

EXPERIMENTAL STUDY ON HOT BOX SOLAR COOKER FOR DIFFERENT SPACINGS BETWEEN ABSORBER AND GLASS COVER

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Abstract-A detailed experimental study has been carried out to investigate the effect of spacing between absorber plate and glass cover (that is height of the cooking chamber) in a domestic box type solar cooker. In order to investigate the effect of spacing between absorber plate and glass cover, 10 cm spacing and 8 cm spacing between absorber plate and glass cover have been compared with 12 cm spacing which is available in a normal domestic box type solar cooker. By reducing the spacing between absorber plate and glass cover heat transfer to cooking food increases very much. This enhancement in heat transfer is due to enhancement in convective mode of heat transfer mainly. By reducing the spacing between absorber plate and glass cover; bulk, weight and cost of solar cooker can be reduced considerably.

Keywords-Box type solar cooker, Spacing between absorber plate and glass cover, height of cooking chamber, Rectangular enclosure, Natural convection

I. INTRODUCTION

A solar cooker is a solar energy exchanger designed specially to deliver heat to foods, for the purpose of raising their temperature and causing the chemical changes associated with the process of cooking. Solar cooker can be classified mainly into three types, which are box type, reflector/focusing type and heat transfer typ. Box type solar cookers are popular and widely used in many countries due to their simplicity and low cost. Box type cookers depend on heat retention. They are slow to heat up, but work well even where there is diffuse radiation, convective heat loss caused by wind, intermitted cloud cover and low ambient temperature [1].

Solar cookers are designed to utilise energy from sun in the process of cooking. Solar cookers have attracted the attention of many researchers so far. Different types of solar cookers have been developed and tested all over the world. There has been a considerable interest recently in the design, development and testing of various types of solar cookers.

II. LITERATURE REVIEW

Telkes (1959) has designed, fabricated and tested some excellent models of solar cookers incorporating features such as mirror boosters, inclined aperture and side loading [2].

Mullick et al. (1987) outlined a test procedure for the solar box cooker. They have developed methods of evaluating box type solar cookers using two figures of merit. Thus, a method of cross comparison of different models becomes available. Also single design could be evaluated for their accuracy and effectiveness [3].

Mullick et al. (1996) also conducted a few experiments to study the effect of the number of pots and the load on the second figure of merit [4].

Thulasidas et al. (1994) modelled a box type solar cooker with a reflector and loaded with one, two or four vessels and studied the effect of base plate thickness, cooker size etc. [5,6].

Funk et al. (1998) presented a parametric model of solar cooker performance based on three controlled parameters (solar intercept area, overall heat loss coefficient, and absorber plate thermal

conductivity) and three uncontrolled variables (insulation, temperature difference, and load distribution) [1].

Funk (2000) presented the international standard testing procedures for evaluation of solar cooker [7].

Gaur et al. (1999) studied the performance of a box type solar cooker with modified utensil having a concave lid and found that it was about 2-7% more efficient than the utensil with normal lid [8].

Kumar (2004) presented simple thermal analysis to evaluate the natural convective heat transfer coefficient in trapezoidal enclosure of hot box type solar cooker [9].

2.1 Optimization Factor of Solar Ovens (Malhotra et al., 1983) [10]

Malhotra et al. (1983) tried to optimise the cooking chamber volume of hot box solar oven. The performance of a hot box solar oven depends upon the area of energy collecting window, concentration ratio of reflecting assembly (The concentration ratio is the ratio of the total intercepted area of incoming sunlight to the area of the oven window), insulation between outer shell and hot box (cooking chamber) and volume of the hot box. They observed that there was a steep fall in temperature with increase in volume of cooking chamber.

2.2 Natural Convection in Enclosed Spaces—A Review of Application to Solar Energy Collection (Buchberg et. al. 1976) [11]

Based upon the theory and some experimental measurements Buchberg et. al. (1976) showed that the spacing between the tilted hot solar absorber and successive glass covers should be in the range 4-8 cm to assure minimum gap conductance. Poor choice of spacing can significantly affect thermal conversion efficiency, particularly when the efficiency is low or when selective black absorbers are used.

In the case of two parallel flat plates tilted and heated from below, Buchberg et. al. showed that conduction-convection heat losses decrease with an increase in plate spacing to reach an apparent minimum just as natural convection is initiated, then increase thereafter until a maximum is reached, and then fall gradually with further increase in plate spacing to reach values below the conduction minimum. The spacings at which the apparent minimum and maximum occur, change greatly with temperature difference and somewhat with temperature level. They also found that a partial vacuum serves well to reduce convective heat losses. These losses are reduced when the temperature of the surface interfaces with the surroundings is lowered.

2.3 Study of Convective Heat Losses in Solar cookers (Shukla and patel,1990) [12]

An analytical study to obtain the effect of air gap dimension on convective heat losses in solar cooker assuming it as rectangular enclosure was undertaken by Shukla and Patel (1990). The study revealed that pure conduction from hotter lower surface to colder upper surface, is evidently the primary mechanism while buoyancy driven convection between horizontal surfaces is the secondary mechanism and is due to adverse temperature gradients in vertical direction. Shukla and Patel found that the convective heat losses in solar cookers are aspect ratio (width / gap height) dependent and that these losses can be eliminated by selecting a suitable gap height.

2.4 Heat transfer studies on hot box solar cooker (Karwa and Varshney, 2010) [13]

Karwa and Varshney (2010) have presented results of an experimental study to see the relative strength of different modes of heat transfer in a conventional hot box solar cooker. They conducted a series of experiments by excluding one or other mode/modes of heat transfer by using insulation under the pot, raising the pot on the lugs, using low emissivity bright buffed surface stainless steel pots, or insulating the pot from sides and cover by applying insulation and aluminium foil covering.

They found that the contribution of radiation heat transfer is marginal but conduction and convective modes of heat transfer are practically equally strong.

III. OBJECTIVES

It is an established fact that contribution of convective mode of heat transfer to cooking vessel in conventional hot box solar cooker is very strong. This indicates that efforts should be made to enhance the convective mode of heat transfer in hot box solar cooker.

The performance of a hot box solar cooker depends upon the area of energy collecting window, total intercepted area due to reflecting assembly, insulation between outer shell and cooking chamber and volume of the cooking chamber.

Pure conduction from hotter lower surface to colder upper surface, is evidently the primary mechanism while convection between horizontal surfaces is the secondary mechanism and is due to adverse temperature gradients in vertical direction. Convective heat losses in solar cookers are aspect ratio (width / gap height) dependent and that these losses can be eliminated by selecting a suitable gap height. Poor choice of the spacing between the hot solar absorber and successive glass covers can significantly affect thermal conversion efficiency.

From the literature survey it can be seen that an experimental study to see the effect of spacing between absorber plate and glass cover in a conventional hot box solar cooker (by varying the height of cooking chamber) is still required. Hence, the objective of the present experimental study, to be carried out as per BIS 13429:2000 [14] and recommendations of other investigators, is to investigate the effect of spacing between absorber plate and glass cover in a domestic box type solar cooker.

IV. EXPERIMENTAL METHODOLOGY

4.1 Experimental Setup

4.1.1 Solar cooker

The box type solar cooker used in the study is shown in Fig. 1. As per claim of supplier, solar cooker has been fabricated to meet the standards prescribed by BIS for solar cookers. The cooker consists of a 0.6 m X 0.6 m X 0.22 m box made of GI sheet with a mat black painted trapezoidal tray of (43 cm X 43 cm at bottom, 50 cm X 50 cm at top and 10 cm height) made of 28 SWG thick GI sheet. Four cooking vessels/ pots can be kept inside it. Aluminium pots with mat black painted on outside of size 170 mm diameter and 50 mm height have been used in the study.

The total absorber area is 0.382 m²; the bottom surface of the tray is 0.185 m² in area. The cover plate is double glazed. Spacing between inner and outer glazings (4 mm thick each) is about 15 mm. The glazing area is $L_g \times W = 498 \text{ mm} \times 498 \text{ mm}$. Provision on the side is made to keep the cover plate at inclined position for loading and unloading of the cooking pots.

A plane mirror (reflector) is hinged at the side of box to increase the solar irradiation on glazing. Mirrors are free from bubbles and waviness. The reflecting area of mirror is 506 mm X 506 mm which is greater than the glazing area. Provision on the sides is made to keep the mirror in any inclined position. There is a provision to keep the mirror in any inclined position.

The solar radiation falls upon the glazing directly and indirectly after reflection from mirror. The maximum projected area of glazing is known as aperture area. The maximum projected area of mirror is known as reflector area. The sum of aperture area and reflector area is termed as intercept area. The ratio of intercept area to the aperture area is known as concentration ratio.

Joint between glazing and absorber tray is sealed by polyurethane foam. The space between the absorber tray and outer sheet of box is filled with glass wool insulation on all sides and bottom. Thermal resistance $R (= \delta/k)$ of about 40 mm thick glass wool (thermal conductivity = 0.06 Wm⁻¹K⁻¹ at 380 K) is about 0.66 m²KW⁻¹. However BIS recommends a minimum value of 0.96 m²KW⁻¹ at 100 °C.

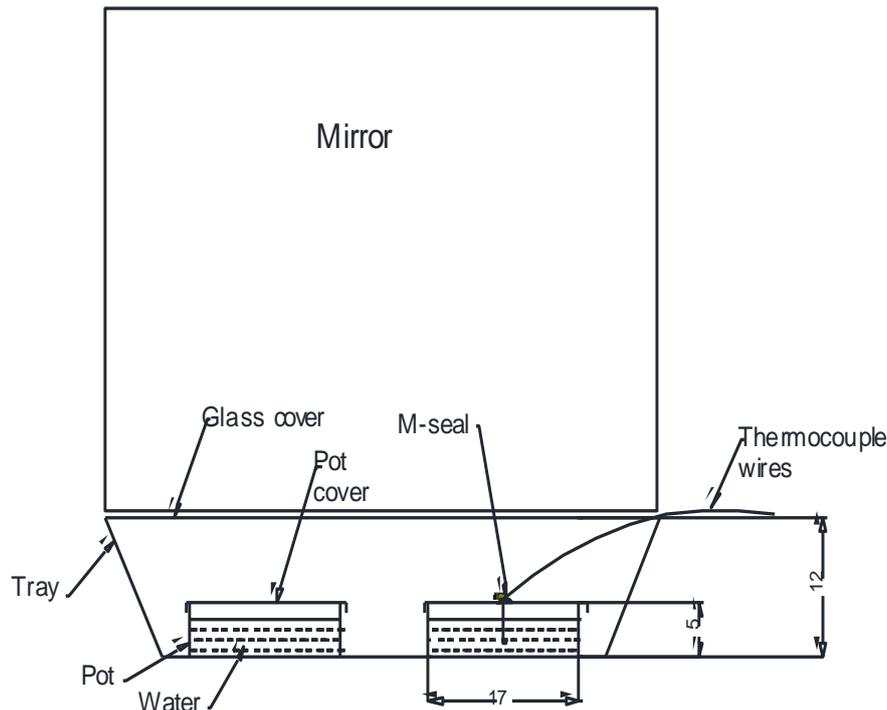


Figure 1 Schematic diagram of experimental set up (one solar cooker) (all dimensions are in cm).

4.1.2 Experimental devices

The experimental study has been made by recording temperature rise of the water in the vessel with a calibrated HTC digital K type thermocouple (Ni Cr / Ni Al Alloy). The temperature probe of the thermocouple has been placed in the cooking vessels with measuring tip of the thermocouple submerged in the water. Thermocouple wires have been sealed using epoxy resin to make the vessel vapour tight. The ambient temperature has also been measured by the thermocouple. The solar Irradiance on the horizontal plane has been measured using a Tenmars solar power meter TM-206 (solarimeter) calibrated against a precision pyranometer available in IIT Jodhpur.

4.2 Schemes of Experiment

The heat to the conventional cooking vessel and its contents (water in the present study) flows by conduction through the bottom of the vessel from heated absorber tray, though there exists a thermal contact resistance between the bottom of the vessel and absorber tray surface. Heat flows by convection from the heated absorber tray to vessel's side walls. Heat also flows from the heated cover/ lid of vessel to the contents of the vessel by conduction through the side walls of the vessel though there is a thermal contact resistance because of uncertain contact between the lid and vessel's side surface. The contribution of radiative heat transfer to cooking vessel is not direct but the absorber tray and vessel's lid are heated by radiation.

In order to investigate the effect of spacing between absorber plate and glass cover in a domestic box type solar cooker, 3 different configurations (schemes) have been designed which have been described in Table 1. Present experimental study is based on these schemes. In all the schemes, a direct comparison of temperature rise of a known quantity of water in two identical conventional pots directly kept on absorber tray of one solar cooker with temperature rise of same quantity of water in two identical pots in another solar cooker with changed spacing between absorber tray and glazing cover. In the first scheme, resemblance of both solar cookers used in the study have been tried to establish with solar cooker 1 and 2 both with cooking chamber height 12 cm (12 cm spacing between absorber plate and glass cover). In the second scheme, solar cooker 1 has been kept in its original form that is, with 12 cm spacing between absorber plate and glass cover while solar cooker 2 has been kept with modified absorber tray of 10 cm height that is with 10 cm spacing between

absorber plate and glass cover. In the third scheme, solar cooker 1 has been kept in its original form that is, with 12 cm spacing between absorber plate and glass cover while solar cooker 2 has been kept with modified absorber tray of 8 cm height that is with 8 cm spacing between absorber plate and glass cover.

Table 1. Various schemes used in experimental study

Scheme No.	Details
1	Solar cooker 1 with cooking chamber height 12 cm and Solar cooker 2 with cooking chamber height 12 cm. (Standardisation of both cookers)
2	Solar cooker 1 with cooking chamber height 12 cm and Solar cooker 2 with cooking chamber height 10 cm.
3	Solar cooker 1 with cooking chamber height 12 cm and Solar cooker 2 with cooking chamber height 8 cm.

4.3 Experimental Procedure

The experimental study has been made by recording temperature rise of the water in the vessel with a thermocouple. The temperature probe of the thermocouple has been placed in the cooking vessels with measuring tip of the thermocouple submerged in the water above 10 mm from pot bottom. Thermocouple wires have been sealed using epoxy resin to make the vessel vapour tight. The ambient temperature has also been measured by the thermocouple.

The solar irradiance on the horizontal plane has been measured using the solarimeter. The tests were conducted in still air (wind velocity less than 1.0 m/s).

All components and instruments were checked for proper functioning. The pots were placed in the cooker as per the schemes of the experiment described in Table 1. A measured quantity (1700 cc) of the water was filled in the pots in each solar cooker.

The tests were started in the morning between 9 AM and 10 AM IST. Solar irradiance and temperatures have been measured at 20 min interval in the beginning. This interval was reduced to 10 min after the water temperature reached about 65-70°C. The upper limit of the water temperature for the time period analysed cannot be taken as 100°C (the boiling point at atmospheric pressure) because the rate of variation of water temperature approaches zero as the water temperature approaches 100°C. Therefore, the upper limit of sensible heating (T_{w2}) has been fixed in the temperature range 90°C – 95°C (Mullick et al., 1987). The data recording was continued until the water temperature reached about 95°C as per suggestion of BIS.

The tilt of the reflector was varied every 30 minutes so that the reflected radiation does not fall outside the glazing and covers the glazing completely. The cooker was also tracked every 30 min.

A direct comparison of temperature rise of a known quantity of water in two identical conventional pots directly kept on absorber tray of one solar cooker with temperature rise of same quantity of water in two identical pots in another solar cooker with changed spacing between absorber tray and glazing cover.

In order to investigate the effect of spacing between absorber plate and glass cover, 10 cm spacing and 8 cm spacing between absorber plate and glass cover have been compared with 12 cm spacing which is available in a normal domestic box type solar cooker.

In all the schemes both pots have been kept centrally in the solar cooker. Aluminium pots with mat black painted on outside (Fig. 1) of size 170 mm diameter and 50 mm height have been used in the study.

To reduce effects of uncertainty and errors, the experiments have been repeated two or three times.

The tests were conducted at Department of Mechanical Engineering, Faculty of Engineering & Technology, Jodhpur National University, Jodhpur (India). Jodhpur is located at 26.25°N latitude, 73.03°E longitude and 235 m elevation of sea level.

4.4 Load Test (Sensible Heating Test)

The solar cooker has been tested by measuring the rise in temperature of a known quantity of water in the cooking vessels with time.

Cooking pots have been filled with 1700 CC of water, which works out to be about 7.5 litres of water per m^2 of the glass area. This is in the range suggested by BIS for standard conditions for load of 8 kg of water / m^2 of aperture area. Equal quantity of water at ambient temperature has been used in the cooking pots in both the solar cookers and they are of the same size in the tests.

4.5 Experimental Data

Ideally the experiment must be conducted in a clear weather but sometimes there were intermittent clouds and the diffuse radiation was observed to be 20-30%. The solar radiation exceeded 600 W/m^2 (which is the recommendation of all standards including BIS most of the time) after 10 am except during the short periods of cloudy conditions on some days of experiment. The tests were conducted in still air (wind velocity less than 1.0 m/s). The ambient temperature T_a varied from a 30°C in the morning to a maximum of 42°C in the afternoon. The opening area ($L \times W$) of hot box solar cooker varies by about 10% because of the adjustment of the tilt of the mirror.

V. RESULTS AND DISCUSSION

5.1 Standardisation of Both Identical Solar Cookers (Establishing Resemblance of Cookers)

Initially both the construction wise identical solar cookers have been tested for their similar performance in similar conditions. It can be seen from Fig. 2 that performance of both solar cookers is almost similar.

Temperature of water in pot of solar cooker 2 remains equal to temperature of water in pot of solar cooker 1 up to 70°C . Temperature of water in pot of solar cooker 2 leads by only 1°C over temperature of water in pot of solar cooker 1 when temperature of water crosses 70°C . It can be claimed that both the solar cookers used in the study are identical in all respect. Hence both cookers can be used to see the effect of one particular modification which is change in spacing between absorber plate and glass cover, here.

5.2 Solar Cooker 1 with Cooking Chamber Height 12 cm and Solar Cooker 2 with Cooking Chamber Height 10 cm (12 cm Spacing Versus 10 cm Spacing)

In the second scheme, solar cooker 1 has been kept in its original form, that is, with 12 cm spacing between absorber plate and glass cover while solar cooker 2 has been kept with modified absorber tray having 10 cm spacing between absorber plate and glass cover.

From Fig. 3, it can be seen that temperature of water in pot of solar cooker 2 leads by 4 - 5°C over temperature of water in pot of solar cooker 1 when temperature of water of solar cooker 2 crosses 90°C .

5.3 Solar Cooker 1 with Cooking Chamber Height 12 cm And Solar Cooker 2 with Cooking Chamber Height 8 cm (12 cm Spacing Versus 8 cm Spacing)

In the third scheme, solar cooker 1 has been kept in its original form that is, with 12 cm spacing between absorber plate and glass cover while solar cooker 2 has been kept with modified absorber tray having 8 cm spacing between absorber plate and glass cover.

From Fig. 4, it can be seen that temperature of water in pot of solar cooker 2 leads by 8°C over temperature of water in pot of solar cooker 1 when temperature of water of solar cooker 2 crosses 90°C . This increase is significant and establishes the dominance of convective heat transfer mode in hot box solar cooker over other modes of heat transfer.

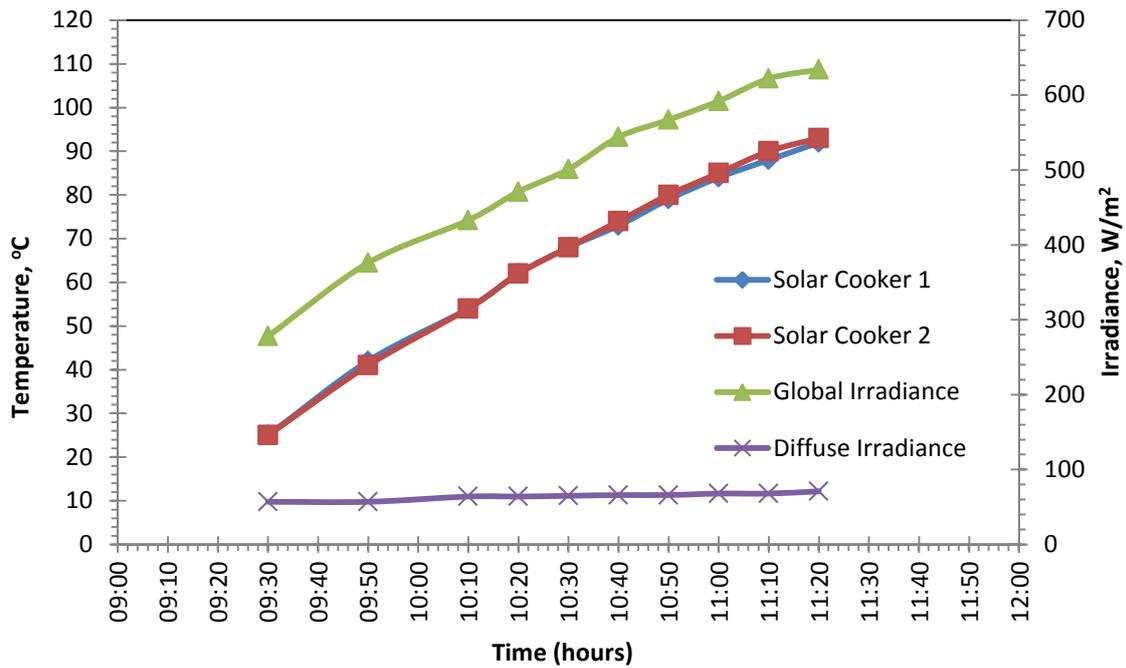


Figure 2 Standardisation of both solar cookers

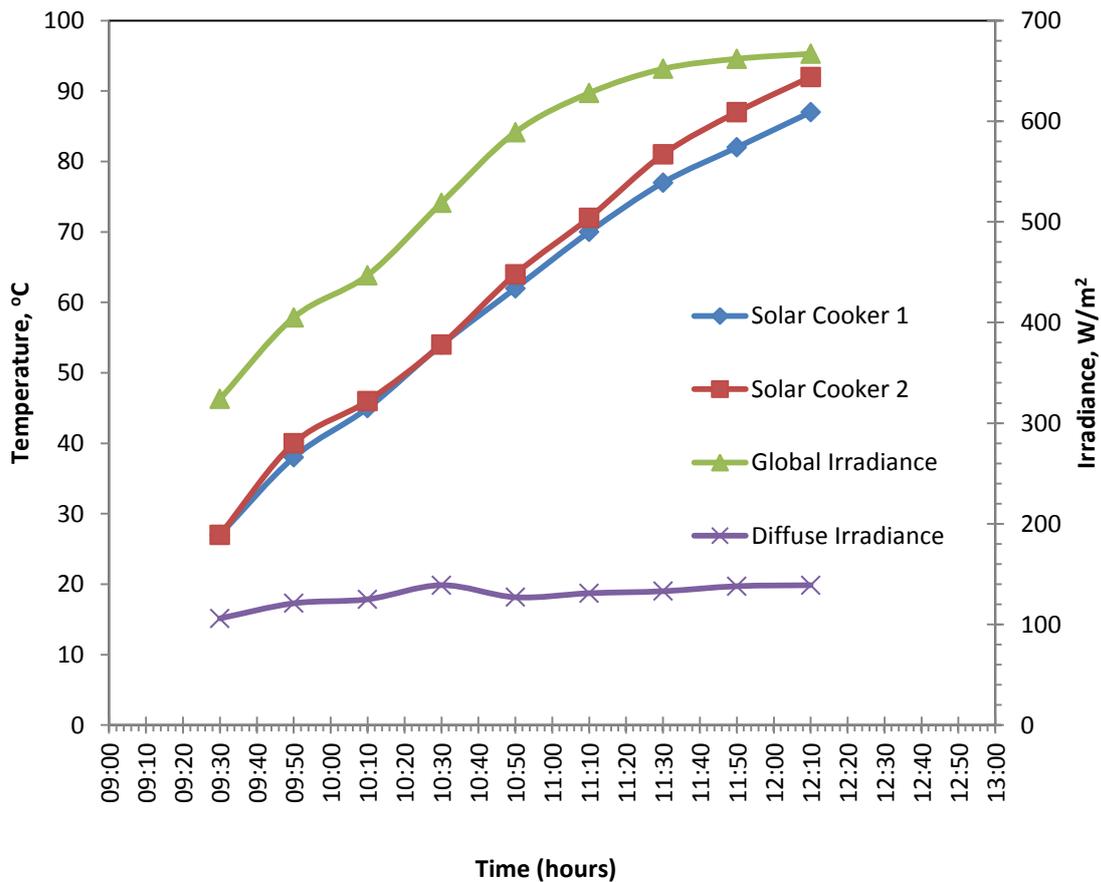


Figure 3 Solar cooker 1 with cooking chamber height 12 cm and Solar cooker 2 with cooking chamber height 10 cm.

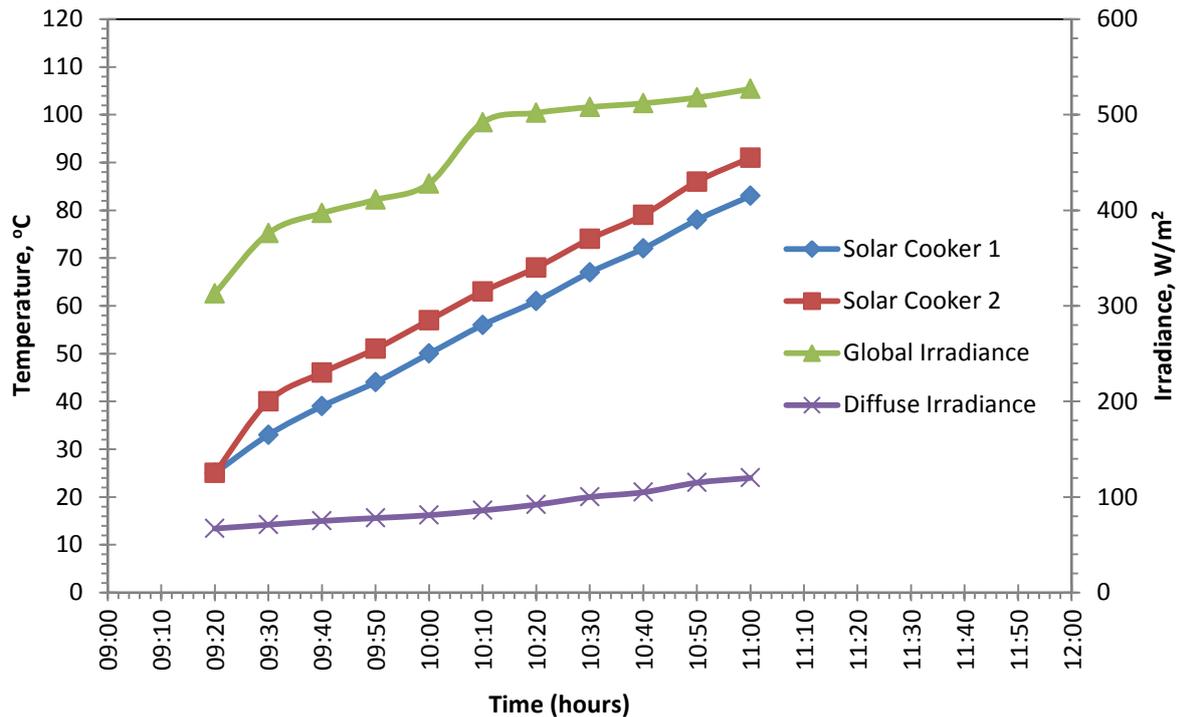


Figure 4 Solar cooker 1 with cooking chamber height 12 cm and Solar cooker 2 with cooking chamber height 8 cm.

VI. CONCLUSIONS AND RECOMMENDATIONS

A detailed experimental study has been carried out to investigate the effect of spacing between absorber plate and glass cover in a domestic box type solar cooker. In order to investigate the effect of spacing between absorber plate and glass cover, 10 cm spacing and 8 cm spacing between absorber plate and glass cover have been compared with 12 cm spacing which is available in a normal domestic box type solar cooker.

The main findings of the study are:

1. By reducing the height of the cooking chamber (spacing between absorber plate and glass cover) heat transfer to cooking food increases very much. This enhancement in heat transfer is due to enhancement in convective mode of heat transfer mainly.
2. For a load of 7.5 kg/m^2 opening area, temperature of water, in pot of solar cooker with reduced cooking chamber height of 8 cm, leads by 8 - 12 °C over temperature of water in pot of solar cooker with cooking chamber height of 12 cm in normally available cookers, when temperature of water, of solar cooker with cooking chamber height 8 cm, crosses 90 °C
3. By reducing the height of the cooking chamber (spacing between absorber plate and glass cover); bulk, weight and cost of solar cooker can be reduced considerably.
4. Since height of commonly used cooking pot is 7 cm, cooking chamber height should be kept 8 cm. Presently it is 12 cm in normally available solar cooker.
5. Since contribution of convective heat transfer to the food is significant, some mechanical means (clips etc.) must be provided to make glazing cover well tight to ensure prevention of leakage of hot air.

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