ISSN: 0976-3376

Available Online at http://www.journalajst.com

ASIAN JOURNAL OF SCIENCE AND TECHNOLOGY

Asian Journal of Science and Technology
Vol. 16, Issue, 03, pp. 13542-13545, March, 2025

RESEARCH ARTICLE

EXPERIMENTAL STUDY OF THE PERFORMANCE OF A BOX-TYPE SOLAR COOKER WITH FOUR REFLECTORS

DIANDA Boureima[1], OUEDRAOGO Bénéwendé Edwige[2], ÈME Jumelle[1], BAGRE Sara[1], AOUE Safiatou[2], OUEDRAOGO Issaka[1] and BATHIÉBO Dieudonné Joseph[2]

[1]National Center for Scientific and Technological Research, PO: 03 7047 Ouagadougou 03, Burkina Faso
[2] Thermal and Renewable Energy Laboratory, Joseph KI-ZERBO University, PO: 03 7021 Ouagadougou 03, Burkina Faso

ARTICLE INFO

Article History:
Received 17th January, 2025
Received in revised form
19th January, 2025
Accepted 27th February, 2025
Published online 24th March, 2025

Keywords:

Solar cooker, box type, reflector, merit factors, efficiency

ABSTRACT

Cooking is a transformation technique (preparation) by exposure to heat. This heat generally comes (in our regions) from wood, thus causing deforestation. To this can be added diseases due to the soot produced during the combustion of wood. The sun, this source of available and free energy can be used to replace wood for cooking. The development of solar cookers is proving to be a necessity for countries with strong sunshine. This work consists of setting up a solar cooker type reflector box and determining its performance in the city of Ouagadougou. In order to determine the performance of the cooker, readings were taken empty and loaded. These readings concerned the temperatures of the ambient air, the air in the cooker of the absorber and the water as well as the solar flux. From these measurements it can be seen that the absorber temperature reaches about 140°C, the water temperature reaches about 90°C and the air inside the oven reaches about 91°C under a sunshine of about 765 W/m ^{2}. The merit factors F1 and F2 gave values of 0.152 and 0.42 respectively. The estimated efficiency is about 32.66%. These values testify to the performance of the designed cooker.

Citation: ***DIANDA Boureima et al.* 2025.** "Experimental study of the performance of a box-type solar cooker with four reflectors", *Asian Journal of Science and Technology*, 16, (03), 13542-13545.

INTRODUCTION

The planet Earth receives about 3.85 million EJ of solar energy annually (Johansson TB *et al*, 1993). Solar energy can be used for several purposes. Among the thermal applications of solar energy, solar cooking is considered as one of the simplest, most viable and attractive options in terms of solar energy use (Lahkar PJ et al, 2010). In developing countries especially in Africa and India, wood is still the main source of energy used for cooking. This situation is the cause of deforestation (Toonen HM, 2009). In addition to this, it is necessary to note the efforts or difficulties in accessing firewood. Indeed, people (especially in rural areas) have to travel a great distance every day to collect this firewood. Also in cities wood is expensive, butane gas subsidized by some states remains inaccessible for poor families. In addition to the environmental and economic burdens of using firewood, there are serious health problems such as burns, eye disorders and lung diseases. Developing countries have a very significant solar potential because solar radiation is between 5-7kWh/m2 / day and with more than 275 sunny days in a year (Muthusivagami RM et al, 2010; Nahar NM, 2003). Based on these facts, it can be easily said that solar cookers are a solution to the energy demand especially in the domestic sector. In addition, the use of solar cookers offers many advantages such as no recurring cost, high nutritional value of food, reduction of lung diseases, reduction of chores and high sustainability (Muthusivagami RM et al, 2010). This is how researchers have developed and studied several types of solar cookers, some of which we will present. Suhail Zaki Farooqui Suhail Zaki Farooqui, 2015, has realized box type double mirror solar cookers having three different aspect ratios. He shows that fully loaded box type solar cookers with two auxiliary mirrors inclined at suitable angles become optimal with an aspect ratio of 2.66. AA EL-Sebaii et al 1994 have designed and constructed a box type solar cooker with multi-level internal reflectors. They have been able to show that the cooker can be used three times a day in summer and twice a day in winter for consecutive cooking with an overall utilization efficiency of about 30%. A. Soria-Verdugo, 2015 studied experimentally and numerically a box-type solar cooker. The results obtained showed good performance of solar cookers in developing countries.

Harmim *et al*. 2012, designed a box-type cooker equipped with an asymmetric compound parabolic concentrator as a reflector-amplifier. The results of their numerical study showed good performance of this cooker which could be easily integrated into the building facade. Tariku Negash Demissie et al, 2024 studied a foldable solar cooker. Their study showed that the average cooking powers were estimated at 26.0 W for the water tests with the glass enclosure and 31.8 W for the empty tests. The average cooking times for tomatoes, rice and potatoes were always less than two hours. Hailemariam M. Wassie et al, 2022 experimentally studied the effect of different reflectors

Corresponsding author: DIANDA Boureima,
National Center for Scientific and Technological Research, PO: 03 7047 Ouagadougou 03, Burkina Faso

(reflectorless, aluminum foil reflectors, and mirror glass reflectors). The results showed that mirror glass reflectors exhibit the best performance. Alan W. Bigelow et al, 2024 tested different solar cookers and obtained efficiencies of 18.9% for the box type cooker, 28.5% for the reflective panel solar cooker, 35.2% for the parabolic reflector and 34.6% for the evacuated tube solar cooker. The sun is an intermittent source of energy. To overcome this intermittency of the sun, researchers such as C. Thirugnanam et al, 2020; Nahar. M, 2003; A Mawire et al, 2010 have added a storage system to the solar cooker. Others like Prasanna UR et al, 2011; Mekonnen BY et al, 2018; Saxena A et al, 2018; Joshi SB et al, 2015 have coupled another heat source to the solar cooker. Of all these works, box-type cookers are the most used because of their simplicity and good efficiency, hence our choice of this type of cooker. Although the literature presents box-type cookers equipped with reflectors, the number of reflectors is generally less than four. This work consists of experimentally carrying out and determining the performance of a box-type solar cooker equipped with four reflectors in the city of Ouagadougou. We will present in the following section the experimental device and the measuring equipment. In the third section we will present the results and a conclusion.

MATERIALS AND METHODS

The experimental device: It is an experimental device made with simplicity and easily accessible parts. It consists of a frame (box shape) made of wood, a box lined with internal reflectors, a window that covers the box to promote the greenhouse effect, four reflectors made of aluminum film that return solar radiation to the inside of the cooker and an insulator made of cotton fiber. The bottom is a black painted metal acting as an absorber. Figure 1. Shows the box-type solar cooker studied

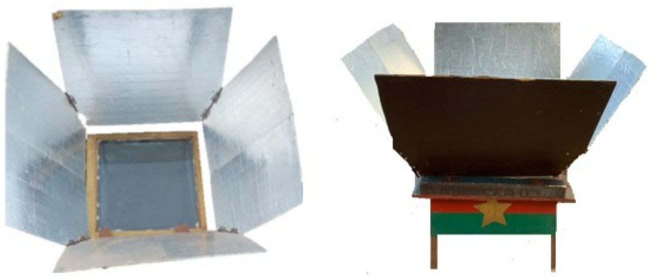

Figure 1. Photo of the box-type solar cooker with four reflectors

Measuring devices

Temperature and sunshine readings are taken to determine the performance of the device. The temperatures are recorded by a GL220 brand data logger with ten (10) output channels on which type K thermocouples are fixed.

Figure 2. GL220 midi logger type datalogger

The solar flux is measured by a pyranometer. The pyranometer is also connected to the datalogger.

Figure 31. The pyranometer

Mathematical Formulation: The difficulties in evaluating many solar cooker designs have led to the establishment of three major testing standards for their evaluation worldwide. They include: American Society of Agricultural Engineering (ASAE) Standard S580, the standard developed by the European Committee for Solar Cooking Research (ECSCR) and the Bureau of Indian Standards, based on the work (Mirdha, US et al, 2008). Although all three standards have their shortcomings, the Indian standards provide testing standards based on thermal testing procedures for box type solar cookers. The performance of the solar box based reflector cooker implemented in this study was carried out based on the Indian standard, IS 13429:2000 (Ayoola, MA et al, 2014). The standard highlighted two testing methods: a stagnation test (no-load test) and a load test.

Thus two figures of merit and an efficiency were calculated in order to determine the performance of the cooker.

The first figure of merit F1

The first figure of merit of the box type cooker is defined as the ratio of the optical efficiency of the cooker (η_0) and the total heat loss coefficient (U_L) [22].

$$F1 = \frac{\eta_0}{U_L} \tag{1}$$

Experimentally (F1 in Km^2W^{-1}) is determined by the following expression:

$$F1 = \frac{Tps - Tas}{I_s} \tag{2}$$

Where T_{ps}, T_{as} and I_s denote respectively the stagnant temperature of the absorber, the ambient temperature at stagnation and the intensity of solar radiation.

The second factor of merit: The second figure of merit is evaluated under load and is given by the following expression:

$$F_2 = \frac{F_1(M_eC_e}{At} ln\left\{\frac{1-\frac{1}{F1}(\frac{T1-Tas}{Is})}{1-\frac{1}{F1}(\frac{T2-Tas}{Is})}\right\} \tag{3}$$

With F_1 the first figure of merit, M_e the mass of the water (kg), C_e the specific heat of the water in (J/kg°C), Tas the average ambient temperature (°C), I_s the average solar radiation captured on the glass (w/m ^{2}), T1 the initial temperature of the water (°C), T2 the final temperature of the water, A the surface of the glass (m ^{2}) and t the time difference between T2 and T1 in (s).

The cooker's performance: The overall thermal efficiency of the solar cooker is given by the following relation (Khalifa, AM A et al, 2005; Olwi, I et al, 1993; El-Sebaii et al, 2005):

$$\eta = \frac{M_e C_e \, \Delta T}{A \, Is \, \Delta t} \qquad (4)$$

Where ηrepresents the overall thermal efficiency of the solar cooker, Me the mass of water (kg), Ce the specific heat of water (J / kg / °C), ΔT the temperature difference between the maximum temperature of the cooking fluid and the ambient air temperature, A the opening surface (m^2) of the cooker, Δt the time required to reach the maximum temperature of the cooking fluid, I_S the average solar intensity (W / m^2) during the time interval Δt.

Experimental protocol: Two types of tests were carried out, namely no-load tests and load tests. The load test consists of heating the water. Before the no-load test, the cooker is cleaned and oriented according to the sun. The thermocouples are placed on the absorber, in the cooker enclosure and in the ambient air. The datalogger is set to a time step of five (05) minutes for data recording. For load testing, the same arrangements as above are made and another thermocouple is placed in the water to monitor its temperature over time.

RESULTS AND DISCUSSIONS

No-load test: The first experiments were carried out in empty conditions. They consisted of determining by experimental measurement the stagnation temperatures of the absorber, the air inside the cooker and the ambient air. The solar flux was also recorded. The values of these parameters are shown in Figure 4.

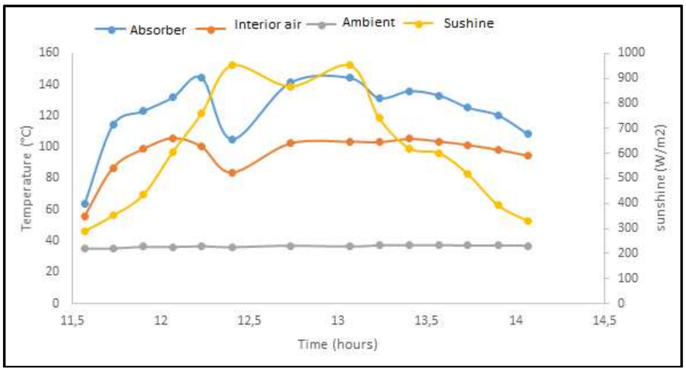

Figure 4. Evolution of temperatures as a function of time and sunshine

We note a very similar general appearance of the temperatures of the absorber and the interior air. These appearances are close to that of the sunshine. These temperatures are therefore a function of the sunshine.The highest temperature values are those of the absorber. The maximum temperature of the absorber is about 140°C. This value is higher than those obtained by A. Soria et al (125°C) and AA .El Sebaii et al (130°C) with a single reflector cooker.In the operating principle of a solar cooker the temperature of the interior air is very important. Indeed it is this temperature which is largely responsible for cooking.In our vacuum device the stagnation temperature of the air is about 100°C.The ambient temperature, fairly constant, revolves around 37°C. All these temperatures were obtained under sunshine quite influenced by bad weather conditions, as evidenced by the low values at the beginning of the experiment and the drops in values. The sunshine of the day evolves globally in a bell shape. The maximum value reached by the sunshine is approximately 950W/m ^{2}. Unfortunately a slight drop is around 2 p.m. already the sunshine measured only 330W.m $^{-2}$

Load test: The load test consisted of heating one (01) kg of water. During this test different temperatures were recorded, as well as the solar flux. Figure 5 shows the changes in the temperatures of the ambient air, the absorber, the water, the air in the cooker and the sunshine received on the site.

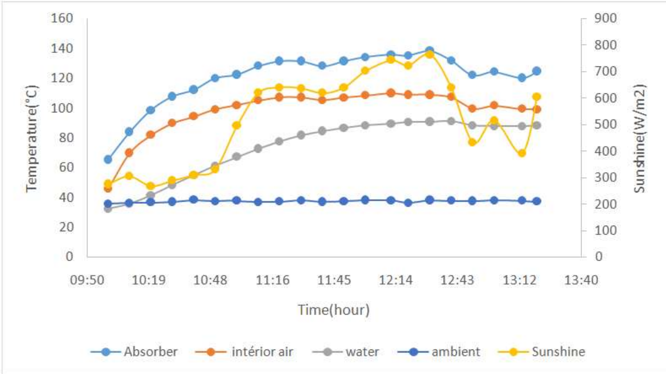

Figure 2. Curves of temperature evolution as a function of time with 1kg of water

The sunshine of the day was disturbed by cloudy passages. This explains its growth and decrease patterns. The maximum value reached this day is approximately 765W/m$^{2.}$ The ambient temperature is almost constant throughout the day. The temperatures of the water, the absorber and the indoor air evolve in the same way. Indeed, once the rays are absorbed at the absorber and transformed into heat, it will transmit its heat to the water (via the container) and to the indoor air. The stagnation temperatures of the water, the absorber and the indoor air have respective values of 91.2°C, 138.5°C, and 109°C.

Device performance

Merit factors: The first figure of merit F1 was determined by equation (2).We obtain F1 = 0.158. Our first figure of merit is higher than that of the commercial box cooker whose F1 is between 0.11 and 0.12. According to the Indian level a cooker is efficient and classified as level A if F1 is greater than 0.12 otherwise it is classified as level B (Negi, BS et al, 2005).

The second factorof merit: The second figure of merit is related to the heat transfer capacity. To calculate it we use equation (3). We found a second figure of merit F2=0.435. The criterion to evaluate F2 by the Indian standard is that F2 is greater than 0.42 (BZ Adewole et al, 2015). Our F2 value of 0.435 obtained in this study shows the performance level of our cooker.

The cooker's performance: The thermal efficiency is determined by equation (4). We obtained an efficiency of 32.66%. This efficiency is that of a fairly efficient cooker. It is better than those of some cookers in the literature presented in the introduction.

CONCLUSION

In this work we have made a box type solar cooker. The cooker is equipped with four reflectors in order to increase the solar intensity in the cooker. An experimental study was conducted in order to determine the performance of the cooker. The merit factors F1 and F2 were calculated. Their values show according to the Indian standard that the cooker is efficient. The efficiency of the cooker is estimated at 32.66%. The box type cooker developed and studied therefore has good thermal performance.

REFERENCES

A Mawire, M. McPherson, RRJ van den Heetkam. Discharging simulations of a thermal energy storage (TES) system for an indirect solar cooker. *Solar Energy Materials and Solar Cells.* 2010. 94(6): 1100-1106

A. Harmim, M. Merzouk, M. Boukar, M. Amar.Mathematical modeling of a box-type solar cooker employing an asymmetric compound parabolic concentrator. *Solar Energy.* 2012; 86:1673–1682

A. Soria-Verdugo. Experimental analysis and simulation of the performance of a box-type solar cooker. *Energy for Sustainable Development* 2015; 29:65–71

AA EL-SEBAII, R. DOMANSKI, and M. JAWORSKI. Experimental and theoretical investigation of a box-type solar cooker with multi-step inner reflectors Energy 1994; 19(10):1011–21

Alan W. Bigelow, Justin Tabatchnick, Caitlyn Hughes. Testing solar cookers for cooking efficiency. *Solar Energy Advances.* 2024.4; 100053

Ayoola, MA, Sunmonu, LA, Bashiru, MI and Jegede, OO Measurement of net all-wave radiation at a tropical location, Ile-Ife, Nigeria. Atmósfera, 2014, 27(3);305-315.

BZ Adewole, OT Popoola, AA Asere. Thermal Performance of a Reflector Based Solar Box Cooker Implemented in Ile-Ife, Nigeria. *International Journal of Energy Engineering* 2015, 5(5): 95-101.

C. Thirugnanam, S. Karthikeyan, and K. Kalaimurugan, "Study of phase change materials and its application in solar cooker," Mater. Today Proc., 220(33): 2890–2896

El-Sebaii, AA and Ibrahim, A. Experimental testing of a box-type solar cooker using the standard procedure of cooking power. *Renewable Energy.* 2005.30: 1861-1871.

Hailemariam M. Wassie, Muluken Z. Getie, Mulat S. Alem, Teshome B. Kotu, Zelalem M. Salehdress. Experimental investigation of the effect of reflectors on thermal performance of box type solar cooker. Heliyon.2022; 8 e12324

Johansson TB, Kelly H, Reddy AKN, Williams RH. Renewable energy sources for fuels and electricity. Earthscan Publications Ltd. and Island Press; 1993.

Joshi SB, Jani AR. Design, development and testing of a small scale hybrid solar cooker. *Sol Energy* 2015; 122:148–55.

Khalifa, AM A, Taha, MM A, Akyurt, M. Solar cookers for outdoors and indoors. *Energy,* 2005; 10(7): 819–29.

Lahkar PJ, Samdarshi SK. A review of the thermal performance parameters of box type solar cookers and identification of their correlations. *Renew Sust Energy Rev* 2010; 14:1615–21.

Mekonnen BY, Hassen AA. Design, construction and testing of hybrid solar-biomass cook stove. Advances of Science and Technology. 6th EAI International Conference, ICAST 2018.

Mirdha, US and Dhariwal, SR Design Optimization of Solar Cooker. *Renewable Energy.* 2008; 33(3):530 – 544.

Muthusivagami RM, Velraj R, Sethumadhavan R. Solar cookers with and without thermal storage: a review. *Renew Sust Energy Rev* 2010; 14:691–701.

Nahar NM. Performance and testing of a hot box storage solar cooker. Energy Converse Manage 2003; 44:1323–31.

Nahar. M. Performance and testing of a hot-box storage solar cooker. Energy Convers Manag.44: 1323–31.

Negi, BS and Purohit, I. Experimental investigation of a box type solar cooker employing a non-tracking concentrator. *Energy Conversion and Management.* 2005, 46:577-604.

Olwi, I, Khakifa, AMA Numerical modeling and experimental testing of a solar grill. *Journal Solar Energy Engineering.*1993; 115:5–10.

Prasanna UR, Umanand L. Modeling and design of a solar thermal system for hybrid cooking application. *Appl Energy* 2011; 88:1740–55.

Purohit, I. and Purohit, P. Instrumentation error analysis of a box-type solar cooker. *Energy conversion and management.* 2009, 50: 365-3675.

Saxena A, Agarwal N. Performance characteristics of a new hybrid solar cooker with air duct. *Sol Energy* 2018;159:628–37.

Suhail Zaki Farooqui. Angular optimization of dual booster mirror solar cookers – Tracking free experiments with three different aspect ratios. *Solar Energy* 2015; 114:337–348

Tariku Negash Demissie a, Sebastiano Tomassetti, Claudia Paciarotti, Matteo Muccioli, Giovanni Di Nicola, Celestino Rodrigues Ruivo. Experimental characterization of a foldable solar cooker with a trapezoidal cooking chamber and adjustable reflectors. *Energy for Sustainable Development*. 2024 ; 79:101409

Toonen HM. Adapting to an innovation: solar cooking in the urban households of Ouagadougou (Burkina Faso). *Phys Chem Earth* 2009; 34:65–71.

****