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Comperative Analysis Of Thin-Foil And L-Shaped Parabolic Reflectors On The Performance Of Concentrating Solar Cooking System

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Abstract: *The paper presents an investigation into the comparative analysis of L-shaped and thin foil parabolic reflectors on the performance of concentrating solar cooking system. The performance evaluation of concentrating solar cooking system was carried out using two different types of parabolic reflectors namely L-shaped and Thin foil paper parabolic reflectors. Each reflector was fixed at a height from cooking vessel of the concentrating solar cooker stand.Boiling test for the determination of the system performance was carried out.. The water temperature, wind speed, diffuse solar radiation, direct solar radiation and global solar radiation were recorded while carrying out the test. The experimental results obtained showed that, the L-shaped parabolic reflector made up of reflective mirror performed better with maximum temperature of 94.1^{O}C compared to the thin foil parabolic reflector which attained 72.4^{O}C.Similarly, test results of the two different reflectors were employed to calculate the efficiency of the concentrating solar cooker. The efficiencyof the system was obtained to be 7.58% and 5.98% for L-shaped and thin foil parabolic reflectors respectively. The results therefore indicated that L-shaped parabolic reflector has much influence on the performance of concentrating solar cooking system then thin foil parabolic reflector, this can be attributed to the nature of the reflective materials used in the construction of the reflectors.*

Key words: *reflector, thin foils paper, efficiency, temperature and global solar radiation.*

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I. Introduction

The rate at which our environment is being exposed to global warming, ozone layer depletion and desert encroachment as a result of human interference cutting down trees for energy needs for cooking is alarming in the developing world. Averagely over 80% of energy consumption for cooking/water heating in the developing world relied on fuel wood and charcoal on a daily basis (Garba, 2010). Apart from the CO_2 released to the environment, the use of fuel wood is causing desertification and other ecological degradation which drastically affects the land fertility (Schwarzer and Silver, 2003).Electric cookers are excellent source of heat energy, unfortunately the high cost of electric energy generation and distribution added to erratic power supply as witnessed in underdeveloped economics constitute obvious drawbacks. Nigeria as well as other countries in the tropics is readily blessed with abundant supply of solar energy which can be conveniently harnessed to fill this gap. In Nigeria for instance, there is hitherto no serious work done to develop a solar cooker that can serve as excellent alternative heat source to fossil fuel-based cookers (Basil, 2013).Concentrator collectors are those in which the incident solar radiation is concentrated by means of reflection or refraction devices onto the receiver. Concentration method always produced a high temperature rising which may exceeds the boiling point of water. Therefore, it is always being used in electric generator, steam generation, solar cooking system and etc. A concentrating collector is essentially characterized by its concentrating ratio (CR) which is given as the ratio of the collector area to the area of receiver (Kothari *et al.,* 2012). Gang *et al.* (2012), studied the compound parabolic concentrator type solar heater with a U-pipe and investigated its performance in meeting higher temperature requirements. It found that when the water temperature was heated from 26.9^{O}C to 55^{O}C, 65^{O}C, 75^{O}C, 85^{O}C and 95^{O}C, thermal efficiency was found to be decreasing function. In other words, the lower thermal efficiency has been found at 95^{O}C and to be above 49%. The energy efficiency has been found to be decreased in nature i.e. highest efficiency was found to be at 55^{O}C and found be always above 4.65^{O}C.The energy output of a concentrating cooker varied between 20.9 and 78.1. It was found that the energy and energy efficiencies of the cooker were in the range of 2.8 to 15.7 and 0.4 to 1.25 respectively. (Ozturk, 2004). Several researches were conducted by different researchers on the application of solar cooking system. Gaur *et al.,* (1999)] made a performance study ofthe box-type solar cooker with special emphasis on the shape of lid of the utensilsused. The study revealed that the performance of a solar cooker could be improvedif a utensil with a concave shape lid is used instead of a plain lid generally providedwith the solar cookers.Buddhi*et al.,* (1999) also analyzed the thermal performance of abox type solar cooker on the basis of first and second figure of merit with and withoutload respectively and found that the second figure of merit depends on the quantityof water loaded in the solar cooker and emphasized that the test method should specify the amount of water to be taken.Petela (2005) worked on the energetic analysis of simple parabolic type solarcooker (SPC) of the cylindrical trough shape. Cooking pot, reflector and imaginedsurface making up the system are the foremost important parts of the solar cookerstudy therefore the equations for heat transfer between these three surfaces weredeveloped. The model allowed the theoretical estimation of the energy and energylosses, unabsorbed insulation, convective and radiative heat transfers to theambient. Kaushik and Gupta (2008) studied the performance analyses of community-size anddomestic-size paraboloidal solar cooker based on energy and energy analyses. Thestudy showed that the community-size solar cooker (CSC) has the high energy,energy efficiencies and low characteristic boiling time as compared with thedomestic-size paraboloidal solar cooker (DSC). In other words, the performance ofCSC was found to be better than that of the DSC. They also suggested that theenergy efficiency can be increased only up to some extent by increasing thereflectivity of the reflectors, proper designing of cooking place and using a suitablecooking pot. The time required to heat the water up to boiling temperature was alsoestimated and this indicated that such cookers are suitable to cook a meal faster. Besides the quality of the meal cooked was found to be better than that cooked bytraditional cookers,the low efficiency of DSC was found to be lower due to theoptical and thermal losses from the reflector and pot. As the solar radiation is rich inenergy and being utilized in the form of heat at low temperature therefore, the energyefficiency of any solar cooker or solar thermal device is very low.Mawire*et al., (*2008) had worked on the thermal energy storage (TES) system ofan indirect solar cooker using simulated energy and energy analyses, an oil–pebblebed was used as the TES material in their study. For the performance analysis ofthe TES system using energy and energy analyses two different charging methodswere used. The constant flow rate for charging the TES system was used in firstmethod however, in the second method, the flow rate was made variable to maintaina constant charging temperature. From their study it was found that the energystored in constant-temperature charging method had larger than that of constant-flowrate charging method. This paper therefore, is aimed at a comparative analysis of L-shaped and thin foil parabolic reflectors on the performance of a concentrating solar cooking system.

II. Materials And Methods

The construction of the concentrating solar cooking systemwas made using locally available materials i.e. plywood, plank wood, plane mirror, cooking vessel, thin foil paper and nails.Figures 1.0, 1.1 and 1.2 show the schematic diagram of cooker stand, L-shaped and thin foil parabolic reflectors respectively. The research wascarried out at mechanical workshop ofSokoto Energy Research Centre, UsmauDaU,Sokoto, Nigeria

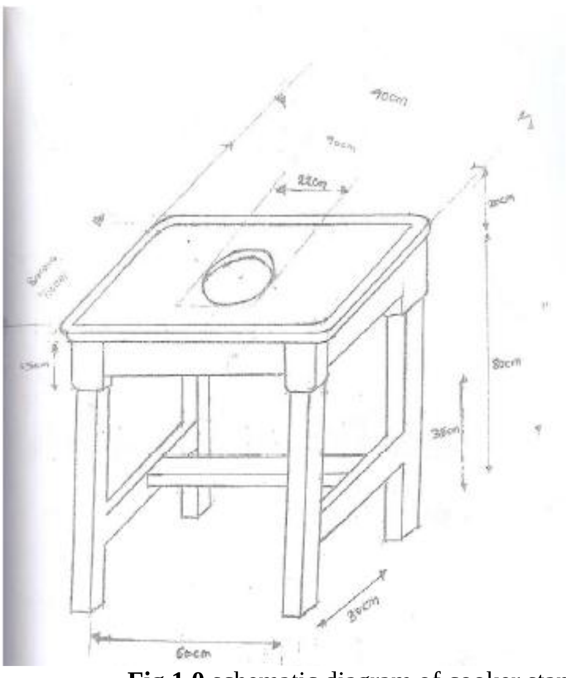

Fig 1.0 schematic diagram of cooker stand

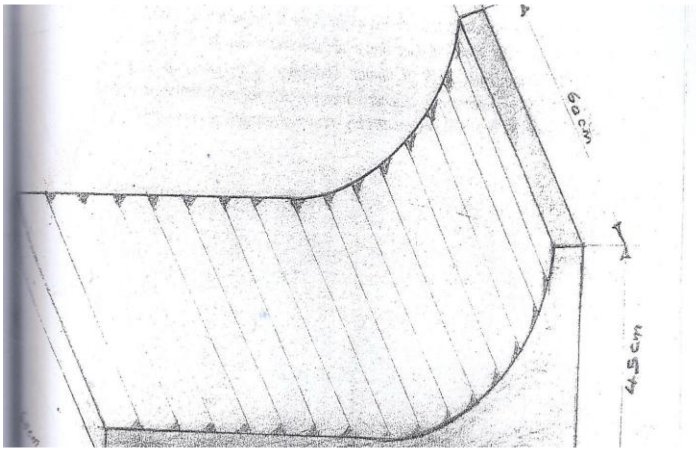

Fig 1.1 Schematic diagram of L-shaped parabolic reflector

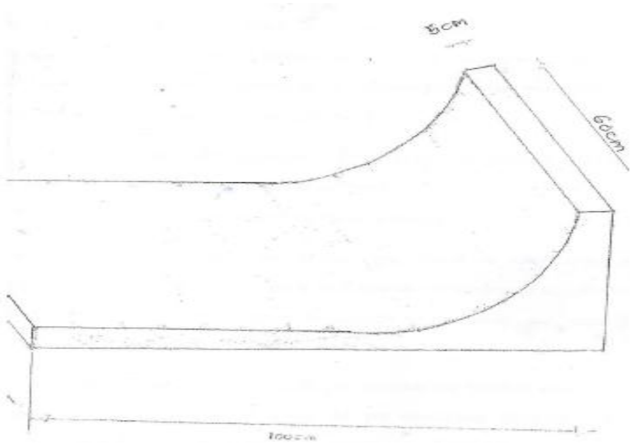

Fig 1.2 Schematic diagram of Thin foil parabolic reflector

The concentrating solar cooker was designed by constructing two different types of parabolic reflectors using two different reflective materials i.e. reflective mirror and thin foil paper, the distance between the reflectors and cooking vessel was set at 65cm and accurate focal zone of reflector for the effective performance of the system was obtained at this height. The L-shaped parabolic reflector uses reflective mirror applied or fixed on a woody L-shaped frame. The mirror was in rectangular shaped of 8cm × 60cm fixed with shiny side surface of mirror facing, which in turns formed the parabolic reflector mirrors shaped Fig 1.1. While the Thin foil paper was pasted on the woody frame of parabolic shaped of the same size, for the formation of Thin foil parabolic reflector of the same size with that of L-shaped parabolic reflector Fig 1.2. Focal point of two different reflectors was determined by using equation (1) (Basil, 2013)

$$x^2 = 4f \quad (1)$$

Where: x is half of the total length of parabola (cm), $y$is the height of the parabola measured from base and f is the focal point of the reflector.

Table 1.0: Measurement of the design parameters

Types of reflectors	Total length of the reflector (cm)	Focal Point of the Reflector (cm)	Height of parabolic (cm)
L-shaped parabolic reflector	100	30	20.8
Thin foil parabolic reflector	100	30	20.8

2.1 PRINCIPLES OF OPERATION

The concentrating solar cooking system works by concentrating sun energy (solar radiation) onto a small area in which a pot or other cooking utensil is placed, under very intense sunlight; solar radiation is focused toward the focal point where the cooking pot is held or placed, the cooker require frequent adjustment toward the sun. Three basic phenomena are employed in the operation of the system, these involved

i. When solar radiation strikes the black surface, it changes to infra radiation.
ii. When light falls on a shiny surface (transparent surface or object), it is reflected and so can be directed to desired point.
iii. In optics it is well known that parabolic mirror (concave mirror) will reflect a parallel beam of light to focal point (Basil, 2013).

Whenever the parallel rays of solar radiation is incidence on a reflecting surface of parabolic reflector, the solar energy would be reflected and converge at a line called focal point. The solar energy converge at focal point is absorbed to give rise to an increase in temperature, and generate higher temperature steam or heat energy. The amount of which the collector (reflector) concentrates solar radiation is governed by optical property of the surface according to Sadik*et al.*, 2013

2.2. EXPERIMENTAL SET UP

The boiling test experiments were performed and maximum temperature attained of the concentrating solar cooker using L-shaped and Thin foil paper parabolic reflectors were measured by using mercury in glass thermometer and recorded, the efficiencies of the systems using different parabolic reflectors as a solar concentrating devices were also evaluated. The instruments used during instrumentation, includes:

- Digital Thermocouple Data Logger
- Anemometer to measure wind.
- Digital thermometer to measure ambient temperature.
- Pyranometer to measure global, direct and diffuse solar radiations.

Fig 1.3 Digital thermocouple data logger

Fig 1.4 Digital Anemometer for Wind Speed Measurement

Fig 1.5:.Digital Thermometer for Ambient Temperature Measurement

Fig 1.6: Pyranometer for Global Solar Radiation Measurement

The parameters recorded during experimental test were: water temperature T_w, ambient temperature T_a, global solar radiation I_{gr}, direct solar radiation $I_{dr}$and wind speed in order to observe their effect on the performance of the system (concentrating solar cooker). The mercury in glass thermometer was placed inside the black painted aluminum pot containing 0.75kg of water. Different temperature values were measured and recorded at 30minutes intervals between 10:30am to 14:30pm.

III. Results And Discussion

The efficiency of the concentrating solar cooker using L-shaped and thin foil parabolic reflector were obtained using equation (2)

$$\eta_C = \frac{(T_f - T_i)M_W C_W}{dtAI_b} \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where T_i initial temperature of water 44.6^{O}C,T_f final temperature of the water 94.2 ^{O}C,M_w mass of water contained 0.75kg, C_w specific heat capacity of water 4200J/kgK, d_t time for waterrise to desire temperature 30min ($30\times 60 =$),A collector aperture area 11.25m^{2}andI_b average solar radiation 790W/m^2. while for the thin foil reflector,T_i initial temperature of water 45.5^{O}C, T_f final temperature of the water 72.4 ^{O}C and I_b average solar radiation 787W/m^2. The same mass of water and specific heat capacity of water are same (constant) during experimental tests.

The maximum temperature of the concentrator with L-shaped and thin foil parabolic reflectors were recorded and the results were depicted in figure 1.7 and 1.8 respectively.

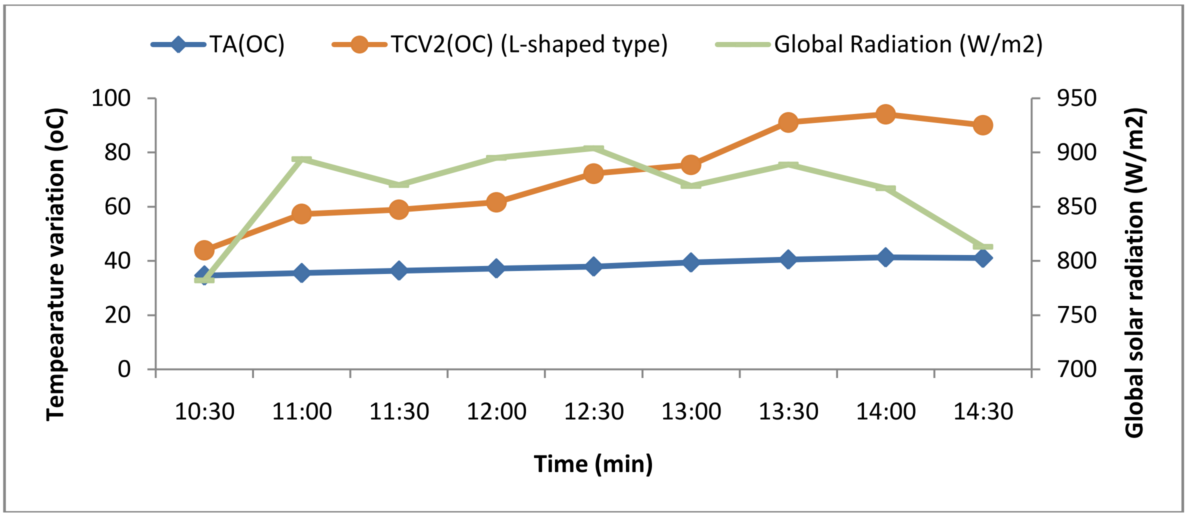

Fig 1.7: The variation of water temperature with corresponding global solar radiation of L-shaped parabolic reflector

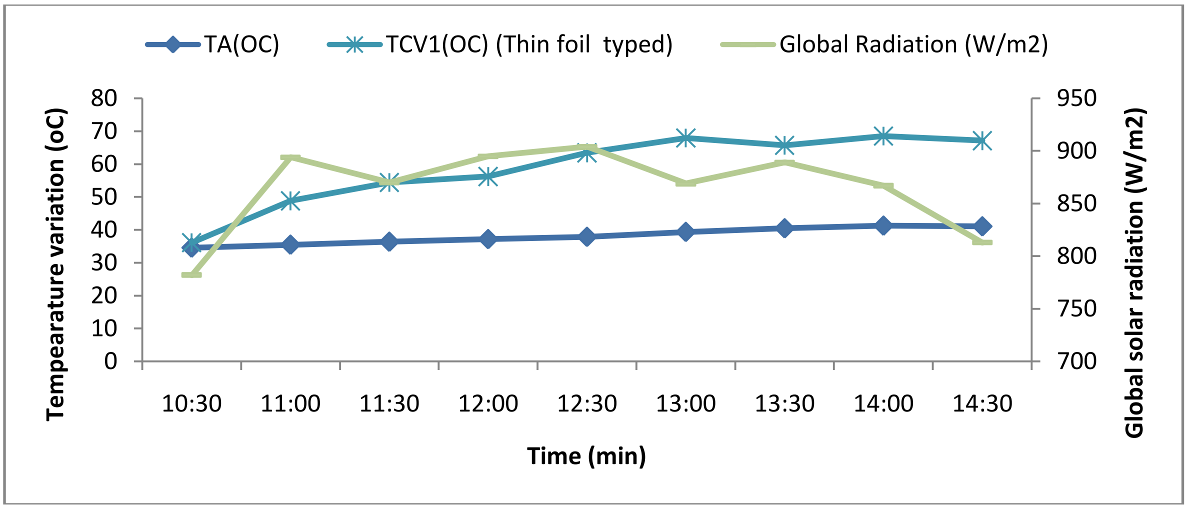

Fig 1.8: The variation of water temperature with corresponding global solar radiation of thin foil parabolic reflector

3.1 DISCUSSIONS

Figure 1.7 shows the variation of water temperature with corresponding global solar radiation of L-shaped parabolic reflector, the figure shows that, the highest recorded temperature of water and corresponding global solar radiation were 94.1^{O}C and 867W/m^2 respectively at time of 14:00pm. This shows that the temperature of T_{CV} and ambient temperature T_a continuously increased to a maximum temperature value, as the in the intensity of solar radiation continuously increased gradually. 14:30 the temperature of water gradually decreased to a certain temperature value while the global solar radiation was not decreased, this could be as results of gradual decreased of ambient temperature and cloud covered the intensity of solar radiation (uncontrolled factors) due to the environmental cloud change that laid to the gradual decreased of water temperature contained in a cooking vessel during water boiling test experiment, similar result was reported by (Funk, 2000)Similarly, figure 1.8 presents the variation of water temperature with corresponding global solar radiation of thin foil parabolic reflector as a concentrating solar collector, the figure shows that, the highest recorded temperature of the water and corresponding global solar radiation were 72.4^{O}C and 867W/m^2 respectively at the same 14:00pm the water temperature and ambient temperature were continuously increased. By 14:30pm the water temperature and ambient temperature gradually decreased to a certain temperature value without decreased of global solar radiation, this could be as results of same factors affecting the performance of the L-shaped parabolic reflectorsi.e increased of wind speed and cloud change and covered the intensity of solar radiation..Looking at the experimental results showed in fig 17 and 1.8 for L-shaped and thin foil parabolic reflectors, the performance of the reflectors are affected by almost the same factors. While the maximum temperature attained was 94.1^{O}C and 72.4^{O}C for L- shaped and thin foil parabolic reflectors respectively, and the efficiency of reflectors on concentrating solar cooker for L-shaped parabolic reflector was 7.58% and 5.98% for thin foil reflectors.The differences of temperature and efficiency of the reflectors could be as a result of reflectivity differences between reflective materials used in construction L-shaped and thin foil parabolic reflectors.

IV. Conclusions

The results of the experimental test conducted using two different types of parabolic reflectors of the concentrating solar cooker, shows that the cooker using L-shaped parabolic reflector was able to produce highest water temperature of 94.1^{O}Cwhile for thin foil it was 75.4^{O}C.

The results shows that, the L- shaped parabolic concentrator made up of reflective mirror performed batter compared to parabolic reflector made up of thin foil paper. This could be as a result of high reflectivity of the reflective mirror than the thin foil paper. Similar results were reported by (Arenas 2007).Therefore, to increase the performance efficiency of the concentrating reflectors, material with high reflectivity than mirror and thin foil paper e.g., like film of metallised polypropylene of reasonable thickness with a light reflective index of 99.9% can be used, since material with higher reflectance at the surface concentrate more rays of sun.

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