DESIGN AND EXPERIMENTAL ANALYSIS OF SOLAR PARABOLIC TROUGH COLLECTOR SYSTEM – A NOVEL WAY TO TRAP THERMAL ENERGY FOR EFFICIENT COOKING

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ABSTRACT

Human civilization has been witnessing a gradual shift towards cleaner fuels-from wood to coal, from coal to oil, from oil to natural gas; renewables are the present demand. The present work reports the design, construction and experimental testing of a Solar Parabolic Trough Collector (SPTC) System for efficient cooking to reduce the cost of thermal energy. The light energy from the sun is reflecting by reflective sheet in the parabolic trough solar collector. Then it is absorbed by evacuated tube called as absorber which is placed at the focal line of the SPTC. Water is passed to the tube from reservoir through the water hose tube. Inside the evacuated tube, water is starting to boil and converted to steam by continuous focus of reflecting mirror by tracking mechanism. Further, the generated steam is sent to the cooking tank using a separate pipe line. Preliminary test results show that the overall performance of the solar thermal cooker is satisfactory. The SPTC is capable of cooking 3.0 kg of rice within 60 to 90 minutes, and various ingredients within maximum of 45 minutes at peak hours of sun. From the test result and the collector performance, the working model is seen fairly acceptable for thermal energy usage in cooking processes. Physical output indicates that, by using envelope Evacuated Tube Absorber (ETA) in SPTC; high quality steam can be produced for efficient cooking of rice, dhal, vegetables and eggs, etc.

Keywords: Solar Parabolic Trough Collector, Evacuated Tube absorber, Cooking, Tracking

ABBREVIATIONS

SYMBOLS	EXPLANATION
D_I	Internal Diameter of Absorber
D_O	External Diameter of Absorber
L	Length of the Absorber
A_a	Aperture Area
A_p	Absorber Area
C	Concentration Ratio
$\emptyset$	Acceptance Angle
Ψ_{rim}	Rim Angle
F	Focal Length
H	Height of Parabola
m_w	Mass of water flow rate
C_w	Specific Heat Capacity of Water
T_i	Inlet Temperature of Water
T_o	Outlet Temperature
Q	Heat Stored in Receiver

1. INTRODUCTION

Concentrating collectors are of various types and can be classified in many ways. They may be of the reflecting type mirrors or of the refracting type utilizing Fresnel lenses. The reflecting surfaces used may be parabolic, spherical or flat. They may be continuous or segmented. By using reflectors to concentrate sunlight on the absorber of a solar collector, the size of the absorber can be dramatically reduced, which reduces heat losses and increases efficiency at high temperatures. Another advantage is that reflectors can cost substantially less per unit area than collectors. This glass of collector is used for high-temperature applications such as steam production for the generation of electricity and thermal detoxification. These collectors are best suited to climates that have an abundance of clear sky days. There are four basic types of concentrating collectors: Parabolic trough, parabolic dish, Power tower, Stationary concentrating collectors. Parabolic troughs are devices that are shaped like the letter "u". The troughs concentrate sunlight onto a receiver tube that is positioned along the focal line of the trough. Sometimes a transparent glass tube envelops the receiver tube to reduce heat loss. Parabolic troughs often use single-axis or dual-axis tracking. In rare instances, they may be stationary. Temperatures at the receiver can reach 400 °C and produce steam for generating electricity. In California (Fritz 1981), multi-megawatt power plants were built using parabolic troughs combined with gas turbines.

Geographic location plays a vital role in harnessing solar energy. India is located in the equatorial sun belt of the earth, thereby receiving abundant radiant energy from the sun. In most parts of India, clear sunny weather is experienced 250 to 300 days a year. The country has the capacity to receive 4500 trillion kWh of pure solar energy each year. This allows solar energy in India to be a viable option. The highest annual global radiation is received in Rajasthan and northern Gujarat. In Rajasthan, large areas of land are barren and sparsely populated, making these areas suitable as locations for large central power stations based on solar energy.

Cooking is one of the very important and necessary household chores in every society of the world. Energy consumption for cooking in developing countries is a major component of the total energy consumption, including commercial and non-commercial energy sources (Fritz 1981 and Nahar 2009). In the rural areas of most developing countries cooking is usually done in open fires fuelled by firewood. In the cities, stoves are more common, fuelled by wood, charcoal, kerosene and sometimes fuel gas. In many regions, especially East Africa and West Africa (including Nigeria), oil-derived fuels are expensive, and wood-based fuels are becoming increasingly scarce, as rising demand presses hard on dwindling number of trees (Brooks 2006). In developing countries like Nigeria, cooking is the main source of demand for firewood, and is an important cause of deforestation. Solar cookers are divided into four main categories (Sharma 2004): (i) Concentrator cooker; (2) Box cookers; (3) Solar ovens, and (iv) Indirect solar cookers. The concentrating type of solar cookers is further sub-divided into parabolic dish/trough, cylindrical, spherical, and Fresnel. This type of cookers usually employs mirrors/ reflectors to concentrate the total solar energy incident on the collector surface, so the collector surface is usually very wide and the temperature achieved is very high. Parabolic dish/trough cooker has the highest efficiency in terms of the utilization of the reflector area because in fully steerable dish system there are no losses due to aperture projection effects. Also radiation losses are small because of the small area of the absorber at the focus (Rai 2005). Additional advantages include higher cooking temperatures, as virtually any type of food can be cooked and short heat-up times (Siddharth Arora 2011, Soteris Kalogirou et al .1994 & Hank Price et al. 2002).

Ricardo Vasquez Padilla et al. 2011 discussed about design and testing of a solar parabolic concentrating collector. The collector and the receiver can be optimized to the required length for selected power required. The average collector efficiency is about 37% which is fairly acceptable. Joshua Folaranmi 2013 discussed about the performance evaluation of a double glazed solar oven with reflector. The experimental results obtained from the thermal performance tests carried out show that the box-type solar cooker employing a non-tracking solar concentrator could provide improved heat collection and hence efficient cooking. It can therefore be used for fast and effective cooking of various types of foods. Arunachala UC et. al., 2014 explained about the design, fabrication and experimental analysis of solar cooker for night cooking. Compound Parabolic Concentrator (CPC) system has been used for solar cooking and galvanized iron was selected for trough material. They concluded that CPC design and fabrication was good enough to cater to the need of cooking energy and the present innovative non-tracking CPC system can absorb maximum amount of solar radiation throughout the day. Paranthaman 2015 suggested a cost effective Fresnel reflective concentrator to concentrate the solar beam to the bottom of the utensil. This enabled evenly distributed heat to the base of utensils and concluded that the food was cooked uniformly. Adewole O T et. al., 2015 experimentally analysed the thermal performance of a low cost reflectors solar box cooker implemented in Ile-Ife, Nigeria. The average solar radiation and ambient temperature observed during the period of test were 403 W/m2 and 40°C respectively. The highest water temperature of 67°C was occurred at 3.00 pm. They concluded that the experimental results obtained for thermal performance of the cooker demonstrated its suitability for cooking even during fluctuating weather conditions. Elamin O. M. Akoy and Abdalla I. A. Ahmed 2015 fabricated three different types of solar cookers namely; box-type, panel-type and parabolic solar cooker and studied their performance. They concluded that the constructed box-type solar cooker efficiency was found to be superior to parabolic and panel solar cookers. Kulkarni Hrushikesh Bhujangrao 2016 discussed about the design and development of prototype cylindrical parabolic trough system for water heating and it generated hot water at an average temperature of 50°C throughout day by using mild steel as absorber tubes.

Above all literature shows mild steel or copper tube has been used for absorber in concentrating solar collector. In mild steel tube absorber, thermal losses are more. By using of evacuated tube, convection and conduction heat losses are eliminated due to vacuum. Further, no literatures reported about parabolic trough collector for solar cooking process and mostly dealt with box type, solar oven and paraboloid collector system. The present design and fabrication work specially focused on parabolic trough collector system with evacuated tube absorber which is not reported in previous literatures.

2. MATERIALS AND METHODOLOGY

Concentration of solar radiation is achieved using a reflecting arrangement of mirror or a refracting arrangement of lenses. The optical system directs the solar radiation on to an absorber of smaller area which is usually surrounded by a transparent cover. Because of the optical system certain losses are introduced. In order to overcome that losses, Evacuated Tube Absorber (ETA) are used in the present work and it's contain only few losses as compare to transparent cover. The concentrating collector usually has to “follow” or “track” the sun, so that the beam radiation is directed on to the absorber surface. Both manual and automatic tracking system is adopted in the present fabrication. Almost all of them are line-focusing cylindrical parabolic collectors, and yield temperatures up to 400° C. Since collectors efficiency depends on the solar isolation and ambient weather condition, the collector performance depending on the parameters like aperture (W), concentration ratio (C), angle (θ). Four different reflective materials available in the market (glass, highly polished anodized, aluminum sheet, acrylic sheet, and chromium coated sheet) among that, acrylic sheet is selected. A simple parabolic trough collector is designed, fabricated and tested

2.1 Experimental Setup:

2.1.1 Parabolic Trough Collector

From the standard available reflective sheets (Acrylic sheet), a trough-receiver (Fig.3) unit is developed. Acrylic sheet 1m x 1.8m was chosen as reflecting surface. The collector is designed with simple parabolic equations. From geometrical relations of the parabolic section, the cross section for the parabolic trough is traced as shown in Fig.3. The sheet is curved to form a parabolic trough module of 1.8m length and 1m aperture width with effective aperture area of 1.8m^2.

Figure 1 Solar Parabolic Trough Collector System for Cooking

2.1.2 Collector Supporting Structure

For collector stability and accuracy, a rigid supporting structure (Fig.2) is designed. The structure frame is supported to the rotation axis of the parabolic reflecting surface. It used for the rotation of the horizontal axis for daily tracking of the sun. For test purpose and cost reduction, the unit is designed for easy manual tracking (Fig. 3) as well as automatic tracking (Fig. 4).

Figure 2 Collector Supporting Structure

Figure 3 Provisions for Manual Tracking System

Figure 4 Provisions for Automatic Tracking System

2.1.3 Reflective Sheet

The reflective sheet used in the parabolic trough collector is the acrylic sheet coated with magnesium alloy. The reason for choosing the acrylic sheet is it is highly malleable in nature so that it can be easily shaped into a parabolic. An also it is highly reflective in nature and it will not be corroded.

Characteristics of the material

Half the weight of glass

Impact resistant

Unaffected by sun or salt spray

Temperature range of -30 to 160 degrees F for continuous service

2.1.4 Receiver

Evacuated tube collector (Fig.5) is one of the methods used normally for improving the performance of liquid flat-plate collectors is to reduce or suppress the heat lost by convection from the top. This is done by having a vacuum above the absorber plate as a consequence, it becomes essential to use a glass tube as the cover because only a tubular surface is able to withstand the stresses introduced by the pressure difference.

A design is used for domestic water heating. In the design, the evacuated tubes are connected directly to a storage tank. In the present work, water is supplied from storage tank through hose and steam generated from ETA is connected to the cooking tank. The configuration is referred to as the water-in-glass design and is manufactured in china. It is widely used their besides being exported to other countries. The design is reasonable cost effective because of the development of low cost sputtering technique for producing the selective surface on the outer surface of the inner wall. The radiation falling on the absorber surface in the module consists of the beam and diffused radiation falling directly as well as the radiation reflected from the back reflector. Because of the suppression of convection and provision of a selective surface, the overall heat loss coefficient of an ETC is low. Consequently is efficiency is significantly higher than that of a conventional collector at high inlet fluid temperature.

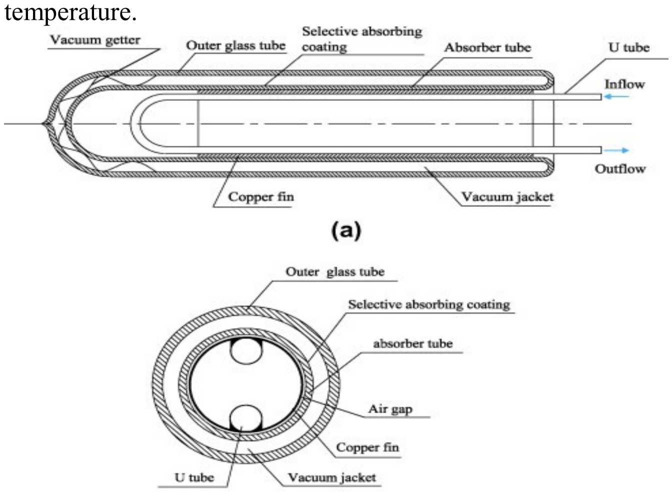

Figure 5 Evacuated tube (a) Side View (b) Front View

2.1.5 Valves

Valves are used to control the flow rate and to open or close the inlet, outlet and storage tank.

2.1.6 Insulation Tank

The insulation tank (Fig. 6) is the place where the outlet steam from the receiver is stored here and cooking has also been done. The tank is covered by the glass wool and it is enclosed inside the outer tank which provides suitable insulation.


Figure 6 Insulation Tank

2.1.7 Working Principle

The experimental setup for testing the collector consists of the constructed collector, 25 liters storage tank, and throttling valve .The storage tank is fixed above the receiver pipe level to allow the heating fluid to flow naturally without pumping system. The storage tank is filled from main water supply and flow is done in an open system. The water inlet and outlet of the absorber tube, the water flow rate and the solar radiation intensity are continually measured during the experiment. The light energy from the sun is reflecting by reflective sheet in the parabolic trough solar collector. Then it's absorbed by ETA. Water is passed to the tube from the reservoir through the water tube. Since line focus is produced at the focal point of the parabolic collector, the water inside the ETA is starting to boil by continues focus of tube and water is converted to steam. Steam has been sent to the cooking tank through the separate pipe line. The concentrating collector usually has to follow or "track" the sun, so that the beam radiation is directed on to the absorber surface. In the present work, both manual and automatic tracking systems (as shown in Fig. 3 and 4) are adopted by designing and fabrication the tracking system as per the procedures given in literatures (Ashish Bhateja et al. 1996, Rhushi Prasad et al. 2010 and George 2006). Manual tilting mechanism can be used to focus the solar at any time to trough.

2.2 Instrumentation

2.2.1 Temperature Measurement

Calibrated K-type (make: LUTRON TM – 902C) digital thermocouple (**Fig. 7**) has been used to measure the absorber surface temperature, glass cover temperature and storage tank temperature. The specifications of the thermocouple is as follows:

Measurement range : -50ºC ~ 1300ºC
Resolution : 0.1ºC
Accuracy :
0ºC ~ 500ºC: 0.75% +1ºC
501ºC ~ 1300ºC: 1% +1ºC
0ºC ~ -20ºC: +2ºC
-20ºC ~ -40ºC: +3ºC
-40ºC ~ -50ºC: +4ºC
Power supply : 1 x 9V 6F22 battery (Included)
Dimension : 102 mm x 71 mm x 23 mm

Figure 7 Temperature indicator with K-type thermocouple

2.2.2 Radiation measurement
Solar radiation received at the earth's surface without change of direction, i.e. in line with the sun is called beam or direct radiation. For the present system, it is measured with the help of a direct radiometer with sunshine duration sensor manufactured by LSI – LASTEM (ITALY).

The C300R model (Fig. 8) represents a low cost direct radiation data acquisition alternative with respect to traditional direct radiometers equipped with an expensive tracking mechanism. It supplies a direct radiation reading and heliophytic status (sunshine referred to a certain threshold). Measurement is made in the visible range, near infrared, to second class WMO pyrometric specifications. Once set up for the latitude and location, the sensor does not require seasonal positioning unless greater precision, accomplished by two annual adjustments, is required. The principle of measurement is the following: a series of sensors detect the illumination of a small sphere that reflects light received from the sky in a 90º annular beam and which has the location's equinoctial line as its equator. A rotating band periodically intercepts the sunbeam. For each rotation, the instrument determines the two radiation levels of the beam, with and without the direct action of the sun disc, and calculates the difference, which gives a good approximation to the direct radiation level. The instrument also supplies the sunshine status, defined as present when direct radiation is above 120 W/m² (WMO standard, 1981).

Figure 8 C300R type direct radiometer with sunshine recorder

The sensor has two actionable heaters: a continuous anti-condensation heater and a thermostatic one for defrosting. In conditions of darkness, the band is stopped and the sunshine status is set to "no". The instrument can be connected to acquisition units, graph recorders and elapsed time counters.
The salient features are as follows,

- Sensitive element: photodiode
- Direct radiation measurement range: 0 - 1500 W/m^2
- Heating: N.2 heaters, the first one continuous anti-condensation, the second one with thermostat for defrosting.
- Accuracy: 5%+5 W/m^2
- Output: contact TTL ON-OFF for sunshine status, 0 - 300 mV for direct radiation
- Power supply: 12 V-DC

2.3 Mathematical Modelling
The simple parabolic equation in Cartesian coordinates is,

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

From equation, the height of the parabola in terms of the focal length and aperture diameter is (Heinz Marty *et al*. 2011 & Ming Qu *et al*. 2006):

$$(a/2)^2 = 4fh \quad (2)$$

The rime angle ψ_{rim} is given by:

$$\frac{\tan\psi_{rim}}{2} = \frac{a}{4f} \quad (3)$$

$$\Psi_{rim} = 90^0 \quad (4)$$

Focal length = A / 4 (5)
Aperture area= length x breath of trough (6)
Absorber tube area = $\pi/4$ x D^2 (7)
Concentration ratio = A_a/A_p (8)

2.3.1 Total Heat Energy (Q)
The total heat energy required for cooking is modelled as follows,

$$Heat_{Total} = Heat_1(q_1) + Heat_2 (q_2) + Heat_3 (q_3) \quad (9)$$

Where Heat required for 1 litre of water to reach boiling temperature,

$$q_1 = M \times C_w \times \Delta T \quad (10)$$

Heat required to convert 100 °C water to 100 °C steam,

$$q_2 = m \cdot \Delta H_v \quad (11)$$

Heat required to convert 100 °C steam to 106 °C steam,

$$q_3 = M \times C_w \times \Delta T \quad (12)$$

2.3.2 Design Specifications

The construction of the cylindrical parabolic collector for cooking is made taking into account following assumptions and specifications:

- Diameter of the sun: 1.39x10^6km
- Average distance of the sun from the earth: 1.5x10^8km
- Radius of the earth: 6400km
- Effective temperature of the surface of the sun 5762K
- The sun's central interior region temperature (estimation): 8x10^6K to 40x10^6K
- Density of the sun: 80 to 100 times that of water
- Solar constant 1353w/m^2
- Extraterrestrial radiation: 1398w/m^2 (maximum) 1310w/m^2 (minimum)
- Geographical location of Madurai: Latitude 9.9300°N Longitude 78.1200°E

The dimensions obtained for the present system based on the design calculations is given in **Table 1**,

Table 1 Design dimensions

ITEM	SAMPLE	VALUE
Length	L	1.8m
Aperture	A	1m
Rim angle	Ψ	90o
Focal length	F	0.25m
Receiver diameter	D	500mm

3. RESULTS AND DISCUSSION

The outcomes of the techniques are considered for the experimental investigations of the present SPTC system. The details of experimental investigation procedure are described in this section. The present experiment setup is tested outdoors at Madurai (9°93'N and 78°12'E).

3.1 Estimation of Solar Intensity

This experimental setup described above has been fabricated, installed and tested at Madurai, Tamil Nadu, India, during March 2015 to April 2015. Madurai is located at 9.93°N, 78.12°E. It has an average elevation of 101 meters. The city of Madurai lies on the flat and fertile plain of the river Vaigai which runs in the northwest-southeast direction through the city dividing it almost into two equal halves. Madurai lies southeast of the Eastern Ghats; the surrounding region occupies the plains of South India containing several mountain spurs. The municipal corporation of Madurai has an area of 147.977 km^2. Madurai is hot and dry for eight months of the year. Cold winds are experienced during February and March. The hottest months are from March to July and readings are taken during this period for the present work. The city experiences a moderate climate from August to October, tempered by heavy rain and thundershowers, and cool and climate from November to February. Fog and dew are rare and occur only during the winter season. Being equidistant from mountain and sea, it experiences similar monsoon pattern with Northeast monsoon and Southwest monsoon, with the former providing more rain during October to December. The average annual rainfall for the Madurai district at large is about 85.76 cm.

Temperatures during summer reach a maximum of 40°C and a minimum of 26.3°C, though temperature over 42°C is not uncommon. Winter temperatures range between 29.6°C and 18°C. A study based on the data available with the Indian Meteorological Department on Madurai over a period of 62 years indicate rising trend in atmospheric temperature over Madurai city, attributed to urbanization, growth of vehicles and industrial activity. The maximum temperature of 42°C for the decade of 2001 – 2010 was recorded in 2004 and in 2010.

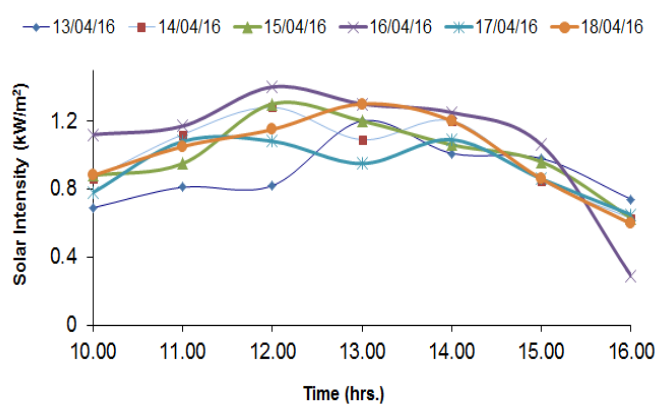

Figure 9 Variation of solar intensity with respect to time for the month of April 2016

Fig. 9 shows the solar intensity variation for the month of April, 2016. The solar radiation is measured for the 6 days i.e. from 13th to 18th of the month to study the behaviour of SPTC system experimental set up.

3.2 Temperature Measurement

The experiment is conducted for SPTC system at three different mass flow rates on clear sunny days. For the temperature analysis, the observations are made during the days of 15th to 17th on the month of April 2016 as explained in above section. The values of the temperature at storage tank (T_{tank}), outlet (T_o) temperature through the tubes, bottom glass temperature (T_c) of ETA and ambient temperature (T_a) are shown in Table 2(a – c).

Table 2 Various temperatures measured in the SPTC system at the mass flow rate of (a) 0.03kg/s (b) 0.025 kg/s (c) 0.02 kg/s during April '16

Time	**T_c (ºC)**	**T_o (ºC)**	**T_{tank} (ºC)**	**T_a (ºC)**
10.00 am	32	42	34	28
11.00 am	38	65	60	31
12.00 pm	42	95	94	39
1.00 pm	48	98	97	38
2.00 pm	50	75	73	34
3.00 pm	60	61	60	34
4.00 pm	61	52	51	35

(a) 15/04/16

Time	**T_c (ºC)**	**T_o (ºC)**	**T_{tank} (ºC)**	**T_a (ºC)**
10.00 am	36	45	37	30
11.00 am	41	67	60	31
12.00 pm	48	98	97	40
1.00 pm	56	98	95	39
2.00 pm	61	73	70	35
3.00 pm	68	64	62	35
4.00 pm	68	56	55	34

(b) 16/04/16

Time	**T_c (ºC)**	**T_o (ºC)**	**T_{tank} (ºC)**	**T_a (ºC)**
10.00 am	37	42	39	30
11.00 am	42	68	66	32
12.00 pm	54	94	93	39
1.00 pm	62	99	98	37
2.00 pm	71	79	78	35
3.00 pm	73	67	64	36
4.00 pm	73	56	53	36

(c) 17/04/16

3.3 Performance of SPTC

It is found that the temperature of water tends to rise rapidly in all cases during start up. However, in most of the cases, it reached a stagnant value around 12.00 pm to 1.00 pm. This stagnant temperature may be assumed to be peak value for all practical purposes. The storage tank temperature is raised to maximum of 98ºC for the mass flow rate of 0.02 kg/s. The range of variation in the storage tank temperature is from 34ºC to 102ºC at different mass flow rates.

Figure 10 Steam generation during rice cooking

The test is done by four different samples like Rice, Egg, Dhal and vegetables. The testing of the solar parabolic trough is done in the month of April 2016 for five days as explained earlier sections. The whole set is placed in an open space in the sun from 10:00am in the morning to 04.00 pm in the evening each day for three to five days. As an example, the steam generated during rice cooking is shown in Fig. 10. The results obtained for every 15 min reading of 4hours cooking everyday are tabulated. Fig. 11 shows the temperature achieved when heating water in the present project work. The maximum temperature achieved during steam formation is 115ºC.

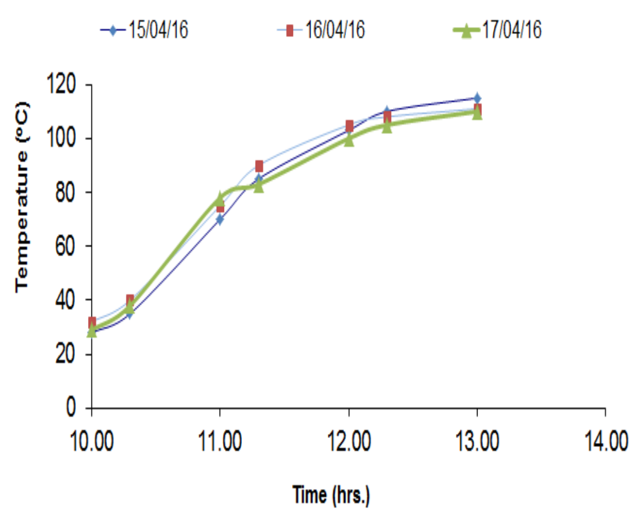

Figure 11: Steam Temperature achieved during solar cooking on the measured days

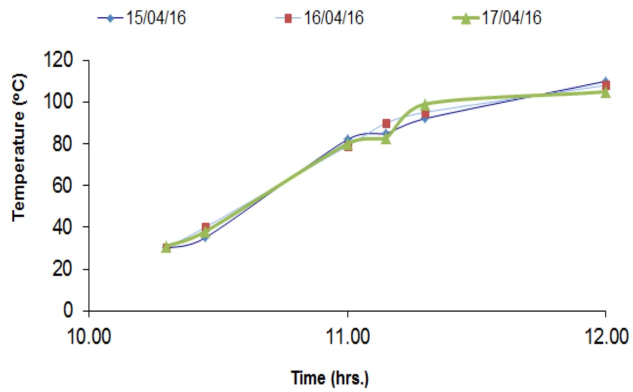

Figure 12: Temperature achieved during Rice cooking on the measured days

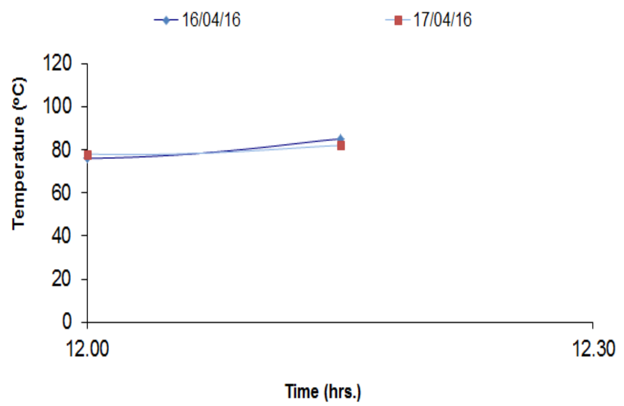

Figure 13: Temperature achieved during Egg boiling on the measured days

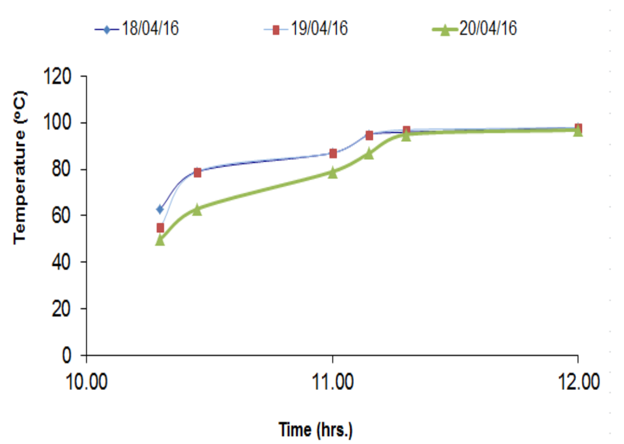

Figure 14: Temperature achieved during Dhal preparation on the measured days

Figs. 12 to 14 shows the time versus temperature achieved during cooking rice, egg and dhal respectively. The maximum time to cook rice is achieved within 60 to 90 minutes. Similarly the maximum time to boil egg is achieved within 20 minutes during peak hour of sun's intensity. Further the time required to boil dhal is achieved within 60 to 90 minutes as similar to rice. The trend of variation of temperature achieved during day time is similar to the trend achieved by Joshua Folaranmi, 2013 and Adewole, B.Z., Popoola, A., Asere, A. A., 2015. The temperature of 110ºC is achieved during peak hour and it is similar to the compound parabolic collector found in the literature (Arunachala U.C., et. al., 2014).

4. CONCLUSION

In conclusions, the need for the construction of solar parabolic trough as an alternative to solve the thermal energy needs of the society. It will also reduce the total dependency on fossil fuels and other non-renewable as such deforestation and other environmental populations are reduced to a minimum. Water boiled faster using the SPTC generator than when using ordinary charcoal or kerosene stove. The need to utilize the free abundant natural resource of energy which is freely in abundance requires no recurrent expenses as other source of energy. Thus, it is regarded as the cheapest source of fuel for man. Based on the result obtained during the test, temperature above 200°C was obtained at base of the absorber. The water temperature values between 60 and 115°C were observed between the hour of 12.00 pm and 2.00 pm with the highest steam temperature of 115ºC at 1.00 pm. The obtained results show that the solar parabolic trough collector system with ETA is a very efficient heating equipment for cooking and thermal heating processes.

REFERENCES

Adewole, B.Z., Popoola, A., Asere, A. A., 2015. Thermal Performance of a Reflector Based Solar Box Cooker Implemented in ILE-IFE, Nigeria, International Journal of Energy and Engineering, 5(5), 95-101.

Arunachala, U.C., Anuj Jhalaria, Sheikh Madhhood, 2014. Design, Fabricaiton and Performance Analysis of Solar Cooker for Night Cooking, International Journal of Renewable Energy and Environment Engineering, 2(4), 288-293.

Ashish Bhateja, Agrawal, V.P., Athre K., 1996. Total Design Concept of springs-A Novel Approach Using MADM, Methodology and Advances in Mechanical Engineering, 401-424.

Brooks, M.J., Mills, I., Harms, T.M., 2006. Performance of a parabolic trough solar collector, Journal of Energy in Southern Africa, 17(3).

Fritz, M., 1981. Future Energy Consumption, Pergamon Press, New York.

George C. Bakos, 2006. Design and construction of a two-axis Sun tracking system for parabolic trough collector (PTC) efficiency improvement, Renewable Energy, 31, 2411–2421.

Elamin, O.M. Akoy, Abdalla, I.A. Ahmed, 2015. Design, Construction and Performance Evaluation of Solar

Cookers, Journal of Agricultural Science and Engineering, 1(2), 75-82.
Hank Price, Eckhard Lupfert, David Kearney, Eduardo Zarza, Gilbert Cohen, Randy Gee, Rod Mahoney, 2002. Advances in Parabolic Trough Solar Power Technology, Journal of solar Energy Engineering, 124 / 111.
Heinz Marty, Elimar Frank, 2011. Investigations on Solar Thermal Process Heat Integration with Parabolic Trough Collectors, ISES Solar Word Congress, Kassel, Germany.
Joshua Folaranmi, 2013. Performance Evaluation of a Double-Glazed Box-Type Solar Oven with Reflector, Journal of Renewable Energy, 183452, 1-8.
Kulkarni Hrushikesh Bhujangrao, 2016. Design and Development of Prototype Cylindrical Parabolic Solar Collector for Water Heating Applications, International Journal of Renewable Energy Developments, 5(1), 49-55.
Ming, Q.U., David H. Archer, Sophie V. Masson, 2006. A Linear Parabolic Trough Solar Collector Performance Model, Renewable Energy Resources and a Greener Future VII-3-3, ESL-IC-06-11-267.
Nahar, N.M., 2009. Design and Development of a Large Size Non-Tracking Solar Cooker, Journal of Engineering Science and Technology, 4(3), 264- 271.
Paranthama, S., 2015. Overcoming the Low Efficiency of Box Type Solar Cookers, Indian Journal of Science and Technology, 8(S2), 82-84.
Rai, G. D., 2005. Solar Energy Utilisation, Khanna Publishers, New Delhi, India.
Rhushi Prasad, P., Byregowda, H.V., Gangavati, P.B., 2010. Experiment Analysis of Flat Plate Collector and Comparison of Performance with Tracking Collector, ISSN 1450- 216X, 40(1), 144 -155.
Ricardo Vasquez Padilla, Gokmen Demirkaya, D., Yogi Goswami, Elias Stefanakos, Muhammad M. Rahman, 2011. Heat transfer Analysis of Parabolic Trough Solar Receiver, Applied Energy, 88, 5097–5110.
Sharma, S. K., 2004. Solar Cookers, Encyclopedia of Energy.
Siddharth Arora, Shobhit Chitkara, 2011. Thermal analysis of evacuated solar tube collectors, Journal of Petroleum and Gas Engineering, 2(4), 74-82.
Soteris Kalogirou, Polyvic Efeftheriou, Stephen Llyod, John Ward, 1994. Low Cost High Accuracy Parabolic Troughs Construction and Evaluation, Renewable Energy, 5(1), 384-386.

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