International Journal of Advanced Scientific Research
ISSN: 2456-0421; Impact Factor: RJIF 5.32
Received: 29-07-2019; Accepted: 30-08-2019
www.allscientificjournal.com
Volume 4; Issue 5; September 2019; Page No. 05-08

Study and experimental analysis of single reflector indoor solar cooker

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Abstract
The development and use of an indoor solar cooking system powered by solar thermal energy is described. The system uses a concentrating evacuated tubular collector to supply thermal energy to a high temperature cooking surface so that heat can be used for cooking in day time. The system incorporates a passive downward energy transfer system between the solar collector and the cooking surface. The cooking system can be installed indoors and the collectors placed on any convenient place, without the need for pumps or thermo syphon loops to transport energy from the solar collector to the cooking surface.

Keywords: single reflector indoor solar cooker, stagnation, boiling, cooking, aperture area of the collector

1. Introduction

In recent years, the general public has become aware that fossil and even nuclear energy sources are of limited availability. Consequently, interest in the use of solar energy and other renewable sources has increased rapidly. The sun does not present the solution to all our energy problems but can however, make a significant contribution to easing the world energy situation without creating additional environmental problems [1].For most of human existence, the cooking of food was unknown. People ate food in the condition in which they found it. Then humans found that fire could be controlled and used to cook food, power is essentially solar power stored in the form of wood. Looking at it this way, solar was the first method of cooking on earth. Many poverty stricken families worldwide spend 25% or more of their income on cooking fuel [2].

Solar energyas a cooking fuel is free and abundant. Money saved can be used for food, education, health care, etc [3]. Solar cooker technology is not conceptually new since different solar cookers have been tested by different researchers over the years at specific geographical locations and under different climate and physical conditions. In fabricating a solar cooker, the heat parameters considered includes heat gain, heat storage and heat loss. Solar cooking is simple, safe and convenient [4].

In this work, a single reflector indoor solar cooker is subjected to three different tests namely stagnation, boiling and cooking to analyze its performance.

Nomenclature

Q_{useful} = rate of useful energy leaving the collector
E_{opt} = rate of optical radiation incident on receiver
Q_{loss} = rate of thermal energy loss from the receiver
m= mass flow rate of heat transfer fluid
cp = specific heat capacity of heat transfer fluid
T_{out} = temperature of heat transfer fluid leaving the absorber
T_{in} = temperature of heat transfer fluid entering the receiver.
I_a = beam normal insolation
A_a = aperture area of the collector
Γ= capture fraction (fraction of reflected energy entering the receiver)
ρ = reflective of any intermidiate reflecting surfaces
ι= transmittance of any glass or plastic cover sheets or windows
σ = absorptance of absorber or receiver surface.
P = Cooking Power (w)
T_2 = Final Water Temperature
T_1 = Initial Water Temperature
m = Water Mass
c_p = Heat Capacity (4180KJ/kg.K)
$I_{measured}$ = Measured insolation averaged over the 30 minute interval.
I = interval average insulation (W/m^2)
P = cooking power (W)
P_s = standardized cooking power (P_s)
T_p = temperature of the absorber plate (stagnation)
T_a = ambient air temperature
H_s = insolation on a horizontal surface (taken at time of stagnation)
M = mass of water
C = heat capacity of water
A = aperture area
t = time
T_{w1} = water temperature at state 1 (initial)
T_{w2} = water temperature at state 2 (final)
H = horizontal insolation (average)

2. Procedures, Materials and Methods

2.1. Materials

The single reflector indoor solar cooker is primarily constructed from plywood, galvanized iron sheet, plane mirror, black paint, aluminum pot, nails, plank wood and cotton wool.

Fully constructed single reflector solar cooker is composed of;

- High temperature solar collector consisting of a non-tracking concentrator with evacuated tubular absorber.
- Passive downward heat transport system to transfer energy from the solar collector to the cooking surface.
- Cooking surface to work with thermal energy input.
- 43-45 litres of water in circulation from collector to cooking surface.
- Inlet and outlet pipes for hot and cool water exchange.

- High-Tech instruments used during the test analysis are pyranometer CMP_3 type, digital anemometer, constantan wire, digital temperature indicator, steel bar weighing scale and clock.

The main cooking surface (of approximately 1ft × 1ft) and collector (of 3ft × 6ft) were constructed separately, but are connected with pipes to facilitate energy transfer. The collector is constructed and installed in such away to receive direct solar radiation.

2.2 Experimental procedures

Stagnation, boiling and cooking tests were conducted to accertain the performance of the cooker. In each of the test carried out, the temperatures of different parts of the cooker (collector's, inlet and outlet) ambient temperature, air temperature wind speed and solar radiation were recorded.
Stagnation test to ascertain temperature output of the system was carried in three consecutive days, where collector's temperature, Inlet, outlet, and ambient temperatures are measured from 9:00 am to 3:00 pm respectively. Boiling tests were also carried out. About $30cm^3$ of water was carefully measured using a measuring cylinder, and the weight of the water determined to be 0.07kg, and poured into the pot. Data logger (thermocouple) was used for measuring ambient temperature (T_a), collector's temperature (T_c) and temperature of the water. Cooking tests were also carried out, the content of the black aluminum pot were replaced by $0.30cm^3$ of water. Fresh potatoes of mass 0.13kg were then submerged inside the water in the pot.
The coated aluminum pot was placed on the cooking surface and one of the data logger terminals was inserted into the pot in order to measure temperature of the potatoes, the second data logger terminal was placed on the cooking surface in order to obtain the collector's temperature, the third terminal is suspended inside the cooking surface in order to get the cooking surface air temperature, while the fourth terminal is used to measure ambient temperature. It was observed that the water started boiling at temperature of 100^oC.Digital temperature indicators with thermocouple (data logger) were used for the temperature measurements. CMP_3pyranometer was used to measure solar radiation in the horizontal plane. A digital anemometer was used for the measurement of wind speed.
Thermal performance testing of the indoor solar cooker was conducted at the Sokoto Energy Research Centre (SERC) Sokoto State (13.0059^0 N, 5.2476^0 E) Nigeria. TheSingle Reflector Indoor solar cooker used in this work is shown in Figure 1.

Fig 1: Single Reflector Indoor solar cooker

2.3 Theoretical formulations

2.3.1 Thermal Energy Balance

The energy balance on a solar collector receiver [5] is given by equation (1)

$$Q_{useful} = E_{opt} - Q_{loss} \qquad (1)$$

The useful energy for a solar thermal collector is the rate of thermal energy leaving the collector, usually described in terms of the rate of energy being added to a heat transfer fluid passing through the receiver, i.e.

$$Q_{useful} = mc_pT_{out} - T_{in} \qquad (2)$$

The rate of optical radiation incident on an absorber/receiver is the direct solar irradiance for a concentrating collector. Since the capture area of the collector may not be aimed directly at the sun, this resource must be reduced to account for the angle of incidence. The incident solar resource then is:

$$E_{inc} = I_aA_a \qquad (3)$$

The solar resource is reduced by a number of losses as it passes through the aperture of the collector to the absorber. The rate of optical energy is therefore the product of incoming solar resource multiplied by a number of factors, ie.

$$E_{opt} = \Gamma\rho\iota I_aA_a \qquad (4)$$

2.3.2 Calculating the Cooking Power

The change in water temperature for each 30minute interval shall be multiplied by the mass and specific heat capacity of the water contained in the cooking vessels. This product shall be divided by the 1800 seconds contained in a 30minute interval as given by [6]:

$$P = \frac{mc_p(T_2 - T_1}{1800} \qquad (5)$$

Equation 5 is then further reduced by normalizing the power obtained to 850 W/m^2 through Equation (3) giving Equation (6).

$$P_n = P\left(\frac{850W/m^2}{I_{measured}}\right) \qquad (6)$$

2.3.3 Testing standards for Solar cookers

Currently, there are three major testing standards for solar cookers employed throughout the world. These standards differ widely in their scope and complexity. These standards are; American Society of Agricultural Engineers Standard (ASAE) S580, Basis for the bureau of Indian standards testing method and European Committee on Solar cooking Research testing standard (ECSCR)
The primary Figure of merit used by ASAE S580 is the Cooking Power, P. This is calculated from Equation (7) given by [7];

$$P = \frac{T_2 - T_1}{600} mc_p \qquad (7)$$

Equation (7) is divided by 600 to account for the number of seconds in each 10-minute interval.

P is normalized to a figure of 700 W/m^2 through Equation (4).

$$P_s = P\left(\frac{700}{I}\right) \qquad (8)$$

P$_s$ is plotted against ΔT and a regression linear regression performed.
For standard reporting procedures, a Temperature difference of 50°C is used (i.e. T$_{water}$-T$_{ambient}$ = 50°C) and the corresponding P$_s$ is reported as the 'Cooking Power' (ASAE, 2003).
The second testing standard considered is based on Thermal Test Procedures for Box-Type Solar Cookers [6]. Two figures of merit are calculated so as to be as independent of environmental conditions (such as wind speed, insolation, etc.) as possible given by Equations (9 and 10).

$$F_1 = \frac{T_p - T_a}{H_s} \qquad (9)$$

And

$$F_2 = \frac{F_1 (MC)_w}{At} \ln\left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - T_a}{H}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - Ta}{H}\right)}\right] \qquad (10)$$

3. Results and Discussion

Table 1 shows the average temperatures for the stagnation, boiling and cooking tests conducted. The results indicated that the outlet temperature was the lowest. Variation has been observed with respect to the temperature of the days on which the tests were conducted. This is an indication that weather is an important factor of temperature.

Table 1: Average temperature readings for each day

Type of test	Date of test (Dec. 2012)		Inlet Temp. (^{0}C)	Outlet Temp. (^{0}C)	Collector Temp. (^{0}C)
Stagnation	19th		49.66^{0}C	28.38^{0}C	38.11^{0}C
	20th		65.71^{0}C	30.87^{0}C	40.29^{0}C
	21st		71.20^{0}C	34.32^{0}C	47.51^{0}C
------	------	Water Temp (^{0}C)	----------	---------	----------
Boiling	22nd	44.90^{0}C	72.76^{0}C	35.20^{0}C	43.73^{0}C
	23rd	53.34^{0}C	73.86^{0}C	35.71^{0}C	47.12^{0}C
----------	-----	Potato Temp (^{0}C)	----------	-----------	------------
Cooking	24th	48.37^{0}C	62.16^{0}C	30.25^{0}C	47.30^{0}C
	25th	57.40^{0}C	70.10^{0}C	36.42^{0}C	58.20^{0}C

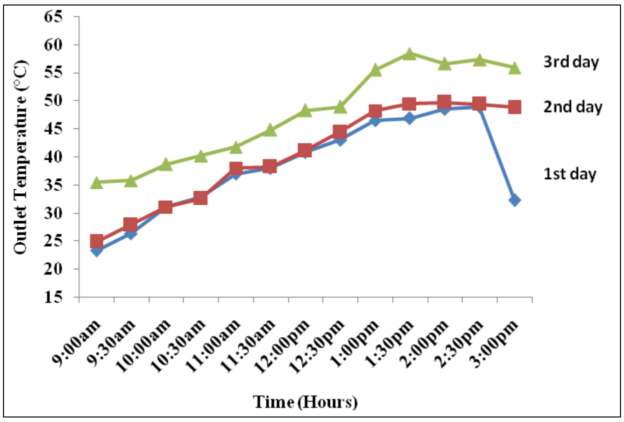

Fig 1: Time versus oulet temperature for stagnation test

Figure 1 shows the relationship between time and the outlet temperature for the stagnation test. It can be seen that the maximum temperatures were attained between the hours of 1.00 pm to 2.30 pm. The lowest temperature was observed on the first day of the test.

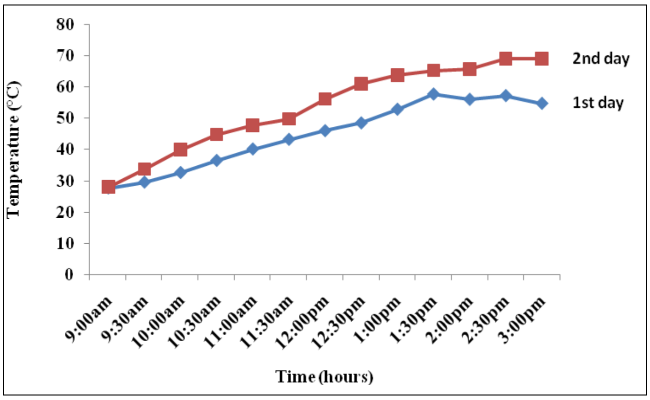

Fig 2: Time versus water temperaturefor boiling testcomductedon1st and 2nddays.

The relationship between time and the temperature for the boiling test has been depicted in Figure 2. There is a constant rise of temperature form 9.00 am to 1.30 pm for the 2 days of the test. It has been observed that typical boiling time is about 1.45 hour.

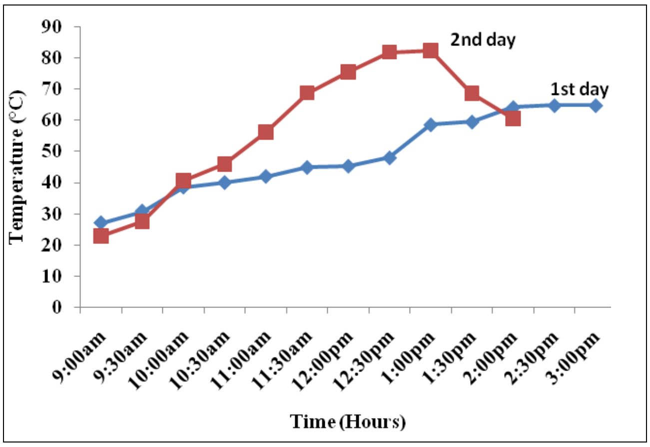

Fig 3: Time versus potato temperature for cooking test on 1st and 2nd days.

Figure 3 shows the relationship between the time and cooking temperature. The highest temperature was attained on the 25th between 12.30 pm to 1.00 pm.. It was observed that the water started boiling at a temperature of 100°c at 12:30 pm. By 1.00 pm the potatoes were done and ready to be served.

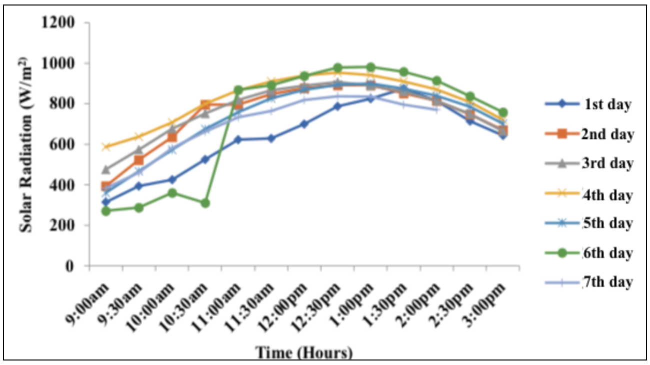

Fig 4: Time versus solar radiation for 7 days.

The relationship between time and solar radiation has been shown in Figure 4. It is observed that the most intense solar radiation is recorded between 12.00 pm to 2.00 pm.

Conclusion

A solar powered hot plate cooking system incorporating a header tank has been developed and demonstrated to have similar cooking characteristics as a conventional box cooker. The solar hot plate has been designed as a direct replacement item of a box solar cooker element that can be used for indoor cooking. The liquid transfer cooking system has been shown to have cooking times similar to box solar cooker for most cooking operations. Stagnation, boiling and cooking tests were carried out to analyze the behavior of thre cooker.

Reference

1. Aman A. “An Analytical Study of a Solar Cooker Augmented with a booster rmirror using PCM Storage”, Energy Conversion and Management. 1985; 25:255- 61
2. Khalifa M, Taha M, Akyurt M. Solar cookers for out doors and indoors,Solar Energy. 1985; 10:829-32.
3. Garg A, Singh P, Singh S, Pandey G. Performance Study of a SolarCooker with Modified Utensils, Renewable Energy. 1999; 18(1):121-9.
4. Chidi CC. Design and construction of a wooden solar box cooker with performance and efficiency test. Journal of Basic and Applied Scientific Research. 2010; 1(7):533-538.
5. William B Stine, Michael Geyer, 1991. Acsessed fromwww.powerfromsun.net 13th February 2018
6. El Sebaii AA. Thermal Performance of a box type Solar Cooker with innerreflector, Energy conversion management. 1997; 22:269-78.
7. Funk PA. Evaluating the international Standard procedure for testing Solar Cookers and reporting performance, Solar Energy. 2000; 68(1):1-7.