FEASIBILITY OF A SOLAR HEATING PLATE WITH PHOTOVOLTAIC ENERGY

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Abstract— **This paper concerns the feasibility of a photovoltaic (PV) heating plate. More particularly, by using a thermal resistance, heating of the water and cooking at temperatures above 200 °C are analyzed during a sunny day. Through a system of acquisition of electrical and thermal measurements, the cooker set up provides for an illumination of 730 W/m² and peak power of the PV panels of the order of 230 W: heating temperature of the resistance 500 °C after 30 seconds, variation of the heating temperature of water and oil 10 °C/min, bake temperatures above 200 °C, and a thermal efficiency greater than 70%. The comparison of these results compared to the best published on conventional solar ovens of the box type, shows very interesting performance: improved temperature rise of 75%, improved cooking temperatures of 164% and thermal efficiency of 16%.**

Keywords-component; heating plate and solar cooker with photovoltaic energy, electric power, cooking temperature, thermal efficiency.

I. INTRODUCTION

Currently, in developing countries, a large number of households (86.1%) use forest wood for their daily cooking [1]. This source of energy is justified by its low cost and in most cases the difficulty of using natural sources such as gas or electricity. This mode of cooking is the origin of the deforestation of wetlands and consequently of serious ecological and climatic problems [2]. To protect the climate and remedy forest exploitation problems, several organizations, governmental and non-governmental NGOs, offer these households solar-friendly ecological alternatives [3-5]: Box-type ovens, ovens with reflectors and parabolic ovens.

The use of these proposed equipment requires a location well exposed to the sun, in addition, its orientation, relative to the sun, during cooking. The performances obtained by this method of cooking are very limited: maximum temperature of 144 ° C in the case of box type furnaces, thermal efficiency not exceeding 54%. As a result, the use of these cookers does not encourage users, especially in forest areas [6].

In this context, our goal is the development of new solar cookers 'hotplate and oven box' operating with solar photovoltaic energy. These equipments are efficient, reliable, low cost and adaptable to the needs of the inhabitants. We offer equipment that works inside and outside the homes at temperatures and efficiencies respectively greater than 200 ° C and 70%.

In this paper, we propose the feasibility of a solar heating plate, powered by photovoltaic panels, power 230 W Crete, producing a temperature and yield respectively greater than 200 ° C and 70%. These performances and cooking methods are largely sufficient for cooking in homes in rural and urban areas. After describing the structures and performance of current furnaces, we present the structure of our proposal and the first results obtained. Particular attention is paid to equipment sizing, followed by water heating and cooking (oil) temperatures, and the estimation of thermal efficiency throughout the day.

II. BIBLIOGRAPHIC SYNTHESIS

Currently, the solar cookers proposed works directly to the sun's rays outside the homes. This equipment requires the intervention of users for their locations and orientations during cooking. The most used solar cookers / ovens are:

- Box type (figure 1.A) [7]: the structure of this type of cooker consists of flat panels with pyramid reflectors

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inside and outside to concentrate the solar radiation in the insulated cooking chamber. The rays that penetrate through the glass will cause the temperature to rise, and thanks to the greenhouse effect, heats up the black container that contains the food to be cooked. Under an illumination of 858.11W/m² and an ambient temperature of 37.9 °C, the maximum temperature reached in the oven after 4 hours is of the order of 140 °C without load and 98.6 °C full load [7]. Overall, the maximum thermal efficiency does not exceed 54% [8]. It should be noted that this type of oven is used outside homes and requires, during use, its orientation and displacement depending on the position of the solar.

- Parabolic type (Figure 1.B) [9] whose base of operation is the concentration and focusing of solar rays by parabolic reflectors on the bottom of the container (Marmite ...). This type of cooker, when properly oriented, has high cooking temperatures between 200 °C and 300 °C [10] and thermal efficiencies ranging from 43.45% to 77% [11-14]. This type of cooker has the disadvantages: high cost, large size, uncontrollable temperature, risk of burns of food and even users (hands, eyes ...).
- Type reflective panels (Figure 1.C) [15] which consists of different flat panels (or reflective parabolic) and a black container embedded in a plastic bag. Under an illumination of 850 W/m² and an ambient temperature of 20 °C, this type of cooker has firing temperatures ranging from 100 °C to 200 °C [10] and thermal efficiencies of the order of 26.6% [15].]. As in the case of the parabolic cooker, the use of this type of cooker requires a lot of precaution at the level of users: uncontrollable temperature, orientation over the sun, burns...
- Currently, designers of solar cookers are moving towards improving the performance of box solar furnaces by integrating photovoltaic (PV) energy (Figure 1 D). The work carried out concerns the heating of the heating elements by means of the solar batteries, of voltage 24 V and capacity of 45 Ah, charged by the PV panels [16]. The use of batteries increases the cost of the cooker and maintenance costs. Despite the use of PV energy, performances are very limited. Under an illumination of 950 W/m² and ambient temperature of 20 ° C, a battery power of 76.9 W, the temperatures inside the cooker and the heating resistor do not exceed 124 °C [17]. In addition, for a quantity of water of 0.385g, the thermal efficiency does not exceed 43.6% [16].

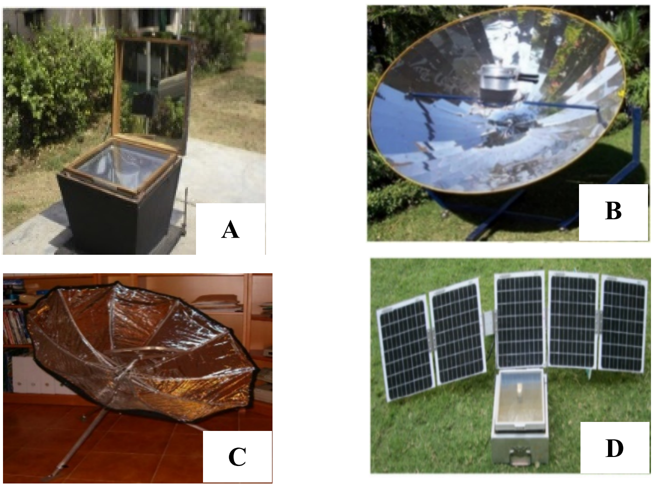


Figure 1 : Cookers powered by solar energy.
A: pyramid box type cooker [7],
B: parabolic cooker [9],
C: reflective parabolic cookers [15],
D: box-type cooker powered by photovoltaic energy [16].

III. STRUCTURE OF THE HEATING PLATE SYSTEM WITH PHOTOVOLTAIC ENERGY

Figure 2 shows the diagram of the PV heating plate proposed in this work. The different blocks of our equipment are:

- **Bloc A**: it is formed by PV panels, with a peak power of 280 W, and produces the electric energy according to the intensity of the illumination during the whole sunny day. They are placed on the roof of the laboratory, facing SOUTH and exposed to the sun under a fixed inclination of 40 °. This latter choice is justified by the preliminary study in [19], which showed us that dual-axis sun followers improve the production of electrical energy by 15 to 20% and increase the cost of the system from 20 to 30% without marked consequences on the temperature of the cooking.

  In order to accurately determine the intensity of illumination and the ambient temperature, a Pyrometer and probe with a suitable circuit are calibrated and installed with the PV panels.

- **Bloc B**: it represents the heating plate, which is constituted by a steel support, in which is placed a ceramic radius of 16 cm, supporting a temperature above 1200 ° C. This ceramic is engraved, in the form of a coil, to house a thermal resistance. This resistance, 16 cm, is dimensioned and chosen to withstand a temperature above 900 °C and produce a sufficient thermal power for cooking.

- **Bloc C**: System for the acquisition and display of electrical quantities (current, voltage and power), thermal (temperature of thermal resistance and cooking), and meteorological (illumination and ambient temperature). This is achieved through a card, set up during this work, using a microcontroller, to track the instantaneous operation of the equipment and communication with a computer, which storage and displays (numerical and graphical) the different electrical quantities measured in real time.

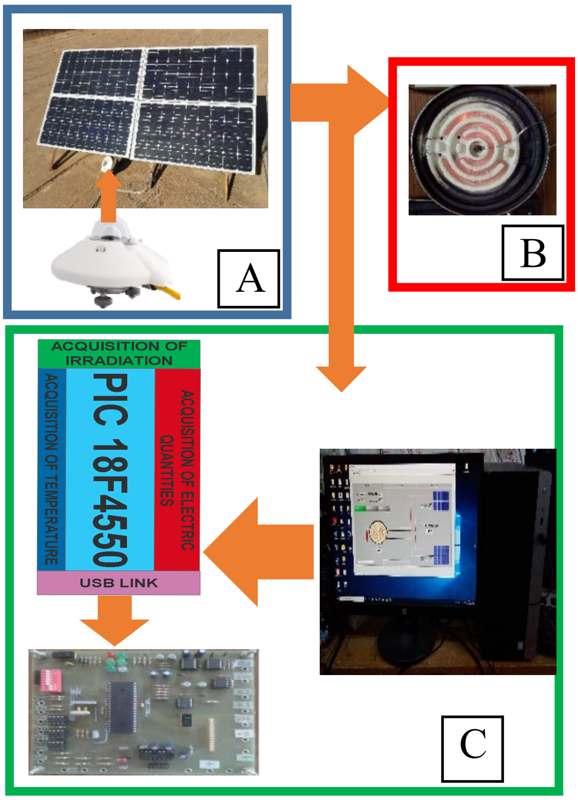


Figure 2: Synoptic diagram of the solar heating plate system equipped with the measurement acquisition system.

IV. RESULS AND DISCUSSION

A. Electrical Characterization of Photovoltaic Panels

In order to size the heating elements of the heating plate and the assembly of the PV panels, knowledge of the electrical characteristics of the PV panels is essential. To do this, we characterized and analyzed the electrical characteristics of a PV panel during a day when the intensity of solar radiation is of the order of 730 W/m² and the ambient temperature of the order of 25 °C. The typical electrical characteristics current-voltage and power-voltage obtained are shown in Figure 3. We can therefore deduce the optimal electrical quantities: a voltage of 15 V, current of 4.5 A, power of 70 W and optimum resistance of 3.4 Ω. These electrical quantities are almost peaks (AM1.5 Spectrum) produced around 12 pm where the intensity of the illumination is maximum. In this feasibility study, we sized the PV array assembly and thermal resistance under these conditions. Therefore, these results allowed us to associate the four PV panels (Figure 2) in series to minimize power losses (less than 25%) [18] and produce an electrical power adaptable to the thermal resistance chosen during the cooking by users.

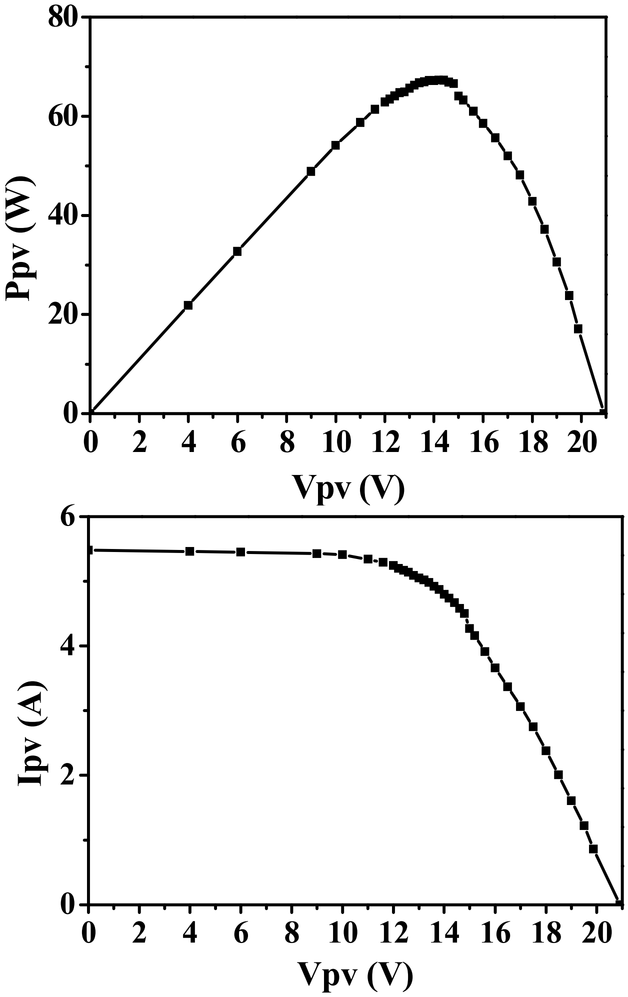


Figure 3: Features current-voltage power-voltage of a photovoltaic panel used. Le = 730 W/m², Temperature = 25°C.

B. Temperature rise of the designed heating plate

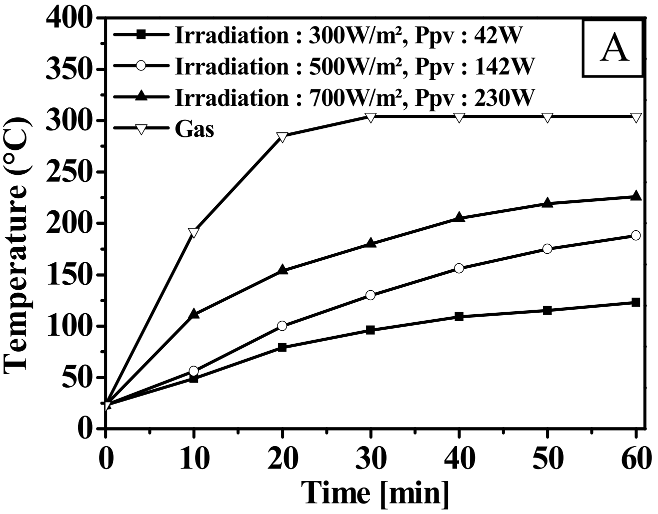
We have experimented the operation of the heating plate with the PV energy, during one hour of heating and three intensities of the illumination, following the rise in temperatures, of the thermal resistance, of a container containing 1 liter of the water, and other container containing 0.33 liter of oil. Under the same heating conditions, a comparative study is made with the gas used in kitchens (Medium fire). The typical results obtained are shown in Figure 4. We can therefore deduce:

- For each experiment, the temperature rise of the heating resistor is very fast: higher than 16 °C/s.
- The rise in temperature strongly depends on the intensity of the illumination. When this varies from 300 W/m² (Ppv = 42 W), to 700 W/m² (Ppv = 230

W), this rise varies from 2.5 °C/min to 10 °C/min in the case of water, and 8.75 °C/min to 10 °C/min in the case of oil. In the case of gas heating, this rise is 3.8 °C/min in the case of water and 12.8 °C/min in the case of oil.

- During 20 minutes of heating, when the intensity of the illumination increases of 200 W/m², around 500 W/m² (an increase of 40%), we observe the increase of: the electric power of 100 W (an increase of 250 %), water heating temperature of 20 °C (ie 40%) and oil of 50 °C (ie 50%).
- When the intensity of illumination is 730 W/m², the power of the PV panels is 230W, the boiling time of the water is of the order of 40 minutes. However, the boiling time of the water by the gas is 20 minutes.
- When panel power increases by 50%, oil and water heating temperatures increase by 50% and 34% respectively.

All the results obtained show the strong dependence of the temperature of the heating with the intensity of the illumination and thus the power of the PV panels. For the same illumination intensities of our experiment (Less than 700 W/m²), when doubling the power of the PV panels (ie 460 W), the heating by the photovoltaic and the gas are practically similar. Moreover, the comparison of these results compared to those obtained on conventional ovens, especially boxes, allows us to deduce better performances on our equipment: speed of heating (higher than 50%), good control of the temperature cooking and therefore the mastery of solar energy inside the homes, ...



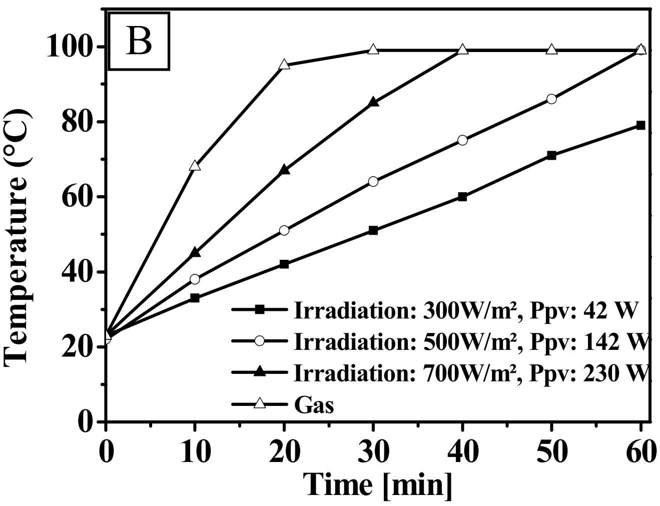


Figure 4: Variation of the heating temperature of the oil (A) and the water (B) according to the illumination. In each plot are shown the results for gas heating 'Medium Fire'.

C. Operation of the hot plate for a whole day

We characterized the hot plate dimensioned in Figure 2 during sunny days, with illuminations and temperatures of the order respectively 750W/m² and 25 °C. We performed measurements by heating one liter of water, to estimate thermal yields for temperatures below 100 °C and 0.3 liter of oil to estimate cooking temperatures above 100 °C. The estimation of the power P_0 and the thermal efficiency η of the plate, is obtained from the rise of the water temperature ΔT during time intervals Δt = 10min, using the Funk model [3, 16], following the expressions.

$$\mathbf{Po} = \frac{\mathbf{m.\,Cp.\,\Delta T}}{\mathbf{\Delta t}} \qquad (1)$$

$$\eta = \frac{\mathbf{P_o}}{\mathbf{P}_{pv}} \qquad (2)$$

Or,
m: mass of heated water (m = 1 liter),
Cp: Specific heat of water (Cp = 4190 J / Kg.K),
Ppv: electrical power of photovoltaic panels.

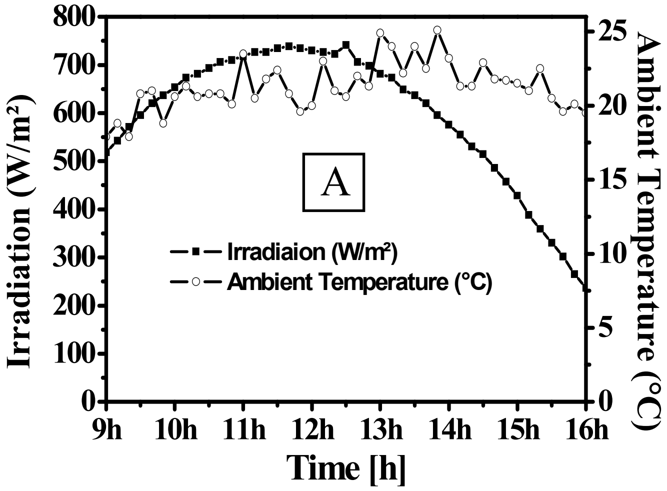
The results obtained are shown in Figure 5. We can deduce:

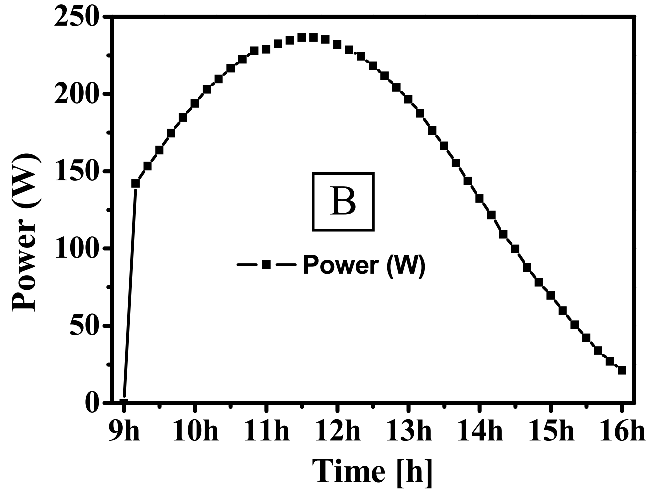
- During the day of measurements, towards noon, the intensity of the illumination holds 750 W/m² and the ambient temperature 25 °C,
- The best performances are obtained around noon when the power of the PV panels reaches 230 W. In our feasibility study, we have dimensioned the whole system (Figure 2) so that it operates under these optimal conditions.
- The temperature rise of the thermal resistance is very fast. When the intensity of the illumination is 500 W/m² and the power supplied by the PV panels is of the order

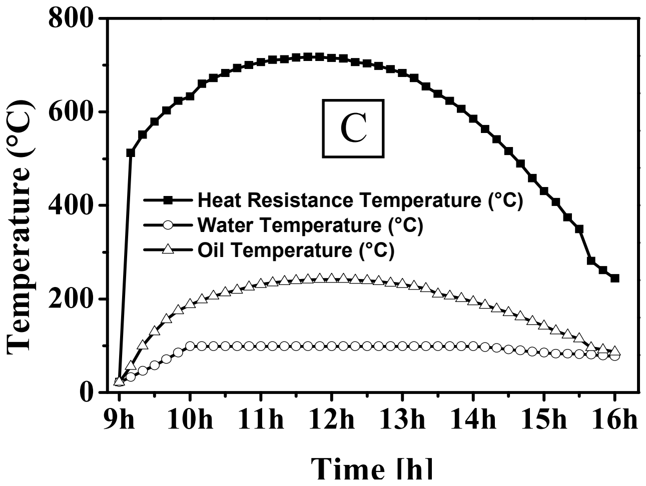
of 150 W, the temperature varies from 24 °C to 500 °C after 30 seconds (ie: 16 °C/sec).

- From 10 o'clock, when the intensity of the illumination is sufficient (600 W/m²) and the electric power of the panels is 175 W, the water reaches the boiling temperature (100 °C) and the oil temperature of 240 °C.
- Around noon, the system operates under optimal conditions: Illumination intensity of 730 W/m², power of 230 W PV panels, temperature of the thermal resistance of 700 °C, the temperature of water and oil are 100 °C and 250 °C, respectively.
- For a quantity of water m = 1 kg, the thermal efficiency is 70%.

The comparison of these results with those found on conventional ovens, we can deduce practically the best performance on our equipment: heating speed, heating temperature which reaches 250 ° C, thermal efficiency of the order 70%, simple use in the homes and not requiring the orientation of the equipment over the sun. All of these results show the feasibility of the operation of the heating plate, designed and sized during this work, to photovoltaic energy in homes.







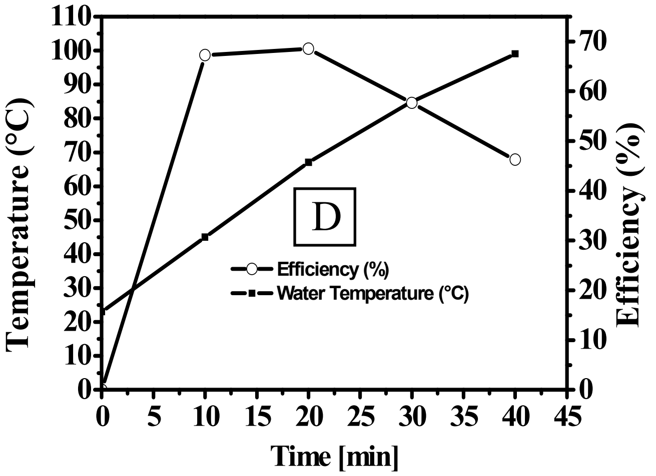


Figure 5 : Characterization of the heating plate of Figure 2.
A : Intensity of radiation and temperature,
B : Electric power supplied by the PV panels,
C : Temperatures of thermal resistance, water and oil.
D : Thermal efficiency.

V. CONCLUSION :

In this paper, we have shown the feasibility of a new cooking method using photovoltaic (PV) renewable energy. We have sized, according to the nature of the PV panels and the thermal resistance used, a hot plate, supplied with 230 W, to heat 1 liter of water and 0.33 liter of the oil.

The comparison of the experimental results obtained from the operation of the system designed, compared to those of the literature in the case of conventional thermal oven shows very interesting performance:

- heating resistor temperature which reaches 500 ° C after 30 seconds of heating,
- Rapid rise of oil and water temperature (10 °C/min) for an intensity of illumination of 700 W/m² (Panels power of 230 W).

- For a power of 230 W, after 10 minutes of heating, the cooking temperature reaches 240 ° C.
- Thermal efficiency around 70%, that’s mean a 20% improvement over conventional ovens.

Furthermore, the comparative analysis of the rise in heating temperature compared to Gas 'Medium Fire' (3.8 °C/min in the case of water and 12.8 °C/min in the case of oil) shows that these performances can be achieved by doubling the power of the photovoltaic panels (ie 460 W).

All the results obtained show very encouraging performances, for an electric power of 230 W Crete PV panels, of this new method of cooking with photovoltaic energy. The rapid rise in the temperature of the water and oil heating, as well as the maximum value reached (240 °C), clearly show the feasibility of the proposed hotplate and its use in homes in rural areas and in particular urban.

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REFERENCES

[1] https://www.notre-planete.info/environnement/deforestation.php.

[2] Miah, M. D., Al Rashid, H., & Shin, M. Y. (2009). Wood fuel use in the traditional cooking stoves in the rural floodplain areas of Bangladesh: a socio-environmental perspective. Biomass and Bioenergy, 33(1), 70-78.

[3] Herez, A., Ramadan, M., & Khaled, M. (2018). Review on solar cooker systems: economic and environmental study for different Lebanese scenarios. Renewable and Sustainable Energy Reviews, 81, 421-432.

[4] Aramesh, M., Ghalebani, M., Kasaeian, A., Zamani, H., Lorenzini, G., Mahian, O., & Wongwises, S. (2019). A review of recent advances in solar cooking technology. Renewable Energy.

[5] S.Talbi, K. Kassmi, A. Lamkaddem, R. Malek, ” Design and realization of a box type solar cooker with thermal storage dedicated to the rural regions of the oriental district” J. Mater. Environ. Sci., 2018, Volume 9, Issue 4, Page 1266-1284.

[6] https://www.urd.org/IMG/pdf/Fiche_technique_REH_Juin_Final.pdf.

[7] Kumar, N., Agravat, S., Chavda, T., & Mistry, H. N. (2008). Design and development of efficient multipurpose domestic solar cookers/dryers. Renewable Energy, 33(10), 2207-2211.

[8] Kumar, N., Chavda, T., & Mistry, H. N. (2010). A truncated pyramid non-tracking type multipurpose domestic solar cooker/hot water system. Applied Energy, 87(2), 471-477

[9] Indora, S., & Kandpal, T. C. (2018). Institutional and community solar cooking in India using SK-23 and Scheffler solar cookers: A financial appraisal. Renewable energy, 120, 501-511

[10] YETTOU Fatiha,’ Conception et réalisation d’un système de cuisson solaire destiné au site saharien (Ghardaïa, Algérie)’’, Thèse de Doctorat en Sciences ,2005, algerie.

[11] Indora, S., & Kandpal, T. C. (2018). Institutional and community solar cooking in India using SK-23 and Scheffler solar cookers: A financial appraisal. Renewable energy, 120, 501-511.

[12] Pohekar, S. D., & Ramachandran, M. (2004). Multi-criteria evaluation of cooking energy alternatives for promoting parabolic solar cooker in India. Renewable Energy, 29(9), 1449-1460.

[13] Badran, A. A., Yousef, I. A., Joudeh, N. K., Al Hamad, R., Halawa, H., & Hassouneh, H. K. (2010). Portable solar cooker and water heater. Energy Conversion and Management, 51(8), 1605-1609.

[14] Grupp, M., Balmer, M., Beall, B., Bergler, H., Cieslok, J., Hancock, D., & Schröder, G. (2009). On-line recording of solar cooker use rate by a novel metering device: prototype description and experimental verification of output data. Solar Energy, 83(2), 276-279..

[15] Arenas, J. M. (2007). Design, development and testing of a portable parabolic solar kitchen. Renewable energy, 32(2), 257-266..

[16] Joshi, S. B., & Jani, A. R. (2015). Design, development and testing of a small scale hybrid solar cooker. Solar Energy, 122, 148-155.

[17] Joshi, Smita B., and A. R. Jani. "Certain analysis of a solar cooker with dual axis sun tracker." 2013 Nirma University International Conference on Engineering (NUiCONE). IEEE, 2013.

[18] MRABTI, T. (2012). Contribution à l’amélioration du fonctionnement des systèmes photovoltaïques pour une meilleure exploitation de l’énergie solaire, PhD, Mohammed Premier University, N° 206/12, 2012, Oujda, Maroc.

[19] GAAMOUCHE, A. LAMKADDEM, S.TALBI, K. KASSMI,”Conception and Realization of a PV System Provided with a Sun Tracker Operating at Dual Axis,” Journal of Renewable Energy and Sustainable Development (RESD), Volume 2, Issue 1, June 2016 - ISSN 2356-8569.