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ABSTRACT

Solar collectors developed over the years can be categorized as concentrating or focusing collectors and flat plate collectors. This paper represents a comparative analysis of the three different configurations of parabolic solar concentrators. The developed systems were varied at different heights to attain an optimum focal length which converges at the cooking pot. Performance evaluation of concentrating solar cooking system was carried out using three different types of parabolic reflectors namely; L-shaped, U-shaped and thin foil L-shaped parabolic reflectors. Each reflector was fixed at 65 cm height from cooking vessel to the reflector during boiling test in order to determine the performance of the system. The measured parameters include; temperatures at different positions, wind speed, global, diffuse and direct solar radiations were recorded. The experimental results showed that, the L-shaped parabolic reflector made up of reflective mirror performed better compared to other two parabolic reflectors. The improvised locally available reflecting surface was ordinary mirror which was sliced to give take the parabolic shape and the maximum recorded temperature was 94.1°C with an efficiency of 7.58%.

Keyword: Thin foil, parabolic reflectors, ambient temperature, wind speed and Global solar radiation

1. INTRODUCTION

The rate at which our environment is being exposed to global warming, ozone layer depletion and desert encroachment 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, 2009). Apart from the CO₂ released to the environment, the use of fuel wood is causing desertification and other ecological degradations which drastically affect the land fertility (Schwarzer and Silver, 2003).

In many developing countries conventional energy sources, are not sufficiently available and therefore people mostly depend on fuel wood for cooking purpose. This has brought fast depletion of our forest and therefore increased fuel wood price which imposes

economic and social burden on the people as well as cause ecological problems (Nuhu, 2012).

Electric cookers are excellent source of heat energy, unfortunately the high cost of electric energy generation and distribution added to erratic power supply as constitute obvious drawbacks. Nigeria is readily blessed with abundant solar energy resources which can be conveniently harnessed to fill in the gap. However there is hitherto no serious work done in the country on the development of solar cooking systems considered as excellent alternative heat source to fossil fuel-based cookers (Basil, 2013). Hence inadequate supply of energy restricts socio-economic activities and therefore limits economic growth and adversely affects the quality of life. In view

of the depletion problem, the concept of using solar energy for cooking is given attention worldwide.

Different researches were conducted based on solar thermal technologies for steam generation in their course to develop solar thermal technology as an alternative and most prospective, suitable source of energy for steam and heat production for both domestic and industrial applications. Dahiru *et al.*(2007) in their effort to generate steam using solar energy, carried out the development of paraboloidal concentrating solar cooking with manually tracking device and tested under hazy weather condition at Maiduguri (Borno). Maximum temperature of 91°C was attained during water boiling test.

Muhammad-Sukket *al.* (2010) posited that solar energy technology offers great potential in terms of supplying the world's energy but, however, ascertained that in spite of the world's abundant sunlight, its current contribution to the world is still limited and related the main factor to high initial cost of building the collecting systems. Today solar energy resources play a vital role in providing free and more affordable energy for domestic and industrial applications (Mekhilef *et al.*, 2011). Conversion of solar radiation into useful energy has been practiced for many generations (Kalogirou, 1998). The easiest way of harnessing the solar energy is to directly convert it into useful thermal energy (Chong *et al.*, 2012).

This paper therefore presents a comparative performance analysis of three different designs of parabolic concentrating solar collectors for cooking applications.

2.0 MATERIAL AND METHODS

2.1 Principle of Operation of the System

The developed concentrating solar cooking system was a horizontal axis focusing towards a fixed cooking vessel. The focal point directs the collected sun rays towards cooking utensil placed under very intense sunlight. The system requires tracking the sun as it moves and this was done manually. Solar radiation is focused towards the focal point where the cooking pot is held or placed, the cooker requires frequent adjustment toward the sun. Three basic phenomena are employed in the operation of the system, these involved; 1) When solar radiation strikes the black surface, it changes to infra radiation. 2) When light falls on a shiny surface (transparent surface or object), it is reflected and so can be directed to desired point. 3) 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 are incidence on the reflecting surface of parabolic reflector, the solar energy would be reflected and converged at a line called focal point. The converged solar energy is then absorbed by the cooking vessel which resulted to an increase in temperature that could be transformed as useful energy for cooking heating steaming etc. The amount of which the collector (reflector) concentrates solar radiation is governed by optical property of the surface (Sadiket *al.*, 2013).

2.2 Description and Design Parameters

The construction of the concentrating solar cooking system was made using locally available materials i.e. plywood, plank wood, plane mirror, cooking vessel, thin foil paper and nails. It was carried out at the mechanical workshop of the Sokoto Energy Research Centre, UDU Sokoto -Nigeria.

Three designs of parabolic reflecting concentrating solar cookers were constructed using locally available materials. Performance evaluation of concentrating solar cooking system was carried out using three different types of parabolic reflectors namely; L-shaped, U-shaped and thin foil L-shaped. Each reflector was fixed at 65 cm height from cooking vessel to the reflector during boiling test in order to determine the performance of the system. Both L-shaped and U-shaped parabolic reflectors uses reflective mirrors fixed on a wooden casing while the third system was a thin-foil L-shaped applied on the frame.

The mirror was in rectangular shape of 8 cm x 60 cm and fixed with shiny side surface of mirror facing, which in turns formed the parabolic reflector mirror shaped of L-shaped and U-shaped. While the thin foil paper was pasted on the same size of woody L-shaped parabolic frame of L-shaped parabolic reflector. Focal point of three different reflectors was determined by using equation given by below (Basil, 2013).

$$x^2 = 4fy$$

(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 Measured values of focal points of the three reflectors

Types of reflectors	Total length of the reflector (cm)	Height of parabolic reflector measured from base (cm)	Focal point of the reflector (cm)
L-shaped parabolic reflector	100	30	20.8
U-shaped parabolic reflector	100	40	15.6
Thin foil L-shaped parabolic reflector	100	30	20.8

2.2 Experimental Set Up and Instrumentation

The thermal performance (boiling test) of a concentrating solar cooker was measured and recorded, the efficiency of system using L-shaped parabolic reflector as a concentrator was also evaluated. The instruments used during instrumentation, includes; Mercury-in- glass thermometer to measure the temperature of water, Anemometer to measure wind speed, Digital thermometer to measure varying temperatures and Pyranometer for measuring global, direct and diffuse solar radiations.

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 0.75 kg of water. Different temperature values were measured and recorded at 30 minutes intervals between 10:30 am to 14:30 pm.

The efficiency of the concentrating solar cooker using L-shaped parabolic reflector fixed at 65cm height from cooking vessel to reflector was obtained using the following

equation (Thomas, 1991) and cited by Sadik *et al.*,(2013).

$$\eta_c = \frac{(T_f - T_i)M_w C_w}{dt A I_b} \times 100\%$$

(2)

Where T_i initial temperature of water 44.6°C, T_f final temperature of the water 94.2°C, M_w mass of water contained 0.75kg, C_w specific heat capacity of water 4200J/kgK, d_t time for water rise to desired temperature 30min, A collector aperture area 11.25m² and I_b average solar radiation 790W/m². While for the U-shaped parabolic reflector, T_i initial temperature of water 41.7°C, T_f final temperature of the water 83.5°C and I_b average solar radiation 965W/m². Also for the thin foil reflector, T_i initial temperature of water 45.5°C, T_f final temperature of the water 72.4 °C and I_b average solar radiation 787W/m², The same mass and specific heat capacity of water were used for both U-shaped and Thin foil reflectors as like that of L-shaped parabolic reflector.

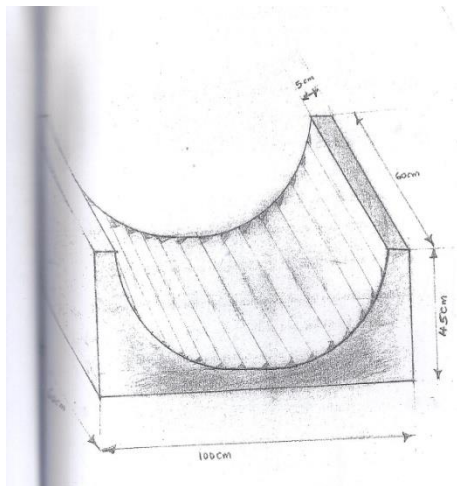


Figure 1 Schematic diagram of U-shaped parabolic reflector

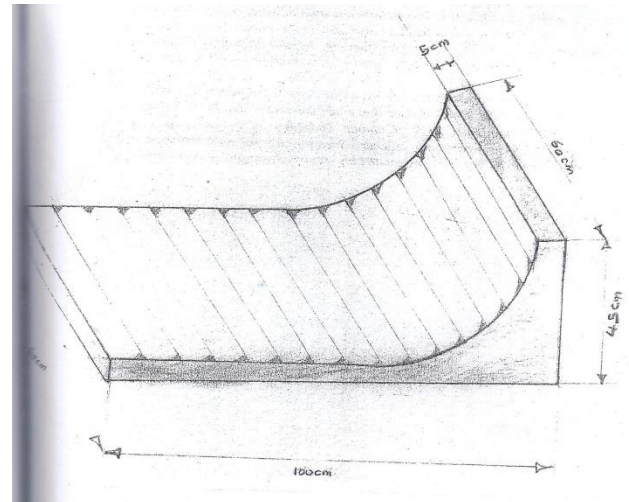


Figure 2 Schematic diagram of L-shaped parabolic reflector

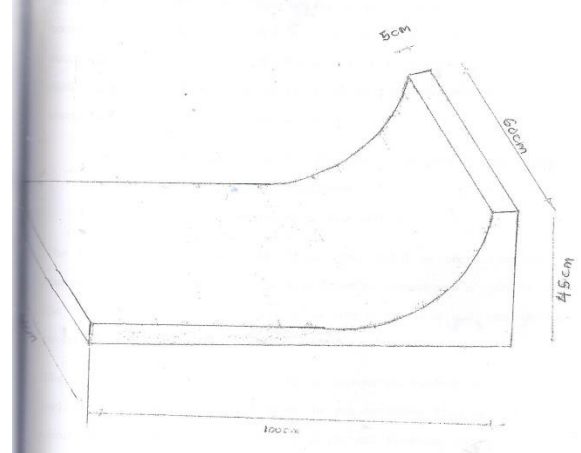


Figure 3 Schematic diagram of thin foil parabolic reflector

3.0 RESULTS AND DISCUSSION

The thermal performance of the three cookers with L-shaped, U-shaped and thin foil parabolic reflectors set at 65cm height from cooking pot to reflector is investigated in this section. The results obtained were reported in Figures 4 to 6.

Figure 4 shows the highest recorded water temperature and the corresponding global solar radiation as 94.1°C and 867W/m² respectively at 14:00pm. This shows the temperature of water T_w and ambient temperature T_a continuously increased to a

maximum temperature value, as the intensity of solar radiation gradually increases.

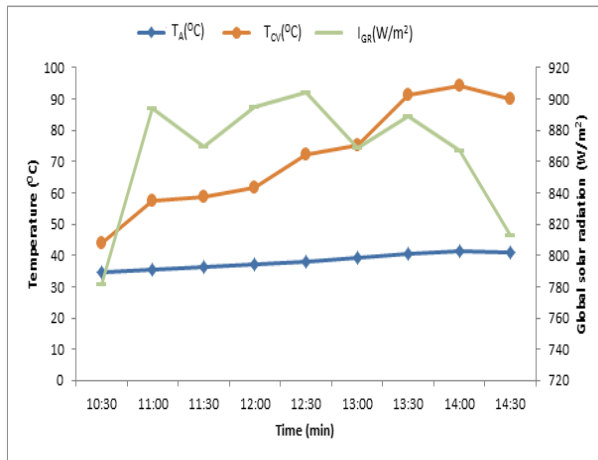


Figure 4: Water temperature variation with time and corresponding global solar radiation of L-shaped parabolic reflector.

Figure 5 shows that, the highest temperature recorded of the water and corresponding global solar radiation were 62.3°C and 797 W/m² respectively at time of 13:30 pm using U-shaped parabolic reflector. The experimental results shows the water temperature T_w and ambient temperatures T_a continuously increased with gradual increase of the intensity of solar radiation, by 14:00 pm the ambient temperature decreased without decrease of water temperature.

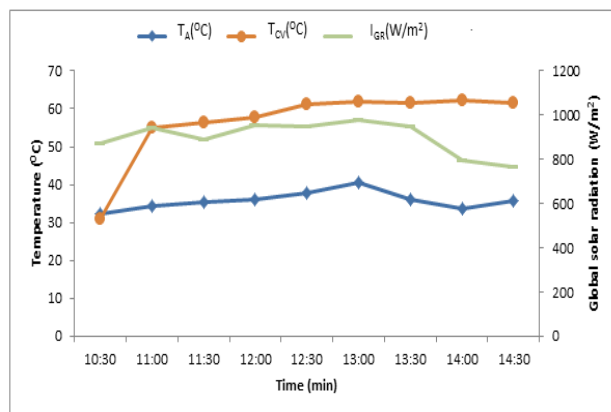


Figure 5: Water temperature variation with time and corresponding global solar radiation of U-shaped parabolic reflector on.

The Figure 6: show that, the recorded temperature of the water T_w and corresponding global solar radiation were 68.5°C and 863 W/m² respectively using thin foil parabolic reflector. This shows the water temperature T_w and ambient temperature T_a was continuously increased with gradual increases of global solar radiation. By 14:30pm both ambient temperature and water temperature decreased to certain temperature values, this could be as a result of cloud cover the intensity of solar radiation.

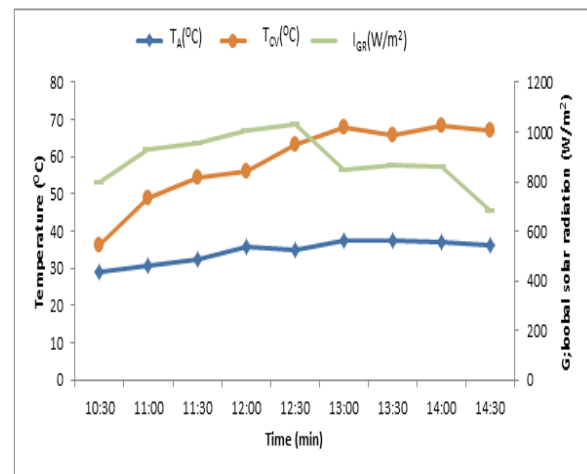


Figure 6: Water temperature variation with time and corresponding global solar radiation of thin foil parabolic reflector.

4.0 CONCLUSION

The experimental test conducted using three 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 about 94.1°C, while 83°C and 75.4°C were the highest temperatures for U-shaped and Thin foil parabolic reflectors respectively.

The experimental results shows that, the parabolic concentrator made up of reflective mirror performed better 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, and the parabolic reflector with high focal point.

Similarly, the results of the focal point obtained for the three systems shows L-shaped parabolic reflectors had the highest value of 20.8 cm. This attributed to the high performance of the system.

5.0 RECOMMENDATIONS

Based on the result obtained by the performance of the system stated in conclusion, the following recommendations were found to be of paramount importance for further work to be done in the area:

Materials with higher reflectivity than mirror and thin foil paper e.g., like a film of metalized 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, therefore this will increase the efficiency of the system. Evacuated tube mechanism of central receiver position to reduce heat loss and optimize heat transfer to cooking vessel. Tracking mechanism would eventually increase ease of operation and the system efficiency.

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