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BOX TYPE SOLAR COOKER

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INTRODUCTION

Solar cookers, in general, have been readily accepted for cooking more than its counterpart solar cooking devices. This acceptance is mainly due to the following reasons:

1. They are easy to build;
2. Can be easily maintained and repaired;
3. Can be easily operated;
4. Are usually portable, therefore can be moved around without stress or strain;
5. Usually need little or no tracking;
6. Have no glare, thus making no fire hazard.

The solar cooker is best operational during sunny days, but they are known to retain some heat and can work even in intermittent cloudy days.

Most developing countries are situated around the equator. and are blessed with abundant amounts of sunlight, especially during the summer months of the year. For this reason this clean energy from the sun, when tapped, would go a long way in helping provide some solution to our energy needs for cooking.

AIMS AND OBJECTIVES

The aim of our project was to replace the insulating material used in the solar cooker prototype that was fabricated and tested by the following participants: Mr. Rahul Parikh, India; Ms. Soad Sidding Hamed, Sudan; and Mrs. Nazma Begum, Bangladesh, during their Training in Alternative Energy Technologies program, Session V, 22 February - 4 June, 1982. And the main objective was to, after changing the insulating material from Fiberglas wool to polycyanurate (Celotex), to subject it to exactly the same test done by the previous group and to compare the following characteristics:

1. thermal efficiency of the oven at load and no load test (heat loss);
2. the overall efficiency of the same solar oven using different types of insulating material in each.

BOX TYPE SOLAR OVEN DESIGN

This solar cooker is made up of inner and outer metal boxes with double glass lid on it. Inside an absorber plate, painted black with flat and heat resistant paint. The wall and bottom of the inner box is lined with one layer of (Celotex) insulation, 1.27 cm thick.

The top cover is made up of a wooden frame with 3 mm thick plain glass mounted on both sides of it, keeping about 25 mm distance between the two glasses. The top is hinged on the outer part of the box for vertical opening and closing. The cover is fitted with a pair of padlock hasps which keep it tightly fitted on the box during use.

Foam weather strips are aligned on all four top sides of the box to provide a tightly sealed contact of the glass cover against the wood frame of the box. A small vent for vapor escape is provided in the seal.

Collector area of the solar cooker is increased by providing a plain reflector mirror, equal to the size of the outer box, and is mounted on a wooden frame and hinged on the top rear side of the glass lid frame.

A sliding-bar type mechanism is mounted on the side and attached to the box to make the adjustment of the reflector mirror to a different angle possible. The reflector mirror is essential for high temperature operation of the oven for baking and for cooking in a relatively short period of time.

This box type solar oven is only large enough for cooking about 1.25 kg of food stuff, enough for a small family of 5 - 7 people.

The detailed production design is provided in the next page.

Experimental set-up (no load):

The prototype solar cooker that was fabricated during the 5th session, after having changed the insulating material inside the box, was hooked up to the recorder using thermocouple wires on the following positions.

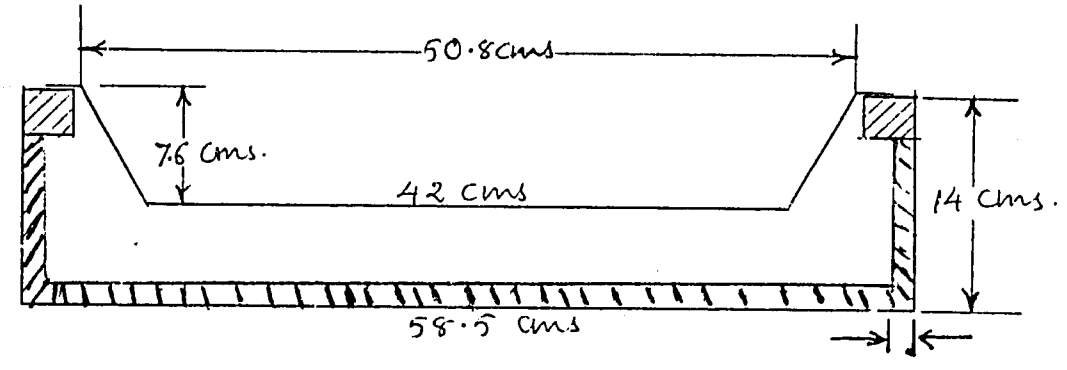
Thermocouple Position	Symbol Used
1) Center of absorber tray	Tpc
2) At a distance of 4" from center of the absorber tray	Tp4"
3) Center of the upper glass cover	Tg
4) Outer box sides, front, left, back, and right side	Ts
5) Ambient temperature	Ta

The measurements were recorded on the strip chart recorder on days and times as given in the load test portion of this report.

Experimental set-up (load):

The evaluation of the performance of any solar oven requires actual food preparation, and is necessarily a subjective criterion. Due to the limited amount of time out evaluation was done using two cooking pots, one painted black and the other covered with mylar tape to eliminate heat transfer to the pot by direct solar radiation. Both pots were filled with 750 ml of water and placed in the oven. The heat output to the cooking pots were measured between 9:50 a.m. - 12:50 p.m. The results obtained were reported in the load-test portion of this report.

HEAT TRANSFER CALCULATIONS



1.2 cm equivalent
to 1/2"

Average area of each side

$\bar{A}$ side = Average width x average height

= 52.5 x 11

= 577.5 cm^2

Average thickness of insulation on each side

= 1.27 cm^2 Celotex

Average area of bottom

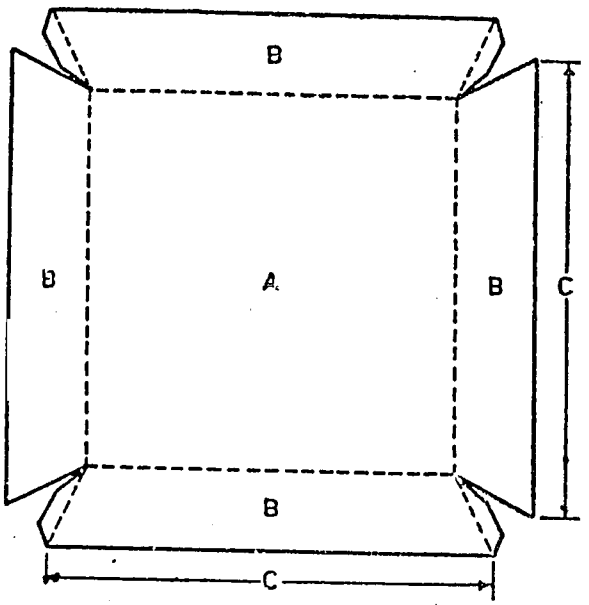
$$\bar{A}_b = \frac{58.5 + 42}{2} \times \frac{58.5 + 42}{2}$$

= 2525 cm^2

Average thickness of insulation at bottom

$\bar{x}_b$ = 1.27 cm Celotex

Production Design of Solar Cooker

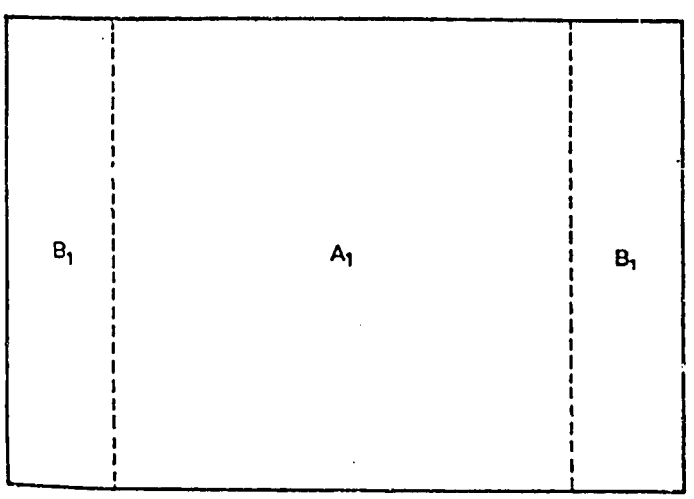


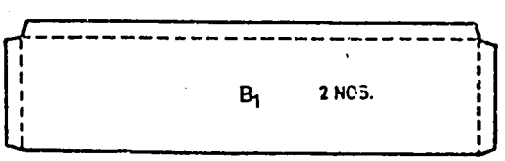
Template for absorber tray

A bottom 420 mm. x 420 mm.

B slant sides 90 mm. wide

C window opening 508 mm. × 508 mm.

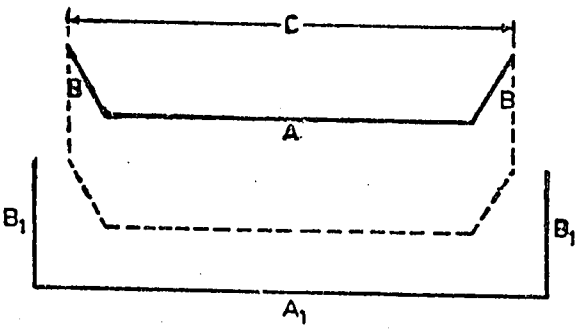




Template for outer box

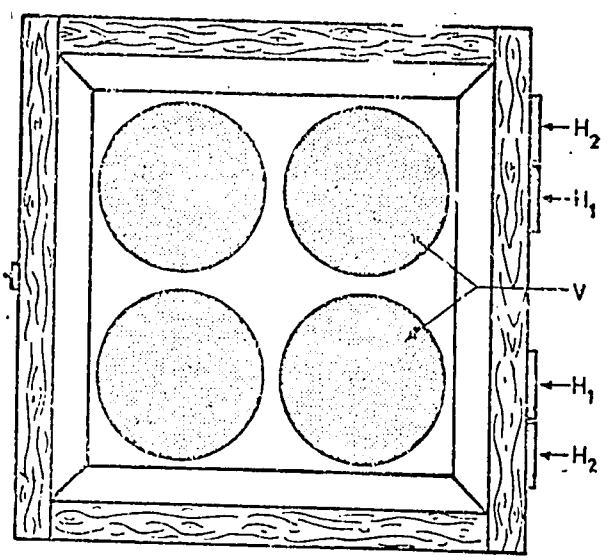
A_1 bottom 585 mm. × 585 mm.

B_1 vertical sides 585 mm. × 140 mm.

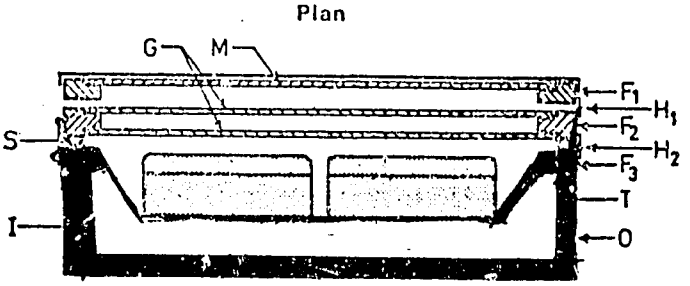


Sectional view of Absorber Tray and Outer Box

Absorber tray	Outer box
A bottom	A_1 bottom
B slant sides	B_1 vertical sides
C window opening	



Plan



Sectional elevation of solar cooker

M	mirror reflector 533 × 533 × 3	H_1, H_2	hinges
G	plane glasses 533 × 533 × 3	V	cooking utensils
S	rubber sealing	F_1, F_2, F_3	wooden frames
I	SELOTEX insulation	T	absorber tray
		O	outer box

All dimensions are in mm.

Designed and developed by : **Agricultural Tools Research Centre, Bardoli**
Manufacturer : Yantra Vidyalaya, P.O. Box 4, Bardoli 394 601 India

Load Test

The Load test was conducted primarily to analyse the modes of heat transfer to the cooking pots and eventually to the materials inside the pots.

Two cooking pots were filled with equal amounts of water, i.e., 750 ml. One pot was painted black on the outside and another was covered with polished mylar tape, for the purpose of eliminating heat transfer to the pot by direct solar absorption. Copper-constant thermocouples were dipped into the water in both the pots.

Both pots were put into the solar cooker at 9:50 a.m. The water in the pot which was painted black on the outside reached the boiling point at 12:59 a.m., and that in the mylar taped pot reached the boiling point at 1:56 p.m. On the average, it can be siad that it took 3 hr., 57 min. to boil 1.5 kg of water.

From the graph on water temperatures in the two pots, it can be siad that the maximum difference between two water temperature at a time was 7.58^{o} C. This temperature difference and 57 minutes time difference between two water boilings, indicates that direct solar absorption is an important mode of heat transfer to water in the pot.

Heat absorbed by water

$$Q_{out} = M\ C_p \Delta T$$

where

m = quantity of water

= 1.5 kg

C_p = specific heat of water

= 1 K Cal/Kg ^oC

$\Delta T = T_{boiling} - T_{initial}$

$$\therefore Q_{out} = M\ C_p\ \Delta T$$

$$= 1.5 \times 1 \times (100 - 30) = 105 \text{ K Cal}$$

Average solar radiation during 9:50 to 12:59 (3 hrs., 9 min.) is

I = 292 w/m^2 (measured by planimeter)

Top area of cooker box = A = $58.5 \times 58.5\ cm^2$

$= 0.3422\ m^2$

Therefore total energy received by the cooker box over the period of 3 hurs. and 9 min. is

$$Q_{in} = \overline{T}\ A\ \tau\ t$$

Where

T = transmissivity of glass

= 0.86 for two layers of glass

$$\therefore Q_{in} = 292 \times 0.3422 \times 0.86 \times 3.15$$

$$= 270.6 \text{ K Cal}$$

Efficiency of heat transfer to water is

$$\eta = \frac{Q_{out}}{Q_{in}}$$

$$= \frac{105}{270.6} = 39\%$$

The previous one is 18.7%

Also relative efficiency of the two pots can be calculated as follows:

$$\eta_{black\ pot} = \frac{M\ C_p\ \Delta\ T}{Q_{in}\ \tau\ A}$$

Where

M = mass of water in black pot

= 0.75 kg

C_p = 1 K Cal/Kg ^oC

ΔT = 100 - 30 = 70^oC

τ = time taken to reach boiling point

= 12.59 - 9.50 = 3.09 hrs.

Q_{in} = solar radiation received by the cooker during the time period mentioned above

$$\eta_{black\ pot} = \frac{0.75 \times 1 \times 70}{292 \times 3.09 \times 0.3414 \times 0.86}$$

$$= 19.8\%$$

The previous one is 11.4%

The efficiency of the silver taped pot can be calculated as follows

$$\eta_{silver\ pot} = \frac{M\ C_p\ \Delta\ T}{Q_{in}\ \tau\ A}$$

τ = time taken for reaching boiling point in silver pot

= 13.56 - 9.50 = 4.06 hrs.

$$\therefore \eta_{silver\ pot} = \frac{0.75 \times 1 \times 70}{292 \times 0.86 \times 4.06 \times 0.3414}$$

$$= 15\%$$

The previous one is 8.95%.

Note:

The difference between the two pot efficiencies is due to the heat transferred to the water in the black pot by the mode of direct absorption which is absent in the other pot. although the silver pot still absorbs a portion of solar radiation.

No Load Testing

During no load testing the solar cooker was put in the sun without any cooking pots inside. Thermocouples were used to measure the temperature at various points in the solar cooker.

Solar radiation falling on the solar cooker and heat losses were calculated for many hours. Heat losses from the sides and bottom of the solar cooker were calculated by conduction losses through insulation.

Average area of each side = 577.5 cm^2 = 0.05775 m^2

Thickness of insulation on each side $\bar{x}_s$ = 1.27 cm
= 0.0127 m

$$Q_L = \frac{k\ A\ \Delta T}{\bar{x}}$$

where:

k = thermal conductivity of polyisocyanurate (Celotex)
= 0.028 Btu/hr ft F^o
= 0.028 x 1.731 = 0.0484 W/m ^oC

$$Q_L \text{ for 3 sides} = \frac{k\ \bar{A}\ \Delta T}{\bar{x}}$$

where:

$\bar{A}$ = 3 x 577.5 = 1732.5 cm^2 = 0.1733 m^2

$$Q_{L\ bottom} = \frac{k\ \bar{A}\ \Delta T}{\bar{x}}$$

where:

A = average area of the bottom
= 2525 cm^2 = 0.2525 m^2

Time	T_{OG_1}	T_{IG_2}	T_{IG_1}	T_{pc}	T_{sf}	$T_{s_{2,3,4}}$	T_{amb}
10.03	38.8	31.6	93.9	96.1	71.1	27.7	24.4
10.33	45	32.7	104.4	110.5	82.7	30	27.2
11.03	50.5	34.4	116.6	130	90.5	31.6	28.3
11.33	50	31.6	119.4	128.8	94.4	31.6	26.2
12.03	56.1	36.1	128.8	142.2	100	33.3	28.3
12.33	50	35.5	135.5	148.8	105.5	33.3	27.2
1.03	53.3	35.5	136.6	148.8	107.7	35	27.2
1.33	56.6	37.7	133.8	148.8	106.1	37.7	27.7
2.03	53.8	35.5	118.8	132.2	96.6	38.3	28.3
2.33	51.1	35.5	105.5	119.4	89.4	40	28.8

Time	T_{pc} ^oC	T_{sf} ^oC	$T_{s_{2,3,4}}$ ^oC	ΔT $T_{pc}-T_{sf}$	ΔT $T_{pc}-T_{s_{2,3,4}}$	$Q_{L_{sides}}$ w-hr	$Q_{L_{bottom}}$	$Q_{L_{sides\ \&\ bottom}}$
10.03	96.1	71.1	27.7	25	68.4	10.277	10.41	20.687
10.33	110.5	87.7	30	27.8	85.5	12.469	12.52	24.98
11.03	130	90.5	31.6	39.5	88.4	15.175	15.31	30.48
11.33	128.8	94.4	31.6	34.4	97.2	14.485	14.62	29.11
12.03	142.2	100	33.3	42.2	108.9	16.624	16.61	33.24
12.33	148.8	105.5	33.3	43.3	115.5	17.475	17.63	35.11
1.03	148.8	107.7	35	41.1	113.8	17.113	17.34	34.45
1.33	148.8	106.1	37.7	42.7	111.1	16.926	16.93	33.86
2.03	132.2	96.6	38.3	35.6	93.9	14.363	14.40	28.76
2.33	119.4	89.4	40	30	79.4	12.037	12.14	27.18
						146.944	124.38	294.86

Time	T_g ^oC	T_{amb} ^oC	$T_g - T_{amb}$ ^oC	$Q_{L_{top}}$ w - hr	$Q_{L_{total}} = Q_{L_{sides}} + Q_{L_{top,\ bottom}}$
10.03	31.6	24.4	7.2	9.064	29.75
10.33	32.7	27.2	5.5	6.924	31.9
11.03	34.4	28.3	6.1	7.679	38.15
11.33	31.6	26.6	5.0	6.295	35.4
12.03	36.1	28.3	7.8	9.8202	43.06
12.33	35.5	27.2	8.3	10.449	45.56
1.03	35.5	27.2	8.3	10.449	44.9
1.33	37.7	27.7	10.0	12.59	46.45
2.03	35.5	28.3	7.2	9.064	37.82
2.33	35.5	28.8	6.7	8.435	32.62
				90.76	385.61

Average solar radiation falling on the solar cooker for the same time is tabulated below

Time	average solar radiation w/m^2	Q_{in} w - hr
10.03	835.8	122.7
10.33	428.9	62.96
11.03	520.4	76.40
11.33	205	30.09
12.03	208.2	30.56
12.33	510.9	75
1.03	485.7	71.30
1.33	507.8	74.55
2.03	283.9	41.68
2.33	454.2	66.68
		651.917

From these values, the thermal efficiency of the solar cooker at no-load condition can be calculated as:

$$\eta = \frac{Q_{in} - Q_L}{Q_{in}}$$

$$= \frac{651.917 - 385.61}{651.917}$$

$$= 40.8\%$$

The previous project efficiency is 47.9%

DISCUSSION OF FINDINGS

The heat losses of the solar oven after having changed the insulating material from fiberglas wool which had covered the entire space between the two boxes and the black painted absorber plate to Celotex which lined only the inner sides of the box and the bottom was rather minimal. As is reported in the load test and no-load test finding in the preceding pages. The previous insulating material, fiberglas wool, proved to be a better material for heat retention of the solar cooker when used as an insulating material. However, had it been that double or triple layers of Celotex was used for lining in the inner side of the box and bottom, the heat loss would have been much less than the fiberglas wool thus increasing the efficience of the solar oven.