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Thermal Performance Evaluation of the Funnel Solar Cooker of Different Funnel Lengths Implemented in Nagongera, Uganda

Jonah Chepkurui and Saphina Biira*
Department of Physics, Busitema University, P. O. Box 236 Tororo, Uganda
**Corresponding author, e-mail address: bsaphina@yahoo.co.uk*
E-mail co-author: chepkuruijonah@gmail.com

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Abstract

The aim of this study was to evaluate the thermal performance of a funnel solar cooker with different funnel lengths. Four funnel solar cookers of varying funnel lengths were constructed at Nagongera, in Tororo District, Uganda from cheap locally available materials. After construction, four blacked cooking pots of the same size filled with 1 kg of water were each placed in a cooker from 09:00 to 17:00 hrs. The temperature of the water in the pots was recorded after every 2 hours. The maximum temperatures of 93 °C, 84 °C, 68 °C and 58 °C for the funnel lengths of 50 cm, 42.6 cm, 32 cm and 23.3 cm, respectively were achieved at 13: 00 hrs for the average solar intensity of 684 W/m^2 and ambient temperature of 27.9 °C. Similarly, as the funnel lengths increased from 23.3 cm to 50 cm, the thermal efficiency of the cooker increased from to 29.2% to 33.2% due to increased solar collecting surface. This indicates that the cooking temperature and thermal efficiency depended on the funnel lengths of the cooker and the time of the day. The results obtained were suitable and therefore the funnel solar cooker can be introduced to the community.

Keywords: Funnel solar cooker; Thermal performance; Time of the day; Funnel length

Introduction

Uganda, just like other developing countries in the world, has majority of its population depending majorly on wood fuel (firewood and charcoal) and to some extent, non woody fuels such as corn cobs and stalks, plant leaves and livestock dung for domestic cooking. It has been reported that 90% of Ugandan households and institutions use biomass as for cooking and only about 10% use electricity and gas (Ferguson 2012). However, it is important to note that Uganda lies across the equator and it exhibits two main climatic seasons, the wet and dry season. Irrespective of these two seasons, sunshine is received almost throughout the year. This means Uganda is capable of solving the three major challenges the world faces; (i) the continued depletion of fossil fuel reserves (ii) the drastic increase in the environment global pollution and (iii) global warming (Dincer 2000, Balzani et al. 2008).

Solar energy would be the most suitable source of energy to uphold, since it is abundant as it will be there as long as the sun exists (Beltrando 1990, Balzani et al. 2008, Camberlin and Philippon 2002) Therefore, every effort towards developing and implementing technologies basing on solar energy so as to reduce hazards like global warming, pollution, poverty, and diseases are in the right direction. Solar cooker becomes an alternative energy source that can eliminate the dependence on burning of biomass for cooking, thereby saving time and lives, and providing a simple effective way to cooking food and pasteurizing water (Bhutto et al. 2012). There are two potential time-saving elements associated with the use of the solar cooker: Time saving which results from the reduction in wood gathering; and potential time-savings in the actual cooking process (de Lange and Wentzel 2002, Schwarzer and Euge 2008). There are many types of solar cookers available (such as solar ovens, box-type cookers and funnel cookers) and the choice depends on many factors including cost, portability, and durability. (Ouannene et al. 2009). However, limited information is available on the designing, testing and implementation of different categories of solar cookers in Uganda. This may be because they are either expensive for individual families to afford or they are yet to be practically known to the general public.

The parabolic cooker is a reflective dish that concentrates sunlight to a point where the food is cooked. This approach is very dangerous since the sun's energy is focused to a point which is very hot, but which cannot be seen. The parabolic cooker is also a very expensive device (Jones et al. 2005). Whereas the box cooker is basically an insulated box with a glass or plastic lid, often with a reflecting lid to reflect sunlight into the box. Light enters through the top glass (or plastic), to slowly heat up the box. The disadvantage here is that energy enters only through the top, while heat is escaping through all the other sides, which have a tendency to draw heat away from the food. When the box is opened to put food in or take it out, some of the heat escapes and is lost. It has been reported that effective box solar cookers are more complicated to construct than the funnel cooker (Jones et al. 2005, Shukla and Khandal 2016).

To minimize the challenges posed by both the parabolic and the box solar cooker, a funnel solar cooker is the best option (i.e., it is safe, cheap and a more effective cooker). It incorporates the best features of the parabola and the box cooker. It looks like a large, deep funnel (Jones et al. 2005). To make the funnel cooker stable on ground while cooking, the base is made flat by adding a panel and hence the name funnel panel cooker. In this study, the design of funnel solar cooker is discussed. In this case, the solar radiation is funneled so that higher temperatures are easily achieved. When the funnel is pointed directly to the sun, then, most of the radiation entering the funnel is also received by the cooking pot. The funnel solar cooker design has two positions, a low sun position and a high sun position depending on where the pot is positioned. These two pot positions have been investigated to establish the one that gives the highest water temperature.

The funnel solar cooker can be built in one to two hours from a single cardboard box, aluminium foil, a pot, and a bag. However, it can also be used without the plastic bag enclosure if solar intensity is high. This is significant, because traditional solar panel cookers such as the CooKit often require a large sheet of cardboard and a bag for construction (Arveson 2012), hence making it expensive. The funnel can also be adjusted more easily for different sun positions. In these periods of scarcity of cooking fuel and price inflation, the funnel solar cooker will be of great economic help for the family. Though, solar cooking may take longer time if there are increased amounts of fogs, cloud cover or shadows, it is still a good cooking device that need to be considered. The most interesting thing about cooking with the sun is that the food will never get burnt no matter how long it is allowed to cook (Adewole et al. 2015). The environmental pollution from fossil fuels and firewood smoke particles can be minimized if majority of the population use cleaner and environmentally friendly sources of energy such as solar energy.

Materials and Methods

Conditions at the area of study

This study was carried out at Nagongera Campus; Busitema University. Nagongera Campus is approximately 20 km west of Tororo Town. The coordinates of the place are 0.7700 °N latitude and 34.0261 °E longitude (Wikipedia n.d.). Throughout the month of April daytime temperature reached around 27.91 °C with relative daily humidity of around 40.23%. The average wind speed in April was around 1.68 m/s with average solar intensity ranging from 321 W/m^2 at 09:00 hrs (am) to 684 W/m^2 at 13:00 hrs (pm) and the atmospheric pressure of 101.15 kPa. The month of April was chosen because it is one of the months that present the moderate temperatures and sunshine hours in the year at this location. This means if the conditions above can allow the use of the funnel solar cooker, then it can be suitable for use throughout the year. This study was also conducted in order to develop an understanding of the requirements of a successful solar cooker for rural communities in Uganda.

Construction of a funnel solar cooker

In this study, the materials that were used to construct the funnel solar cooker of different funnel lengths are: the cardboard box, aluminium foil, glue, a pair of scissors, marker pens and meter rule. In order to design the funnel solar cooker, standard measurements were done on the card board box using a meter rule and protractor as shown in Figure 1. After drawing the measurements on the cardboard box, it was cut following the solid markings (lines) to come up with the shape of the structure. Two rectangular panels from a cube shaped cardboard box, which had 50 cm sides, were obtained. With a blunt edge of a knife the fold lines were scored to make straight folds. Thereafter, the foil was glued on the cardboard box by spreading glue on its dull side then pressed tightly and smoothly onto one entire side of the cooker. The use of the aluminium foil was to provide a shiny reflecting surface so that all the sun rays and heat falling on it were directed towards the focal point (concentrated). A card box was chosen because it is cheap, readily available and is a poor conductor of heat, thereby allowing the heat trapped inside the cooker to build up.

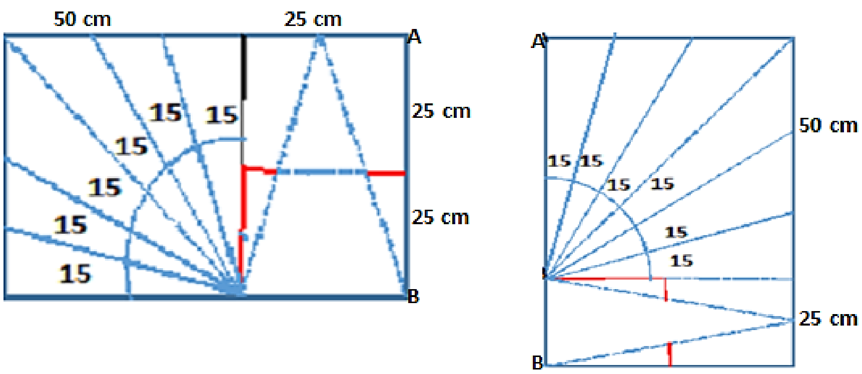

Figure 1: Construction plan of a funnel solar cooker.

After gluing the foil and pressing it, the structure was left flat until dry and then any excess foil was trimmed off. Finally after drying, the structure was folded to give its real shape as shown in Figure 2. The conical reflecting surface of the cooker was made at about 60° to improve its efficiency in capturing sunlight. In this study, four funnel solar cookers were constructed with varying funnel lengths. These were of lengths of 50.0 cm, 42.6 cm, of 32.0 cm and 23.0 cm as shown in Figure 2. Thereafter, cookers were assembled with their shiny surfaces up and placed on a dry, level surface in direct sunshine away from potential shadows.

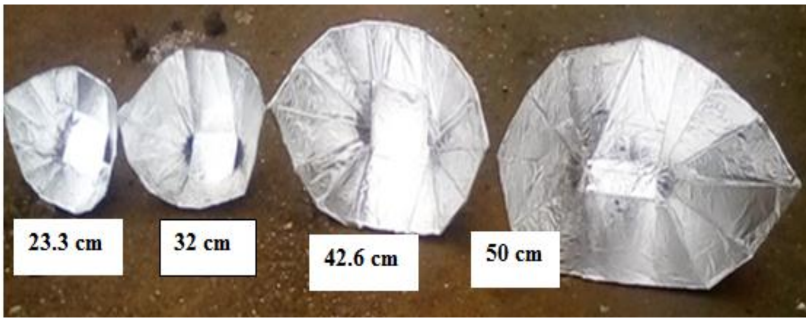

Figure 2: Shapes of funnel solar cookers of different funnel lengths with 50.0 cm, 42.6 cm, 32.0 cm and 23.3 cm.

Cooking in the sun

The positions of the pots in the funnel solar cooker were varied to obtain the best cooking position. The funnel solar cookers were positioned in two orientations towards the sun, a high sun position (Figure 3a) and a low sun position (Figure 3b). To ascertain which of the cooking positions gives the highest temperature of water in the pot, a preliminary experiment was conducted with pots of funnel lengths 50 cm and 23.cm (longest and shortest funnel lengths) on the same day. Blackened cooking pots of the same size were then positioned with their measured content (1 kg of water) into the funnel cookers oriented in the two positions (i.e., the high sun and the low sun positions). The cooking pots and their lids were all painted black to improve their radiation absorption and efficiency. The inside of the cooking pots and the lid were shiny to improve the heat retention by the water.

Figure 3: Cooking in the sun for (a) high sun position and (b) low sun position.

The cooking was conducted from 09:00 hrs (am) to 17:00 hrs (pm). To record the changes in temperature with time, a thermometer was placed in the water and the reading taken after every 2 hours. It was observed that for both cookers (50 cm and 23.3 cm funnel lengths), position (a) achieved the highest temperature than position (b) as shown in Table 1. Therefore, higher temperatures were achieved when the pot was placed at the centre of the cooker which should be corresponding to the focal point of the cooker where the sun rays are concentrated. The temperature of the water in the cooker was raised up to 91 °C at 13:00 hrs due to the direct striking of the surface of the cooker by the sun rays. This means, in position (b) the reflector was less focused and hence there was no continuous, direct sunshine throughout the cooking period. Therefore, the higher sun position (as shown Figure 3a) was adopted for onward experimental investigations in this study.

Table 1: Changes in temperature of water with time of the day in the funnel solar cookers with funnel lengths 50 cm and 23.3 cm at low and high sun positions

Cookers	Funnel length = 50 cm					Funnel length = 23.3 cm				
Time of the day	09:00	11:00	13:00	15:00	17:00	09:00	11:00	13:00	15:00	17:00
Position (a)	35	59	91	80	56	21	35	50	63	31
Position (b)	31	55	80	69	50	20	32	45	59	34

The experiment was then repeated for the 4 cookers of funnel lengths of 50 cm, 42.6 cm, 32 cm and 23.3 cm oriented in only position (a) placed under open sky directed towards the sun. For the assurance of the fact that the reflector surface was fully directed to the sun it had to be observed that the surfaces of the cooking pots have been enlightened on all parts of their outer periphery. After every 2 hours, the cooker was manually tracked for good focusing so as to collect as much radiation as possible at every time the temperature was measured. Apart from comparing the temperature changes with time of the day in each of the cookers of different funnel lengths, their thermal efficiencies were also investigated and compared. As a preliminary study to ascertain the workability of a funnel solar cooker as well as check the variations of temperature with time of the day, the experiments were performed for only three days.

Results and Discussion

Effect of funnel lengths on the cooking temperature

Figure 3(a) shows the changes in average temperature of water in the funnel solar cookers of different funnel lengths with time of the day from 9:00 to 17:00 hrs. It can be observed that, there was a steady increase in temperature from 39.3 °C at 9:00 hrs to 93 °C where temperature was maximum at 13:00 hrs for the cooker of funnel lengths 50 cm, and a steady increase in temperature from 36.3 °C at 09:00 hrs to 84 °C at 13:00 hrs where it was maximum for the cooker of funnel length of 42.6 cm. For the cooker of funnel length of 32 cm, there was an increase in water temperature from 29 °C to 68 °C, and for the cooker of funnel length of 23.3 cm there was an increase from 21.7 °C to 58 °C. After 13:00 hrs, the temperature of the water in all the cookers gradually started decreasing as shown in Figure 3(a). The maximum temperature of 93 °C was achieved at about 13: 00 hrs for the average solar intensity of 684 W/m^2 and average ambient temperature of 27.9 °C (at a high sun position) and reduced with decrease in funnel lengths funnel lengths of the cooker. This indicates that the cooking temperature depended on the funnel lengths of the solar cooker. The longer the length of the funnel of the solar cooker the higher was the cooking temperature.

The water temperature also depended on the time of the day; the heat continuously accumulated throughout the day and therefore the maximum temperature for the day occurred at around 13:00 hrs. At this point of the day, the sun was still high in the sky and continued heating the earth’s surface thereby reducing the relative humidity in the atmosphere and increasing the temperature. After 13:00 hrs, the sun was low in the sky, this means the sun rays travelled long distances in the atmosphere compared to around noon times when the sun was at its highest point. Also, it has been reported that the atmosphere near ground level tends to be mixed in the afternoon due to rising thermals from solar heating (Madronich 1993). The combination of these factors makes the temperatures become reduced in the afternoon as the sun sets. It is important to note that even though the water temperatures started decreasing after 13:00 hrs; still the daily average temperature for the whole measurement time (09:00 to 17:00 hrs) remained high for the funnel length of 50 cm compared to the rest as indicated in Figure 3(b). This is due to increased surface area of funnel solar cooker collecting the sun rays. For all the experimental days, the water temperature was above 60 °C for the solar cookers of funnel lengths of 50 cm, 42.6 cm and 32 cm; a value reported to be the minimum temperature at which food can cook (Adewole et al. 2015). Therefore, the results showed that food could get ready quickly on clear days when longer funnel length cookers are used because the cooking could start earlier than on the partially cloudy day and a very long funnel reflector gathered more light hence making the pot hotter.

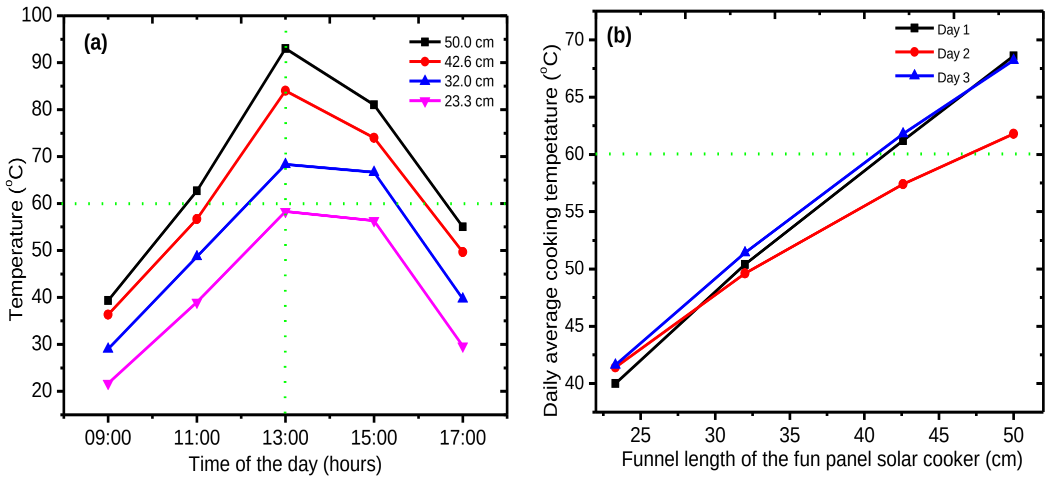

Figure 3: (a) Average water temperature recorded at different times of the day and (b) the daily average water temperature for the funnel solar cookers of different funnel lengths.

Cooker thermal efficiency

The funnel solar cooker heating efficiency of the water in a cooking pot was calculated using Equation (1) (Adewole et al. 2015, El-Sebaii et al. 1994);

$$\eta = \frac{M_W C_W \Delta T}{A_C I_{av} \Delta t} \qquad (1)$$

Where: η is the heating efficiency of the funnel panel solar cooker, M_w = mass of water (kg), $C_{w,}$ = specific heat of water (J/kg/^{o}C), ΔT = temperature difference between the maximum temperature of the water and the ambient temperature of the air, A_c = the area (m^2) of the funnel solar cooker and, Δt = the time it takes to reach the maximum temperature of the water, whereas I_{av} is the average solar intensity (W/m^2) during time interval Δt.

In this case, 1 kg of water (specific heat of water is 4,200 J/kg/°C) was heated for time interval of 2 hours (7200 s) to reach the respective maximum temperature depending on the funnel length. The cross section area of the funnel solar cooker increased with funnel lengths as shown in Figure 4. It can be observed that the thermal efficiency increased from 29.2% to 33.2% as the funnel length increased from 23.3 cm to 50 cm. This may be due to the increase in the radiation collecting surfaces. There is scanty information in the literature about the thermal efficiency of the funnel solar cooker. However, the thermal efficiency calculated for the implemented funnel panel solar cooker in this study competes well with other similar solar cookers (such as the box-type solar cooker) found in the literature and this is an indication of better heat retention ability of the cooker. For a box solar cooker, El-Sebaii et al. (1994) reported thermal efficiency of between 30 and 50%, whereas the thermal efficiencies reported by Balogun et al. (2003) and Currin et al. (1994) were 20% and 30%, respectively.

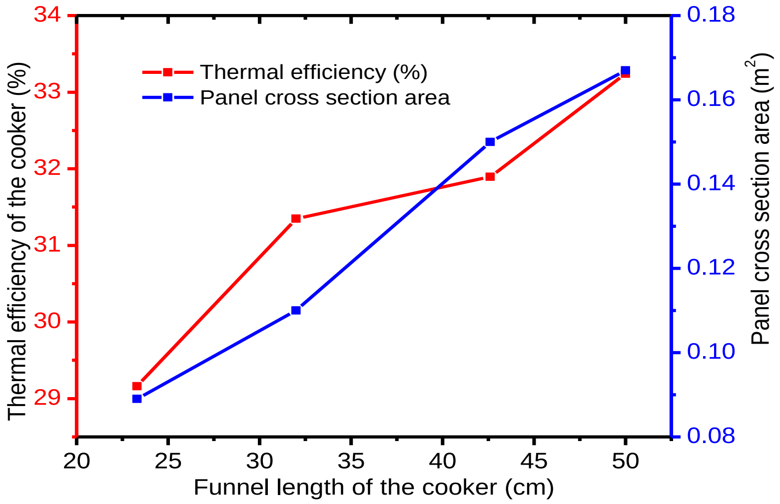

Figure 4: Effect of funnel length on thermal efficiency of the funnel solar cooker.

Conclusion

A cheap, effective and easy to construct funnel solar cooker was constructed and implemented in this study. The technology was made very simple for people with low income and basic or no education in the community to adopt so as to solve the impending problems of scarcity of energy sources for cooking. The rate of temperature gain of water was found to be high with high sun positions compared to the low sun positions. This was because for high sun positions the sun rays could strike at right angles to the surface of the solar cooker, and few sun rays could strike on the surface of the cooker for low sun positions. It was also observed that, the rate of cooking as a function of temperature increased as the length of the funnel of solar cooker was adjusted from 23.3 cm to 50 cm. For all the funnel solar cookers of different funnel lengths, the highest cooking temperatures (93 °C, 84 °C, 68 °C, and 58 °C for funnel lengths of 50 cm, 42.6 cm, 32 cm and 23.3 cm, respectively) were achieved at around 13:00 hrs. It was also found out that the thermal efficiencies increased from 29.2% to 33.2% as the funnel lengths increased from 23.3 cm to 50 cm. Therefore, the longer the funnel length the higher the cooking temperature and thermal efficiency. The funnel solar cookers of lengths above 32 cm positioned vertically upwards are capable of harnessing enough solar energy for cooking.

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