ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 11, Issue, 03, pp.1869-1874, March, 2019

DOI: https://doi.org/10.24941/ijcr.34764.03.2019

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

RESEARCH ARTICLE

EXPERIMENTAL INVESTIGATION OF A SOLAR PARABOLIC TROUGH COOKER

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ARTICLE INFO

Article History:
Received 20th December, 2018
Received in revised form 15th January, 2019
Accepted 19th February, 2019
Published online 31st March, 2019

Key Words:
Parabolic Trough Cooker, Temperature, Coolant, Solar Radiation, Efficiency.

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ABSTRACT

A particular solar cooker namely the parabolic trough solar cooker (low concentration) called "blazing tube" is studied in the present work. It is about determining experimentally its performances. Several tests were conducted, tests while empty, water heating, frying tests and rice cooking. In these tests, temperature readings of the various components were also carried out. The cooking time of certain dishes has also been determined. It emerges from these experiments that the outlet temperature of the fluid depends on the sun and is close to 200 ° C in good weather conditions. The device can be used all day as needed, even in slightly unfavorable times.

***Citation*: *Boureima DIANDA, Thierry Sikoudouin Maurice, KY., Issaka OUEDRAOGO, Mibienpan KI., et al.* 2019.** "Experimental investigation of a solar parabolic trough cooker", *International Journal of Current Research*, 11, (03), 1869-1874.

INTRODUCTION

The sources of energy used for cooking in Burkina Faso as well as in most developing countries are firewood and butane gas. However, the use of firewood causes deforestation and various diseases (Toonem HM, 2009). Indeed for countries like ours, wood is a precious and rare resource, it is therefore imperative to limit its use. Butane gas is not used enough by village populations, it is mainly used by urban ones. In addition to the fact that butane gas is not commonly used, it is expensive. It is then necessary to turn to other available and more accessible sources of energy. Irradiationin Burkina Faso is around 5.5kWh / m^2 /d with a daily duration ranging from 11h to 12.7h (KI Mibienpan, 2018). These values are similar in many developing countries. Such energy from the sun freely available needs to be exploited properly. It is therefore a good alternative to the up-mentioned energies for cooking. For this purpose several works have already been conducted on solar cookers. Already in 1994 El Sebaii et al (1994) designed a box-type solar cooker with internal reflectors with several steps. They conducted practical tests and simulations in the city of Tanta and showed that in spite of the location of the city, the cooker with an opening area of 1m2 could boil 1kg of water in 24min and has an overall efficiency of about 30% during typical days in summer and winter. El Sebaii et al (1997) also carried out studies on a box-type solar cooker with a reflector and were able to show that the boiling and the time characteristics of water boiling respectively decrease from 50% to 30% when the cooking device is used around noon. Das et al. (1994) showed in their study that a cooker of dimensions 0.6 x 0.6 x 0.1 m3 was sufficient to cook a lunch and a dinner even in winter on a clear day. Many other authors have worked on the box-type cooker and showed its performance:Avala et al. (2007); Hilario et al. (2014); Soria et al. (2015); Gonzalez et al. (2014) ... The box type cooker is simple and cooks slowly and uniformly. Although easy to conceive, this type of cooker has shortcomings such as necessary preheating time and cooking hours that are only during direct sunlight period. These deficiencies can be filled by an indirect solar cooker with parabolic trough reflector. Performances of such a device are almost non-existent in the literature. The objective of this work is to determine through experimentation the performance of such a solar cooker.

MATERIAL AND METHOD

Material

Measuring devices: The different temperatures were measured using Midi LOGGER GL 220, a 10-channel data logger with the channels connected to type K thermocouples.

The logger has a margin of error of ± 5.2°C for a range of values between 0°C and 100°C and ± 3°C for a range of values between 100°C and 300°C. The power of the solar radiation is measured using a pyranometer placed on the experimental site during the days of measurement. It is connected to the data logger. The pyranometer has a margin of error of ± 1%.

Description and operation of the solar cooker: The parabolic trough solar cooker called "blazing tube " is an indirect solar cooker. It is made up of: an aluminum reflector that concentrates the sun's rays with a reflectivity coefficient of 0.9; a vacuum transparent pyrex glass tube in which the greenhouse effect occurs; a copper absorber tube coated with a black paint containing a vegetable oil with an absorption coefficient ranging between 0.92 and 0.95; a firebox or cooking box where the container (kitchen utensil) is located. It is also equipped with wheels to facilitate its mobility. The solar cooker concentrates the sun's rays through the reflector on the absorber tube filled with oil (linear concentration). The heated oil rises by thermosiphon to a container (cooking hearth) on which the pot is placed. Figure 1 shows a picture of our device. The characteristics of the collector and the tube are given respectively in Tables 1 and 2 below.

Figure 1: Parabolic trough cooker

Collector length	**L = 1.5m**
Collector width	l = 1.2m
The opening of the collector	D = 0.65 m
Parabolic trough radius	F = 0.065m
Focal distance	r = 0.325m
Useful surface of the collector	Ac = 1.8 m²
Reflectivity	From 0.90 to 0.92

Table 2: Characteristics of the tube

Length	**L = 1.59m**
Thickness of the absorber	e = 0.002m
Inner diameter of absorber	D_(int, abs) = 0.108m
Outside diameter of absorber	D_(ext, abs) = 0.11m
Thickness of the window	e = 3mm (0.003m)
Outside diameter of the window	D_(ext, v) = 0.13m,
Inside diameter of glass	D_(int, v) = 0.127m
Glass surface	S_v = 0.649m2
Absorption coefficient of the absorber tube	0.95
Emissivity of glass	0.1
Emissivity of the absorber	0.97
Transmission rate of glass	0.90

MATERIALS AND METHODS

Before each experimentation, the different elements of the cooker are cleaned. To capture the maximum amount of solar radiation, the device is oriented with the slop going south because the site is in the northern hemisphere. It should be noted that it can easily be manually positioned to track the sun because it has wheels for its mobility. The temperatures of the glass, coolant (outlet) and ambient were recorded. Solar radiation on the site is also recorded. For potato frying, the product is placed in the pot and closed. It is sometimes opened only to check the homogeneity of the cooking. It is the same for rice cooking.

Mathematic expressions: The geometric concentration is determined by the following relation:

$$C_g = \frac{S_c}{S_r} \quad (1)$$

With Sc (m^2) the opening area of the collector and Sr (m^2) the surface of the receiver. Our device has a Cg <10, which ranks it among low concentration devices (Gama et al 2008). The useful power which is the power used by cooking is estimated by the following relation:

$$P_U = \frac{m\, C_{pf}(T_{sf} - T_{ef})}{\Delta t} \text{ (Munish et al 2015)} \quad (2)$$

With m (kg) and Cpf (J / kg.K) respectively the mass heat and the specific heat of the fluid. Tsf and Tef (K) respectively represent the temperatures of the fluid at the outlet and at the inlet of the tube. Δt (s) is the useful time interval. The thermal efficiency of the device is evaluated by the following relation:

$$\eta = \frac{p_u}{I(A_c \times C_g + \frac{1}{2} S_{abs})} \text{ (Jacques Bernard 2011)} \quad (3)$$

where S_{abs} is the surface of the absorber.

RESULTS AND ANALYZES

Several experiments were conducted during this study. These are tests while empty, water heating tests, potato fries and mixed rice with ingredients cooking. The results of each test are presented and analyzed.

Testswhile empty (no load): Figure 2 shows the temporal evolution of the heat transfer fluid outlet temperature, the ambient temperature, the glass temperature and the solar radiation of March 17, 2018. The temperature curves of the glass and the surrounding environment have the same appearance as that of solar radiation. The fluctuations of sunshine justify the fluctuations of these temperatures. They are directly related to solar power.

The value range of the ambient temperature (> 40°C) is indicative of the fairly warm weather. The temperature values of the glass above those of the ambient are justified by the fact that the window in addition to receiving radiant heat from the absorber also stores a fraction of the solar radiation. The temperature curve of the coolant and the solar radiation also look the same. For a maximum radiation of about 930W / m2, we have a heat transfer fluid that can heat up to more than 185°C. Several other vacuum tests had also been carried out previously. Table 3 below summarizes the values of the recorded data.

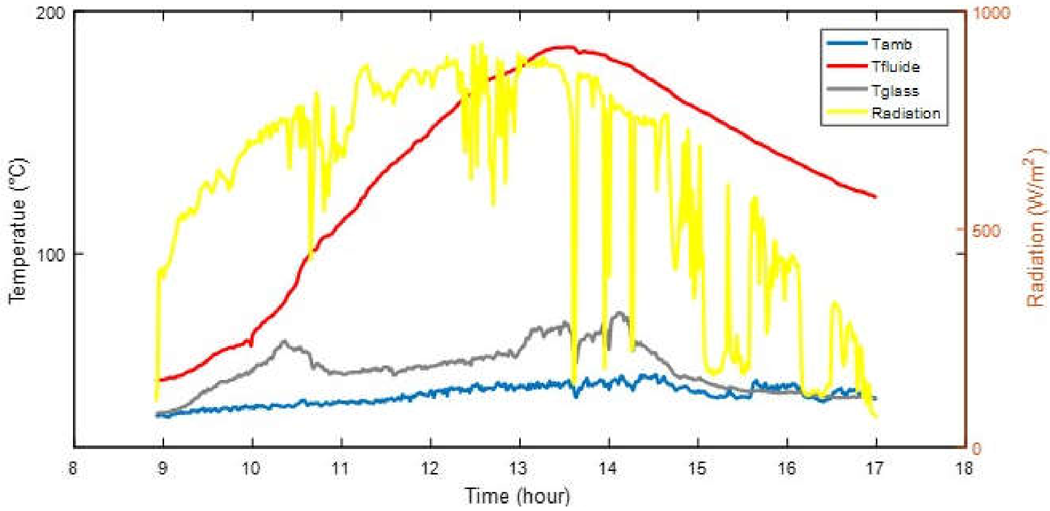

Figure 2: Temporal evolution of heat transfer fluid outlet temperature, ambient temperature and solar radiation

Table 3. Summary of experimental results of vacuum tests

Date	State of the sky	Maximum temperature of the heat transfer medium	Maximum solar radiation
18/09/2017	Partly cloudy	198.8°C	903.1 W/m2
17/10/2017	Partly cloudy	144.3°C	883.5 W/m2
18/03/2018	Clear (dusty)	188°C	981.7 W/m2

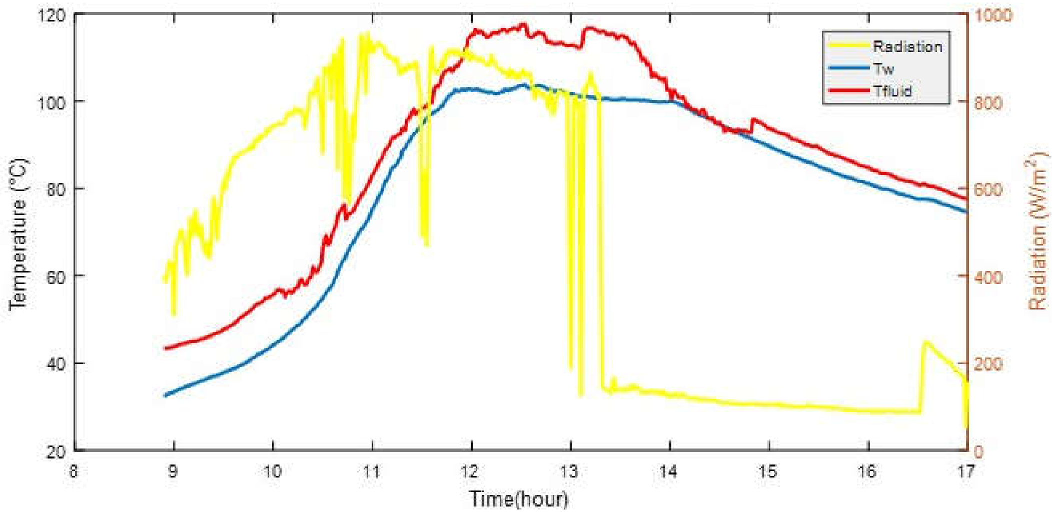

Figure 3. Evolution of water temperature

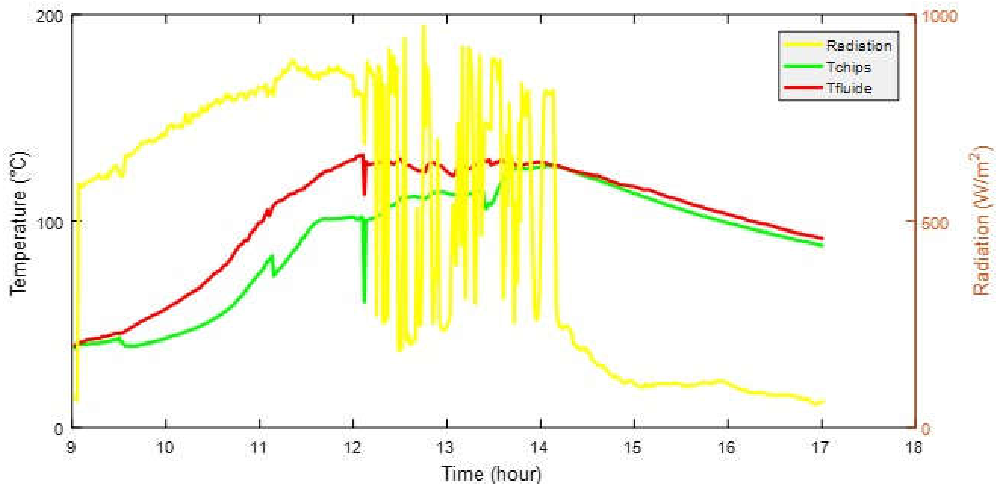

Figure 4. Evolution of coolant temperatures, cooking oil and solar radiation

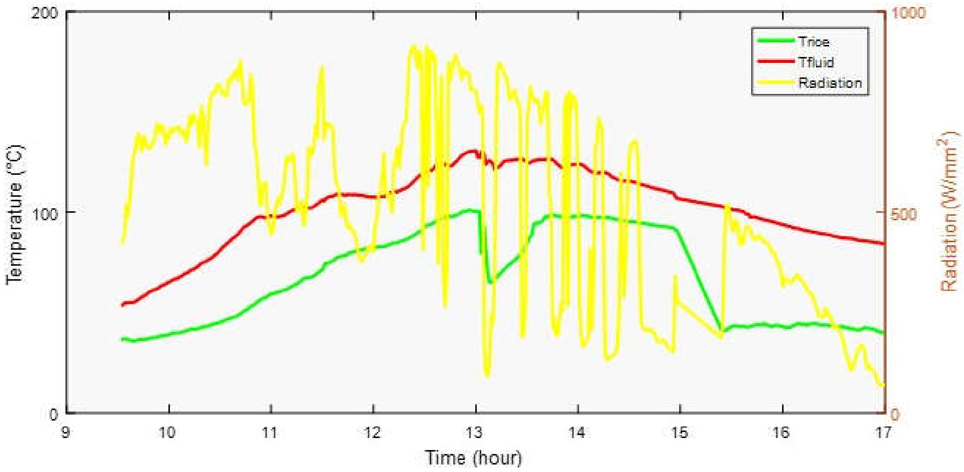

Figure 5. Temperature evolution

Figure 6. Cooked mixed rice with ingredients

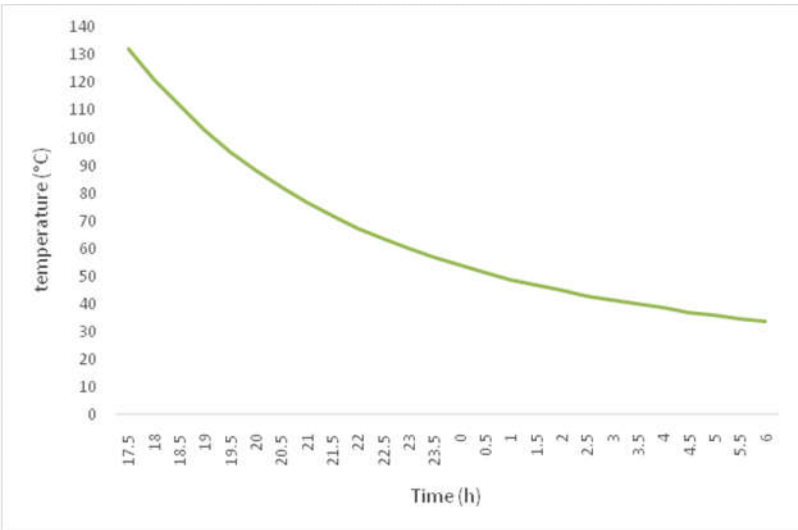

Figure 7. Evolution of the temperature of the coolant for the night of September 18th to 19th

Table 4. Evolution of the temperature of the coolant during the night

Date	Time	Temperature
09/18/2017	17h30mn	132.4°C
	19h30mn	95°C
10/17/2018	17h30mn	86.1°C
	19h30mn	64.3°C
03/18/2018	17h30mn	111.9°C
	19h30mn	84.3°C

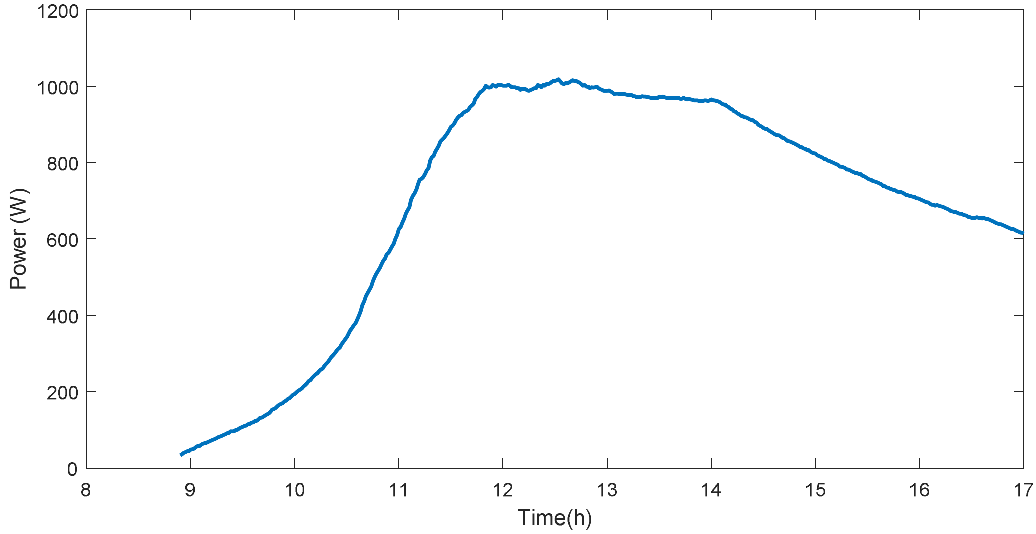

Figure 8. Useful power

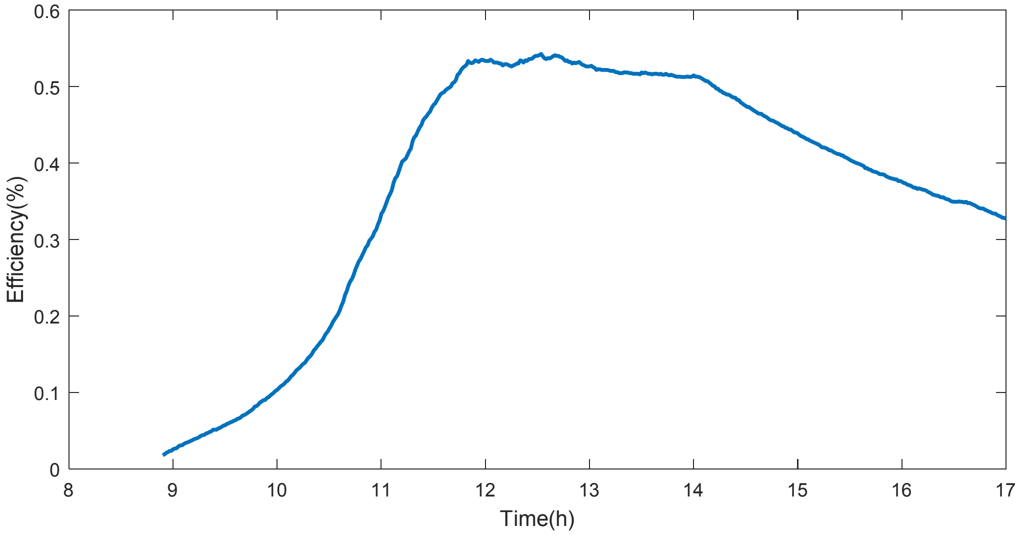

Figure 9. Thermal efficiency

According to these records, solar radiation (global) is higher in the month of March although the temperature of the heat transfer fluid is higher in September. This is explained by the presence of more aerosol during the month of March than in September. As a result, direct radiation is greater in September than in March.

Tests with load: Three types of loads were used for testing: water, potato and rice (and ingredients). During the different testing days, the following parameters were measured: the ambient temperature, the temperature of the coolant, the temperature inside the cooking utensil and the solar radiation.

Water heating: Figure 3 shows the evolution of temperatures of ambient, water and heat transfer fluid, and also the solar radiation as a function of time for two (02) liters of water for the day of 14/03/18. It is obvious that during these experiments the weather was unfavorable as shown by the evolution curve of the solar radiation, which practically disappears in the middle of the day (around 13:30) when it was the most important. Despite this, the temperature of the water reached its maximum and stagnated at this value for nearly 2 hours 30 minutes before starting a slight decrease.

These results indicates in addition to the good properties of the heat transfer fluid, the inertia of the device. These results undoubtedly make it possible to say that cooking can be done even during bad times during the day.

Potato frying: Figure 4 shows the evolution of the temperature of the coolant, the temperature of the frying oil and the solar radiation of 15/03/2018. The observation of the solar radiation curve shows an unfavorable time. Strong fluctuations indicate partly cloudy weather. However, its maximum value exceeded 950W/m^2 but only lasted until 14h instead of 17h. The difference in temperature of the coolant and the frying oil is not as important. This small difference can be explained by the physicochemical properties of both oils but also by the good heat transfer between these two fluids through the aluminum pot. The frying began around 11h40min when the cooking oil begins to reach its stagnation temperature and ended around 12h10min. It therefore had an overall duration of 30 minutes. The cooking time is influenced by the temperature of the oil which is also influenced by climatic conditions such as solar radiation. Given the weather conditions and cooking time we can say that the device is suitable for frying even under unfavorable conditions during the day.

Cooking mixed rice and ingredients: The cooking test of mixed rice and ingredients was performed during a day similar to that of frying that is to say unfavorable. Figure 5 shows the evolution of the temperatures of the coolant, the cooked products and the solar radiation evolution curve of 16/03/2018. A greater difference is observed between the temperatures of heat transfer fluid and cooking products. Indeed the introduction of the products delay the increase of the internal temperature. In addition all the products are not placed at the same moment. The cooking time of the dish is about 2 hours. Figure 6 shows the rice and its various ingredients (cabbage, carrot, meat ...) cooked with the device.

Evolution of the fluid temperature during the night: In order to account for the use of the cooker during the night, we monitored the temperature of the oil (heat transfer fluid) around 17h30min (17.5h) until around 6am in the morning for the night of September 18thto 19th. Figure 7 shows the values of the heat transfer medium temperature read. There is a decrease in temperature due to the absence of heat source which is the sun. However, this decrease is rather slow. It was still possible to cook around 21h and had hot water all night. This result is confirmed with some writings of the literature. The temperature of the fluid decreases during the night. Its decline is much greater in September than in October. It is less important in March because solar radiation lasts longer during this period. It is noted that in all cases cooking remains possible during the night.

Power output and thermal efficiency: The useful power has been evaluated by the relation (2) above. Figure 8 shows the useful power during the day of September 18th. The power obviously has the same overall appearance as that of solar radiation. Indeed it is related to solar radiation. For a maximum solar radiation of approximately 930W / m^2 it can reach a maximum equivalent useful power of 1000Wand a minimum power of nearly 650W towards 17h. The efficiency reflects the performance of the device. It was rated by relation (3) Figure 9 shows the efficiency of the device for the day of September 18thbetween 9h40mn and 17h. In this figure, we also see that the efficiency curve has the same pace as the solar radiation curve and the power curve. The efficiency is then related to solar radiation. It increases during the day and reaches a maximum of almost 55% before decreasing. This value is better for some cookers (El Sabaii 1997, Balogun 2003)

Conclusion

This experimental investigation made it possible to determine the actual performance of the parabolic trough solar cooker. It has confirmed that the temperature of the coolant depends on the intensity of the solar radiation that reaches it, the latter itself depending on natural factors (passage of clouds, the presence of aerosols ...). The device is very suitable for heating, frying and cooking various dishes. It is exploitable all day long including night time.

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