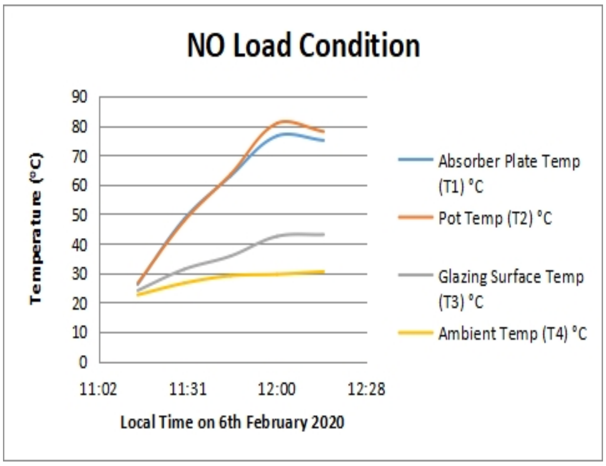


Figure-10(Water heating test analysis on day-1) Figure-11(Temperature comparison on day-2)

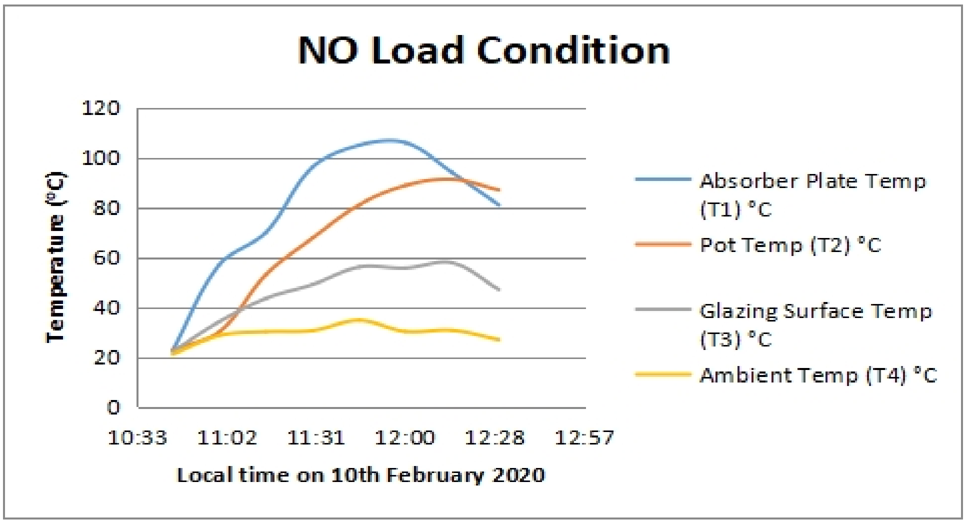


Figure-12(Stagnation test without load analysis with aluminium pot day-3)

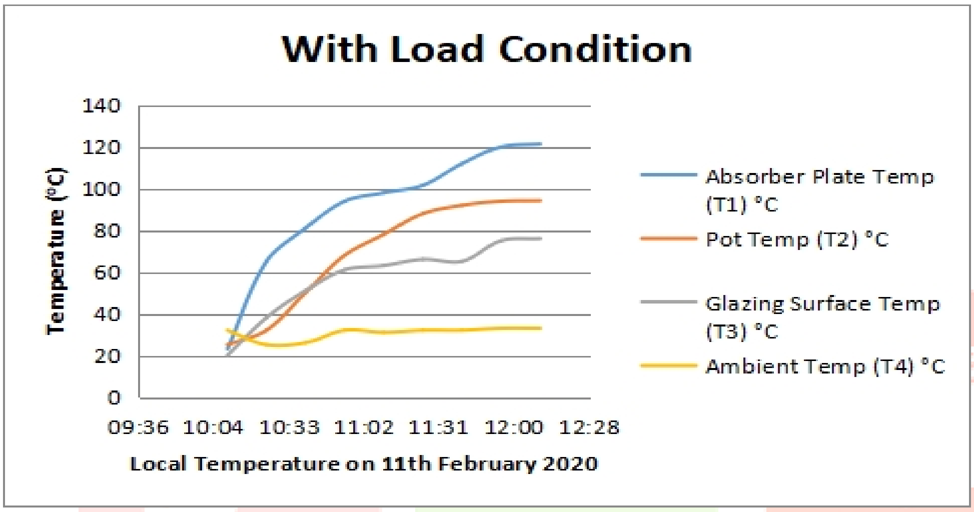


Figure-13(water heating test of analysis day-4)

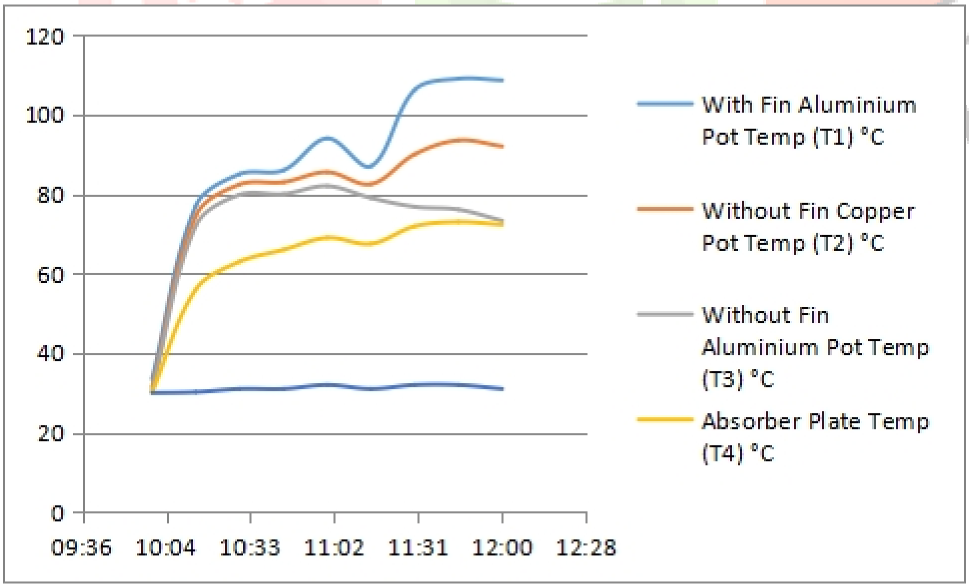


Figure-14(Temperature analysis using finned cooking pot on day-5) With load condition

Rectangle Fin

As, Ac, δ, P

As=Surface area of the fin.

Ac=Crossectional area.

Δ =Thickness of fin.

P = Perimeter.

L = 5 cm

w = 2.5 cm
As = L×w = 5×2.5 = 12.5 cm^2
Ac = bδ = 2.5×0.2 = 0.5
Perimeter = 2(b+δ) = 2(2.5+0.2) = 5.4 cm
Corrected Length = L+Ac/P = 5+0.5/5.4 =5.09 cm
$K_{Aluminium}$ = 205 w/mk
K = 385 w/mk
Overall heat transfer co-efficient = 340-455 w/m^2k

Solar cooker performance rating

The thermal performance evaluation and testing of a box-type solar cooker, which provides performance characteristics of solar cookers, more or less independent of climatic parameters such as solar radiation, ambient temperature, wind speed, etc., as well as on design parameters such as properties of black paint used in tray, number of glazing, insulation properties, and effectiveness of reflector system. There are two thermal performance parameters called figures of merit (F_1 and F_2) associated with testing of box type solar cooker. The first figure of merit, F_1, is determined from a stagnation test under no load condition while the second figure of merit, F_2 is evaluated from tests under full load conditions taking water as the load.

First figure of merit (F_1): Can be calculated by

$$\mathbf{F1 = \frac{no}{Ul}}$$

Experimentally

$$F1 = \frac{(Tps - Tas)}{Gs} \quad \text{--------- Equation (1)}$$

Where T_{ps}, T_{as} and G_s respectively represent the cooker tray temperature, ambient air temperature and the intensity of solar radiation on the aperture of the box type solar cooker at quasi steady state (stagnation test condition).

We have Calculated a first figure of merit, $F_1 = 0.12846\ m^{2\circ}cw^{-1}$ with values of T_{ps}=106°c, T_{as}=22.5°c, and G_s= 650wm^{-2} at stagnation (without load condition), the first figure of merit ensures that the glass covers have a good optical transmission and the cooker has a low overall heat loss factor. These result are analyse by table-3 and analysed by figure-12 of this report.

Second figure of merit (F_2)

The second figure of merits, F_2 of box type solar cooker is evaluated under full load condition and can be expressed from the following expression

$$F2 = \frac{1-\frac{1}{F1}\left(\frac{(Tw1-Ta)}{H}\right)}{1-\frac{1}{F1}\left(\frac{Tw2-Ta}{H}\right)} \quad \text{------------------ Equation (2)}$$

where F_1 represents the first figure of merit, M_W the mass of the water, C_W the specific heat of water, $\overline{T_a}$ the average ambient temperature, $\overline{H}$ the average solar radiation incident on the aperture of the cooker, T_{W1} the initial water temperature, T_{W2} the final water temperature, A the aperture area of the solar cooker and τ the time difference in which water temperature rises from T_{W1} and T_{W2}.

The second figure of merit of the cooker (F2) which corresponds to heat transfer efficiency of the cooker at low heat capacity of cooker interior is calculated from sensible heat test (water heating test) of 1.5 kg of water in the cooker using. The variation in the water temperature placed in the cooker was shown in Figure (14). The time required to raise the temperature of 1.5 kg of water from 35°C to 108.6°C was about 180 minutes which corresponds to the second figure of merit (F_2) calculated from Equation(2) to be 0.85. In calculating the value of F2, reported that some flexibility is allowed in the choice of T_{w1} and the time interval (τ) in second. The criteria for F_2 value by Indian standard is that F_2 should be greater than 0.42. The F_2 value of 0.85 obtained from this experiment compare favourably with the standard.

Thermal efficiency of the solar cooker.

$\eta u = (Mw \times Cw / I \times Ac) \times \Delta T / \Delta t$ --------- Equation (3)

Where ηu represents overall thermal efficiency of the solar cooker, Mw is mass of water (kg), Cw, Specific heat of water (J/kg/oC), ΔT (temperature difference between the maximum temperature of the cooking fluid and the ambient air temperature), Ac is the aperture area (m2) of the cooker, Δt is the time required to achieve the maximum temperature of the cooking fluid, I is the average solar intensity (W/m2) during time interval Δt.

Different thermal efficiency achieved for box type solar cooker.

The Overall daily thermal efficiency of the solar box cooker (ηu) was calculated by equation (3) to be 33% (Mw =1.5 kg, Cw = 4220 J/kg/oC, Ac = 0.245 m 2, I = 450 w/m2, ΔT= 81.5°C, Δt = 10800s). The thermal efficiency measured by using finned aluminium cooking pot is about 43.32 %.

Also, it was reported that thermal efficiency measured by without using fin aluminium pot was 25.62% where ΔT= (79.8-31) = 48.8.

Also reported efficiency of 33.22% for without fin copper pot where ΔT= (93.5-31) = 62.5

The thermal efficiency calculated for the implemented box type solar cooker competes well with those found in the literature and this is an indication of better heat retention ability of the box type solar cooker.

CONCLUSION

In this experiment enhancement of the rate of heat transfer and calculate the values of figure of merit and overall thermal efficiency by experimental investigation and analyse the thermal performance data. (i) The first figure of merit, F_1, is found from equation (1) and the second figure of merit, F_2 from equation (2) in a consistent manner. These figures are relatively independent of the climatic variables and pertain to the cooker. A high value of F_1 indicates good optical efficiency and low heat loss factor. A high value of F_2 indicates good heat exchange efficiency, good optical efficiency and low heat capacity of the cooker interiors and vessels compared to a full load of water **.**The temperature of the cooking space depends on the convective heat transfer coefficient of air in the cooking space. It was found that cooking space temperature can be increased by using a finned aluminium cooking pot as compare to without fin aluminium pot and without fin copper pot. It can be use any time day and night with electrical back up. The temperature of the cooking space depends on the convective heat transfer coefficient of air in the cooking space. It was found that cooking space temperature can be increased by using a finned cooking pot in the cooking environment.in this experiment stagnation test(without load) and water heating test performed and analysed by graphical way by using aluminium and copper finned cooking pot.

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