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PERFORMANCE STUDIES AND ECONOMIC ANALYSIS OF GREEN MATERIAL SOLAR COOKER

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ABSTRACT

This paper presents a study of large size green-material solar cooker. This large size solar cooker is fixed structure with housing made of local masonry bricks and cement plaster. This large size solar cooker is capable of cooking for about 25 persons. Thermal performance studies of large size solar cooker have been carried out at Jaipur (26.92°N, 75.87°E). The highest plate stagnation temperature, without reflector and no-load condition reached 142.1°C and for most of the time of test, the absorber plate temperature remains above 100°C. The obtained results have been used to calculate two figures of merit F_1 and F_2. Two figures of merit F_1 and F_2 are found 0.117°C-m^2/W and 0.416 respectively which are as per recommended values of BIS. The values for initial cooking power and adjusted cooking power at a temperature difference of 50°C are found to be 304.6 and 209 Watts, respectively. The values of cooking power place the community solar cooker in the region of large size and good insulation cooker, as per international standard. The cooker saves 6300 MJ of energy per year. The net present values and payback periods are in increasing order with respect to fuel: electricity, coal, firewood, liquid petroleum gas, and kerosene. The higher net present value and shorter payback periods suggests that the use of large size solar cooker is economical. The use of large size solar cooker would help in conservation of conventional fuels, such as firewood, animal dung cake and agricultural waste in rural areas of India, and LPG, kerosene, electricity and coal in the urban areas. Conservation of firewood help in preserving the ecosystems and animal dung cake could be used as fertilizer, which could aid in the increase of production of agricultural products. Moreover, the use of the non-tracking storage solar cooker would result on the reduction of the release of CO_2 to the environment.

Keywords- Green-material; Large size solar cooker; Net present value; Payback periods

[1] INTRODUCTION

Looking in to the present energy scenario solar cookers seems to be a good alternative for cooking, as it saves the fuel which may be used for other purpose. Various types of solar cookers developed so for can be categorised in mainly three categories viz. hot box type, heat transfer type and concentrating type [1]. Many authors have also developed and studied some purpose specific cookers [2, 3, 4]. Each type of appliance has its own merits and demerits e. g. heat transfer type cookers make indoor cooking possible, which protects the user from direct sun radiation, but heat losses are high and efficiencies are low for these cookers. In case of focusing type cookers fairly high temperatures (180ºC to 300ºC) and good efficiency (50 to 60 percent) can be achieved, but these advantages are completely masked by facts that their design and operations are quite cumbersome. It is found that

cooking pot temperature does not exceed 80ºC for a wind speed more than 10 km/h. So the cooking time for such cookers depends heavily on wind speed. The concentrated light is dangerous especially to operator. Costs are also high for these cookers. Hot box types of cookers are the most favoured ones in the society due to their easy operation and reasonable cost structure. The solar cookers generally studied are suitable for meeting the food requirement of about 4-5 persons. Theses cookers are not suitable for community purposes e.g. hostels, hotels, temples, canteens, and restaurants etc. where various types of conventional fuels are used for cooking [5].

Literature survey reveals that very few efforts have been made towards the development of non-concentrating community size solar cookers, several attempt were made in early 1990's [6, 7] after that no attention has been paid towards the development of this type of solar cookers. The casing of systems studied earlier has been made of mild steel. As the use of metal increases the cost of the system and production of these metals requires a large amount of fossil fuel which adds the burden on limited fossil fuel resources. Some of the researchers have developed; solar collector's mainly employing building material [8, 9, 10, 11, 12]. These systems were made using different type of building materials and were wholly prepared through these building materials. Metal absorber tray or separate insulation were not used hence the performance of these systems was poor, though cost was also less. Further two models of the solar cooker for animal feed were developed by Nahar et al. [11] through clay, locally available material, exfoliated vermiculite and cement tiles. The cooker was capable of preparing 2 kg of animal feed per day. The cost of this animal feed cooker was quite low but these had low efficiencies, as the stagnation temperatures are around 80°C. Therefore in present piece of work an efficient solar cooker has been designed on the basis of theoretical modeling. An attempt has been made to optimise various parameters such as wall shadow, numbers of glass covers, insulation thickness, start up time of cooking, wind speed, glaze material and reflector. The designed system is tested on field experimentally. The outer casing of this system is made of green building material; aluminum sheet is used as absorber tray and glass wool as insulation. Extensive experimental on field studies have been done and results are critically analyzed. The cooking tests have been conducted and various parameters viz. F_1, F_2, efficiency and cooking power have been estimated.

[2]. DESIGN DETAILS OF COMMUNITY SOLAR COOKER

This community size solar cooker is fixed structure so tracking is not possible. The cooker has been designed in such a way that length to width ratio for the reflector and glass window is about four, so maximum radiation reflected from the reflector falls on the glass window. This has helped in eliminating the tracking. The system has been installed at an open place at the rooftop of Department of Physics, UOR, and facing south. The housing of this cooker has been built with local masonry bricks and cement plaster. The inner dimensions of the casing are 205 cm × 67 cm × 16 cm, thickness of walls is 15cm. A trapezoidal tray of aluminum sheet of thickness 0.3 mm is used as absorber tray, which has aperture area 195 × 57 cm^2 and base plate area 185 × 47 cm^2. The slant height of walls is 12 cm and walls are inclined at 26.92° with vertical. The upper surface of the absorber plate is painted with black board paint; therefore it is capable of absorbing most of the incident solar radiation. The top aperture of the solar cooker is covered with double glass covers separated by 13 mm. The inner toughened glass sheet is of 5 mm thickness and upper glass is a plane glass sheet of thickness 4mm. Since aperture of the system is very large therefore, for convenience of handling the glaze has been designed in two pieces, each of dimension 100 × 60 cm^2. The double glass cover minimizes the rate of heat loss through the top of the cooker

Around 5 cm thickness glass wool insulation of thermal conductivity 0.034 W/m-K is filled at the bottom and sides of the cooker to reduce the heat losses through the bottom and sides of the cooker. Three plane mirrors each of dimension 70×74 cm^2 are fixed in the lid of the box. The lid is hinged at the top of cooker and used to reflect the solar radiation onto the cooker aperture. The mirror tilt angle can be adjusted through a mechanical arrangement to maximize the amount of solar radiation onto the cooker top. Cooking vessels are cylindrical in shape with diameter of 19 cm and depth 7 cm and these are made of stainless steel. Fourteen such vessels can be kept inside the cooker. Figure 1 gives the sectional view of community size solar cooker and Figure 2 represents schematic view.

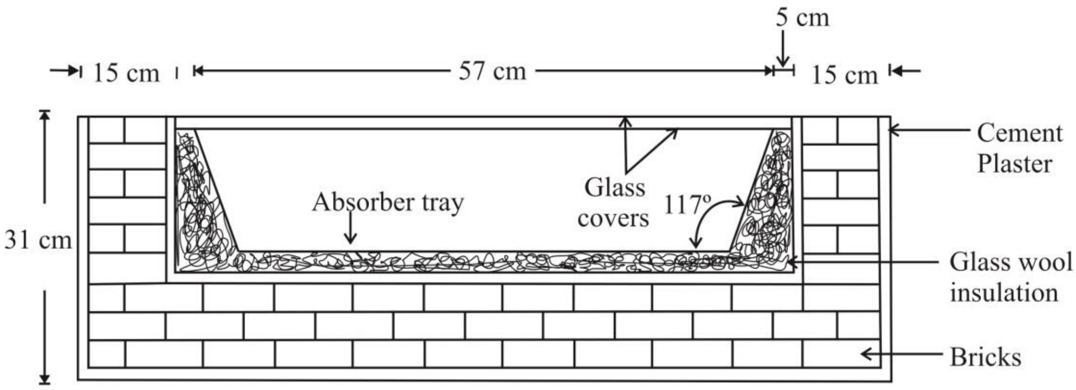

Figure 1 Sectional view of a box type solar cooker

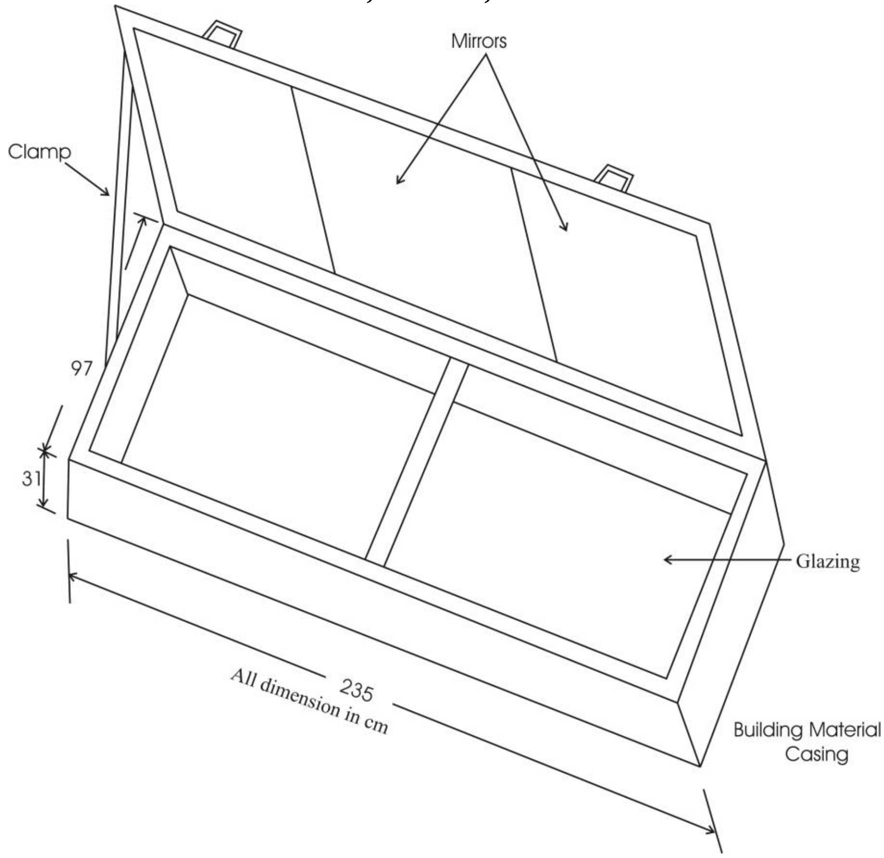

Figure 2 Schematic view of developed community solar cooker

Photograph 1 On-field installation of developed community solar cooker.

[3]. PERFORMANCE RATING OF GREEN MATERIAL SOLAR COOKER

Standard rating procedures for the performance evaluation of solar cookers (community solar cooker in particular) have not been defined uniquely. Various test procedures are available in literature for domestic solar cookers. Two test procedures have been performed on community size solar cooker in the present work. Mullick S. C. et al.[14] suggested this test procedure for the evaluation of the thermal performance of solar cookers and it has been adopted by bureau of Indian Standards (BIS standards IS 13429: 1992). In this test procedure two figures of merit F_1 and F_2 have to be determined by conducting the stagnation temperature test (without load) and by heating known mass of water respectively. Funk P. A. [15] proposed a standard procedure for testing solar cookers based on calculating the adjusted cooking power in Watts for a solar cooker and this procedure serves as the International test Standards for solar cookers.

Experimentation

The on field studies of the community solar cooker were performed on the rooftop of Physics Department at University of Rajasthan, Jaipur (26.92°N, 75.87°E). Thermal performance test were undertaken under no-load conditions to determine F_1 and sensible heat tests were also carried to determine F_2. Sensible heat test were repeated for different loads to see the effect of M_f on F_2. Experiments began at 10:00 a.m. and were continued up to 4:00 p.m. Indian Standard time (IST). Measurements were taken at intervals of 10 min for no-load and sensible heat tests. During all the experiments, the solar radiation intensity on a horizontal surface was measured using a pyranometer (Nation Instruments Ltd. Calculta, instrument no. 0068), CIE-305 thermometer with point contact thermo couples (Accuracy 0.01°C) was used to measure the temperatures of different parts of the

cooker, absorber plate, cooking fluid, vessel, air enclosed, upper and lower glass. The ambient temperature was measured using mercury thermometer (Accurecy 0.1°C) placed in the ambient chamber and the wind speed was measured by an anemometer (Prova instruments inc. AVM-03)

In order to calculate the cooking power and hence the adjusted cooking power, experiments were performed for community solar cooker. During the cooking power experiments fourteen containers were used and the temperature of water was measured in five pots placed at different positions in the system. The average temperature was then calculated and was used to calculate the cooking power and the adjusted cooking power using the method discussed earlier. One reflector on south age of the system was used whenever required as per test conditions. The system is off south oriented and no tracking is possible because it is fixed one.

[4]. ECONOMIC ANALYSIS

Financial analysis seeks to ascertain whether the proposed cooking system will be financially viable in the sense of being able to meet the burden of servicing debt and whether the proposed system will satisfy expectations of those who provide the capital. Solar systems are generally characterized by high initial cost and low operation cost as compared to the relatively low initial cost and high operating cost conventional systems. The economic viability of solar cookers can be estimated by two parameters –

a. Net present value (NPV)
b. Pay-back periods (PP)

The net present value and payback periods have been computed by the following relations [16, 17] .

$$NPV = \frac{(E-M)}{(d-i)}\left[1-\left(\frac{(1+i)}{1+d}\right)^{n}\right] - C_i$$

$$PP = \frac{\log\left(\frac{E-M}{d-i}\right) - \log\left(\frac{E-M}{d-i} - C_i\right)}{\log\left(\frac{(1+d)}{(1+i)}\right)}$$

The net present values and payback periods have been computed by considering the following annual cost

Discount rate d = 10%

Maintenance M=5% of the cost of solar cooker

Inflation rate i = 5%

Life time of cooker n = 10 and 15 years

Energy consumption for cooking in developing countries is a major component of the total energy consumption including commercial and non-commercial energy source. Fortunately, India is blessed with ample amount of solar radiation. Most parts of India receive 4-7 kWh of solar radiation per square meter per day with more than 280 sunny days in a year. As the energy for cooking per person is about 900 kJ of fuel equivalent per meal, so the cooking appliance could save 252 MJ energy/year/person/meal. The community size solar

cooker is capable of cooking for about 25 persons and it will save 50% of cooking fuel per meal. Therefore it will save 11.25 MJ of energy per meal and 6300 MJ of fuel equivalent per

year. Cost of the cooker is Rs 14000. The NPV and PP of the cooker with respect to different fuels has been calculated and is shown in Table 1.

Table 1 NPV and payback periods of community solar cooker

S. No.	Type of fuel	Calorific value	Efficiency (%)	Cost (Rs)	Net present palue (NPV) (Rs)		Payback period
					n=10	n=15	(yr)
1	Firewood	19.89 MJ kg^{-1}	17.3	4.00 kg^{-1}	35278	52542	2.4
2	Coal	27.21 MJ kg^{-1}	28.0	10 kg^{-1}	42316	62046	2.08
3	Kerosene	45.55 MJ kg^{-1}	48.0	14.8 L^{-1}	12780	22162	4.64
4	LPG	45.59 MJ kg^{-1}	60.0	27.80 kg^{-1}	28426	43290	2.81
5	Electricity	3.6 MJ kWh^{-1}	76.0	4.00kWh^{-1}	49317	71500	1.84

The net present values have been estimated using the life cycle of system to be ten and fifteen years and are found to be minimum with respect to kerosene and maximum for electricity whereas pay-back period is least i.e. 1.84 yr, with respect to electricity and maximum i.e. 4.64 yr with respect to kerosene. The net present values are in increasing order with respect to fuel kerosene, LPG, firewood, coal and electricity. We would like to stress here that the prices of kerosene and LPG are highly subsidized by the government of India. There is about 50% subsidy on LPG. These subsidies increase the budget deficit of Central Government, which is growing problem for India and the other developing countries. The higher net present values and shorter pay back periods suggests that the use of large size solar cookers is economical. The net present value and pay-back periods both depends on number of meals cooked by the systems in a year. The number of meals cooked depends on insolation characteristics and food habits of the person using solar cooker. So, the popularization of solar cookers will depend on local conditions where the system used. The type of conventional fuel used for cooking will also play decisive role in the use of cookers. As long people use the illegal wood cutting and low cost conventional fuels subsidized by the governments the motivation to use solar cookers will be poor.

[5] RESULT AND DISCUSSION

Figure 3 represents the diurnal variation in the weather conditions, namely insolation and ambient temperature and the transient response of community solar cooker under no-load conditions. It is clear from the figure that transient response closely follows insolation patterns. The temperatures of cooker elements increase with time of day until they achieve their maximum values at 12.50 p.m. The maximum temperatures of the absorber plate T_p, lower glass T_{gl} and upper glass T_{gu} are 142.1, 93.5 and 67.2°C, respectively. For most of the time of test, the absorber plate temperature remains above 100°C. At the time when absorber plate attains highest temperature the insolation and ambient temperature are 888 W/m^2 and 37.9°C respectively. Using the above results first figure of merit has been calculated and is found to be 0.117 °C-m^2/W. This ensures the high optical efficiency and low heat loss factor for community solar cooker.

The typical diurnal variation of temperatures of the cooker elements, insolation and ambient temperature for 8 kg water load are depicted in figure 4. The results of this figure are used to calculate the second figure of merit. The value of F_2 using T_{w1} = 63.8°C, T_{w2} = 95.1°C, τ = 5400 sec., average values for the ambient temperature 36.4°C and insolation 806.6 W/m^2 is found to be 0.416 for the designed community solar cooker. The effect of load on F_2 has also been studied. Figure 5 shows temperature variations of various cooker elements, with 10 kg of water load for this load the value of F_2 is 0.464, which is higher than previous value. The load dependence of F_1 and F_2 is evident in Table 2. Using Figure 5 and relation obtained by Nahar N. M. [6] the efficiency were calculated and was found to be 27.6%, which is better than the only reported value 24.9% for non-concentrating community solar cooker.

Table 2 various thermal performance parameters and their load dependence

S. No.	Parameter	Load	
		8 kg	10 kg
1.	(i) F_1	0.117 °C-m^2/W	0.117 °C-m^2/W
	(ii) F_2	0.416	0.464

2	Adjusted cooking power (P)	-	209
3	Efficiency (η)	-	27.6%

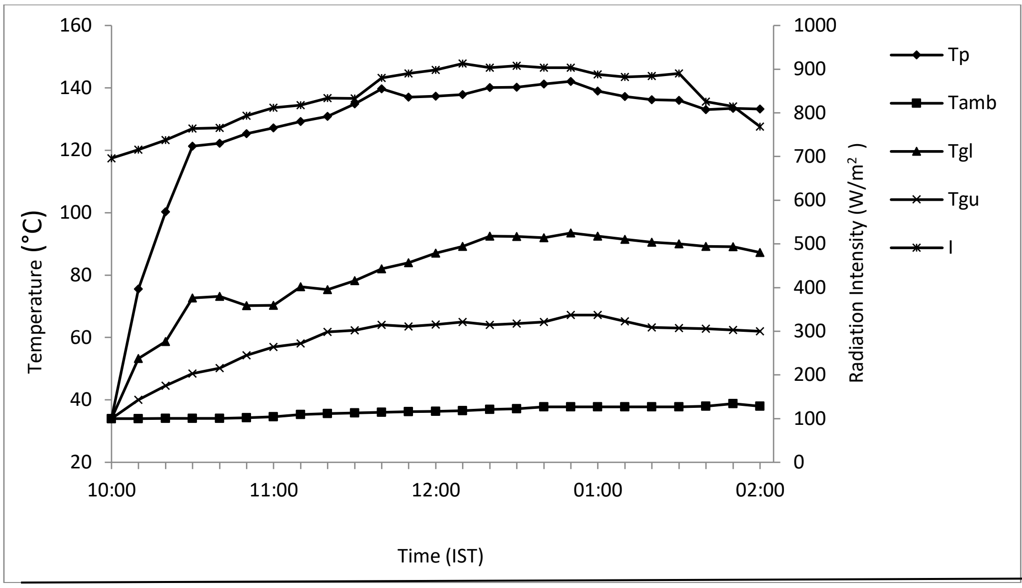

Figure 3 Measured temperature profiles and radiation intensity for cooker elements during stagnation test.

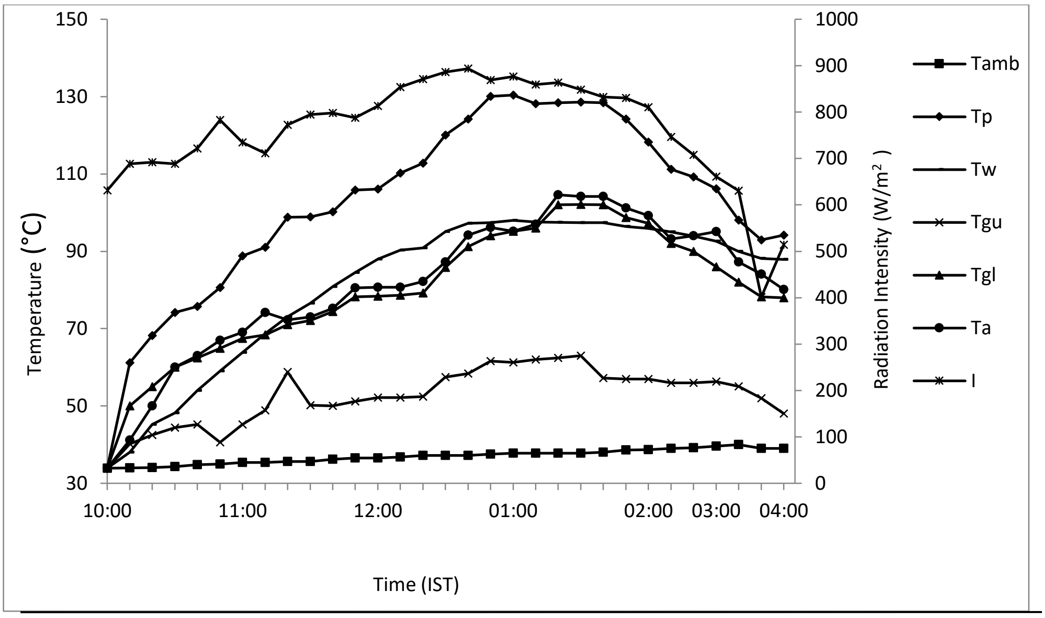

Figure 4 Measured temperature profiles and radiation intensity for the various cooker elements and radiation intensity during sensible heating test with boiling 8 kg water load.

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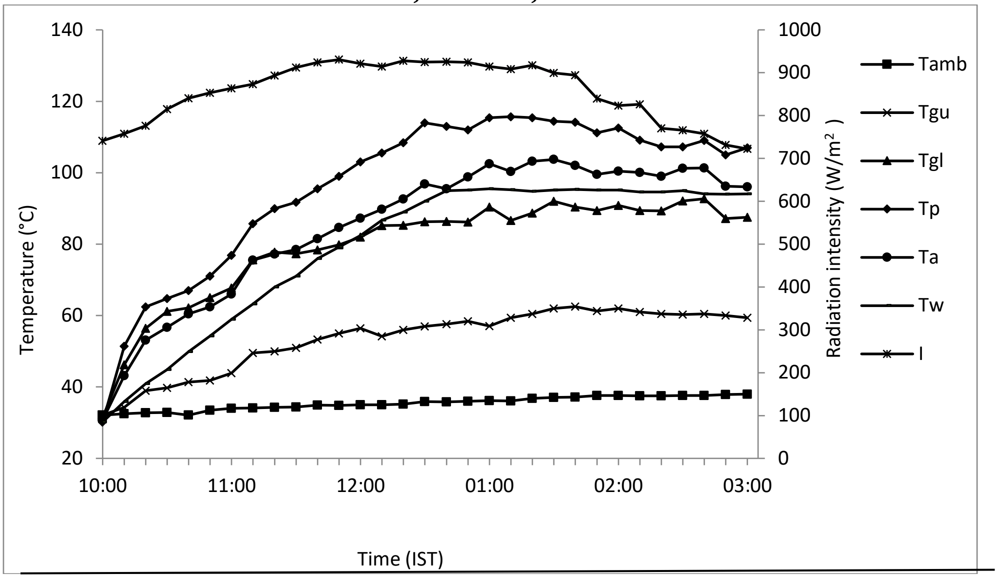

Figure 5 Measured temperature profiles and radiation intensity for the various cooker elements and radiation intensity during sensible heating test with boiling 10 kg water load.

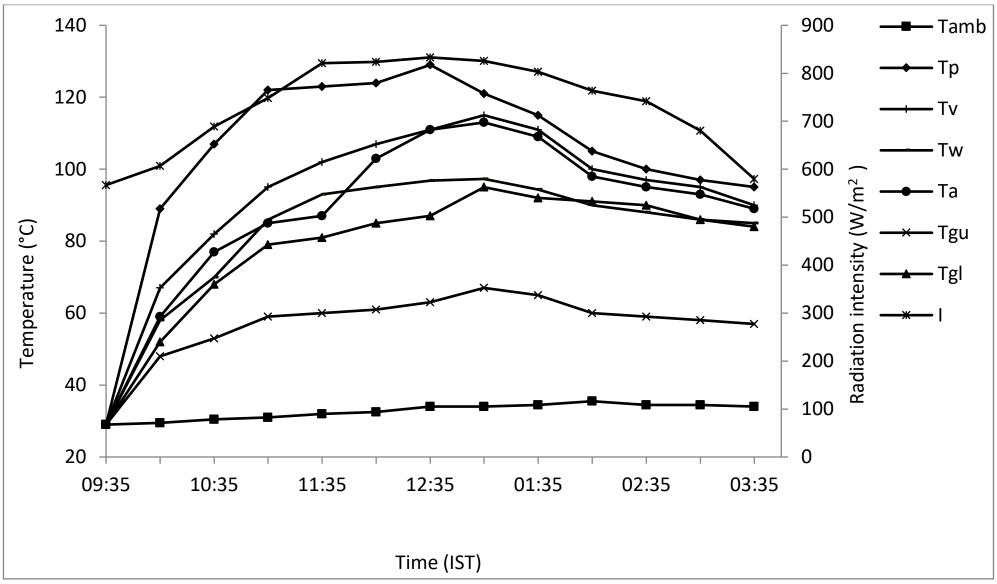

Figure 6 Temperature profiles of various cooker elements and radiation intensity with boiling 7 kg water load (with reflector).

Figure 6 depicts the thermal profiles of various cooker elements viz. water, absorber plate, air enclosed, vessel upper and lower glasses with 7 kg water load in twelve containers. The water temperature rose up to the boiling point in two hours and thereafter remained almost constant.

In the cooking experiments, the test standard requirements were applied. The system with intercept area of 1.5 m^2 was loaded with 10.5 kg of water (7 kg/m^2). The adjusted cooking power and temperature difference between the cooking fluid and ambient air were calculated every 10 min. interval. Figure 7 represents the adjusted cooking power as a function of temperature difference. The adjusted cooking power a function of temperature difference fits in the following relation

$$P = 304.6 - 1.91\ \Delta T$$

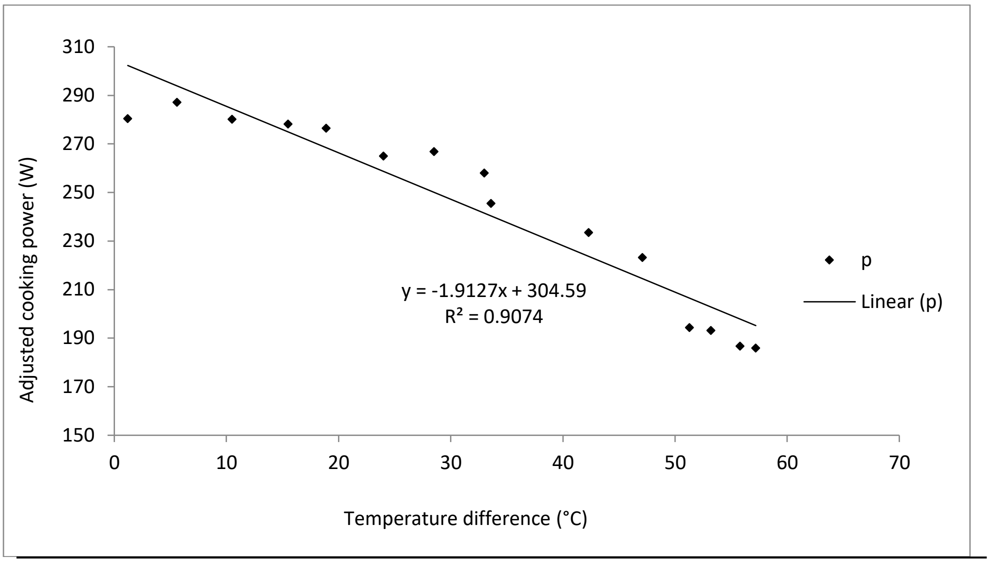

Figure.7 Relationship between adjusted cooking power and temperature difference for community solar cooker.

The value of regression coefficient (R^2) of the above equation is 0.907 which satisfies the test standard. The values for initial cooking power and adjusted cooking power and adjusted cooking power at a temperature different of 50°C are 304.6 and 209 Watts, respectively. The loss coefficient from the slope of the regression line is found to be 1.91 W/ °C. The values of cooking power place the community solar cooker in the region of large size and good insulation cooker, as per international standard.

[6] CONCLUSIONS

- Use of building material as casing structure reduces the cost of large size cooker substantially and this will add no burden to environment also.
- Calculated values of F_1 and F_2 for the developed large size solar cooker are found to satisfy BIS, which ensures good cooking performance.
- Calculated values of cooking power place green material solar cooker in the region of large size and good insulation cooker as per international standards.
- The net present values are found to be minimum with respect to kerosene and maximum for electricity whereas pay-back period is least i.e. 1.84 yr, with respect to electricity and maximum i.e. 4.64 yr with respect to kerosene. The net present values are in increasing order with respect to fuel kerosene, LPG, firewood, coal and electricity.
- The use of large size solar cooker would help in conservation of conventional fuels, such as firewood, animal dung cake and agricultural waste in rural areas of India, and LPG, kerosene, electricity and coal in the urban areas. Conservation of firewood help in preserving the ecosystems and animal dung cake could be used as fertilizer, which could aid in the increase of production of agricultural products.
- Moreover, the use of the non-tracking storage solar cooker would result on the

reduction of the release of CO_2 to the environment.

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