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Experimental investigation of thermal performance evaluation and thermodynamic analysis of domestic box type solar cooker with inclined aperture area

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Abstract – *In this paper, the thermal performances of a box solar cooker were rated with F_1 and F_2 parameters as per Mullick's procedure [1], the efficiency of the cooker was evaluated using energy and exergy analysis. The solar cooker was designed with an inclined aperture area, realized and experimentally tested at Applied Research Unit on Renewable Energies of Ghardaïa (32.39 °N, 3.78 °E, 463 m), Algeria. The developed cooker is equipped with one reflector mirror on its lid. The experiments have been carried out with the cooker empty, filled with one or two liters of water from 08:00 to 15:00 solar time, the thermal profiles of various components of the cooker were assessed at Ghardaïa site Sahara climatic conditions on clear days in both winter and summer months. According to the values of two figures of merits suggested by International Standards and evaluated by the experimental studies, the configuration with an inclined aperture area of the cooker resulted in good cooking performances, especially in winter when the sun's elevation is low; keeping the realized cooker performances in range of the international standard tests. The results of this study indicate also that the average daily energy and exergy efficiency of the realized cooker was 16.2 % and 0.90 % respectively, during the experimental period, which indicate a significant difference between the results of energy and exergy analyses. Thus developing such a box solar cooker can improve the efficiency of the design and use a position of the system to prepare food in a shorter time.*

Résumé - *Dans cet article, les performances thermiques d'un cuiseur solaire ont été évaluées en utilisant les paramètres F_1 et F_2 conformément à la procédure de Mullick. Le rendement du cuiseur a été évalué en effectuant une analyse énergétique et exergétique. Le cuiseur solaire a été conçu avec une zone d'ouverture inclinée, et a été réalisé et testé expérimentalement au niveau de l'Unité de Recherche Appliquée en Energies Renouvelables (URAER) de Ghardaia (32.39 °N, 3.78 °E, 463 m). Le cuiseur est équipé d'un miroir sur son couvercle. Les expériences ont été réalisées avec le cuiseur vide, ou contenant un ou deux litres d'eau, de 08:00 à 15:00 heure solaire. Les profils thermiques des différents constituants du cuiseur ont été évalués dans des conditions climatiques saharienne, avec ciel dégagé, au niveau de Ghardaia, en hiver et en été. Selon deux figures suggérées par des standards internationaux, et évaluées par des études expérimentales, la configuration avec ouverture inclinée possède les meilleures performances, particulièrement en hiver quand l'élévation du soleil est faible. Ceci a permis de maintenir les performances du cuiseur dans la gamme des standards internationaux. Les résultats de cette étude indiquent que les rendements énergétiques et exergétique du cuiseur réalisé étaient respectivement de 16.2 % et 0.90 % durant la période d'expérimentation. Ces résultats indiquent qu'il existe des différences*

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significatives entre les analyses énergétiques et exergétiques. Ainsi, le développement d'un tel cuiseur solaire peut améliorer le rendement et utiliser la position du système pour la préparation de nourriture plus rapidement.

Keywords: Solar radiation - Box solar cooker - Figure of merits - Energy and exergy efficiencies - Inclined aperture area.

1. INTRODUCTION

Algeria lies in the sunny belt of the world. The insolation time over the quasi-totality of the national territory exceeds 2000 h annually and can reach 3900h in the high plains and Sahara [2]. From this point of view, it can be easily said that these are very favourable climatic conditions for all solar energy applications, especially for the domestic sector which accounted for the major energy consummation (higher than 25% of primary energy use in developing nations [3].

If considering thermal applications of solar energy, solar cooking is one of the important applications, solar cookers offer an alternative solution for ecological, economic and health problems [4, 5]. However, in many parts of the world, especially in developing countries; wood and fossil fuel based cooking energy resources still predominate with the highest share in global energy consumption of residential sector. This situation causes some serious ecological problems such as deforestation [6], economic and health problems are also firewood use consequences.

Different types of solar cookers such as; box type, concentrator type and indirect type have been realized and tested around the world during the last years. However, only box types have gained maximum popularity, in developing countries, among all other existing models because of its simple design operation and lowest cost. Extensive research has been conducted by many scientists, researchers and academicians regarding design development of experimentation with BSCs.

In the year 2011, Saxena *et al.* [7] analyzed in their thermodynamic review the major parameters optimization related to box type solar cookers. Another study reported by Cuce *et al.* [8] to describe the state of the art of major parameters and energetic/exergetic evaluation of solar cookers.

Recently, Yettou *et al.* [5] presented the recent advances in research and development of solar cooking technologies, their thermal performance and thermodynamic analysis. Several contributions reveal that various researchers around the world have developed many improved designs of box-type solar cookers. However, their performances are still significantly lower during the winter months due to lower solar radiation availability on the horizontal surface which results to lower temperatures.

There is a need to evaluate solar cookers and compare different designs calls for testing procedures and performance parameters which represent their respective thermal performance [9]. Mullick *et al.* [1, 10] proposed two figures of merits (i.e. F_1 and F_2) in order to evaluate the thermal performance of a box type solar cooker, and the same procedure was adapted by Bureau of Indian Standard (IS13429:2000) [11]. In addition, a test method of solar cookers has also been suggested by Funk [12, 13]; in which the performance is given by two parameters, namely, adjusted cooking power (P_n) and overall heat loss coefficient (U_L) was also adapted. On the other hand, each design needs to be suited to specific climate conditions. This development requires a good fundamental understanding of the relationship between key design variables and performance [13].

The energy efficiency of a solar cooker, conventionally is used to measure solar cooker efficiency. The energy efficiency is inadequate as a measure of efficiency because it does not take into account all the considerations necessary in solar cooker evaluation. Exergy analysis provides an alternative means of evaluating and comparing solar cookers. Exergy efficiency accounts for the temperatures associated with energy transfers to and from the solar cooker, as well as the quantities of energy transferred, and consequently provide a measure of how nearly the solar cooker approaches ideal efficiency [14].

Keeping the above facts in mind a novel design of box type solar cooker with inclined aperture area equipped with a reflector mirror was designed and developed. The thermal performance of the realized cooker in terms of two important parameters F_1 and F_2 was assessed as per the procedure suggested by Mullick [1]. The energy and exergy efficiency of the solar cooker was also estimated.

2. THEORETICAL AND EXPERIMENTAL STUDIES

2.1 Cooker orientation and reflector adjustment

The amount of energy produced by solar cookers depends on the amount of light to which they are exposed. Since the position of the sun changes during the day and in order to collect a maximum of solar radiation, box solar cookers must be redirected continuously to the sun, tracking his course during cooking time; to minimize shading caused by cooker's walls on the absorber tray (figure 1).

If we consider the two main types of cookers: boxes and parables, continuous tracking remains difficult, particularly when the cooker is loaded (boxtypes) and when a manual tracking device is used (parabolic types). An automatic sun tracking system using an electric jack or motors is not interesting for reasons of rentability in the case of box and in reasons of cost and complexity in the case of parabolic cookers. In most cases, a manual tracking is performed at different intervals during cooking time.

The optical and thermal performances of the solar cookers can be optimized if the cookers are oriented efficiently; in such away that incident solar rays fall on the receivers with a zero incidence angle, therefore, the optical losses will be minimized. [15].

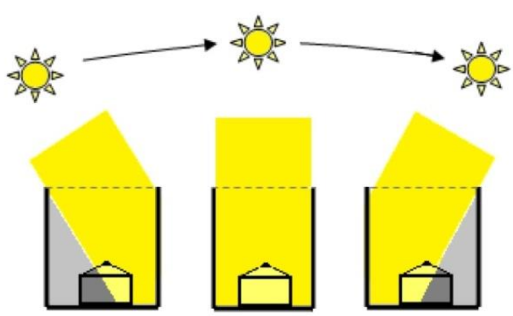


Fig. 1: Illustration of the effect of not adjusting box solar cookers with different dispositions in respect to the sun

2.2 Description of the realized solar cooker

The box solar cooker (BSC) with inclined aperture area consists of an outer wooden box, inner cooking box, the simple glass lid, thermal insulator, mirrors, and cooking containers. The overall dimensions of the cooker are 550 × 450 × 495 × 175 mm. The hot box dimensions are 500 × 400 × 445 × 125 mm.

The space between the outer box and inner tray, including the bottom of the tray, is packed with insulating material to reduce heat losses from the cooker. A glass lid covers the inner box.

The absorber made of aluminium sheet painted matt black absorbs the solar radiation and transfers the heat to the cooking pots. The aluminium cooking pot (18 cm in diameter and 10 cm in height), filled with water and equipped with a black cover, was placed into the solar box cooker.

One reflector (booster mirror) of 640 × 450 mm was hinged on the top of the cooker with adjustable bends. The booster mirror was used to raise the temperature of the hot box. Figures 2**a-** and 2**b-** show a photographic view and a schematic diagram of the realized box solar cooker, respectively. The technical specifications of the cooker are presented in **Table 1**.

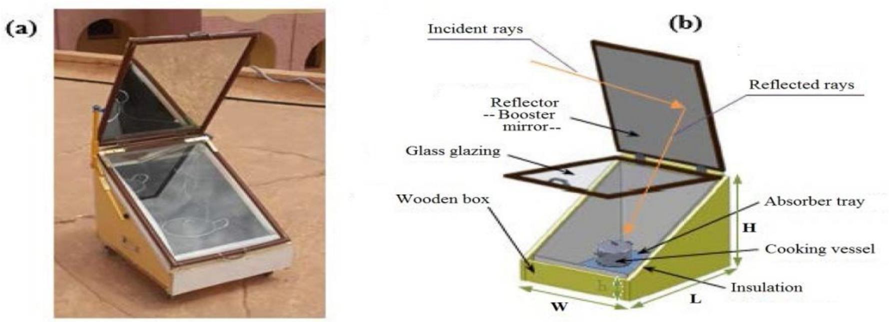


Fig. 2: A photographic view **(a)**, and a schematic diagram **(b)** of box solar cooker with inclined aperture area realized at URAER of Ghardaïa

Table 1: Technical specifications of the realized box type solar cooker

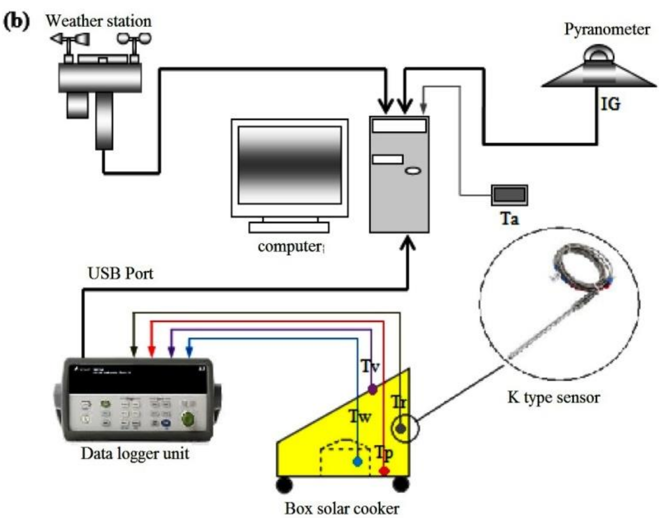
Dimensions of cooker	
Hot box	500 mm × 400 mm × 445 mm × 125 mm
Overall dimension	550 mm × 450 mm × 495 mm × 175 mm
Dimensions of reflector	
Reflector mirror	594 mm × 400 mm
Overall dimension	640 mm × 450 mm
Material for outer box cooker	Wood
Absorber plate	
Material of absorber plate	Aluminum
Emissivity of absorber plate	0.9
Glass covers	
Thickness of the glass cover	3 mm
Emissivity of glass covers	0.85
Insulation	
Insolation material	Glass wool
Thickness of the insulation	30 mm
Specific heat of water	4185 J kg^{-1} $°C^{-1}$

2.3 Instrumentation and measurements

The performance test of the solar cooker was conducted at the Applied Research Unit on Renewable Energies affiliated with the Center of Renewables Energies Development, situated at Ghardaïa, south Algeria (32.39°N, 3.78°E, 463 m above sea level). The box solar cooker experiments was conducted during May 26 to June 12, 2013. The international test standard requirements were applied to the box type solar cooker with inclined aperture area each day. Test days that did not agree with international standards were rejected.

During the experimental period, the following parameters were recorded: ambient temperature T_a, water temperatures in the pot T_w, air temperature inside the box T_i, glass cover temperature T_g, absorber plate temperature T_p, global solar radiation on a horizontal surface I_s, and wind speed W_s. Temperature profiles, solar radiation and wind speed were measured at 5 minutes intervals during heating water.

(a) Displaying measured experimental temperatures



(b) Bock diagram of box solar cooker installation

Fig. 3: Data acquisition system

The water temperature was measured using thermocouple because of its height accuracy and rapid response. The thermocouple has been inserted through a hole in the lid of the cooker and is immersed in the water inside the pot at 20 mm above the bottom of the pot. Three thermocouples were located at different places in the cooker were used to measure the glass, absorber and inside air temperatures. The ambient temperature in °C was measured using a Campbell CS215 Temperature.

The wind speed was measured using NRG 40H Anemometer. The accuracy of the anemometer was 1% ± 0.1 m/s. The wind speed was always below 1.3 m/s and was recognized as small; thus, the effect of wind and its direction was negligible.

The solar radiation on a horizontal surface was measured by a Kipp & Zonen CMP21 pyranometer and the direct normal irradiance in W/m² was measured with K&Z CHP1 pyrheliometer.

A data-logger Agilent 34972A [16] was used for taking the readings from the sensors as resistances. The recorded data were stored in a computer for storage on disk and visualizing on screen. The data were registered by the data-logger in intervals of 5 minutes.

Figure 3 shows the data acquisition system used for experimentation of the realized box solar cooker.

2.4 Parameters of cooker performance

It is known that the thermal performance of a box type solar cooker depends on climatic parameters such as solar radiation, ambient temperature, wind speed etc., as well as on proper design parameters such as insulation material, properties of absorber plate, number of glass cover and use of reflector mirror.Testing and evaluating thermal performances of solar cookers is necessary for characterizing the performance of these devices and provide a basis for comparison of various models. Mullick *et al.* developed a thermal test procedure for box type solar cookers [1].

In this procedure, a complete test method standard IS13429:2000 is available for testing of these systems [11]. According to this standard, two main tests are conducted (a stagnation test and a sensible heat test) for determination of two thermal performance parameters (figures of merits, F_1 and F_2) on the basis of relevant thermal profiles without considering the effect of reflector mirror. The Indian Standards IS13429 proposes the lower limit of F_1 and F_2 as 0.12 and 0.40 for a load of 8 kg/m².

As per BIS [11] and Mullick *et al.* [1], the stagnation test on a box type solar cooker is conducted for the evaluation of first figure of merit T_p which is defined as the ratio of optical efficiency η_0 and overall heat loss coefficient U_1. To determine the first figure of merit, the box type solar cooker without any load is exposed to solar radiation, allowing plate temperature to rise gradually. At stagnation, intensity of global solar radiation, plate temperature, ambient temperature and wind speed were recorded at fixed interval of time. Experimentally, F_1 is a measure of the differential temperature gained by the plate absorber at a particular level of solar radiation; it is given by the following relation:

$$F_1 = \frac{\eta_0}{U_L} = \frac{T_{ps} - T_{as}}{I} \tag{1}$$

Where: T_{ps}, T_{as} and T_s are the absorber-plate temperature, the ambient temperature and the intensity of solar radiation on horizontal surface, respectively at stagnation.

The second figure of merit F_2 is derived from the sensible heat test under full load condition. This test gives an indication of heat transfer from the absorbing plate to the water kept inside the solar cooker.

To determine the second figure of merit F_2, the cooker without reflector was loaded with a known amount of water, i.e. 8 kg/m² must be equally distributed in all cooking pots. The water temperature is then allowed to rise gradually until it reaches up to the boiling point. The second figure of merit F_2 is obtained by using the following relation [1, 11]:

$$F_2 = \frac{F_1 (m C_p)_w}{A_{sc} . \tau} \ln \left(\frac{1 - \frac{1}{F_1} . \left(\frac{T_{w1} - \overline{T_a}}{\overline{I_s}} \right)}{1 - \frac{1}{F_1} . \left(\frac{T_{wf} - \overline{T_a}}{\overline{I_s}} \right)} \right) \quad (2)$$

Where: A_{sc}, the box solar cooker aperture area; $(mC_p)_{wp}$, the heat capacity of water in the cooking pot; τ, the time interval during which water temperature rises from T_{w1} to T_{wf}; T_{wi}, the initial water temperature (60 °C); T_{wf}, the final water temperature (90 °C); $\overline{T_a}$, the average ambient temperature; $\overline{I_s}$, the average solar radiation on the horizontal surface.

According to Mullick Standards [1], in addition to the first figure of merit F_1 and second figure of merit F_2, the time constant for sensible heating period τ_{boil}; from ambient temperature up to 100 °C can be deduced from equation (2) as follows:

$$\tau = \frac{F_1 (m C_p)_w}{F_2 . A_{sc}} \ln \left(\frac{1 - \frac{1}{F_1} . \left(\frac{T_{wf} - \overline{T_a}}{\overline{I_s}} \right)}{1 - \frac{1}{F_1} . \left(\frac{T_{wi} - \overline{T_a}}{\overline{I_s}} \right)} \right) \Rightarrow \tau_{boil} = \frac{F_1 (m C_p)_w}{F_2 . A_{sc}} \ln \left(1 - \frac{1}{F_1} \left(\frac{100 - T_a}{\overline{I_s}} \right) \right) \quad (3)$$

This time is a function of $\left(\frac{100 - T_a}{\overline{I_s}} \right)$ and thus the plot of τ_{boil} versus $\left(\frac{100 - T_a}{\overline{I_s}} \right)$ could be referred to as the characteristic curve of the cooker.

2.5 Energetic and exergetic analysis

As underscored by Panwar *et al.* [17], the investigation of solar systems according to the laws of thermodynamics has attracted the attention of many researchers, been widely discussed by several authors and reviewed by Bejan [18, 19] and Petela [20]. Thermodynamic analysis is an effective means to obtain precise and valuable information about energy efficiency and losses due to irreversibility in a real situation.

Energy assessment is the customary method of assessing the way energy that issued in an operation involving the physical or chemical processing of materials and the transfer and/or conversion of energy [21]. Energy analysis is based on the first law of thermodynamics, i.e. net heat supplied converted into work. Energy analysis thus ignores the reductions in energy potential. Its analysis can provide sound management guidance in those applications in which usage effectiveness depends solely on energy quantities. Thus, energy analysis is suitable for the sizing and analyzing of systems using only one form of energy [22].

Energy input to the solar cooker is energy of solar radiation per square meter of the solar cooker. Then, energy input to the solar cooker can be calculated as follows:

$$E_i = I_t . t . A_{sc} \quad (4)$$

The energy output of the solar cooker can be calculated as follows:

$$E_0 = m_w . C_{pw} (T_{wf} - T_{wi}) \quad (5)$$

The energy efficiency of the box type solar cooker with inclined aperture area can be defined as the ratio of energy output to energy input of the solar cooker. Energy efficiency of the solar cooker was calculated by using the equation below:

$$\eta = \frac{E_0}{E_i} = \frac{m_w \,.\, C_{pw}\,(T_{wf} - T_{wi})}{I_t\,.\,t\,.\,A_{sc}} \tag{6}$$

The term exergy is defined as the maximum amount of work that can be obtained from a system [23]. The rational efficiency based on the concept of exergy is a true measure of the performance of a thermal system. This is based on the second law of thermodynamics and the concept of irreversible entropy production [24, 25]. It is a useful tool for improving the performance of the system by determining the magnitude of energy waste and losses in system [17].

The expression of exergy input to the solar cooker expressed by Petela [20], which has the widest acceptability, was used to calculate the exergy input:

$$\Xi_i = I_t \,.\, t \left(1 - \frac{4\,T_a}{3\,T_s} \right) A_{sc} \tag{7}$$

The sun's black body temperature of 5762 K results in a solar spectrum concentrated primarily in the 0.3-3.0 μm wavelength band [26]. Although the surface temperature of the sun (T_s) can be varied on the earth's surface due to the spectral distribution, the value of 5800 K has been considered for the T_s.

The expression to calculate the exergy output from a box-type solar cooker, expressed by Ozturk [14], was used to calculate the exergy output:

$$\Xi_0 = m_w\, C_{pw} \left(\left(T_{wf} - T_{wi} \right) - T_{ra} \ln\left(T_{wf} \,/\, T_{wi} \right) \right) \tag{8}$$

Exergy efficiency of the box type solar cooker with inclined aperture area is defined as the ratio of the exergy gained by the solar cooker (exergy output) to the exergy of the solar radiation (exergy input). Exergy efficiencies of the box type solar cooker with inclined aperture area were obtained by the following relation:

$$\Psi = \frac{\text{Exergy output}}{\text{exergy input}} = \frac{\Xi_0}{\Xi_i} = \frac{m_w\, C_{pw} \left(\left(T_{wf} - T_{wi} \right) - T_{ra} \ln\left(T_{wf} \,/\, T_{wi} \right) \right)}{I_t \,.\, t \left(1 - \left(4 T_a / 3 T_s \right) \right) . A_{sc}} \tag{9}$$

3. EXPERIMENTAL TESTS, RESULTS AND DISCUSSIONS

3.1 Thermal performance evaluation of the cooker

This part of work is related to thermal performance evaluation and characterization of box type solar cooker with inclined aperture area in respect of two parameters: first figure of merit F_1 and second figure of merit F_2, as described by the Bureau of Indian Standards (BIS) [136, 137], the boiling time τ_{boil} will be calculated and the characteristic curve ($x\tau$) of our cooker will also be determined. The temperature profiles of the various cooker's elements are measured at real time and represented for different climatic conditions in clear skies during winter season.

3.1.1 First and second figure of merit

The first results are related to the tests carried out on the cooker without load and without reflector. Typical variations of global solar radiation on horizontal surface, ambient temperature and absorber plate temperature of the cooker, measured under the stagnation test conditions in clear sky,with absence of wind, are presented in figure 4**a-** for winter season. From the results, it is seen that the maximum absorber plate temperature was 127.6 °C measured at 13 h 05 local time on February 5th, 2013 at a horizontal solar radiation value of 791.9 W/m². For the experimental stagnation winter test (figure 4**a-**), the first figure of merit F_1 is calculated as 0.145 m²K/W by using the equation (1) with values of T_{ps} =127.6 °C, T_{as} =12.5 °C and I_s =791.9 W/m².

In winter season, a water heating test was carried out as per Mullick's procedure [1]. The full water load is 8 kg/m² of aperture area, for the aperture area of our cooker (0.2 m²), full water load has been found to be 1.6 kg; this water load was evenly distributed between two identical cooking pots. Temperature of absorber plate, water in pots, ambient temperature and horizontal solar radiation, with variation in the local time are shown in figure (4**b-**), under clear sky conditions.

During heating of the water in cooking pots on February 4th, 2013, the test was started at 10 h 05 min with initial temperature of water equal to 17.8 °C and ambient temperature equal to 8.9 °C. The boiling point was reached after 85 min. Using equation (2) and figure (4**b-**), the second figure of merit F_2 is calculated as 0.391 using F_1 =0.145 m²K/W with values of m_v =1 kg, C_{pw} =4200 J/kgK, A_{sc}=0.2 m², τ =85 min, T_{wi} = 61.3 °C, T_{wf} =90.9 °C, $\overline{T_a}$ =11.4 °C, and $\overline{I_s}$ = 705 W/m².

According to Mullick *et al.*, the first figure of merit F_1 varies between 0.12 and 0.16 [1]. The second figure of merit F_2 varies between 0.254 and 0.490 according to load and number of cooking pots used (Mullick *et al.* [10]). A high value of F_1 indicates good optical efficiency and low heat loss factor. Our realized box type solar cooker is characterized by good value of F_1 parameter because of its high solar radiation collection due to the designed model with inclined aperture area. A high value of F_2 indicates the effectiveness of the heat transfer from the absorber plate and the inside air to contents of the cooking pots. For our realized box solar cooker, F_2 is satisfactory and the cooker is able to cook meals in relatively short time.

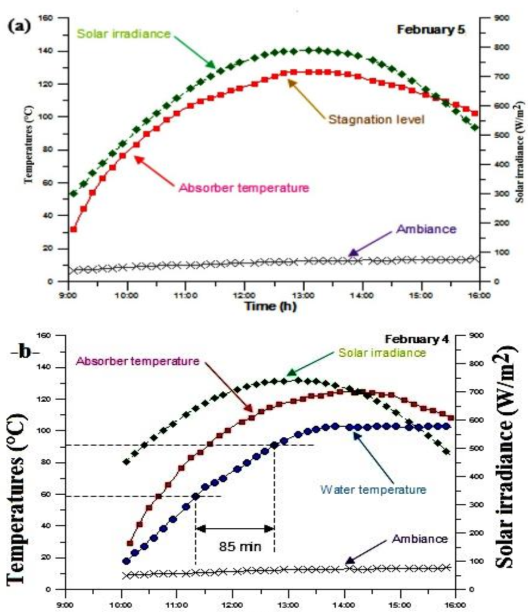


Fig. 4: Diurnal variation of solar radiation and measured plate temperatures of the cooker without reflector on clear winter day

-a- under stagnation test conditions **-b-** during heating of 1.5 kg of water

3.1.2 Boiling time and characteristic curve of the cooker

The boiling timeor the heating period of a box solar cooker in any weather conditions ($\overline{I_s}$ and $\overline{T_a}$) can be calculated using equation (3). The calculated values of F_1 and F_2 are used to determine the performance of the cooker carried out under different solar irradiance values from 500 W/m² to 1000 W/m² with a step of 50 W/m².

According to the obtained results, we noticed that, for example; if the value of solar irradiance increases from 750 to 800 W/m² and the ambient temperature was not changed (20 °C), the time taken to reach the boiling point would be reduced to 152 min. Similarly, if the value of the solar irradiance is 750 W/m² and the ambient temperature increases from 20 to 30 °C for example, the time required to reach the boiling point is reduced to 134 min. This confirm that the average value of solar irradiance $\overline{I_s}$ and ambient temperature $\overline{T_a}$ are directly proportional to the time constant τ_{boil} related to the boiling state.

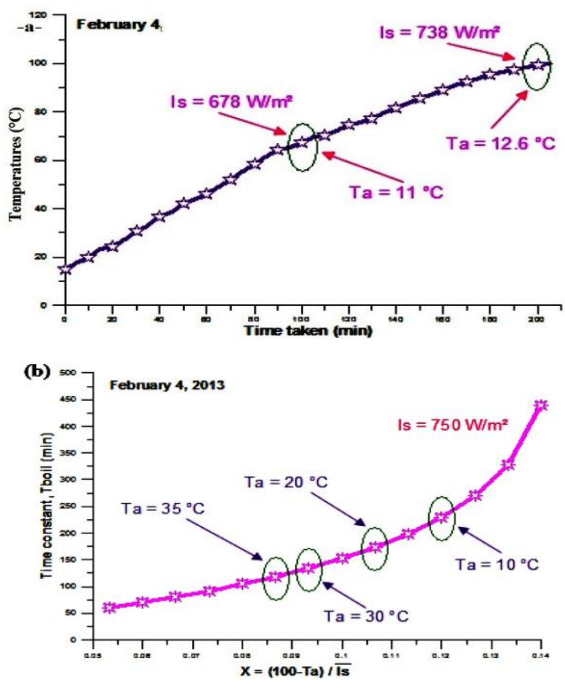


Fig. 5: Characterization of box type solar cooker with inclined aperture area at latitude 32
-a- Evolution of the boiling time curve depending on water temperatures for winter typical day, -**b**- **P**erformance characteristic curve of the cooker at solar irradiance of 750 W/m².

Figure 5-**a-** shows the evolution of boiling time curve in function of water temperatures for the winter test of February 4, 2013. The corresponding characteristic curve of our cooker is illustrated inin figure 5-**b-** for several range of temperature values and for solar irradiance of 750 W/m². The reading of this curve is as follows: at a latitude of 32 ° and for specific values of F_1 and F_2 (0.145 and 0.391, respectively),

with an average solar irradiance value of 750 W/m² and an average ambient temperature of 20 °C, the time required to boil a quantity of water (1.6 kg) is 173 min.

From figure 5-**b-**, it is seen that, for the day test of the February 4, 2013; the time required for water temperature to atteint the boiling point is measured experimentally figure 5-**a-** as 205 minutes (3h 25 min) at an ambient temperature value of 12.6 °C and a solar irradiance of 738 W/m² compared to the time calculated numerically which is 221 min (3h 41 min). An absolute error of 16 minutes was recorded, which is an acceptable error compared to an error of 13 min calculated and published by Sethi *et al.* [27] in their recent article.

3.2 Energy and exergy analysis

In order to evaluate the thermal performance of box type solar cooker with inclined aperture areain terms of energy and exergy efficiencies, several water heating tests were conducted during the months of May and June 2013 using the method described by Funk, presented in the 3rd World Conference on Solar Cooking [12], tested and validated by Ozturk [14] and Panwar *et al.* [17]. The experiments were performed with 1 and 2 liters of water. It should also be noted that the glass cover was not opened during measurements.

3.2.1 Energy and exergy output

Table 2 illustrates the variation in the energy and exergy output with time of the of the realized box solar cooker for the test conducted on June 10, 2013 at Ghardaïa site. The exergy output of the cooker (from equation (8)) was significantly different from the energy output (from equation (5)).

The exergy output varied in the range of 0.05 - 2.46 kJ during the study period while the energy output varied in the range of 0.36 - 27.09 kJ. The average daily exergy output of the cooker was found to be 1.2 kJ/day, whereas the average daily energy output of the box was 10.67 kJ/day during the experimental period as presented in **Table 2**.

Similar trends of energy and exergy output of the box solar cooker were reported by Panwar *et al.* [28] and Ozturk [14]. The difference between the energy and exergy outputs is due; as explained and reported by Ozturk [14], to the fact that the quality of the energy was considered to calculate the exergy output. However, in calculating the energy output, the quantity of the energy considered.

Table 2: Energy and exergy outputs of realized BSC with time

Solar	Input (kJ/day)		Output (kJ/day)	
time (h)	Energy	Exergy	Energy	Exergy
9:00	118.37	110.49	26.06	1.81
10:00	138.27	129.02	14.28	1.58
11:00	150.40	140.29	11.37	1.52
12:00	153.30	142.95	0.53	0.08
13:00	146.67	136.71	1.46	0.21
14:00	131.53	122.58	0.97	0.15
Daily average	**142.79**	**133.17**	**10.67**	**1.20**

3.2.2 Energetic and exergetic efficiency of the cooker

Figures 6 reveals the comparative results of energy and exergy efficiencies of the box solar cooker and illustrate the variation of energy and exergy efficiencies for 1L and 2L of water loaded in the cooker, these tests were carried out for four clear days in

June and May months. The results obtained in figure 6, clearly show that both energy and exergy efficiencies are high initially and then decreases over times because the two parameters (energy and exergy outputs) are being directly proportional to the temperature difference of the water.

Therefore, initially, energy and exergy outputs are higher and initial energy and exergy inputs are low this is due to the lower incident solar radiation initially. Therefore, the output to input ratio was found to be higher at the beginning of the experiments. After 13:00 LT, the energy and exergy efficiencies of the box decreases because of solar intensity increases. This is mainly due to the temperature difference near boiling point will be increasing slowly (stagnant level).

From the results of figures 6, it was clearly seen that energy and exergy efficiency of the solar cooker with $2L$ of water was higher than that with $1L$. This is due to the fact that output energy and exergy are directly proportional to the volume of the water. The mean energy efficiency of the box for $1L$ and $2L$ of water is found to be 6.48 and 9.88 %, respectively, whereas, the mean exergy efficiency is 0.55 and 0.77 %, respectively.

It can be seen that the exergy efficiency was considerably lower than the energy efficiency because the total energy content of the hot water used as the heat storage material in the cooker was considered to calculate the energy efficiency (Panwar *et al.* [28]; Ozturk [14]). In other words, to calculate the energy efficiency, the quantity of the energy transferred is considered, and the quality of the energy transferred is neglected.

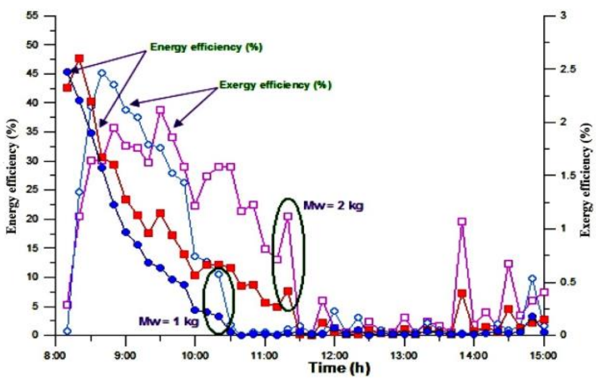


Fig. 6: Energy and exergy efficiencies of the realized box type solar cooker with inclined aperture area with time of day

The effect of the temperature difference on the energy and exergy efficiency of the cooker is shown on figure 7 for the test conducted on February 2, 2014. According to these results; for a water load of $2L$, the energy efficiency of the cooker varies between 8.84 and 20.73 %, when the water temperature registers a variation between 40 and 90°C.

The average daily efficiency during the experimental period (10 h and 16 h) is calculated as 12.27 %. These results are in good agreement with those found by Miller *et al.* [29] in 2001; they found that the average efficiency for box type solar cookers are between 8 to 22 % for the best designs. On the other hand, the exergetic efficiency of the cooker ranges from 1.60 to 3.44 %, the average exergetic efficiency is estimated at 2.57 % for the test conducted on February 2, 2014.

Linear regression points is plotted to find the relationship between energy efficiency and the temperature difference. From the curve of figure 7, we found that energy efficiency is a 2nd order polynomial, the values of energy efficiencies decrease when the temperature difference increases. Energy efficiency depending on the temperature difference for our cooker tested in Ghardaïa is given by equation (10) for the test of February 2, 2014 with a linear regression coefficient $R^2 = 0.88\%$. The value of energy efficiency is calculated for a temperature difference of 50 °C using relationships determined above as 19.74 %.

$$\eta = -0.007\,(\Delta T^2) + 0.424\,(\Delta T) + 15.492 \qquad (10)$$

Similarly, we plotted a linear regression of the points to find the relationship between the exergy efficiency and temperature difference. From the curve of figure 7, we found that the exergy efficiency is a 3rd order polynomial for both cases, the values of exergy efficiencies increase gradually with the temperature difference then decrease slowly. The exergy efficiency as a function of the temperature difference for our cooker tested Ghardaïa is given by equation (11) with a linear regression coefficient $R^2 = 0.77\%$. The value of the exergy efficiency calculated for a temperature difference of 50 °C is calculated as 3.05 % for the test conducted on February 2, 2014.

$$\Psi = -3.7\times 10^{-5}\,(\Delta T^3) + 0.004(\Delta T^2) - 0.048\,(\Delta T) + 0.837 \qquad (11)$$

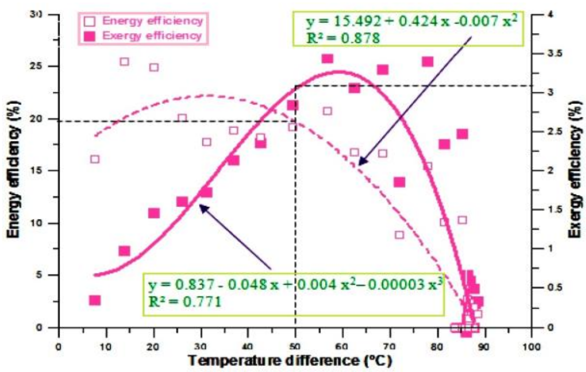


Fig. 7: Effect of temperature difference on the energy and exergy efficiency of the box type solar cooker with inclined aperture area with a water load of 2L

4. CONCLUSION

The global demand for cooking energy is expected to increase with increasing human population over the incoming years. Solar cooking technologies can play a key role to reduce or substitute energy consumption from other sources in the near future. This paper presents results of an experimental investigation of the thermal performance of a box type solar cooker with inclined aperture area realized at Applied Research Unit on Renewable Energies of Ghardaïa, Algeria.

The international standard for testing solar cookers and reporting performance was applied to experimental the box solar cooker. The experimental tests, conducted in winter and summer seasons, shows successful cooking performance of the realized cooker, which can be used around year. The values of thermal performance parameters F_1 (0.15) and F_2 (0.47) are found to satisfy Bureau of Indian Standards.

This experimental efficiencies study of the box type solar cooker based on energy and exergy analysis show also that the box type cookers with inclined aperture area are well suitable for preparing meals and food cooking.

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