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Numerical Simulation of Box Solar Cooker with Four Transparent Holes Covers

Dr.V.K. KRISHNAN, M.E., Ph.D[1], A.K.KARTHIKEYAN.,M.E.,(ph.d)[2], N.DURAIRAJ.,M.E[3]

Dr.V.K. KRISHNAN, M.E., Ph.D[1] Associate Professor Department Of Mechanical Engineering Vinayaka Mission's Kirupananda Variyer Engineering College –Vinayaka Missions Research Foundation (Demmed To Be University),Salem-636 308,Tamilnadu

A.K.KARTHIKEYAN.,M.E[2].,(ph.d), Assistant professor Department Of Mechanical Engineering,Asian College Of Engineering AndTechnology,Coimbatore-641110,Tamilnadu.

N.DURAIRAJ.,M.E[3]., Assistant professor Department Of Mechanical Engineering,Asian College Of Engineering AndTechnology,Coimbatore-641110,Tamilnadu

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Abstract:

Solar cooking is fascinating now a day's around the globe in order to save the energy lost in cooking. The effective utilization of the solar energy is done by devising different designs of solar cooking vessels. Researchers keep on working to enhance the performance of the solar collectors by altering the existing designs of the solar cooker. In this research work, an attempt has been made to investigate the performance of a newly designed and fabricated box type solar cooker through experiments and numerical simulations. Four numbers of transparent covers are introduced so as to reduce the convection loss by the first two transparent covers, the remaining two transparent covers are provided with small holes to recirculate the stored heat energy. Different cooking pot materials like aluminium, silver with and without black coatings are considered in this research work to investigate their influence in the cooking performance by decreasing the cooking time. From the investigations, it is predicted that 10 – 18% of more solar energy has been utilized with the help of the proposed box type solar cooker with four numbers of transparent covers with holes along with black coatings.

Keywords **— Put Cooking pot, Solar cooker, Thermic fluid, Transparent covers.**

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I. INTRODUCTION

Solar energy is a natural source of energy available abundant at free of cost. Harvesting the solar energy by means of panels of photovoltaic cells where the heat energy is converted in to electrical energy or by installing solar collector on the roof the building where the solar energy is converted in to heat energy to do some useful work to the society like water heating or cooking. A solar cooker is a device to utilize the direct heat energy of the sun rays to heat, cook foods. There are many kind of solar cookers which are currently employed to cook food, among which box type cookers are always efficient, low cost and simple in design. A conventional box type cooker with detailed parts are given in Figure 1. The box type cookers are prepared from a wooden box coated with black coloured inner surfaces to absorb more heat. It is covered by a thick transparent sheet of glass, which allows the infra-red rays present in the sun light to pass in to the box. These rays are absorbed by the black coloured surfaces of the box and are reflected back after some time and hence increase the hotness of the inner portion of the box. But the glass cover placed over the box does not allow the heat radiated by the black surfaces to go out from the box. The radiated heat available inside the box subsequently heat the vessel which is provided inside the box with the food material to cook. The glass cover present in the box type cooker is exposed to ambient environments where the atmospheric air is having contact with the glass cover and takes away certain amount of heat by means of convection. Introduction of multiple layer of the glass plates may enhance the efficiency of the box type cooker by protecting the amount of heat generated inside the box and minimizing the heat loss due to convection effect. With a conventionally designed box type cooker, it is possible to achieve a temperature of 108°C. A detailed literature survey is carried out to understand the importance of the glass cover plate in achieving the best performance of the box type cooker and is discussed as follows:

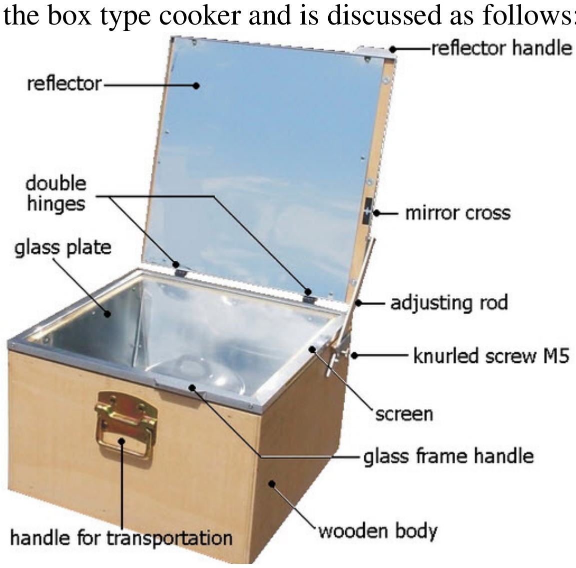


Figure 1 Box type solar cooker[1]

A model was developed by Funk and Larson[2] for prediction of the cooking power of a solar cooker based on three controlled parameters and three uncontrolled variables. They use regression analysis of experimental data for determining the coefficients for each term and further they validated the developed model with a commercially available solar cookers of both the box and concentrating types. Further it is suggested that the proposed model can be used for estimating the cooking capacity of existing box type and concentrating type solar cookers by combining the intercept area and heat loss coefficient required to cook a given quantity of food under a suggested climatic condition. A box-type solar cooker equipped with an asymmetric Compound Parabolic Concentrator (CPC) as booster-reflector has been introduced by Harmim et al.[3] consisting of an insulated box equipped with a vertical double glazing cover on a side, and a vertical absorber plate laid out just behind the transparent cover and is fixed with the booster-reflector on the glazed side of the box. In their proposed design, the absorber plate and the glazing form a vertical channel, open at the top and bottom, and enclosed at the sides. Further, they have introduced two openings to allow the inside air circulation. A mathematical model of the heat transfer processes was also developed by them containing a cooking pot loaded withwater and deposited on the box floor; and the effects of various parameters, such as solar radiation, load of water and clouds on the dynamic behaviour of the cooker were studied.

DESIGN AND DESCRIPTION OF THE APPARATUS

Figure 2 shows the general layout of BSC with four transparent covers. The major components of the solar cooker can be identified as: double transparent covers with holes which receives and transforms the direct solar irradiation into heat by recirculating. Then it transfers this stored heat to the air which flows under and over the cooking pot by the natural convection. A reflector which is made of anodized aluminium coated where the direct radiation sent into cooker; and a trapezoidal box which reflect exactly the heat coming from the direct and reflecting solar radiation.

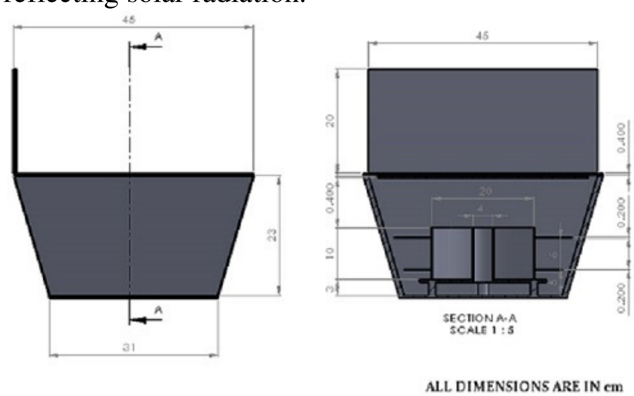


Figure 2.General layout of BSC with four transparent covers

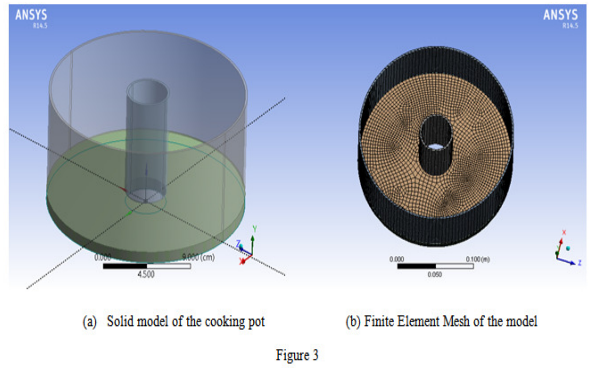
Numerical simulation

Numerical Simulation has been carried out using ANSYS FLUENT with the same parameters and initial conditions as followed in the experimental design to evaluate the temperature distribution with different cooking pot temperatures. The performance of the cooking pot is evaluated for different types of materials, various aspects and design configuration of the cooking pot. The geometrical parameters of the cooking pot and the dimensional details of the trapezoidal box is given in Table 1. Figure 3 shows the solid modelling and the Finite Element meshing of the pot geometry developed in ANSYS.

Table 1 geometrical parameters of the solid models

Cooking pot capacity	2 Liters
Cooking pot Dimensions	
Height	10 cm / 18 cm
Diameter	16 cm / 12 cm
Cavity	4 cm
Trapezoidal Box details	
Top surface	45 cm X 45 cm
Height	23 cm
Bottom surface	31 cm X 31 cm
Lifting stand	3 cm

Fig. 1 A sample line graph using colors which contrast well both on screen and on a black-and-white hardcopy



(a) Solid model of the cooking pot

(b) Finite Element Mesh of the model

Figure 3

The water initial temperature was assigned as 300 K with the solar radiation of 800 W/m^2 – 1100 W/m^{2}introduced at the pot wall surfaces. Table 2 highlights the specified boundary conditions and the appropriate properties considered in the numerical simulation. A laminar kind of flow has been considered along with discrete radiation surface with Energy equation ON in solution control. The temperature contour plot of the solar cooking pot is given in Figure 4. It indicates that the temperature has been increased from 300 K to 398.6 K due to the solar radiation introduced in the numerical model.

TABLE 2 BOUNDARY CONDITIONS

Water wall temperature	300 K
Solar radiation	800 – 1100 W/m^2
Reflectivity of Box Wall surfaces	0.97
Transmissivity of the cover	0.84
Reflectivity of the reflector	0.94

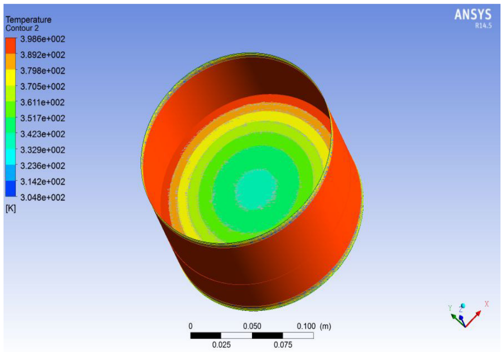


Figure 4 Contour plot showing temperature variations in the cooking pot

Fig. 2 Example of an unacceptable low-resolution image

Construction of the experimental setup

The solar cookers used in this research work has been designed and fabricated in-house. Cardboard is used as outer shield along with glass, aluminium foil and iron sheets as layers. Transparent convers with holes are introduced in order to reduce the convection losses by which the recirculation of the heat energy gained by the reflector effectively inside the cooker. This will ensure that the cooker may even be used during cold season to cook two meals per day. This is not possible with the hot box solar cooker without transparent cover. Use of one more reflector will enhance the performance of the solar cooker be effectively reflecting the solar radiation. By keeping this in our mind, three reflectors are introduced facing east, west and south. This arrangement of the reflectors will further eliminate the necessity of tracking mechanism to focus the solar rays to fall always on the cooking pot. Provisions are made to tilt the reflector for various angles ranging from 0° to 120° with reference to the horizontal plane. The various arrangements of the reflectors is illustrated in Figure 5(a) – (b). The inner surface of the cooker is made of trapezoidal shape with foam insulation. Absorber plate is made of steel sheet, coated with black paint along with some absorptance. Four glasses with high transmissivity are used as covers. The cooking vessel of two different types such as cavity cooking pot and dimpled cooking pots (Figure 6) were used in this research work.

The experimental trials were conducted during 22ndDecember, 2022 – 13thMarch 2023 at Government College of Engineering Salem, Tamil Nadu, India, between 10 AM to 4 PM. The experiments were conducted simultaneously on a solar cooker with single transparent cover without holes and solar cooker provided with four transparent covers with holes. The fluid temperatures were recorded with the help of digital thermometers (Measurement range:-50^o C to +200^{o}C; Accuracy : ±1^{o}C; Resolution: 0.1; Probe size: 3.5 mm diameter and 120 mm long) installed with the experimental facility and the solar intensity was measured by solar power meter (Model: TM2017; Accuracy ±10 W/m^2). Table 3 gives the heat capacity values and the corresponding areas of various parts present in the solar cooker.

(a) Single reflector (b) three reflectors

Figure 5 Box type solar cooker

(a) Cavity (b) Dimpled

Figure 6 Cooking pots

Table 3 Heat capacity values

Elements	Heat capacity (J/K)	Area (m^2)
Absorber plate	297.43	0.1224
Side walls	443.72	0.1826
Inside air	21.01	–
Transparent cover 1,2	1638	0.2025
Transparent cover 3	1638	0.1521
Transparent cover 4	1638	0.1296
Cooking pot water	1699	0.0296
Pot cover	69.43	0.0259
Air inside pot	0.87	–
Cooking pot	188.47	0.05

5. Results and Discussion

5.1 Variation of water temperature with Time

Figure 7 shows the comparison curves of the temperature rise in water for two different types of cookers. Initially the cooking pot water temperature is calculated with single transparent covers and varying number of transparent covers with holes. From the result it is understood that increasing the number of transparent covers with holes increases the cooking water temperature even the solar radiation is reduced.

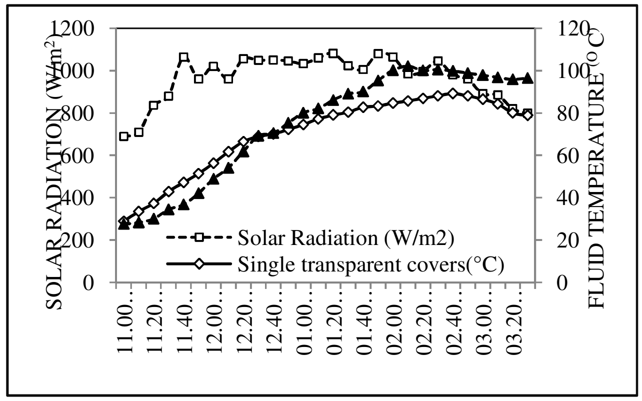


Figure 7 Variation of water temperature with time

5.2 Variation of ambient and cooker fluid temperature with time

Figure 8 shows the comparison curves of the Variation of ambient and cooker fluid temperature with time. The solar radiation values are marked in the curve. The solar cooker temperature is higher when compared to the solar radiation. It shows the heat gained by the solar cooker is higher for the mentioned ambient temperature.

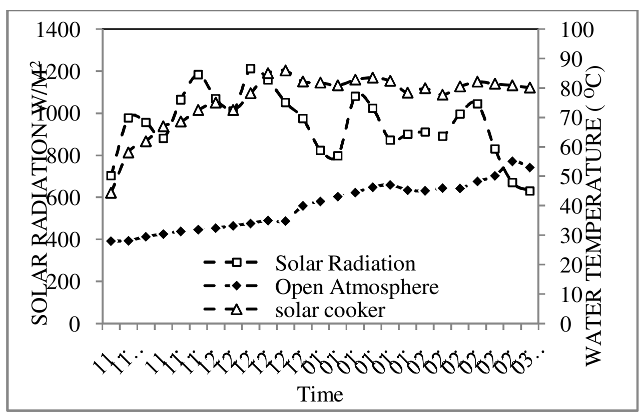


Figure 8 Variation of ambient and cooker fluid temperature with time

5.3 Variation of validation temperature with time

Single transparent cover can get direct attraction of solar radiation (Figure 9). Once solar radiation increases we can get more water temperature .In using four transparent covers with holes we can get more water temperature even solar radiation decrease in evening time. The validation result from numerical and experimental are considerably matched with up to 5% of errors.

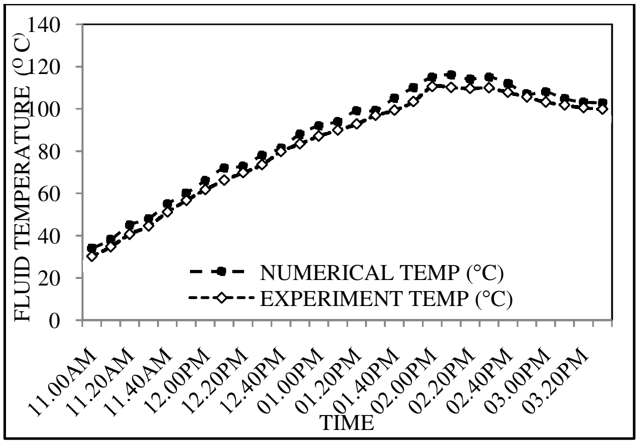


Figure 9 Comparison of numerical and experimental results

II. Conclusions

The present work is to deliver actually if we increase number of transparent covers the heat transfer rate is decreased in nature. Because the solar radiation to reach the cooking fluid difficult and duration is too high and. But in my work if we use transparent covers with holes, the solar radiation heat energy is re-circulated within the system and got 43.6% thermal efficiency. So this is one technique in performance enhancement of BSC to get more cooking water temperature even solar radiation fall at evening time. Once getting solar radiation, it is capable of storing maximum heat within the System. So it can reduce cooking time. There is no more need of heat storage medium. In this work it was found that box type solar cooker having two transparent covers mainly to reduce convective losses and others two with holes to increase water temperature. So BSC with transparent covers with holes is recommended for obtain maximum heat circulation and without holes is recommended for reducing convective heat losses.

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