Design details of a novel lightweight low cost solar cooker and its experimental study

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ABSTRACT

The world is facing severe energy crises and the mode of conversion of various fuels into utilizable form affect economy, environment and health adversely. Utilization of renewable energy resources particularly solar energy can decrease these to a considerable extent. Solar energy is most promising renewable source for India and all underdeveloped and developing nations which within 40° of equator. Solar energy can be utilized in both direct and indirect form. Utilization of solar energy in the form of solar thermal applications can save a lot of conventional energy resources. In country like India on the one hand solar cooking needs to be promoted while on the other hand there is a need for development of more efficient and user friendly solar cookers. Solar cooking would be popularized only when a good number of models are made available to the masses with appropriate characterizations and performance figures clearly mentioned for each model. Therefore a uniform strict test protocol must be followed for solar cookers. Only then users will have correct choice and would be attracted for maximum use of solar cookers. With this view we have discussed at length various test protocols. With study of L.S.C. clearly reveals that the cooker design developed and studied in the present work has good weather ability, life, thermal performance and cooking performance.

Key Words: L.S.C.: Low cost solar cooker, C.S.C.: Commercial type solar cooker, Pyranometer: An instrument used to measure broadband solar irradiance on a planar surface and is a sensor that is designed to measure the solar radiation flux density (in watts per meter square), Ambient temperature: The temperature of surroundings.

Introduction:

The structural details of this cooker as follows. The materials chosen are mainly solid waste materials like cardboard, thermo Cole, oilcans, etc. This provides a way for utilization of solar energy through use of solid waste material. The body of the cooker has been fabricated through cardboard boxes that have sufficient load bearing capacity (about 20 kg) and mechanical strength. The insulation is of thermo Cole and the metal tray that has been used is prepared through empty oilcans. The glaze has been fabricated through a transparent polymeric material which is three times lighter and has transmissivity 10% higher than glass glaze. It is not as fragile as glass, and has good weathering resistance and UV stability along with good mechanical strength. Two cardboard boxes of dimensions 54.6 cm × 52.0 cm × 24.0 cm and 42.0 cm × 39.3 cm × 10.2 cm are used, the smaller box has been placed inside the bigger one and complete space between them is filled with insulation. The edges are sealed with cardboard and binder. Metal tray has been painted with dull matt paint that acts as absorber surface. Glaze has been fabricated through two 3mm thick polymeric sheets with 1.3 cm air in between with special frame around it

to allow expansion. No screwing has been done in it. Lightweight polymeric mirror is used as reflector on wooden frame kept on solar cooker. The dimensions of mirror are 45 cm × 45 cm. A view of the structure of the LSC has been shown in Fig.

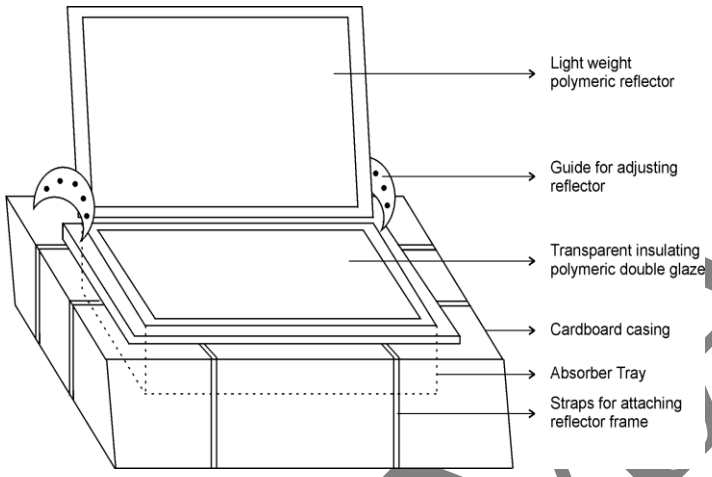

Fig: Novel lightweight low cost solar cooker (LSC)

Experimental studies:

Since there is no unique figure of merit or test procedure for the study of solar cookers, we have performed the experimental studies suggested by both S.C. Mullick and Funk as discussed below:

Thermal performance study:

For studying thermal performance the cooker was placed in Sun and the temperatures as well as insulation and wind speed have been measured at the intervals of 10 min. from about 10 A.M. to 5 P.M. insulation has been recorded through Pyranometer.

The test has been performed for various possible modes viz. without reflector, with reflector, without load and with full load. Using these data's we have calculated figure of merit F_1, F_2 and thermal performance data is also shown in the form of temperature profiles for these combinations. For comparative studies a fibre body commercial box solar cooker (CSC) is also place by the side of LSC. The temperatures have been measured using J/K type of thermocouples and CI305 thermometer.

Various tables are shown here:

Table-1 A comparison of base plate temperatures without reflector of L.S.C. and C.S.C.

Standard time (hour)	Base plate temp. T(˚c)		Ambient Temp.(˚c)	Insulation (W/m^2)
	C.S.C.	L.S.C.		
10:00	28.1	28.1	31	490.61
10:10	62.7	65.5	31.5	526.11
10:20	79.15	81.75	32	640.1
10:30	93.4	98.2	33	771.62
10:40	105.05	112.11	33.8	800.56
10:50	114.25	121.4	33.2	759.35
11:00	119.9	128.4	33.8	861.06
11:10	123.3	133.95	34	935.59
11:20	119.11	130.75	34	707.61
11:30	122.05	132.3	33.9	615.54
11:40	121.85	132.4	34	890.87
11:50	122	133.75	34.3	755.84
12:00	129.1	142.3	35	1050.46
12:10	136.4	148.6	34.2	762.85
12:20	132.1	144.4	35.5	757.59
12:30	118.55	132.85	35.2	583.1
12:40	123.25	136.75	36	1003.98
12:50	143.3	155.05	36.9	1080.27
13:00	146.5	158.45	36.3	1027.88
13:10	145.5	158.7	36.4	1011
13:20	145.2	158.4	35.5	944.36
13:30	141.9	157.65	36	914.55
13:40	139.4	155.85	35	911.04
13:50	139.45	153.85	36	909.28
14:00	137.95	150.75	36	860.18
14:10	126.45	139	35.5	644.48
14:20	117.45	130.2	35.6	968.04
14:30	129.25	140.5	36.4	854.92
14:40	127.8	138.45	36	784.77
14:50	125.5	135.6	36	755.84
15:00	121.55	131.95	35	717.26
15:10	116.65	126.75	35.2	582.22
15:20	116.25	125.5	35.9	679.55
15:30	113.35	121.8	35.7	644.48
15:40	108.65	117.05	35.5	583.1
15:50	104.95	113	35	539.25
16:00	99.15	105.85	35	576.08

16:10	96.05	102.15	34.9	532.24
16:20	92.05	96.9	34.9	461.22
16:30	86.9	91.05	34.9	419.13
16:40	81.75	84.45	34.5	376.16
16:50	76.05	76.2	34.5	338.46
17:00	70.3	69.75	34.5	299

Table-2 A comparison of base plate temperatures with reflector of L.S.C. and C.S.C.

Standard time	Base plate temp. T(˚c)		Ambient	Insulation
(hour)	C.S.C.	L.S.C.	Temp.(˚c)	(W/m ²)
10:10	33.25	38.1	31.2	751.4569
10:20	104.45	119.95	31.7	804.9483
10:30	133.45	148.8	32	827.7464
10:40	147.45	154.2	32.5	855.8056
10:50	155.3	157.9	32.5	873.3426
11:00	160.2	176.55	33.7	882.988
11:10	163.35	182.25	34	898.7677
11:20	162.6	176.15	34.5	904.9092
11:30	167.05	184.5	34.2	909.2899
11:40	157.9	173.8	34.5	919.8121
11:50	159.55	177.6	34.4	919.8121
12:00	164.65	181.15	35.5	923.3195
12:10	163.8	174.95	34.5	951.3787
12:20	160.9	170.8	34.6	946.998
12:30	161.45	177.2	35.5	902.2751
12:40	155.5	179.5	35.4	942.6102
12:50	159.95	180.65	35.9	943.4906
13:00	159.4	175.95	35.2	912.7973
13:10	155.75	175	35.2	869.8352
13:20	158.5	161.35	35.5	835.6345
13:30	157	157.6	35.7	870.7085
13:40	155	162.35	36	825.9927
13:50	154	159.2	35	885.6185
14:00	136	155	35.4	783.0235
14:10	137.95	147.4	36.9	791.792
14:20	148.7	151.95	35.6	809.329
14:30	145.3	146.55	35.7	740.9347
14:40	142.35	142.5	36	749.7032
14:50	137.55	145.1	36.2	753.2106
15:00	142.8	146.4	36	735.6736
15:10	136.45	143.5	35.9	666.406
15:20	130.15	137.65	35.8	675.1745
15:30	122.65	127.75	35.8	601.5191
15:40	115.4	116.95	35	555.0425

15:50	114	116	34.9	569.9525
16:00	108.75	114.55	35	511.2
16:10	112.3	115.1	35	508.573
16:20	107.65	109	35	254.2865
16:30	109.25	106.35	35.4	409.4854
16:40	100.75	100.6	35	348.9863
16:50	96.8	100.4	34.5	302.5097
17:00	89.75	96.85	34.5	289.3605

Table-3 A comparison of base plate and water temperatures with reflector & full load of L.S.C. and C.S.C.

Standard time (hour)	Temperature for L.S.C.(˚c)		Temperature for C.S.C. (˚c)		Ambient temp. (˚c)	insolation (W/m²)
	Base plate	Water	Base plate	Water		
10:40	31.06	29.68	41.045	37.99	32.6	815.4705
10:50	40.085	46.43	36.785	37.8	32.8	866.3278
11:00	44.24	53.43	31.185	34.1	33	826.866
11:10	48.265	60.56	40.155	30.24	34	910.1703
11:20	53.04	68.36	53.44	48.2	34	907.5362
11:30	55.55	72.14	59.73	53.1	34.1	894.387
11:40	57.985	76.36	67.1	59.86	34	909.3112
11:50	71.1	77.63	70.23	63.2	34.5	888.2455
12:00	74.5365	77.023	88.335	97.44	34	885.6185
12:10	76.69	80.02	92.83	102.3	35.5	903.1555
12:20	76.67	76.91	95.41	103.2	36	902.2751
12:30	79.61	78.42	97.7	105.7	35.7	920.6925
12:40	81.575	78.59	100.26	107.06	36	916.3047
12:50	81.535	78.42	100.23	107.89	36.4	944.3639
13:00	85.16	83.3	99.865	106.28	35.9	885.6185
13:10	84.79	83.84	98.995	107.2	36	912.7973
13:20	88.16	87.09	100.03	106.73	35.9	884.7381
13:30	89.29	86.76	97.945	100.67	35.8	605.0265
13:40	88.6	90	100.92	107.51	36.3	885.6043
13:50	88.94	88.32	100.155	106.1	36.8	882.9844
14:00	92.295	92.8	89.56	83.3	35.9	842.6493
14:10	89.15	88.07	86.79	80.42	36.1	864.5741
14:20	94.37	91.99	91.38	83.72	36.2	805.8216
14:30	92.42	90.25	85.15	77.35	36.5	833.8808
14:40	91.83	87.68	85.96	79.1	36.4	559.4303
14:50	94.15	90.2	87.785	81.95	36.9	412.1195
15:00	95.425	92.08	89.6	83.84	35.9	768.1206
15:10	89.545	86.58	87.725	76.89	36	713.7559
15:20	91.76	87.98	88.32	77.81	36.3	671.6671
15:30	87.84	82.11	89.13	78.76	35.7	673.4208
15:40	88.265	83.4	88.305	78.99	35.3	595.3776

15:50	87.645	82.64	86.67	76.06	35.5	617.3024
16:00	86.89	78.48	89.8	80.44	35	189.3996
16:10	84.41	76.05	88.925	79.53	35	154.567
16:20	82.08	73.76	83.59	75.18	35	253.4061
16:30	85.605	77.66	83.79	73.35	35.7	485.7749
16:40	85.145	76.23	83.595	72.82	35.4	421.7613
16:50	82.395	72.83	82.87	73.8	34.5	140.296
17:00	78.085	67.18	80.14	71.64	34.7	135.9082
17:10	79.8	71.62	78.045	68.57	35	323.5541
17:20	79.73	72.31	77.935	68.88	35.5	299.8827
17:30	78.49	70.59	77.265	67.88	35	255.1598

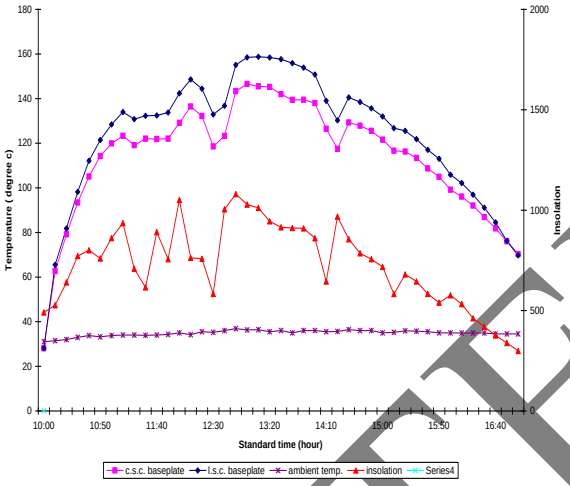

Fig:1 Temperature profiles of the base plate of the LSC and CSC with standard time when cookers are without load and without reflector (April 4, 2009)

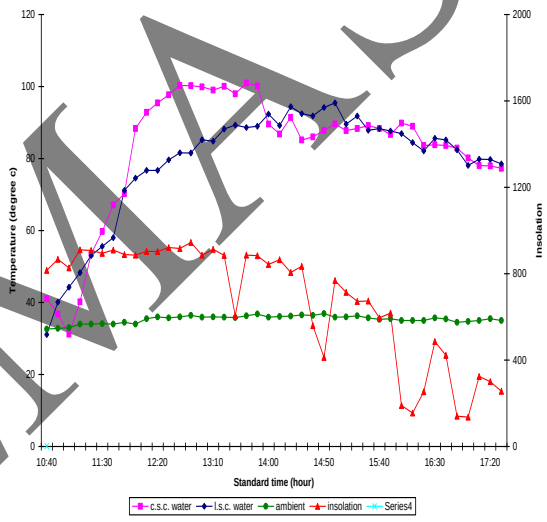

Fig:2 Comparison of temperature profiles of the base plate of the LSC and CSC without reflector and with reflector with standard time when cookers are without load (April 6, 2009)

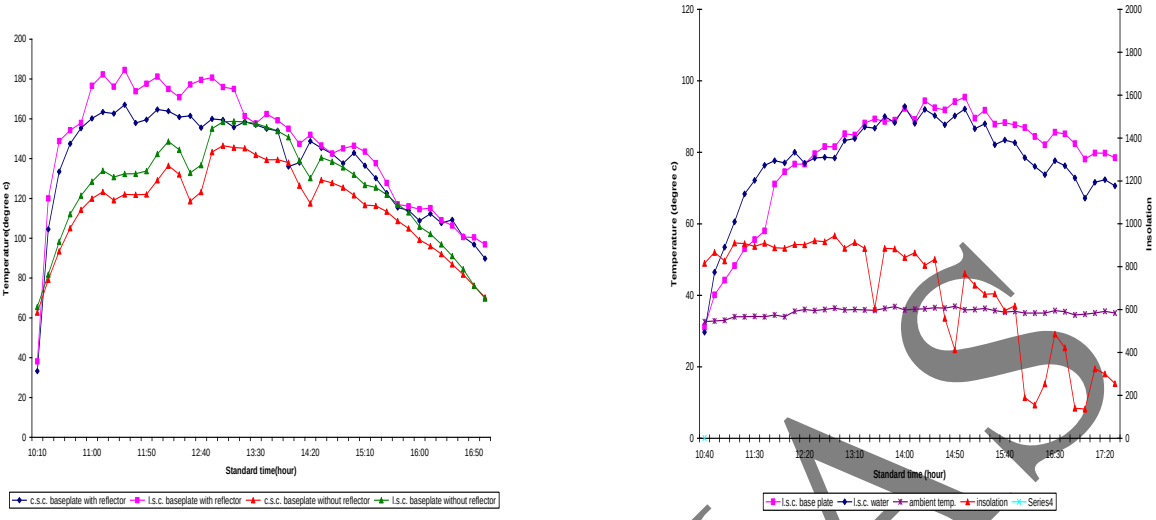

Fig: 3 Temperature profiles for the LSC and CSC with standard time when cookers are loaded with 2 lt. of water as net load and are with reflector (April 7, 09)

Cooking power study:

Cooking power test has been performed as per the procedure suggested by Funk. The cooker was loaded with 2 liter water as net load. The observations are shown in table 4.

Table 4. Adjusted Cooking power through thermal profile

Standard Time (hour)	T (pot) (˚c)	T (ambient) (˚c)	Temp. Diff.(˚c)	T (plate) (˚c)	Insulation (kw/m²)	Cooking power (W)	Tp-Ta (˚c)	Adjusted cooking Power(W)
10:10	36.5	35.5	7.7	45	526.11	107.4407	1	142.4407
10:20	44.2	35.5	7.3	52.3	640.1005	101.8593	8.7	111.3912
10:30	51.5	36	6.7	57.8	771.628	93.48733	15.5	84.80917
10:40	58.2	36.2	7	66.3	800.5641	97.67333	22	85.40395
10:50	65.2	36.8	7.4	70.2	759.3521	103.2547	28.4	95.18413
11:00	72.6	36.8	6.4	75.1	804.9483	89.30133	35.8	77.65832
11:10	79	37	4.9	82.5	836.5149	68.37133	42	57.21349
11:20	83.9	37	4.8	88.4	852.2982	66.976	46.9	55.00798
11:30	88.7	37	4.2	92.4	862.8204	58.604	51.7	47.545
11:40	92.9	37	4.1	96.2	866.3278	57.20867	55.9	46.22507
11:50	97	37	2.7	98.7	882.988	37.674	60	29.86655

12:00	99.7	37.5	1.9	99	890.8796	26.51133	62.2	20.83102
12:10	101.6	37.5	0.8	101	904.9092	11.16267	64.1	8.634973
12:20	102.4	37.9	0.1	103	905.7861	1.395333	64.5	1.078327
12:30	102.5	38	0.1	103.6	899.6481	1.395333	64.5	1.085684
12:40	102.6	38.3	0.1	103.7	904.9092	1.395333	64.3	1.079372
12:50	102.7	38.5	0.1	103.5	896.1407	1.395333	64.2	1.089933
13:00	102.8	38.5	0.3	103.4	883.8648	4.186	64.3	3.315213
13:10	103.1	38.9	0.3	104.7	863.6973	4.186	64.2	3.392624
13:20	103.4	39.4	0.1	105.1	861.9436	1.395333	64	1.133176
13:30	103.5	39	-0.2	104.5	847.914	-2.79067	64.5	-2.30385
13:40	103.3	39	0	101	862.8204	0	64.3	0
13:50	103.3	39	0	103.3	793.5493	0	64.3	0
14:00	103.3	39	-103.3	103.3	811.9631	-1441.38	64.3	-1242.62

Calculations:

Conversion factor for measuring insulation (W/m²) =87.685
Power = (M C x temp. difference)/600
Adjusted power = (Power x 700)/ insulation (W/m²)
Where M = 2 Kg. (water weight), C =4186 J/Kg. K (specific heat of water)

First figure of merit:

$$F_1 = \frac{T_{ps} - T_{as}}{H_s}$$

From table-1
T_{as}=36.3˚c
T_{ps}=158.45˚c (for LSC)
=146.5˚c (for CSC)
H=1027.88 W/m^2

So F_1 for LSC
=(158.45-36.3)/1027.88
=0.118

F_1 for CSC
=(146.5-36.3)/1027.88
=0.107

Second figure of merit:

$$F_2 = \frac{F_1 (MC)_w}{A \tau_m} ln \left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - T_a}{H}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - T_a}{H}\right)} \right]$$

Here F_1 for LSC = 0.118
M = 2 Kg., C =4186 J/Kg. K for water
A =0.40 x 0.40= 0.16 m^2
From table-4
ζ_m = 2 hour 10 minutes = 130 x 60 sec.
$T_{w1} = T_a$ = 37 ˚c, T_{w2}= 102˚c, H = 807.50 (W/m^2)
So F_2 = (0.118 x 2 x 4186) ln [1/{1-(65/0.118 x 807.50)}]
= 0.79158 x ln (3.1466)
= 0.907 (for L.S.C.)

Cooking test:

Rice, Porridge, Dal, Sweet potato, leafy vegetable etc. can be cooked and bread, cake etc. can be baked in the cooker. The material to be cooked is kept ready with spices, onion, water, oil, salt etc. and put inside the box. The cooker should be kept in the Sun out of the shadow preferably on the roof or in the courtyard where Sun stays at least 3-4 hours.
Actual cooking was also done with 2 kg. full load which was equally distributed in four pots by 300 gm. Rice and 200 gm. Arhar dal. It was found that cooking time was about 2 hours. Cooker was loaded at 11:00 A.M. Food was taken out at 1:00 P.M. food was cooked well and had good taste and aroma.

Results and conclusions:

From table 1, it is clear that rise in temperature is faster in L.S.C. as compared to C.S.C. Since cooking performance depends on rate of rise of temperature. It is quite evident that L.S.C. would show much better cooking performance than C.S.C. At all times the temperature of L.S.C. remains 5-10°c higher than C.S.C. which reveal the better thermal performance as well as lower loss coefficient of L.S.C. as against C.S.C.
Due to limitations of time we had to conduct the test up to ambient temperature 36.9°c which is little more than recommended i.e. 35°c. However at place of work this ambient temperature is experienced for more than 6 months in a year.

From table 2, it can be seen easily that both the rate of rise and temperature are higher with reflector as against without reflector for both types of cooker. At all times the temperature remains 10°c higher than that without reflector.

From table3, it is quite evident that cooking starts 1 hour 20 minutes later the loading time and temperature remains adequate for cooking for 5 hours. This range is sufficient to cook two meals a day in summers. All the above-mentioned observations are very clear from fig 1, 2 and 3.

Fluctuations in temperature are due to partial clouds and transient high wind speed. This was a compulsion due to time limitation.

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