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STUDY OF A SOLAR COOKING PROCESS FOR ALIMENTS IN TROPICAL ZONE

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ABSTRACT
An experimental analysis of solar cooker with parabolic collector is presented. The established transfer equations result from heat balances on the level of each component of the aforesaid cooker. The experimental device was designed and carried out at the University of Bangui (Republic of Central Africa).Owing to it we heated 1,5kg of water and also cooked 0,5 kg of potatoes, 300g of rice and 0,5 kg of yams. Then, it outcomes that after 50min, the 1,5 liters of water reach their boiling point. The maximum temperatures reached are,101°C for rice cooking after an exposition of 1h30min inside the concentrator, 107,5°C for potatoes cooking after 1h10min and 105°C for yam cooking after 1h20min. Results were validated by comparing with experimental results carried out by other authors.

Keywords: Contribution-Experiment - Solar cooker - Solar concentrator.

1. INTRODUCTION
In Republic of Central Africa (RCA), the global solar radiation is about 6.6 GJ.m²/an (5 KWh/m²/day) for an average duration for sunniness of 2600 hours per year ; for a daily duration of 7.1 hours. In great urban centers and the secondary centers, requirements in wood energy are very high, about 91.6% of households are concerned, involving a massive traffic of wood, having as consequence a drastic projection of deforestation. Consumption of electricity remains very low on national level, only 5.1% of households use it. In spite of the expensive price of the consumption of one liter of domestic fuel, it accounts for 57.3% of consumption while wood represents 89% of consumption in urban environment and 92,9% in rural environment [1]. Thus, solar cookers with concentration system can contribute to supply thermal energy for the cooking of food. It was designed in 1767 by Switzerland Horace BENEDICT [2] and allowed him to cook vegetables in parallelipipedic device of which one of walls was made up with pane. Thereafter, in 1860, the French engineer Augustin Bernard MOUCHOT worked out in Algerie a solar cooker with concave concentrator [3].

Many works on various types of solar cookers were the main concern of several researchers like the box solar cookers with multiple reflectors with and without tracker which were the subject of many experimental work [4]-[14]. For measurement of temperatures of water and other various components (panes, walls) of the solar cooker, thermocouples of type K and type T are positioned in various places of the cooker. Pyranometers of type 2CM11 and Kipp&Zonen for measurements of solar flow were used. The presented results related to thermal effectiveness, temperatures of walls of the cooker and water, coefficient of total lost heat, the difference in temperature between the ambient environment and that in the cooker and the duration of cooking. After performing tests with vaccum, several tests with load had been carried out where measurements were made every 10 seconds during 5 minutes.

Many experimental work also intended for the determination of the energetic efficiency of solar cooker, temperature of water and oil, duration of cooking were carried out [15]-[27]. Two types of cookers were considered, the first one was classical and the second one included a pot known as "Finlandaise". These studies showed in particular that, for a density of solar flow ranging between 600W/m² and 900W/m², the temperature

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of walls reached 99°C on classical cooker 10 min later than the "Finlandaise" cooker. For cookers including plates like absorber, temperature can exceed 120°C.

In the light of this bibliographical study, we discover about solar cookers that the concentration of solar flow is one of the most alternatives promising way in the current energy context. It is a long-term viable energy, it does not produce gas of greenhouse effect. In addition to their simple design, construction and handinesses, The box-type solar cookers are well adapted to zones deprived of classical sources of energies.

2. EXPERIMENTAL APPARATUS

2.1- Description

The selection one model of solar cooker was done after analysis of various existing solar cookers. The seclected solar cooker is composed of a solar concentrator and a parallelepipedic enclosure in which the pot containing food to be cooked is laid out (figure 1). This pot in which food is laid out is a semi-spherical tank whose external face is painted with black color.

Figure 1 : Picture of the solar concentrator cooker

Figure 2 : Picture of box containing the pot

The concentrator is constituted of reflectors of parabolic shape (0.64 m diameter) intended to concentrate solar flow in its focal distance. Except the face opposite to the concentrator, walls of the parallelepipedic enclosure are timber material. Dimensions of the enclosure are 0.65m x 0.50m x 0.50m. Glass wool with thickness of 30mm is inserted for insulation issue. A pane of which thickness is worth 4mm allows the transfer of solar flow reflected by the concentrator on the pot laid out in this enclosure. Access inside the enclosure is ensured by one of the vertical walls adjacent to the wall in pane.

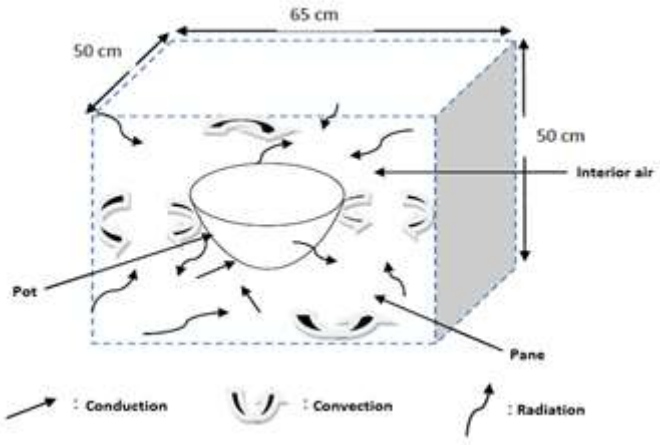

Figure 3 : synoptic scheme of the box solar cooker

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2.2- Operating principle

The solar flow reflected by concentrator is transmitted inside the enclosure through the pane and one part is absorbed by the pot border. As result of this absorption, heat flow is transmitted by conduction through wall of semi-spherical tank towards the interior of the pot and, which consequently induced the supply of heat to fluid and aliment of the pot.

2.3-Instrumentation

In order to trace thermal performances of the cooker over time, we installed thermocouples of type K with precision of±0,01°C, on the wall of pot and in air inside the enclosure of the cooker. These thermocouples are connected to one dated logger (±0,5°C) of type Agilent 34970A which allows the recording of temperature every 5 minutes (figure 3).Temperature of fluid inside the pot is determined by a microcontrolor arduino of type 18b20 (±0,2°C)connected to a personal computer. The combined weight of water and foodstuffs laid out in the pot is measured with a balance of precision(±0,01g) and the solar flow collected by a horizontal plane near the experimental device is estimated by a small solar station of type Vantage pro2.

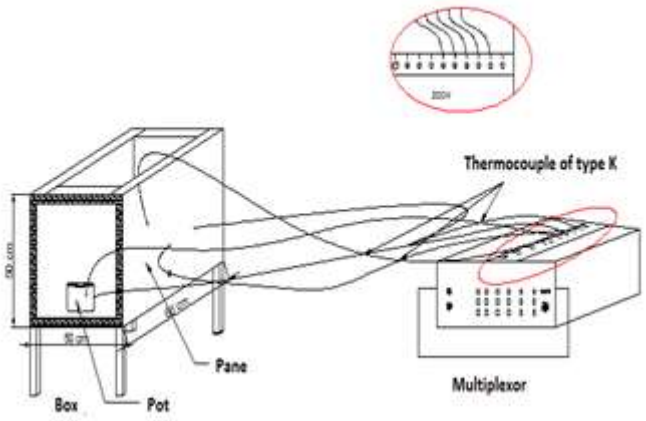

Figure 3 : Connexions between experimental device and data logger

2.4- Experimental Protocol

When solar flow reaches a threshold value of 800 W/m², we begin the experimental tests. Initially, we carry out tests with vacuum to analyze the transitory behavior of the cooker over the time. After that, real tests are performed during which measurements are done.

2.5-Evaluation thermal performance

Evaluation of thermal performance is done by calculating the thermal efficiency and the thermal power of the cooker thanks to various parameters of the cooker.

Thus, the thermal power is calculated by the relation established by FUNK [1999]:

$$P_{th} = \frac{M_{water} C_{pwater} (T_{f(water)} - T_{i(water)})}{dt} \quad (1)$$

FUNK introduced the term of thermal power of standard cooking by the expression:

$$P_{th} = \frac{700 M_{water} C_{pwater} (T_{(water)f} - T_{(water)i})}{600 \bar{I}_s} \quad (2)$$

He proposed the method of calculation of thermal efficiency of solar cooker by the relation:

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$$\eta_{th} = \frac{(m_{water} \times C_{Pwater} + m_m \times C_{Pm})(T_f - T_i)}{S \times I \times \Delta t} \quad (3)$$

The specific boiling time is calculated by the relation (Khalifa et al. 1985):

$$t_s = \frac{\Delta t \times A_c}{M_{water}} \quad (4)$$

3. RESULTS AND DISCUSSION

3.1-Tests performed with vacuum

Figure 4 shows the time evolution of various components in the enclosure of the cooker during October 24. On this day, the average solar flow is worth 905 W/m².We notice that temporal evolution temperatures is according to the solar flow. The maximum value of temperature of the wall is worth 108°C and that of the interior air is worth 96°C. Likewise, temperatures increase during the day until reaching the maximum values around 12h (TL). It should be noted that these maximum values are preserved until 15h (TL), time from which these values decrease with the time. This evolution results from the drop of the solar flow.

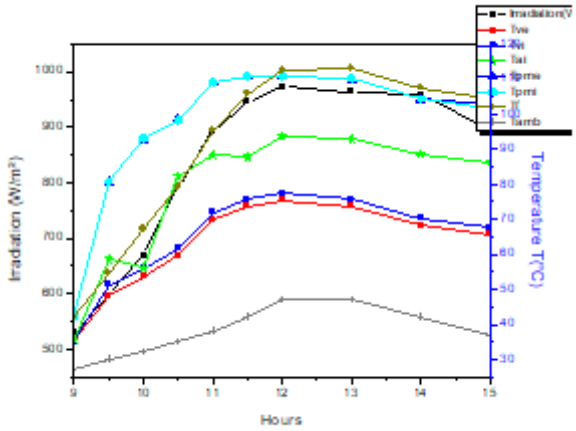

Figure 4 : Temperatures Profile of the parameters of the cooker with vacuum(24/10/2017)

3.2-Tests performed with aliments

Mechanism of heat transfer towards food to be cooked and water to be heated

Pot is the spot where take place a supply of radiation heat coming from solar concentrator and where heat is lost by natural convection. The absorbed solar flow is converted into heat which is transmitted by conduction and convection to foodstuffs founding inside the pot. It results from it an increase in temperature of matters contained in the pot up to a value which depends on the volume of fluid and the type of foodstuffs.

Temperature profiles of parameters of the cooker

Figure 5 show the influence of quantity of water contained in the pot on the temperature over time of various components of the solar cooker. We observe that temperatures of components of cooker are all the more high as the low is the amount of water. Indeed, for the same solar flow collected by the cooker, temperature devoted to water decreases with its volume. The quantity of remaining heat is used to increase temperature of components of the cooker.

Figure 6 illustrates the variation in temperature of parameters of the pot (internal air and wall of pot).It should be noted that values of temperatures of internal and external faces of the pot are almost identical during the day.

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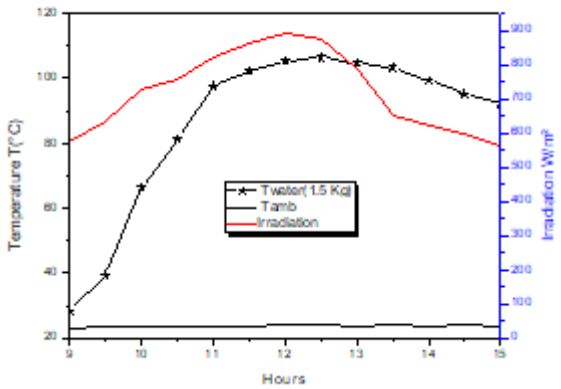
The thermal conductivity of material of which it is built and the thickness of the wall lead to a high transfer of heat between both faces of the wall; that is justified by this result.



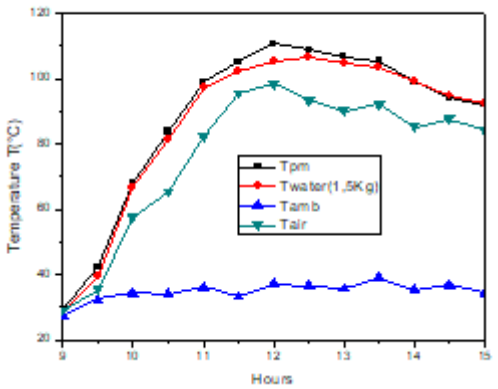


Figure 5 : Evolution of temperatures for 1.5Kg of water (25/10/2017) Figure 6: Evolution of temperatures for 1.5Kg of water (25/10/2017)

Cooking of foods tuffs

Cooking of Potatoes

Figure 7 shows the evolution over time of the ambient temperature and those of the internal and external faces of the wall of pot. As one can observe on figure 7, duration of the cooking of sweet potato is worth 70min, with an average solar flow of 968 W/m².

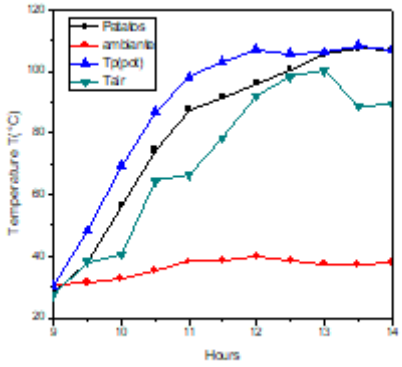


Figure 7 : Temperatures of parameters during the cooking of Potato (20/11/17)

Cooking of Yams

We carried out the cooking of Yam, a duration of 01h27 min is sufficient to cook it well under an average solar flow of 972W/m².The drop of temperatures observed at 11h results from the passing of clouds covering the sky throughout 30 min (figure 8).

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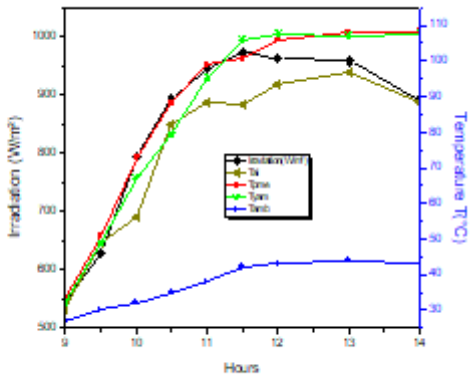

(figure 8).

Figure 8: Temperatures of parameters during the cooking of Yams(29/11/2017)

4-COMPARISON OF THERMAL EFFICIENCY OF COOKING

Table 1 : durations of tests with foodstuffs

Foodstuffs	Duration of cooking	Date
500g of potatoesin 500g of water	70 min	20/01/2017
1500g of water	50 min	25/10/2017
500g of yams in 500g of water	87min	24/02/2017

For better evaluation of thermal performance of the cooker, the obtained results on the temperatures are compared with those obtained by other models.

For these various tests, durations of various cooking's are in adequacy with those deferred in work of Nahar [2001] and Harmim [2012].The calculated thermal efficiency is worth 28.34%, the thermal power is worth 29.86 W and the specific boiling time is worth 19,02 min.m²/kg. A comparison between our results with those of El-Sebaii [2005] and Nahar [2001] shows that efficiency obtained in this study is agreement those deferred by those authors. Indeed, they got respectively 26% and 30.5% against 28.34% in the present study (table 2).This difference is explained by latitude of place, design, orientation and choice of materials used to manufacture all these solar cookers.

A comparison between our results and those deduced from experimental studies carried out by other researchers, shows a good general agreement. The variation of temperature on various parts of solar cooker, measured experimentally, is satisfactory. Even if there is sometimes litle difference between results. One could allot these differences to the precision of apparatuses used.

Wind, at time it is passing, also influences the thermal performance of the cooker. This delays change of temperature thus, energy provides for the increase in temperature can be carried away by its excessive passage.
So, certain results remain dissatisfied, that are justified by the use of thermocouples at a long distance. It could be that these thermocouples lose some information's because of signals of apparatuses in the environment of data recording.

4. CONCLUSION

The performance evaluation of box type cooker with solar concentrator was carried out. The results obtained are satisfactory, in term of thermal performances even if, there is some irregularity on the catch of experimental data due to the material used for the recording of data. Never the less, a requirement of extensive experimental tests and analysis of their results prove to be essential.

In addition, we highlighted the influence of solar radiation on temperatures of our cooker. It proves that in the cloudy passing, we notice a disturbance of temperature in the enclosure of the cooker. During these various tests, it arises that our experimental results seem to be efficient owing to the fact that they agree with other results of the literature. With this record, we could estimate a cooking of twice per day of foodstuffs.

COMPETING INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this paper.

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