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Design, Fabrication and Experimental Study of Solar Parabolic Dish Concentrator for Remote Area Application

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Abstract

The sustainability of our ecosystem is under threat due to the frequent use of fossil fuel for cooking purpose in the rural communities. Therefore, efforts are being made to replace our existing cooking fuel with renewable energy source. The design fabrication and testing of a solar parabolic dish concentrator for application in remote areas is presented in this paper. The solar concentrator was design and fabricated with low cost available material and skills that can be operate and easily repaired by the users and can be track manually to follow the movement of the sun. The performance test carried out reveals that the concentrator can attain a very high temperature of 180^{o}c for frying oil on a clear sunny day and boiling water of 100^{o}c. The study also reveals that the concentrator can be used for cooking and drying purpose.

Keyword**:** Solar collectors**;** parabolic Concentrator; Solar energy; alternative energy; satellite dish.

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1. Introduction

Energy is considered as a prime agent in the generation of wealth and a significant factor in economic development of any nation, thus the important of energy in economic development is recognized universally [1].

Atmospheric levels of carbon dioxide (CO_2) have increased steadily since the beginning of the industrial revolution and these levels are projected to increase even more rapidly as the global economy grows except if appropriate measures were put in place. Approximately, 65% of the global anthropogenic GHG which is CO_2 comes from energy –related activities. Globally, 89% of primary energy consumed comes from fossil fuels [2]. Cooking and heating is an integral part of each and every human being as food is one of the basic necessities of life. The commonly used sources of energy for cooking and heating process in the rural areas are firewood, crop residue, and cow dungs [3]. The combustion/ burning of these fossil fuels as sources of energy for heating and cooking purpose by the rural communities introduces many harmful pollutants into the atmosphere and contributes to environmental problems like the global warming [4]. According to the World Health Organization (WHO) reports, In 23 countries, 10% of the deaths are due to indoor air pollution due to solid fuel usage for cooking, In under developed countries, women have to walk 2 km on average and spend significant amount of time for collecting the firewood for cooking. The cooking energy demand in rural areas is largely met with bio-fuels such as fuel wood, charcoal, agricultural residues and dungs cakes [3]. To avoid this, alternative renewable energy such as solar energy should be utilized for rural area applications [4].

2. Solar Energy

Solar energy strikes our planet a mere 8 min 20 s after leaving the sun which is 1.5 x 10^{11} m away. The sun's total energy output is 3.8 x10^{20} MW which is equal to 63MW/m^2 of the sun's surface [1]. The world's overall solar energy resource potential is around 5.6 gigajoules (GJ) (1.6 megawatt-hours (MWh)) per square meter per year. The highest solar resource potential is in the red sea area, including Egypt and Saudi Arabia [5]. Solar energy is the most favorable alternative energy which can serve as a substitute for fossil fuel; it is non-polluting source of energy which if properly harness and utilized can help to curtail the amount of CO_2 emitted to the atmosphere due to the combustion of fossil fuel [4]. Widespread use of solar energy for domestic, agricultural and agro-industrial activities has been practice almost since the development of civilization, the increasing threat of acute shortage of the commercial sources of energy coupled with serious environmental pollution problems has accelerated interest in the scientific exploration of renewable sources of energy. It is estimated that the small fraction of solar radiation falling on the earth is equal to the world energy demand for one year [1]

2.1 Solar Technology

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium, it is the major component of any solar energy systems [1]. Different solar energy collectors may be used in order to convert solar energy to thermal energy [6]. Basically there are two types of solar collectors; the non-concentrating or stationary collector and the concentrating collectors.

2.1.1 Stationary solar collector

Stationary solar energy collectors are collectors that are permanently fixed in position and do not track the sun, three set of collectors fall in this category: the flat plate collectors (FPC), compound parabolic collectors (CPC), and the evacuated tube collectors (ETC) single axis tracking and two axis tracking.

2.1.2 Solar concentrating collectors

Solar concentrating collector concentrates solar irradiance for conversion into othe forms of usable energy; it directs solar irradiance from a relatively large collection field and concentrates it to a small receivers area, the concentrating ratio of the area off the collection field to the receiver area [7]. In the types of concentrating collectors, the temperatures far above those attainable by FPC can be reached if a large amount of solar radiation is concentrated on a relatively small collection area. This can be achieved by interposing an optical device between the source of radiation and the energy absorbing surface. Concentrating collectors exhibit certain advantages as compared with the conventional flat-plate types, the categories of collectors that falls under this are; Parabolic trough collector (PTC), parabolic dish collectors (PDC) and Linear Fresnel reflectors [8]. Many studies have been conducted on parabolic dish collector; most of these efforts involve construction of a curved paraboloid support structure fixe with small mirrors or reflecting surfaces to form the paraboloid reflector. Sadaghiyani et al [9] presented a study on two new designs of parabolic solar collectors, the results obtained from the study shows there is an improved efficiency of about 10 % and 20% for linear and convoluted models respectively. A new design approach for solar concentrating parabolic dish based on optimized flexible petals was reported by Lifang and Steven [10]. El Ouederni et al [11] presented an experimental study of a parabolic solar concentrator, the solar flux and temperature distribution on the receiver was carried out, the results describe correctly the awaited physical phenomena. Mohamed et al [12] conducted a study on the design and study of portable solar dish concentrator for medium temperature application, the results shows that the water temperature increases up to 80^{O}C, and the system efficiency increased by 30% at noon time. In this study, the experimental investigation on of parabolic dish collector for domestic application in rural area is investigated

2.1.3 Parabolic Dish Collectors

Using parabolic dishes is a well-tested approach to concentrate solar radiation, and was an early experimental tool at many locations worldwide. The optical efficiency of parabolic dishes is considerably higher than that of parabolic trough, Linear Fresnel reflector or Power tower systems because the mirror is always pointed directly at the sun [13]. In this study, the reflector for the parabolic concentrator is made is made of a mirror; the interior of the parabolic concentrator is covered with the reflective mirrors, which reflect the solar rays on the face of a receiver placed at the focal position of the parabolic concentrator.

2.2 Design of solar parabolic concentrator

In a parabola, all the incoming solar rays from a light source are reflected back to the focal point of the parabola. The solar concentrator was developed using a semi-spherical surface covered with many small sections of mirrors to form a segmented, spherical concentrator. The frame of the parabola was made from a mini dish satellite receiver plate. The solar concentrator takes advantage of all incoming solar radiation and concentrates it at the focus.

. Figure 1 shows the parabolic dish concentrator parameters. The equation for the parabola in cylindrical coordinates is given by:

$$Z = \frac{r^2}{4f} \tag{1}$$

The diameter of the opening parabolic surface is d, and the focal distance of the parabola is f. the surface of this parabola is given by :

$$S = \left\{ \left[1 + \left(\frac{d}{4f} \right)^2 \right]^{\frac{3}{2}} - 1 \right\} \tag{2}$$

The cross-section of the opening is :

$$A = \frac{\pi d^2}{4} \tag{3}$$

To calculate the focal distance, the following equation is use

$$f = \frac{d^2}{16h} \tag{4}$$

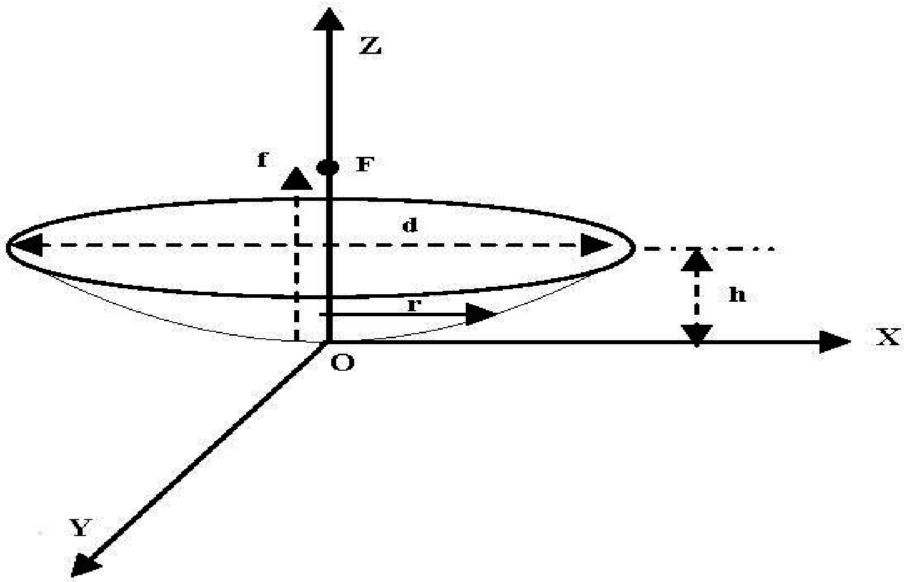

Figure 1: parabolic dish concentrator parameters [11].

Where

h is the height of the dish

d is the diameter of the dish

f is the focal point

F is the load

r is the radius

2.3 Operating principle of parabolic dish concentrators

Concentrators are only a portion of an energy collection system. To be useful, the concentrated rays must be directed to a target called the receiver, which converts the rays into another form of energy, heat. The concentrator and receiver must be matched for optimum performance. For parabolic dish concentrator, the concentration of light is achieved with mirrors (reflection) or with transparent lens (refraction). The solar parabolic concentrator works on the principle of solar energy concentration. A very high temperature can be obtained from the system since the sun's rays are concentrated on the pot which is painted black for good absorption. The solar concentrator is very simple to operate and easy to maintain, the solar concentrator can be oriented manually to face the sun's direction. And the operating period is from 6-8 hours. The operating principle of the parabolic dish concentrator is as shown in figure 2.

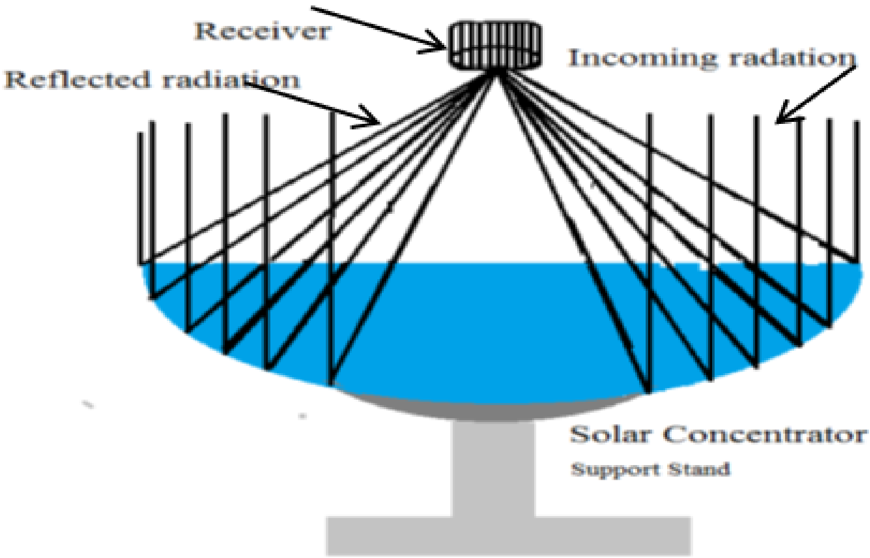

Figure 2: parabolic dish concentrator [12].

The real world application of parabolic solar concentrator is as shown figure 3

Figure 3: application of parabolic solar concentrator for cooing [14].

2.4 Concentrating ratio

The Concentrator ratio CR is use to describe the amount of light energy concentration achieved by a given collector. It is define as the area of the collector aperture A_a divided by the surface area of the receiver A_T. As shown in the equation

$$CR = \frac{A_a}{A_r} \quad (5)$$

Where;

A_a is the area of the concentrator

A_r is the area of the receiver

3. Materials and Method

A satellite dish (mini-dish) of size 55 x 70 cm was used for the construction of the solar parabolic dish concentrating collector. A reflective mirror was cut using a glass cutter into small square pieces of size 4 cm, x 4 cm, these reflective mirrors was used to cover the interior of the concave surface of the satellite dish by using a glue to stick the small square size mirrors to the interior surface of the satellite dish which form the parabolic concentrator. The dish was rigidly supported by mounting it on top of block with the reflecting surface pointing to the direction of the sun. The entire setting was kept on an elevated site. A square of dimension 2 cm was marked out on ground with sub calibration of 1.5cm made to locate the x-y direction. As the rays of the sun falls on the surface of the dish the focus of the reflected rays was located using a plane white sheet of paper. The position of this focus was carefully traced in two dimensions i.e , x and y. using a meter rule. The ambient temperature (Ta) and the temperature of the collector (Tc) was recorded between the hours of 8:30am-4:30pm local time. Care was taken to locate the position of focus accurately.

3.1 Experimental set up

The experiment setup is as shown in figure 4. The set up was place in front of faculty of science; the parabolic dish concentrator was set to move freely in any direction by rotating dish manually. A retort stand was placed in particular direction where the focal point was found during any time of the day. The distance from the focal point to the retort stand is recorded and also the height of the retort stand from the ground is also measured using a meter rule. A calorimeter whose base was painted black was hung on the retort stand; the base of the calorimeter was painted dull black to minimize loss of heat by radiation.

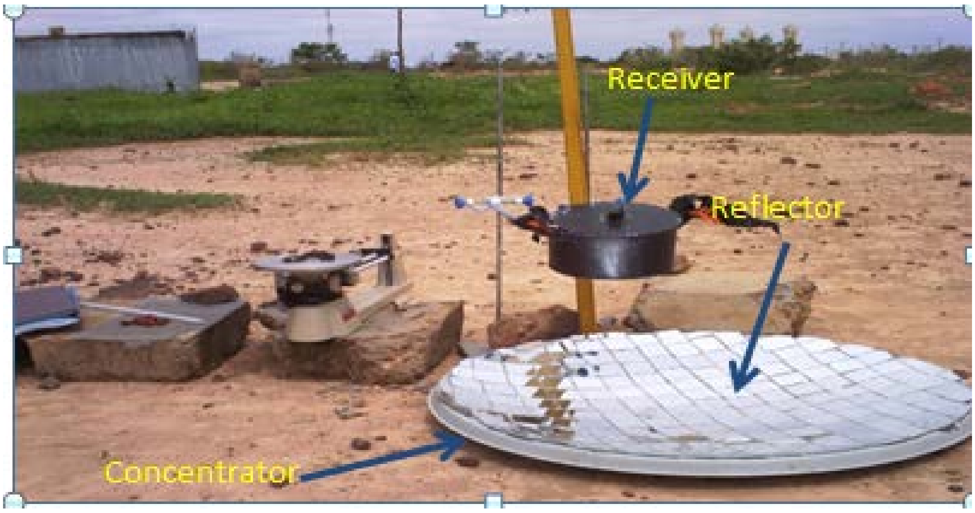

Figure 4: experimental set up.

Two Mercury in glass thermometer were used for recording data collection, one of the thermometers was used for measuring ambient temperature (T_a), and the other for measuring the temperature of the parabolic dish concentrator (T_c). The temperature of the concentrator was taken by inserting the thermometer into the calorimeter, the temperature of the water and the ambient temperature was taken simultaneously at 30 minutes interval.

3.2 Application experiments

Four different experiments were conducted using the solar concentrator in order to test the performance of the concentrator for domestic purpose. These experiments includes, boiling of water, drying of pepper, frying of palm oil and cooking of rice

3.2.1 Boiling water

The content of calorimeter was replaced by a volume of water 0.07cm^3 and mass of 2kg, and was hang on a retort stand positioned at the focus of the dish. The retort stand carrying the calorimeter was adjusted in order to get the real focus of the solar radiation that is reflected from the concentrator. Mercury in glass thermometer was used for measuring ambient temperature at 30 minutes interval. A mercury thermometer is placed in the calorimeter in order measure the temperature of water in the calorimeter. Another thermometer was placed on the immediate surrounding for measuring ambient temperature. It was found that at 12:30pm high temperature was attain up to the level of boiling the water. At 3:30pm the ambient temperature increases to 40^{0}c and temperature of the concentrator increases to 103^0c. The water boils at 100^oc, which is the boiling point of water. The temperature was observed to be decreasing after 4:00pm when the sun is almost getting to set off.

3.2.2 Drying of pepper.

A net was hung on a retort stand, and placed on the concentrator. Two set of fresh pepper of equal initial weight of 14.9g used for the experiment; the weight of this pepper was measured using portable electronic beam balance with respect to time. The Fresh pepper were dried at two different location, one on the top surface of the solar concentrator and the other set was dried on the open space surrounding surface, this is to compare the effects of the concentrator in drying agricultural products. The experiment was setup and the data was recorded. New measurement for the sample was taken at 30 minutes interval each from 8:00am to 4:00pm.

3.2.3 Frying of palm oil.

The content of the calorimeter was replaced by equal volume of red oil. The volume of red oil was measured using measuring cylinder; a mercury thermometer was placed inside the calorimeter in order to measure the temperature of the red oil. The data was collected and recorded after every 30 minutes in order to observe the changes in temperature.

3.2.4 Cooking rice

An aluminum put was used for the cooking purpose, the outside surface of the aluminum pot was painted black, and as black object are good absorbers of heat. 0.30cm^3volume of water was placed inside the pot, and the mass of the water was 2g. The mass of the rice weights 13g. The coated aluminum pot was position at the focus. All the experiment was conducted by manually tracking the sun's ray. The results were recorded at every 30 minutes.

4. Result and Discussion

The results from the various experiments performed using parabolic dish solar concentrator was presented from figure 5-10. Figure 5 shows the plot of ambient temperature (Ta), temperature of the collector (Tc) and time for boiling water. From the figure it was observed that the highest temperature obtained was 103^oc for concentrator and 40^oc for ambient at 3-3:30 pm. Since the boiling point of water is 100 degrees, the water was able to boil at those particular boiling points.

Figure 6 shows the plot of the concentrator temperature (Tc) and the ambient temperature (Ta) for drying pepper, the highest temperature obtained for drying pepper is $85o^c$ at 1:30 pm. Furthermore the plot for the weight of pepper on concentrator and on the open space surrounding surface was presented in figure 7, the figure shows the decrease in weight of the sample with respect to time, from the plot, it can be observed that the pepper dried on the concentrator dry faster than the pepper that is dried on an open space surroundings, the minimum weight of the pepper as at sun set is 3g while that of the open space surrounding 6.8g . It was observed that the weight of the pepper dried on the concentrator reduces almost twice faster than the open space drying thus drying the pepper faster than the surrounding, this confirm the effect of concentrator on the pepper.

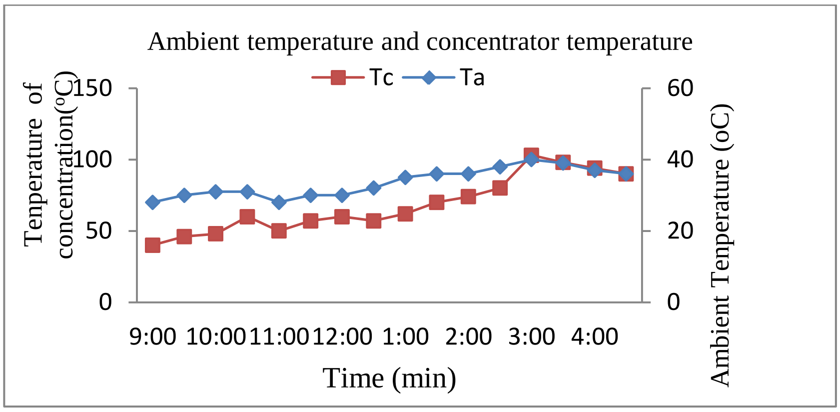

Figure 5: boiling water

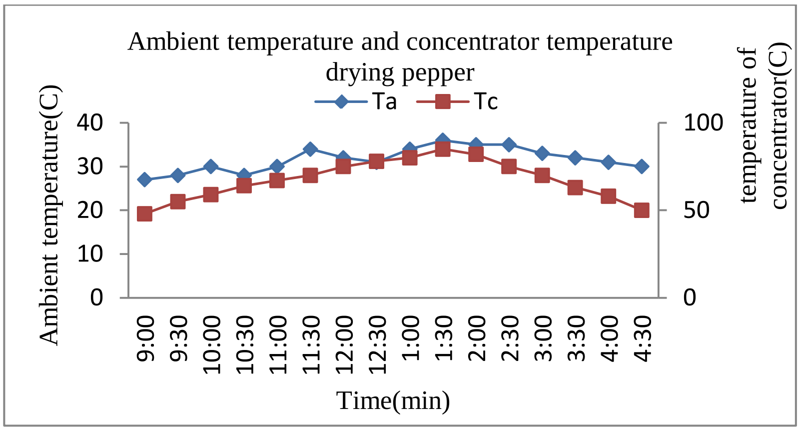

Figure 6: Plot for drying pepper

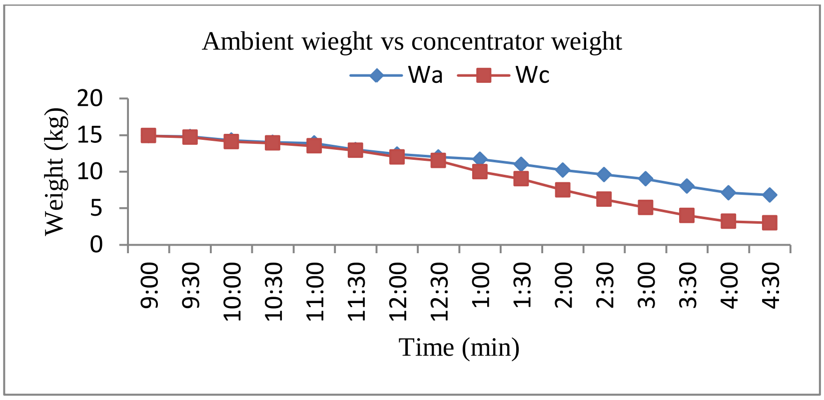

Figure 7: Weight of pepper for ambient temperature and concentrator temperature

Figure 8 shows the plot for frying oil, from the plot one can observed that a very high temperature was attained up to 120^{o}c at 1:30pm with a corresponding ambient temperature of 36^{o}C.

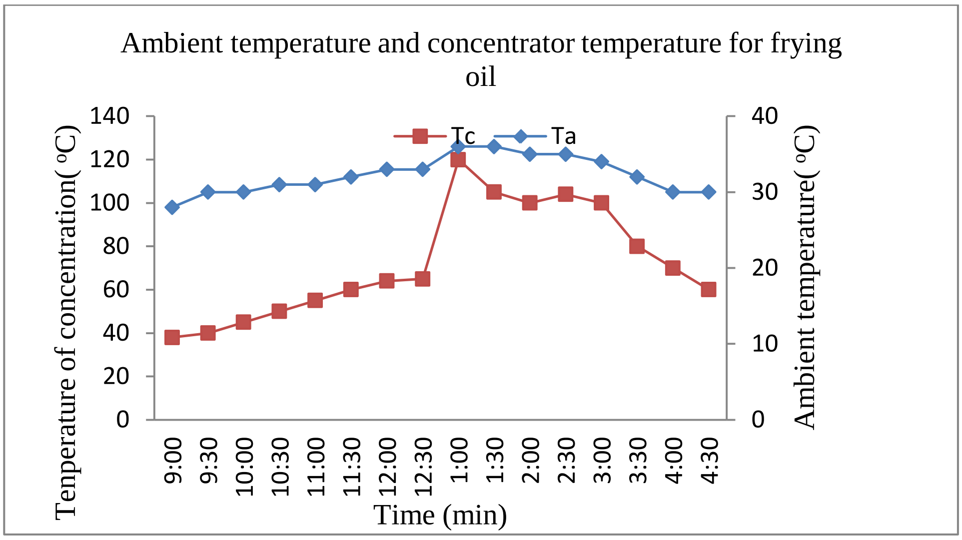

Figure 8: Plot for frying palm oil

The experiment was repeated with frying of meat and the result is as shown in figure 9, from the figure it was observed that high temperature of 186^{o}C was attained which makes it easier for the meat to be fried at 2: 00pm with an ambient temperature of 38^{o}C

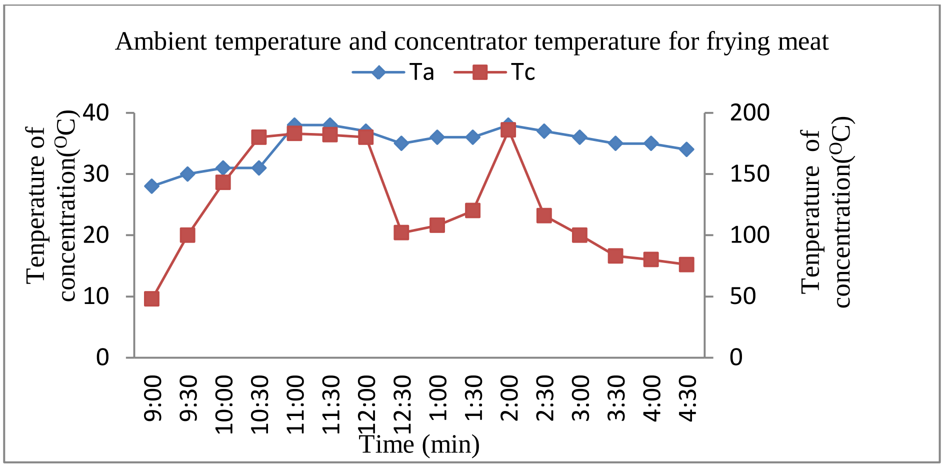

Figure 9: Plot for frying meat

Figure 10 shows the experiment for cooking of rice. From the figure, it was observed that the concentrator was able to attain a temperature of 106^{o}c and the temperature of the surroundings is 41^{o}C. The water started boiling by 11:30am. And the rice got cooked at 12:00 noon.

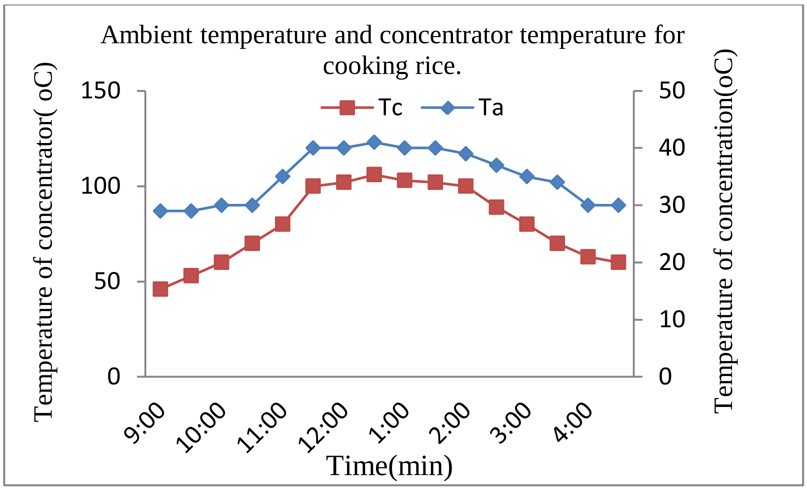

Figure 10: plot for cooking rice

5. Conclusion

In this study, a solar parabolic dish concentrator for rural area application has been designed, fabricated and tested. From the results of the experimental study carried out, one can conclude that the solar concentrator can be adopted as an alternative way for cooking for remote areas. It can attain a temperature of 100^{o}c for boiling water and 180 for frying oil, The use of this technology for cooking purpose in rural areas will reduce the indiscriminate falling down of trees for fuel woods by the rural areas thereby reduce deforestation, the solar concentrator technology will assist in tackling the problem of climate change as solar energy is cheap, readily available, free and environmental friendly as compared conventional fuels used for cooking Purpose.

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