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Construction and Testing of One-Reflector Solar Oven for Solar Panel Lamination

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Abstract: *A one-reflector solar oven for solar panel lamination was constructed using locally available and low cost materials. The oven was tested for thermal performance through three tests. The first test was a no load test with the oven positioned to face 180^0S. This test produced a maximum oven laminating platen temperature of 118^0C at an ambient temperature of 33^0C and solar irradiance of 1046W/m^2. A second no-load test was carried out with the oven being turned every 30 minutes to face the sun through a method which we discovered and termed manual shadow tracking. Manual shadow tracking is a method of turning a box type solar oven to face the sun by aligning the bottom edge of the oven with the edge of the oven's shadow. The second no-load test produced a maximum temperature of 124^0C at an ambient temperature of 36^0C and solar irradiance of 1010W/m^2. With these values, the first figure of merit for the oven was calculated as 0.09. A third test which was carried out with the oven loaded with a solar panel to be laminated, produced a maximum temperature of 110.5^0C at an ambient temperature of 35^0C and solar irradiance of 1021W/m^2. A 160W solar panel was laminated with the oven.*

Keywords: *solar oven, solar panel, solar irradiance, lamination, shadow tracking*

I. Introduction

An oven is a device with thermally insulated chamber used for heating, baking, drying or cooking. The earliest recorded use of oven dated around 29,000BC in Central Europe. These ovens were in the form of pits used to cook mammoth [1]. From 20,000BC, pit ovens with hot coals covered in ashes were used in Ukraine. Culinary historians credit the Greeks for developing bread baking into an art after front-loaded bread ovens were developed in ancient Greece.

Ovens derive their type and name from a variety of considerations such as the material with which they are made, as in earth oven or ceramic oven; source of heating energy as in electric oven, microwave oven or solar oven. Solar oven is the type of oven that uses free energy of direct sunlight to heat, bake, dry or cook food items and other items that require heating. A box type solar oven is able to serve as oven because the interior of the box is heated by the energy of the sun. Sunlight enters the solar box through the glass window and turns to heat energy when absorbed by the dark absorber plate or pot. This heat input causes the temperature inside of the oven to rise until the heat loss is equal to the solar heat gain. Temperatures sufficient for cooking food, baking bread, and doing other heating activities are easily achieved on a bright sunny day. The heat energy produced by the sun is immense. In equatorial regions the solar radiation can exceed 1000watts/m^2 [2]. If this is effectively harnessed in solar oven, the temperatures required for boiling water, cooking, baking, etc, can be realized in a short time.

About two billion people, which represent one-third of the population of the world, are daily dependent on firewood as the source of their domestic cooking and heating energy. They live in the tropics, which is the most favorable area for the use of solar energy [3]. According to Petri (1995), every year the cutting of firewood results in the loss of 20,000 – 25,000 km^2 of tropical forest. Nigeria lies in the tropics (Latitude $4^0$16`and $13^0$52`N) and is endowed with abundant sunshine all the year round with daily sunshine hours in the southern part averaging about 8 hours during dry season and about 4 hours during the wet months. Higher values of daily sunshine hours are obtainable in the northern part of the country, averaging about 10 hours during dry season and 6 hours during the wet months [4]. Therefore, Nigeria is one of the Countries where solar oven can be effectively used for most cooking and heating activities and consequently, research in various kinds of solar oven should be intensified to develop highly efficient solar ovens such that the ovens will serve their users well. If the ovens are meeting the oven needs of their users, others will be encouraged to turn to solar oven, and our climate will be the better for it as Nigeria's Carbon footprint will be gradually reduced.

The box-type solar oven is made up of flat-plate collector or the absorber plate whose function is to absorb solar radiation and convert it to heat; the glazing or window part which can be glass or other highly transparent material that can stand the oven temperature; casing which comprises of inner and outer walls separated by lagging material to reduce heat loss by conduction; and reflector which can be plain mirror or any reflective surface.

A solar oven functions on the principle of greenhouse effect, whereby radiation from the sun, primarily in the form of visible light, is trapped within a closed system and converted into thermal energy. This is made possible through the use of glass or plastic, which is permeable to visible light but reflects radiation in the infra-red range. Once visible light has passed through the glass or plastic barrier, it is converted into thermal energy through absorption by a dark object. Dark objects appear dark because they absorb visible light; however, they emit the energy they have absorbed in the form of heat. A solar oven therefore includes both a glass or plastic panel and some type of dark object or surface on the interior for the conversion of light into heat. This creation of heat inside the oven, given appropriate insulation on the exterior, allows the oven's interior to increase in temperature, often quite quickly. The oven may then be used to heat food, boil water, or perform most other activities generally possible in conventional ovens.

One of the mostly used international standards for evaluating performance of solar oven is the Bureau of Indian Standard Testing Method [5]. This standard, presented in a more technical framework than ASAE S580, provides two figures of merit, calculated so as to be as independent of environmental conditions (such as wind speed, insolation, etc.) as possible. The first figure of merit, F_1 is defined as the ratio of optical efficiency, ηo and the overall heat loss coefficient, U_L. A quasi-steady state (stagnation test condition) is achieved when the stagnation temperature is attained. High optical efficiency and low heat loss are desirable for efficient oven performance. Thus the ratio $\eta o/U_L$ which is a unique oven parameter can serve as a performance criterion. Higher values of F_1 would indicate better oven performance:

$$F_1 = \frac{\eta_0}{U_l} = \frac{\alpha\tau}{U_l} = \frac{T_p - T_a}{H_s} \qquad (1.1)$$

Where: T_p = temperature of the absorber plate (stagnation), T_a = ambient air temperature, H_s = insolation on a horizontal surface (taken at time of stagnation), τ = the optical transmission coefficient of the window material ($0 \leq \tau \geq 1$).

The second figure of merit, F_2 of the box type solar oven is evaluated under full-load condition and can be defined as the product of the heat exchanger efficiency factor and optical efficiency.

The oven used for solar panel lamination is the double vacuum oven. This oven is very expensive and high power consuming. For instance, the semi-automatic Solar Panel Laminating Machine marketed by Changzhou Steer Trade Co., Ltd, China, costs about $200,000 (about N33million) and consumes electrical power of 45KW. It is obvious that no right thinking company would like to establish an industry that will require such a device in Nigeria where erratic power supply is the order of the day. Solar oven can attain temperatures over 120^0C in Nigeria, which is the temperature at which the solar panel laminating film, EVA (Ethylene Vinyl Acetate) fuses completely with glass. This means that solar oven, which operates with free energy, can serve the purpose of this high energy consuming solar panel laminating oven.

The aim of this research work is to produce a solar oven which can effectively be utilized to laminate solar panel of up to 160W size, and the objectives include: to construct a large size one reflector solar oven using locally available and inexpensive materials, to realize temperatures of over 120^0C with the oven, and to laminate solar panel with the oven.

II. Materials And Methods

2.1 Material Consideration

Plywood of thickness 15mm was selected for the outer box so as to give the box some strength and rigidity as it is going to be a big box and therefore, smaller thickness sizes of plywood cannot serve the purpose. Since the inner box was going to be inside and supported by the outer box, the 9.0mm thick plywood was selected for it. Glass of 4.0mm thick was selected for the window. This is not because it is the best but because it is what was available, as the maximum size of the 3.0mm thick glass in the market in Owerri Nigeria, which would have been a better choice, is below the size of the oven window. Steel plate of 3.0mm thick was chosen for the laminating platen so that it will have enough weight for its purpose. The reflector was selected to be of 3.0mm plywood, pasted with aluminum foil. The inner wall surface was also chosen to have aluminum foil pasted on it. The lagging material was chosen as tissue paper to reduce cost. Cotton wool would have been better but at a higher cost.

2.2 Construction

The solar oven project was realized by constructing the different units of the oven and putting them together as follows:

2.2.1 Oven Box and Reflector Construction

The 15mm and 9mm thick plywood were cut into the dimensions required for the sides of the outer and inner boxes, respectively. The boxes were then constructed by nailing the boards into their right positions. The next thing was the pasting of the aluminum foil on the faces of the inner box and on the face of the top cover board of the outer wall box which serves as the reflector. Some pieces of the 15mm plywood were cut into widths of 30mm, four pieces were nailed at equal centers on the bottom wall of the outer box to serve as separation stand for the inner box, one piece was equally nailed to each inner side of the longer outer box walls while one piece was nailed to each side of the shorter walls. The outer box was painted black. The constructed boxes are as shown in Fig.2.1 and 2.2. Tissue paper was now used to fill the bottom of the outer box up to the 30mm height of the separation woods. The inner box was placed inside the outer box and the space between them also filled with tissue papers. At the end, a set of four rollers was fixed to the bottom of the box for easy movement and turning of the oven.

Fig. 2.1 The constructed outer box with reflector

Fig. 2.2 The constructed inner box

2.2.2 Glazing Part Construction

Aluminum frame was constructed for the window glass as it was designed to be a removable cover for the oven. The glass was then fixed to the frame with the help of silicone gum.

2.2.3 Laminating Platen Construction

Steel plates of 3mm thick were cut to the required dimension to be able to contain a standard size of 160W solar panel. The plates were two in number with one to serve as the base plate and the other, as the top laminating platen. Square steel pipe of 30mm was used to frame the plates and construct fixed standing legs for the base plate. The laminating platen top and base parts were then sprayed with black paint.

The different units were put together to form the solar oven which is as shown in Fig. 2.3. Table 2.1 gives the specification of the materials used for the construction.

Table 2.1 Materials used for the Oven Construction

S/N	PARTS	MATERIAL	DIMENSIN (cm)	QUANTITY
1	Outer box bottom board	plywood	180 x 119.4 x 1.5	1
2	Outer box top cover board	plywood	183 x 122.4 x 1.5	1
3	Outer box longer side board	plywood	183 x 52 x 1.5	2
4	Outer box shorter side board	plywood	119.4 x 52 x 1.5	2
5	Bottom separator for the boxes	plywood	119.4 x 3 x 1.5	4
6	Side separator for the boxes	plywood	47 x 3 x 1.5	4
7	Inner box bottom board	plywood	172.2 x 111.6 x 0.9	1
8	Inner box longer side board	plywood	172.2 x 45 x 0.9	2
9	Inner box shorter side board	plywood	113.4 x 45 x 0.9	2
10	Oven window	glass	178 x 117.4 x 0.4	1
11	Oven window frame length	aluminum	179.5 x 2 x 0.4	2
12	Oven window frame width	aluminum	119 x 2 x 0.4	2
13	Laminating platen base and top	steel	154 x 72 x 0.3	2

Fig. 2.3 The one reflector solar oven for solar panel lamination

2.3 Testing

Three tests were carried out on the constructed oven. The first one was the no load test with the oven fixed and faced due south. The second was the no load test with the oven turned to track the sun. And the last was the load-on test. These tests were carried out in March, 2014.

2.3.1 No Load Test 1

The oven was faced due north with the help of a digital compass and the reflector was fixed at 110^0 to the horizontal. The sensor end of two digital temperature meter probes were attached 15cm to the ends of the laminating platen and the plug ends were brought out. The oven was then covered with glass window and the first platen temperature, ambient temperature and solar irradiance measurements were taken and the values recorded. This was at 9.00am Nigerian time. The solar irradiance was measured with the solar radiation sensor entrance of the solar irradiance meter, facing vertically upwards. Readings were subsequently taken at 30 minutes intervals and the results tabulated. A total of twelve readings were taken, and the last one was taken at 2.30pm.

2.3.2 No Load Test 2

The second test carried out on the oven was done with the oven being turned to face the sun after every reading, using the method which we called “manual shadow tracking method”. This is the method of tracking the sun’s direction during box solar oven test by aligning the box side edge with its shadow edge. The test was started at 9.00am with the reflector fixed at 110^0 to the horizontal and the oven turned to face the sun. The oven orientation was measured with digital compass and it read 116^0ESE. The temperature was measured as in the first test with two probes. The ambient temperature and solar irradiance were also measured, and the results were recorded. Subsequent readings were taken at 30 minutes intervals with the sun being shadow tracked. The results were also tabulated.

2.3.3 Load-On Test

The process of the second test was repeated here but with the oven being used to laminate a 148 x 68 cm sized 160 watts solar panel. The results were tabulated.

III. Results And Discussion

3.1 Results

The results of the three tests, that is, the no load test 1, no load test 2, and the load-on test, were put in a table as shown in Table 3.1, 3.2 and 3.3, respectively. They were also plotted as shown in Fig. 3.1 to 3.3. The laminated solar panel is shown in Fig. 3.4.

Table 3.1: Results of the solar oven no load test with oven orientation fixed at 180^0S

time (hours)	t_{p1} (^{0}C)	t_{p2} (^{0}C)	t_p (^{0}C)	t_a (^{0}C)	H_s (W/m^2)
9.00	36	30	33.0	30	583
9.30	54	45	49.5	30	616
10.00	72	56	64.0	30	857
10.30	95	80	87.5	31	1017
11.00	93	84	88.5	32	784
11.30	103	94	98.5	32	948
12.00	105	97	101.0	32	1210
12.30	109	104	106.5	32	1112
13.00	115	110	112.5	33	1108
13.30	119	115	117.0	33	1083
14.00	119	117	118.0	33	1046
14.30	108	103	105.5	32	677

Table 3.2: Results of the solar oven no load test with oven turned to track the sun

time (hours)	oven orientation	t_{p1} (^{0}C)	t_{p2} (^{0}C)	t_p (^{0}C)	t_a (^{0}C)	H_s (W/m^2)
9.00	116^0 ESE	37	37	37.0	32	600
9.30	117^0 ESE	54	58	56.0	32	640
10.00	118^0 ESE	76	82	79.0	32	750
10.30	122^0 ESE	84	91	87.5	33	919
11.00	128^0 SE	91	100	95.5	33	1068
11.30	132^0 SE	98	110	104.0	34	1085
12.00	142^0 SE	101	115	108.0	35	1101
12.30	146^0 SE	110	118	114.0	34	1119
13.00	182^0 S	115	122	118.5	34	1053
13.30	200^0 SSW	118	124	121.0	35	1037
14.00	212^0 SSW	122	126	124.0	36	1010
14.30	224^0 SW	108	110	109.0	36	757

Table 3.3 Results of the load-on test

time (hours)	oven orientation	t_{p1} (^{0}C)	t_{p2} (^{0}C)	t_p (^{0}C)	t_a (^{0}C)	H_s (W/m^2)
9.00	115^0 ESE	36	35	35.5	32	628
9.30	117^0 ESE	40	38	39.0	32	653
10.00	118^0 ESE	56	56	56.0	32	763
10.30	122^0 ESE	73	75	74.0	32	914
11.00	128^0 SE	84	83	83.5	33	1050
11.30	132^0 SE	92	91	91.5	33	1090
12.00	142^0 SE	90	90	90.0	34	1098
12.30	146^0 SE	98	100	99.0	34	1133
13.00	182^0 S	102	103	102.5	34	1046
13.30	201^0 SSW	102	108	105.0	35	1035
14.00	212^0 SSW	106	115	110.5	35	1021
14.30	224^0 SW	101	110	105.5	35	755

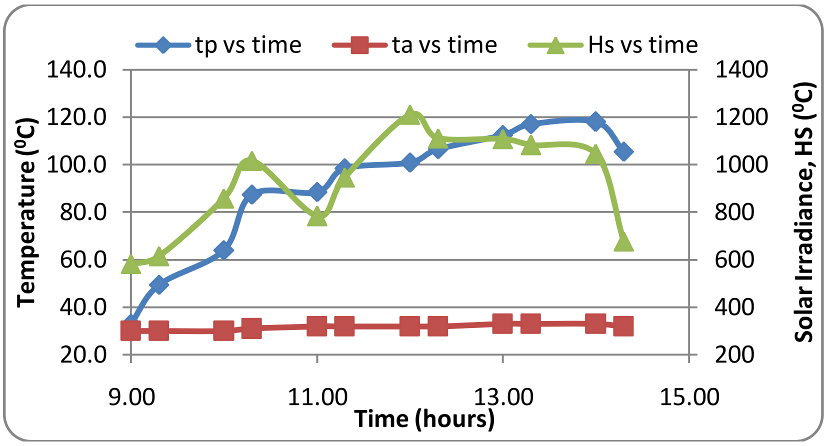

Fig. 3.1 Graph of platen temperature, t_p, ambient temperature, t_a, and solar irradiance, H_s against time for the solar oven no load test 1

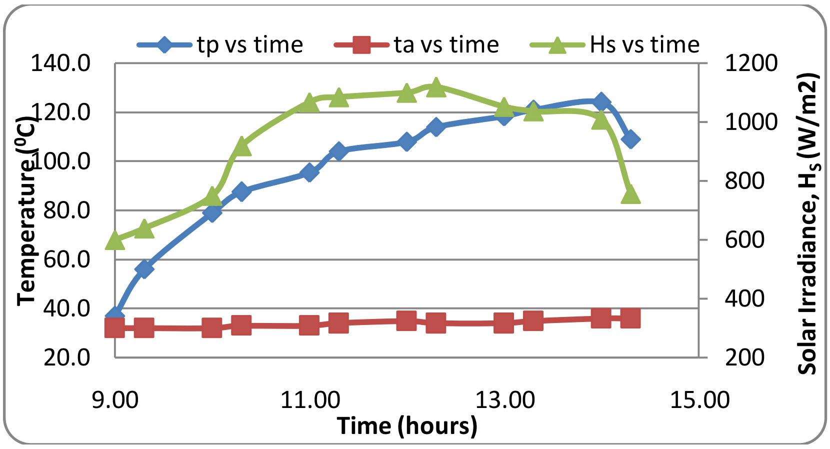

Fig. 3.2 Graph of platen temperature, t_p, ambient temperature, t_a, and solar irradiance, H_s against time for the solar oven no load test 2

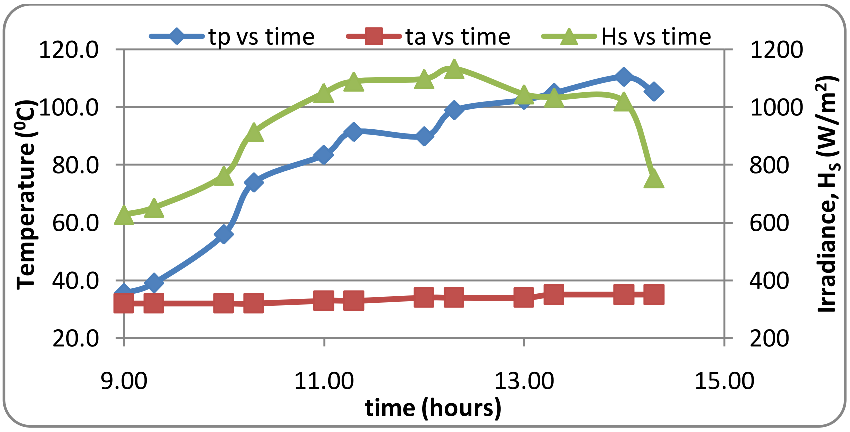

Fig. 3.3 Graph of platen temperature, t_p, ambient temperature, t_a, and solar irradiance, H_s against time for the solar oven load-on test

Fig. 3.4 The constructed solar panel

3.2 Determination of the First Figure of Merit for the Oven

Using the readings got from the second no load test which met the conditions for determining first figure of merit, as the oven was turned every 30 minutes to face the sun, the first figure of merit, F_1 for this oven was calculated. From this second no load test, the maximum (stagnation) temperature got was $t_{ps} = 124^0C$, ambient temperature at stagnation, $t_{as} = 36^0C$, and solar irradiance at stagnation, $H_{ss} = 1010\ W/m^2$**.** Using the formula,

$F_1 = \frac{t_{ps} - t_{as}}{H_{ss}}$, the first figure of merit, F_1 for the oven was calculated as 0.09.

3.3 Discussion

When the first no load test with the oven fixed at a position to face south was carried out, a maximum average platen temperature of 118^0C was realized, which was below the required temperature of 120^0C for solar panel lamination. With the oven turned to face the sun every 30 minutes, a higher stagnation temperature of 124^0C was realized meaning that for this oven to be used for solar panel lamination, it must be turned to always face the sun in the course of the lamination. When this process was followed to laminate a 160W solar panel with the oven, the temperature could only get to 110.5^0C due to loading. As a result of this, the EVA laminating film did not completely fuse with the glass but the quality of the produced panel was good. By observation, the fusion level of the EVA film could be judged as about 70%.

The calculated first figure of merit, F1 for this oven was 0.09. If a solar oven has F1 greater or equal to 0.12, the oven is classified as A-Grade but if F1 is less than 0.12, the oven is classified as B-Grade [6][7]. Therefore, this oven is a B-Grade oven.

IV. Conclusion And Recommendation

4.1 Conclusion

A one reflector solar oven for solar panel lamination was constructed. The oven was tested for thermal performance and maximum no load temperature and load on temperature were obtained as 124^0C and 110.5^0C, respectively. The first figure of merit calculated for the oven was 0.09 which categorized the oven as a B-Grade oven.

The aim of this research project was achieved as the oven was successfully used to laminate a 160W solar panel with the fusion level of EVA laminating film physically observed and adjudged to be up to 70%.

4.2 Recommendation

The oven achieved a temperature of 124^0C when no load was applied, but with load the maximum temperature reduced to 110.5^0C which was below the required temperature for complete fusion of the EVA laminating material with the glass. Therefore, I recommend that more research work be done to improve the efficiency of the oven so as to realize load-on temperatures of above 120^0C.

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