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Performance Appraisal of a Solar Box Water Heater

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Abstract *- Emissions from house hold stoves, gas cookers and firewood for heating water and cooking contributes significantly to environmental pollution, health hazards and global warming crises. In most parts of the world, little change is being made to slowdown this effect on the environment by reducing technological devices which makes use of fossil fuel and finding an alternative technology which will make use of clean energy source. Utilizing a clean renewable energy source from the sun for cooking and heating, will contribute immensely in reducing the environmental effect caused by fossil fuel. In this paper, the solar box water heater has been shown to serve as an alternative device for harnessing the sun's energy for heating water especially in rural areas. The efficiency of the solar box water heater was found to be 53.465% with an average standard effective power of 227W. Using this device will reduce the cutting down of trees for firewood and consequently reduce the effect of global warming and climate change.*

Keywords - solar box, heater, cooker, renewable energy, appraisal, firewood

1. INTRODUCTION

Most people in Nigeria especially in rural areas and many developing countries depend largely on fossil fuels or firewood for cooking (Nahar, 2002; Kwasi-Effah, 2011). Every year the cutting of trees for firewood results in the loss of 20,000 - 25,000 km^2 of tropical forests which greatly increases global warming and greenhouse effect on the environment (UNIDO, 2008).Women and children are most exposed to high levels of harmful smoke and suffer the most serious health damage when cooking with firewood. Studies in China found that smoke offered a strong risk factor for lung cancer among non-smoking women. Also in Gambia, it was found that girls aged under five carried on their mother's back during cooking had six times higher risk of lung cancer which is a substantially higher risk factor compared to their parents (Amer, 2003). Independent research indicates that indoor air pollution is a contributory cause of around two million deaths in developing countries. Acute respiratory infections, ear and eye problems, breathlessness, chest pains, headaches and giddiness are just some of the symptoms that poor woman and children suffer in their rural homes which thus a result of smoke from cooking (Hoda, 2001).

Since Nigeria is located in the tropics with climatic zone range from hot to wet tropical rain forest and moderate temperature of about 27^0C and high relative humidity of 70-90% over most of the year, solar energy is favorable as an alternative energy for use (Adegoke and Fasheun, 2002; Medugu and Yakubu, 2011) in the region. Solar radiation energy is widely distributed and available. This energy source is renewable, has zero or low GWP (global warming potential) and ODP (ozone depletion potential), and is thus more environmentally friendly (Taha and Eldighidy, 1980; Aburime et al., 2013). Therefore, this study was carried out to examine the possibility of utilizing solar box water heater which can serve as an alternative device in harnessing the suns energy for heating water.

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2. EXPERIMENTAL

A solar box water heater was designed and fabricated using the following specification and materials shown in Table 1.

Table 1: Material specification of the solar box water heater

S/N	Part	Dimension (mm)	Material
1	Outer box	950 x 500 x 500	Ply wood
2	Inner box	850 x 450 x 400	Aluminum sheet
3	Transparent glass cover	835 x 325 x 4	Plain glass
4	Reflective mirror	912 x 156 x 5	Coated glass
5	Insulator	4 x 2 x 2	Hardboard
6	Suspended heating tray	210 x 200 x 10	Aluminum sheet

Figs. 1 and 2 shows the sectional diagram and picture of the solar water heater.

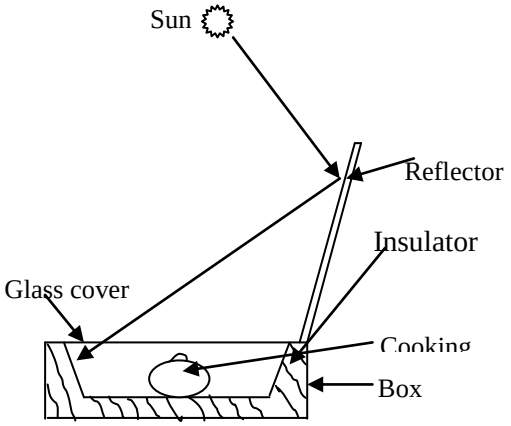

Fig. 1: Sectional View of the Solar Box Water Heater

Having fabricated the solar box water heater, an experimental test was carried out using standard international procedure adopted by (UNIDO, 2008). The test was conducted during the harmattan period from 10th -18th November, 2013.

Fig 2: Picture View of the Solar Box Water Heater

Equations (1) and (2) were used to evaluate the performance characteristics of the solar box heater based on the energy gain (E) and efficiency respectively (η_c). The temperature change of the water was measured over 10-minute interval per hour.

$$E_o=\frac{M_w\, C_w(\Delta T_w)}{600} \quad (1)$$

$$\eta_c=\left(\frac{M_p C_p+M_w C_w}{A_c Q_c t}\right)(T_w - T_a) \quad (2)$$

The standard effective heating power (P_s) was determined using Equation (3) and (4).

$$P=\frac{M_w\, C_w(T_{w(final)}-T_a)}{600} \quad (3)$$

$$Ps=\frac{P\ X\ 700}{I_s} \quad (4)$$

From the heating power (P), each interval is corrected to a standard insolation of 700 W/m^2 using Equation (4) where I_s is the interval average solar insolation (W/m^2). Equation (1) is divided by 600 because there are 600 seconds in each 10-minute interval.

Some amount of water was filled into a pot weighing 0.66kg. After filling, the total mass of the pot (M_p) was 1.016kg, which means that mass of water (M_w) in the pot is 0.5kg.

3. RESULTS AND DISCUSSION

Table 2 shows the result of average reading of each parameter carried out hourly on daily basis within the test period.

Table 2: Average daily reading of the solar box water heater

Time (hrs) GMT	$T_{base\ plate}$ (°C)	T_a (°C)	T_w (initial) (°C)	T_w (final) (°C)	ΔT_w (°C)	$T_{w\ (final)} - T_a$(°C)	P (W)	I_s (W/m^2)	P_s (W)
10	45	25	18	47	29	22	77	255	211
11	52	28	20	52	32	24	84	268	219
12	59	30	22	56	34	26	91	294	217
13	58	32	21	59	38	27	95	310	213
14	55	35	22	63	41	28	98	325	211
15	54	30	24	74	50	44	154	370	291

Thus, the average value of the water temperature and ambient temperature is used to obtain the value of heat gain (E_0) and efficiency (η_c) as follows:

Average water temperature (ΔT_w) =

$$\frac{29+32+34+38+41+51}{6} = 37.33^oC \quad (5)$$

Average ambient temperature (T_a) =

$$\frac{25+28+30+32+35+30}{6} = 30.00^oC \quad (6)$$

Giving specific heat capacity of water (C_w) to be 4200J/kgK, mass of water from initial analysis is 0.5kg and average water temperature is 37.33°C. The average energy gain of the solar box water heater daily can be found using Equation (1). Thus,

$$E_0 = \frac{213228.96}{600} = 355.38W \quad (7)$$

Based on the design parameters, area of solar collector (A_c) is 0.33m x 0.47m = 0.1551m^2, given solar radiation (Q_C) = 398.83W/m^2 (Adegoke and Fasheun, 2002), specific heat capacity of pot = 920J/kgK and mass of pot = 0.66kg and substituting these values into Equation (2), the efficiency (η_c) of the solar box heater is:

$$\eta_c = \frac{(0.66\ x\ 920) + (0.5\ x\ 4200)}{0.1551\ x\ 398.83\ x\ 600} \text{ x } (37.33 - 30.00) = 53.465\% \quad (8)$$

Increasing awareness of the growing global need for alternative cooking fuels has resulted in an expansion of solar heaters, cookers research and development. Figure 3 shows the variation of temperature versus time of day. Clouds cover lower the heating temperature and thus increase the time needed for cooking. According to Nahar (2002), the more direct sunshine is available, the better a solar box heater works. Figure 4 shows that as the difference in ambient temperature and temperature of the water increases, the standard heating power decreases. This means that the effectiveness of the solar box water heater will drop at certain high temperature of the sample. But designing with proper insulated material will save a lot of heat loss into the environment hence, leaving the sample at its desired temperature. It is also imperative to paint the inner chamber black so as to increase the amount of heat absorbed by the system.

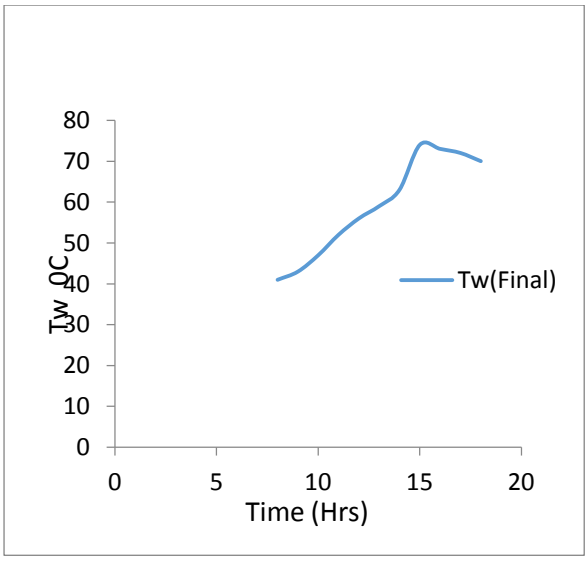

Fig. 3: Temperature versus Time Plot

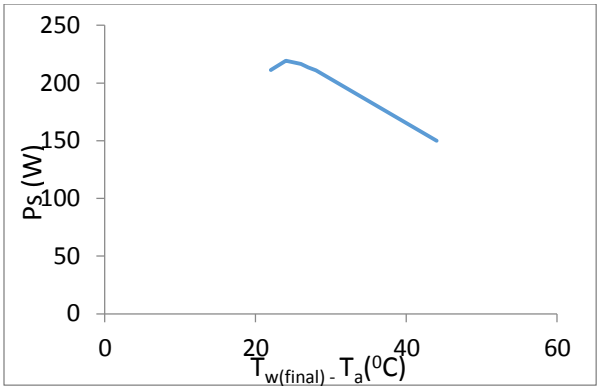

Fig. 4: Standard Effective Power versus Temperature Difference Plot

Due to variable environmental factors like insolation, wind effect and other uncontrollable parameters, the committee of experts on solar cooking in India during the Third World Conference on Solar Cooking stated that "The one figure best representing thermal performance of a solar water heater is the effective heating power, which accounts for both different heater sizes and heat gain rates (Paul, 2012). A linear regression was used to determine the relationship between the standard heating power and temperature difference. Figure 4 shows that the value of the coefficient of correlation (R^2) is 0.91, which is above the recommended standard of 0.75. Thus the effective heating power of solar box water heater is acceptable. The solar box water heater is a partial solution to many serious global problems. UNICEF has made an evaluation of solar cookers and heaters. They estimate that one third of global fuel wood used (350 million tons per year) could be preserved with solar cookers and heaters. Pay-back time is estimated to be less than 1 year (UNICEF, 2004). Although solar heating and cooking would be economically viable, the poorest people and areas need supportive actions for purchasing them. Solar heating and cooking will never fully replace traditional forms but can complement it and significantly cut down on fuel costs.

4. CONCLUSION

A 950 x 500 x 500 mm solar box water heater has been evaluated. The average energy gain and efficiency was found to be 355.38W and 53.465% respectively. Also, using linear regression, the coefficient of correlation (R^2) was found to be is 0.91, which is above the recommended standard of 0.75. As the number of people longing for comfort, cleaner environment, reduction in agricultural and medical loss increases, it has been demonstrated that solar energy can be used to assist in achieving this purpose.

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