Innovative Solar Pressure Cooker with Parabolic Trough Concentrator using Water Vapor InnovSoPre

N. El Moussaoui*, M. Rhiat*, A. Lamkaddem*, R. Malek*, K. Kassmi*‡, K. Schwarzer**, H. Chayeb***, N. Bachiri****

* Department of Physics, Faculty of Science, Mohamed First University, Oujda, 60 000, Morocco

** Engineering Office of Energy and Environmental Technology (IBEU), Jülich, 52 428, Germany.

*** Solar-Institut Jülich (SIJ), Aachen University of Applied Sciences, Jülich, 52 428, Germany

****Association Humain and Environnement of Berkane (AHEB), Berkane, 63 300, Morocco.

(ndn.moussaoui@gmail.com, mohammed.rhiat@ump.ac.ma, ali.lamkaddem@gmail.com, rch_malek@hotmail.com, khkassmi@yahoo.fr, schwarzer@sij.fh-aachen.de, chayeb@fh-aachen.de, n_bachiri@hotmail.com)

‡ Corresponding Author; K. KASSMI, 60 000, Tel: +212 6 78 07 52 14,

Fax: +212 5 36 50 06 03, khkassmi@yahoo.fr

Received: 19.05.2022 Accepted: 13.06.2022

Abstract- In this paper, we propose the design and operation of a concentrating parabolic trough solar cooker, working with water vapor. This cooker operation's principle is based on the concentration of solar radiation on a vacuum tube, containing two tubes, for which the cold water descends and the hot water rises towards the cooking pot (pressure cooker). The closure of the pot is ensured by a cover provided with a valve that releases the vapor of the water when the pressure in the pot reaches the value of 1.8 bar. The experimentation of the cooker, exposed to the sun, shows, for a solar irradiation intensity of 863 W/m^2 and an ambient temperature of 37°C, cooking temperatures which reach 104°C after 22 min, the heating power of 351.62 W, and thermal efficiency of 34.18%. Heating water or cooking 1 kg of food (potatoes, etc.), under vapor in the pot, shows a heating or cooking temperature above 100°C for 30 min. The analysis of these results compared to the conventional heating of cookers by electricity, or butane, shows comparable temperatures and cooking times, and consequently the feasibility of the solar vapor cooker, under pressure, proposed in this work. Also, we can notice an exciting improvement compared to the concentration thermal cookers of the literature, with an improvement of the efficiency of 28% and a heating time reduced by 50%.

Keywords Solar thermal energy, innovative concentrating parabolic trough solar cooker, solar water pressure cooker, water vapor cooking, efficiency and thermal power

1. Introduction

Renewable solar energy sources have a significant role to play in implementing the 2030 Agenda and the Sustainable Development Goals (SDGs) [1,2]. They represent a critical alternative to conventional fossil fuels [1,3-7], which are the causes of environmental degradation and global warming [8-12], which has increased forest burning [12,13]. These degradations and the massive exploitation of forests by man for various uses (cooking, heating,) have pushed the governments of countries and non-governmental organizations NGOs to implement strategic projects to fight against deforestation, due to fire and human uses, using solar energy [14,15]. Among these orientations is the commitment to innovate on cooking equipment and to propose cookers working with solar energy, low cost and adaptable to the cooking needs of the users of the rural and especially urban world [10, 16-20].

Solar cooking is therefore a clean and ecological cooking technology since it uses the sun as fuel and does not produce smoke and greenhouse gases. It is current and provides attractive socio-economic and environmental benefits [21]. In the literature, there are thermal solar cookers based on flat thermal collectors [23-24], concentrator type parabolic trough [25,26], and parabolic [23,27,28]. Their operating principle is based on the concentration of solar radiation on a utensil containing food (direct cookers) [16, 27], or a fluid (thermal oil) (indirect cookers) [22, 23, 28, 29]. For direct cookers, performance is very low (temperatures below 100°C) and not adaptable to user needs [27, 30, 31]. In the case of indirect cookers, the heating is based on the use of heat transfer fluids, which makes the technique expensive and leads to additional heat losses through the piping, during the circulation of the heat to the cooking block [15,16].

In this context, the objective of our research work, within the framework of national and international cooperation, is to develop indirect solar cookers operating on concentrated solar thermal energy. This equipment is mobile, efficient, reliable, easy to use, low cost, and adaptable to the needs of the inhabitants. It allows cooking by exploiting the heat produced by a parabolic trough concentrator that reaches temperatures above 300°C [29]. These temperatures are more than enough to cook foods that require temperatures of 80-250°C. In earlier research, we proposed an indirect cooker [29], with a parabolic trough concentrator which concentrates the solar irradiation on a heat transfer fluid (oil). Through the phenomenon of heat transfer, the cooker heats a pot, immersed in the heat transfer oil, to a temperature that reaches 300°C. To make this cooker more reliable and to overcome the use of oil as a heat transfer fluid, we propose the design of an ecological cooker that works only with water , and the cooking, in the pot, is done with water vapor. In this cooker, the pot is covered with a lid with a valve to regulate a pressure of approximatively 1.8 bar inside the pot. The pot is connected to a closed circuit of two tubes: one containing cold tap water and the other (formed by two sub-small tubes) allowing the circulation of hot water, which arrives, at high pressure, in the pot. The concentration of the radiation on the tube containing the cold water, heats this water to a temperature higher than 100°C and thus the pot under the vapor at a temperature higher than 100°C. This method of cooking is equivalent to the usual cooking with pressure cookers, at high pressure, using the usual energy sources of butane or electrical energy [27, 31].

In this paper, we present the structure and the experimentation of the new parabolic trough concentration cooker working with vapor water. In particular, we experiment with the operation of the cooker in the Moroccan climate (Africa), on sunny days, by following the temperatures of the tubes and the pot of the cooker. The validation of the operation is then carried out by estimation of efficiencies and thermal powers and measurements of temperatures by heating with a liter of water and cook 1 kg of food (Potatoes).

2. Structure and Operation of the Cooker InnovSoPre

2.1. Structure

Fig. 1 and Fig. 2 represent the synoptic diagram of the solar parabolic trough cooker InnovSoPre proposed in this work. The different blocks and characteristics (Table 1) of this cooker are:

- Dimensions of the cooker: length 204 cm, height 108 cm, and weight 35 kg.
- Parabolic trough mirror (concentrator) of length L, height h, aperture A_a, and concentration factor C. Its role is to concentrate the solar rays to a focal line of distance f, where a glass tube with a double envelope is placed. The concentrator is covered by a reflective layer, characterized by a high reflection rate, to improve the thermal performance of the cooker.
- Vacuum tube with double-walled glass, similar to a long transparent "thermos" bottle (concentric). It has a length L_g and an inner diameter D_{i-g} an outer diameter D_{e-g} and a thickness e_g. It is placed in the focal line of the mirror at a focal distance f to form a Rim Angle and Rim Radius of φ_r and r_r. This vacuum tube is used to avoid convection losses to the outside and also to trap heat inside by the greenhouse effect. This glass tube, with transmission coefficient τ_g, is considered as a barrier to the infrared radiation emitted from the interior elements. The heat absorbed by the interior is transferred to the copper tube circuits containing the cooking water.
- A copper circuitry, of conductivity λ_{ab}, is formed by hermetically sealed tubes (Fig. 2, B), of length L_{ab}. They are installed vertically or slightly inclined in the double-walled vacuum tube. As shown in Fig. 2, these tubes are formed by a tube of diameter D_{p-ab} containing cold water, another type is formed by two sub-small tubes, with secondary outlets of diameter D_{g-ab}. These allow the hot water to rise to the pot (casserole).
- Cooking box contains a cooking vessel (casserole) with a capacity of 5 liters, a diameter of 22 cm, and a height of 17 cm. The lid of the vessel, equipped with circular vapor seals, is formed by a manual locking system and a safety valve (steam trap), to release the steam (vapor) and ensure a pressure lower than 1.8 bar and a temperature boiling point of 120°C in the container. This allows cooking and avoids overpressure in the cooker tubes.
- Two orientable wheels allowing the cooker to be moved with the sun.
- Evacuation tube, equipped with a tap, is connected to the large tube in order to clean the cooker and the tubes at the end of the cooking.

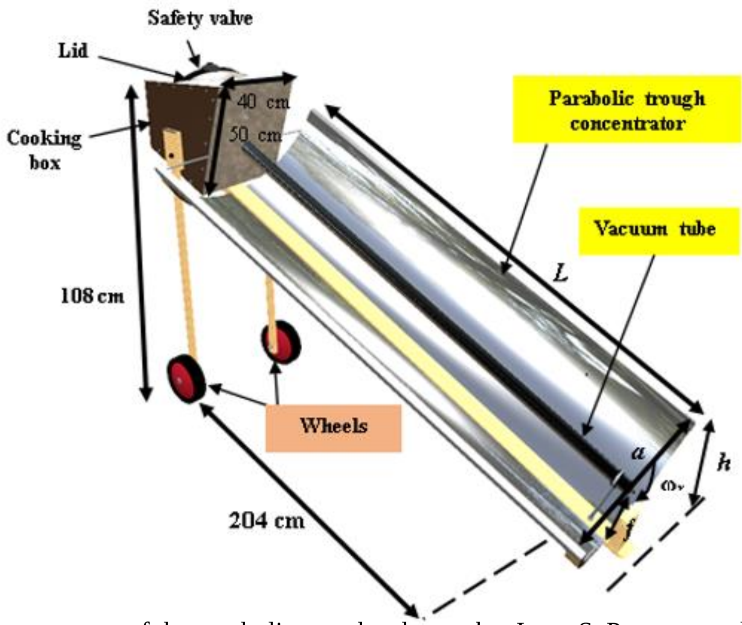

Fig. 1. The structure of the parabolic trough solar cooker InnovSoPre proposed in this work.

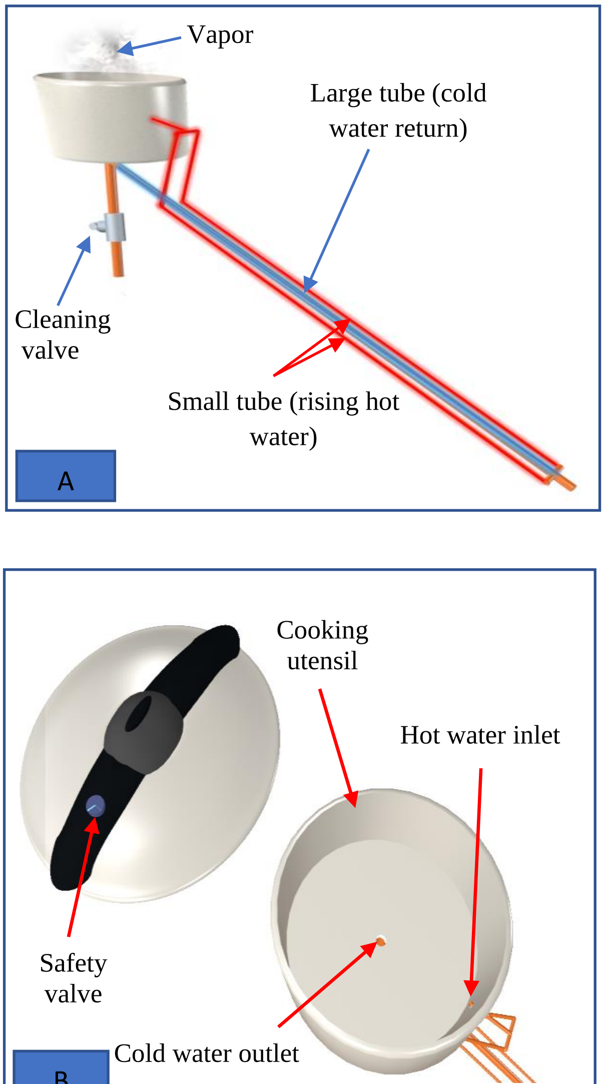

Fig. 2. Cooker tubes (A), pot (pressure cooker) cooking with vapor (B) in Fig. 1.

Table 1. Geometric and thermal specifications of the cooker in Fig. 1.

PTC model			
Paramter	**Symbol**	**value**	**unit**
Rim radius	r_r	0.4	(m)
Rim Angle	φ_r	90	(°)
Distance focal	f	0.2	(m)
Geometric concertation ratio	$C=A_a/A_g$	13.79	-
Mirror			
Collector length	L	1.50	(m)
Collector height	h	0.2	(m)
Aperture width	a	0.84	(m)
Aperture area	A_a	1.2	(m²)
Parabolica curve length	S	1.08	(m)
Glass enveloppe			
Inner diameter	$D_{i\text{-}g}$	47	(mm)
Outer diameter	$D_{e\text{-}g}$	58	(mm)
Length	L_g	1.5	(m)
Aperture area	A_g	0.087	(m²)
Thickness	e_g	4	(mm)
Transmittance	τ_g	0.9	-
Absorber tube			
Diameter of the large tube	$D_{p\text{-}ab}$	16	(mm)
Diameter of the small tube	$D_{g\text{-}ab}$	8	(mm)
Length	L_{ab}	1.7	(m)
Conductivity	λ_{ab}	380	$(w.k^{-1}.m^{-1})$
Tube material	Copper		
Heat transfer working fluid	Water		
Thermal insulation	Glass wool		

2.2. Operation of the cooker and performance of the cooker InnovSoPre

The operating principle of the parabolic trough cooker InnovSoPre of Fig. 1, is as follows:

- The capture of solar energy and heating of the tubes: The parabolic trough mirror concentrates the solar rays in the double-walled glass tube.
- Heat production: As this double-walled tube is vacuumed and made of glass, the convection losses are low and the heat generated is trapped inside by the greenhouse effect. The heat is then transferred to the copper tubes inside. In the tubes, the water circulates and heats up by heat exchange, then naturally circulates from the bottom to the top of the tube, through the two small tubes (Fig. 2), which communicate with the pot. Since the temperature in the two small tubes exceeds 100°C, the pot is heated by hot water, the pressure of which is regulated by the valve.
- Heat transfer to the cooking chamber: In the cooking chamber, the rising hot water (vapor) in the two small tubes heats the cooker, and hence the food under this vapor. This water cools and releases heat (sensible heat). Then the cold water descends from the recipient through the central cold-water tube, and the cycle repeats itself to transfer heat to the cooking chamber again. During operation, the rising hot water, and the falling water, therefore, cross each other inside the tube. During operation, the thermal efficiency η, during the variation of the water temperature from **ΔT** in the cooker from 30 to 95°C, for a period of Δt=600s, is thus defined as a function of the solar radiation power I (W/m²) by the expression [22, 27, 28] :

$$\eta = \frac{\dot{Q}}{I.A_a} \tag{1}$$

Where: $\boldsymbol{A_a}$: Aperture area of parabolic trough concentrator (1.2 m²).

$\dot{Q}$: Sensible heating power absorbed by the water during the temperature increase of ΔT. It is a function of the mass of water (1kg) and the specific heat capacity of water at constant pressure ***Cp***:

$$\dot{Q} = \frac{m_w.c_p.\Delta T}{\Delta t} \tag{2}$$

Taking into account expressions 1 and 2, the efficiency is written by the form:

$$\eta = \frac{m_w.c_p.\Delta T}{I.A.600} \tag{3}$$

3. Experimental Results

3.1. Experimental procedure

Fig. 3 represents the solar cooker **InnovSoPre** suggested in this work. In the same figure, we have represented the circle that shows the displacement of the cooker, to capture the direct radiation, perpendicular to the parabolic trough concentrator, in the course of the sun during a sunny day. During our experimentation, we recorded, at each moment of the day, the meteorological parameters (solar irradiation intensity and ambient temperature) and thermal parameters (Temperatures of the tubes and in the pot), and the position of the cooker (Alpha parameter). The meteorological and thermal quantities are recorded using:

- A CMP6 pyranometer, accurate to ± 5%, connected to a digital multimeter (Keithley model 2700) and a computer. The set allows to measuring the solar irradiance with an accuracy of ± 30 W/m^2 and a resolution of 0.1 W/m^2.
- Temperature probes (type k), allowing the measurement of temperatures with a precision of approximately ± 1°C. We have connected these probes in the cooker, to follow the temperature of a pressure cooker, and on the tubes, to follow the temperatures of the tubes where cold and hot water circulates. These probes are connected to the Multimeters type UNI-T U171C 5. The set allows measuring the different temperatures, in a range between -40°C and 400°C, with a resolution of 0,1°C- 1°C and precision of ± 1°C.

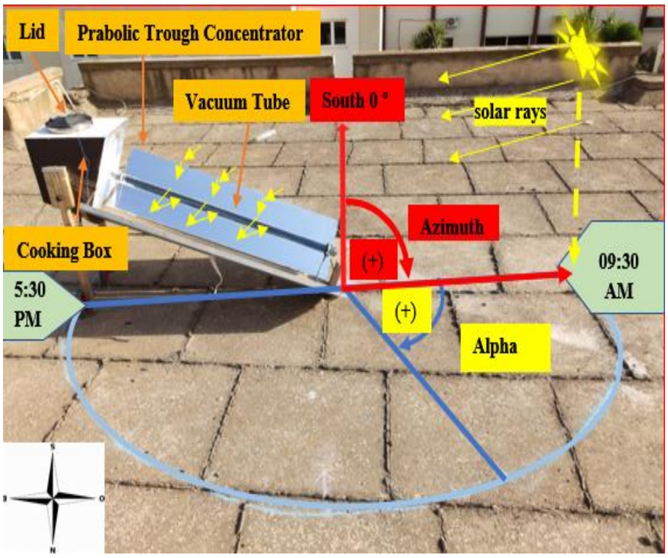

Fig. 3. Photo of the vapor cooker InnovSoPre proposed in this work (Fig. 1).

3.2. Heating One Liter of water

We experimented with the cooker in Fig. 3 by heating one liter of water in the pot, then we measured the meteorological (intensity of solar irradiation, ambient temperature) and thermal quantities (temperatures of the large tube, the two small tubes, and the water in the casserole), the positioning of the cooker (the Alpha angle). The typical results obtained are shown in Fig. 4. From these results, we have reported in Table **2**, between 12:00 and 13:00, the water temperatures, heat, powers, and thermal efficiency. It should be noted that at the end of the heating, we fill the cooker (Large tube) with water, adding the water inside the pot. We can thus deduce:

- The intensity of the solar irradiation and the ambient temperature vary respectively between 462 W/m^2 and 863 W/m^2, and 25°C and 38°C.
- The maximum temperatures of the small tube, the large tube, and the casserole are respectively 104°C, 100°C, and 100°C around 1 p.m., where the solar irradiation intensity and the ambient temperature are 863.07 W/ m^2 and 35°C.
- When the solar irradiation intensity increases (decreases) by 300 W/m^2, these maximum temperatures increase (decrease) by 20°C (i.e. 2°C/min), 7°C (i.e. 0.7 °C/min), 6°C (i.e. 0.6°C/min),
- The boiling time of water depends on the intensity of the solar irradiation: At 9:30 AM, when the solar irradiation is 432W/m^2 and the ambient temperature is 27°C, it is around 30 minutes. Around 12:30 AM, when the solar irradiation intensity is 841 W/m^2, and the ambient temperature is 34°C, it takes around 22 minutes. We can deduce that when the solar irradiation intensity increases by 409 W/m^2 and the boiling time decreases by 8 min (i.e. 26 %).
- The average orientation of the cooker is about 3.93 degrees per 10 minutes and 24 degrees per hour,
- The total orientation of the cooker, during this day of experience, is 181 degrees,
- The cooker is oriented South towards 1:15 PM (Azimuth= 0°). In this situation, the one-hour operation of the cooker requires a low orientation which is 0.8 degrees/min.
- The azimuth variations of the concentrator and that of the sun (-90° to + 90°) as well as the orientation (Alpha) (0 to 180°C) show a very good agreement and therefore good tracking of the sun during our experience.
- Efficiency and thermal power reached their maximum values of 34.18 % and 351.62 W around 12:40 (Table 2).

All the results obtained in this paragraph show cooking temperatures and efficiencies comparable to those obtained in the case of complex and expensive direct and indirect thermal cookers [26, 27, 32, 33, 34]. Also, we note a clear improvement of 50% in the heating time [26, 31, 35] and 28% in the thermal efficiency, compared to the parabolic cookers [26, 27, 33]. We can thus deduce the feasibility of heating by casserole with vapor, from the concentration of solar radiation on a tube containing only water.

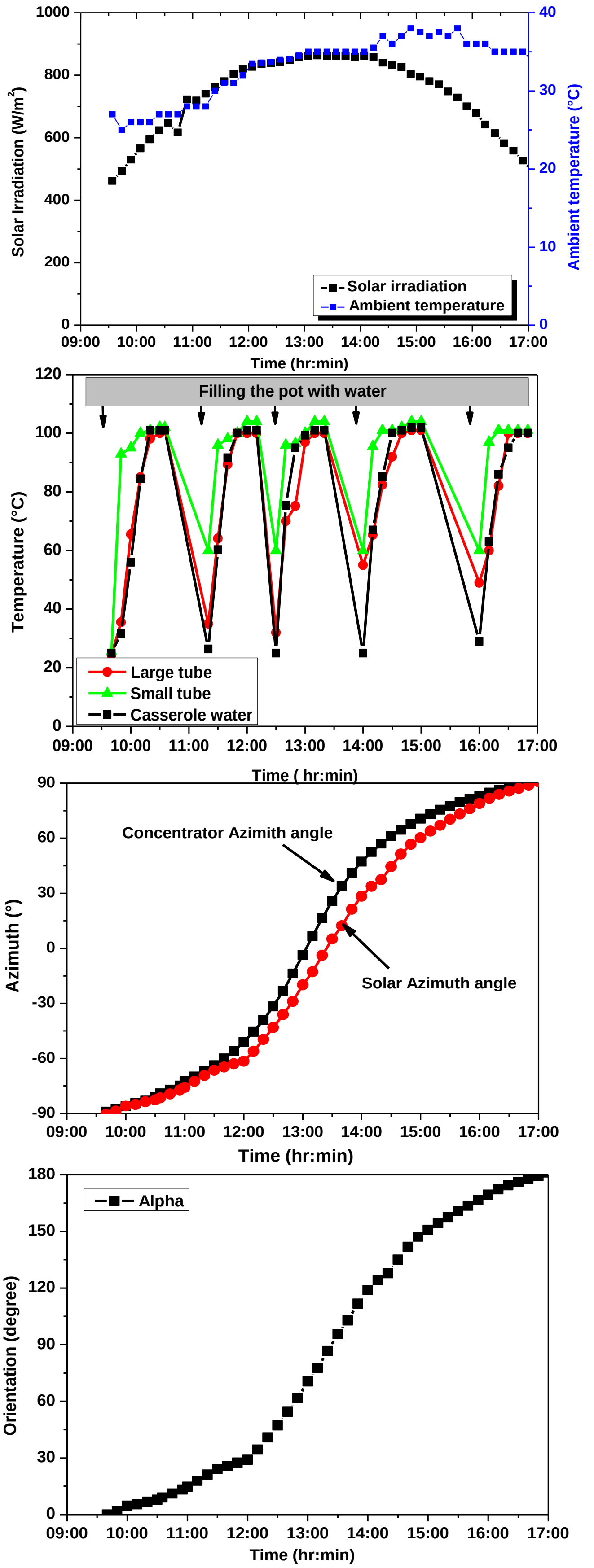

Fig 4. Variations of solar irradiation intensity and ambient temperature, temperatures in the tubes and in the pressure cooker, Azimuth angle (concentrator and sun), and orientation of the cooker during the experiment. July 2021

Table 2. Power and thermal efficiency of the cooker InnovSoPre .

Time Hr :min	12:30	12:40	12:50	13:00
Water Temperature (°C)	25	75,4	95	99,3
Solar irradiation intensity (W/m²)	847,88	857,13	861,31	863,07
Output Puissance (W)	1017,45	1028,55	1033,57	1035,68
Sensible heat (J)	0	210974	82045,6	17999,8
Heating output power $Q^{\cdot}$ (W)	0	351,62	136,74	29,99
Efficiency (%)	-	34.1861	13.23	2.89

3.3. Cooking (Steaming) of vegetables

In this paragraph, we experimented with the cooker of Fig. 3 by steaming food (1 kg of potato). As before, we recorded the temperatures of the tubes and inside the pot, and the alpha angle of the sun tracking. The typical results obtained in Fig. 5 show :

- The intensity of the solar irradiation intensity and the ambient temperature vary respectively between 649 W/m² and 812 W/m², and 30°C and 37°C.
- The maximum temperatures of the small tube, large tube, and water of the casserole are respectively 104°C, 102.5°C and 100°C. They are obtained around 12:40 p.m. when the solar irradiation intensity is stable (around 780 W/m²). During the day, from 11h to 11h50 min, the solar irradiation intensity varies from 649.33 to 754.66 W/m², and these temperatures increase from 22 to 100°C (a variation of 78°C, or 354 %).
- The average orientation of the cooker is about 2 degrees per 10 minutes and 20 degrees per hour,
- Water boiling is reached after 32 minutes of heating.
- During the cooking of the potatoes, the solar irradiation intensity varies from 754.66 to 790.56 W/m², the ambient temperature from 32.6 to 33.1°C, and the temperatures of the tubes and in the casserole remain stable respectively 101°C 100°C and 98°C. This is due to the thermal insulation (glass wool) of the cooking box and the lid of the pressure cooker, equipped with a safety valve, which maintains a constant temperature. It allows a constant pressure to be maintained in the cooker, and consequently

a cooking time of around 30 minutes. This time is comparable to cooking with conventional energy sources [26,27]: butane, electricity, etc.

- The total orientation of the cooker during this food cooking experiment is about 39 degrees.

The comparison of the cooking temperatures and yields obtained on our cooker with those obtained on direct and indirect thermal cookers, shows a clear improvement of 50%. Also, the cooking temperature (around 95°C) and the cooking time (around 30 min) are comparable to those obtained from conventional energy sources, such as butane and electricity. We can thus conclude the feasibility of our cooker, working with water vapor, for the cooking of food and meals; currently, prepared by expensive conventional cookers [35, 36] or by using fossil energy sources. The cooker proposed in this work (Fig. 1) is therefore efficient, reliable, low cost, and ecological. It is considered to be environmentally friendly and could be used by rural and urban inhabitants.

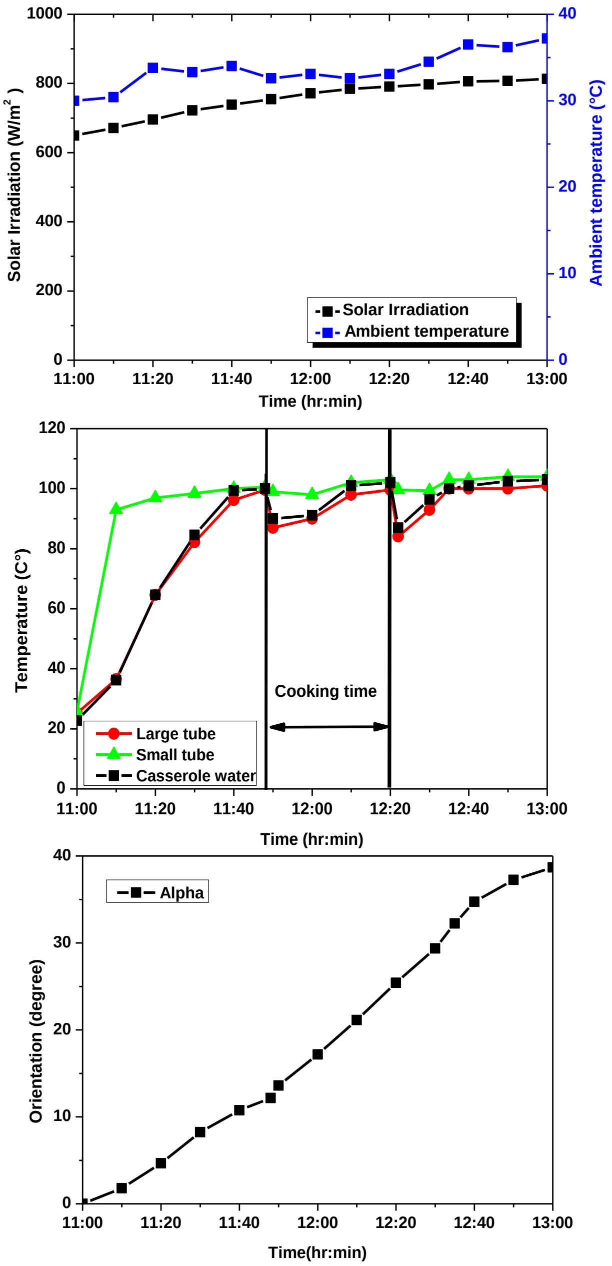

Fig. 5. Variations of solar irradiation intensity and ambient temperature, temperatures of the tubes and water in the pressure cooker, and orientation of the cooker during the experiment. July 2021;

4. Conclusion

In this paper, we have shown the feasibility of the operation of an innovative parabolic trough concentrator pressure cooker ISPCPTCWV. The heating of the cooker is based on the concentration of irradiations on a double-walled glass tube, containing two types of copper tubes that communicate with a pot, via holes. The pot is equipped with a stainless-steel lid, which is surrounded by rubber seals and incorporated a valve to regulate the temperature and pressure in the pot. The experimentation of the cooker, on sunny days, shows:

- The concentration of solar radiation on the tubes heats the cold water going down the large tube, and then the hot water rises through the two smaller tubes to the inside of the pot.
- Heating one liter of water to boiling at 12:30 AM, when the solar radiation intensity is 841 W/m^2 and the ambient temperature is 34°C, shows a heating time, efficiency; and thermal power of 22 minutes, 34.18 %, and 351.62 W.
- The cooking of 1 kg of potatoes at 12:40, when the solar intensity irradiation is stable (around 780 W/m^2) and ambient temperature of 34°C, shows temperatures of the small tube, large tube and water casserole, respectively of 104°C, 102.5°C, and 100°C. Under these conditions, these temperatures remain stable respectively 101°C 100°C, and 98°C during the cooking time which is about 32 minutes.

The comparison of the results with those obtained on expensive thermal type cookers shows improved performance of 50 % and 28 %, in terms of heating time, to reach the boiling temperature and thermal efficiency. All of these results and performances allow us to conclude the feasibility of the parabolic trough cooker, designed and produced during this work. Its use for cooking in the rural world, and particularly urban, meets the energy needs of the inhabitants and contributes to the protection of forests and the environment.

Acknowledgements

This research is supported within the framework of the project and collaborations :

- National Initiative for Human Development INDH, Berkane Province, Morocco, project 2017//29.
- Engineering Office of Energy and Environmental Technology (IBEU), Jülich, Germany.
- Solar-Institut Jülich (SIJ), Aachen University of Applied Sciences, Jülich, Germany.
- Association Humain and Environnement of Berkane (AHEB), Berkane, Morocco

References

[1] A. A. Adenle, "Assessment of solar energy technologies in Africa-opportunities and challenges in meeting the 2030 agenda and sustainable development goals", Energy Policy, vol. 137, pp. 1-16, 2020.

[2] D. M. Ibrahiem and S. A. Hanafy, "Do energy security and environmental quality contribute to renewable energy? The role of trade openness and energy use in North African countries", Renewable Energy, vol. 179, pp. 667-678, 2021.

[3] S. K. Sansaniwal, V. Sharma, and J. Mathur, "Energy and exergy analyses of various typical solar energy applications: A comprehensive review", Renewable and Sustainable Energy Reviews, vol. 82, pp. 1576-1601, 2018

[4] W. Wu, S. Dai, Z. Liu, Y. Dou, J. Hua, M. Li, X. Wang, and X. Wang, "Experimental study on the performance of a novel solar water heating system with and without PCM", Solar Energy, Vol. 171, pp. 604-612, 2018

[5] Harrouz and O. Harrouz, "Application of Solar Energies to Reinforce the Flow Water of Foggara in the Adrar Region", International Journal of Smart Grid, Vol 2, No 04, pp. 203-208, 2018.

[6] A. Annuk, M. Hovi, J. Kalder, T. Kabanen, R. Ilves, M. Märss, B. Martinkauppi, and P. Miidla, "Methods for increasing shares of self-consumption in small PV solar energy applications", 9th International Conference on Renewable Energy Research and Application (ICRERA), Glasgow, pp. 184-187, 27-30 September 2020

[7] N. K. Kasim, H. H. Hussain, and A. N. Abed, "Performance analysis of grid-connected CIGS PV solar system and comparison with PVsyst simulation program", International Journal of Smart Grid, Vol. 3, No. 04, pp. 172-179, 2019

[8] R. Khatri, R. Goyal, and R. K. Sharma, "Advances in the developments of solar cooker for sustainable development: A comprehensive review", Renewable and Sustainable Energy Reviews, Vol. 145, p. 111166, 2021

[9] A. Saxena, E. Cuce, G. N. Tiwari, and A. Kumar, "Design and thermal performance investigation of a box cooker with flexible solar collector tubes: An experimental research", Energy, Vol. 206, p. 118144, 2020

[10] S. Tibebu and A. Hailu, "Design, Construction, and Evaluation of the Performance of Dual-Axis Sun Trucker Parabolic Solar Cooker and Comparison of Cooker", Journal of Renewable Energy, Vol. 2021, pp. 1-10, 2021

[11] T. Watkins, P. Arroyo, R. Perry, R. Wang, O. Arriaga, M. Fleming, C. O'Day, I. Stone, J. Sekerak and D. Mast, "Insulated Solar Electric Cooking–Tomorrow's healthy affordable stoves? ", Development Engineering, vol. 2, pp. 47-52, 2017.

[12] A. G. Bhave, and C. K. Kale, "Development of a thermal storage type solar cooker for high temperature cooking using solar salt", Solar Energy Materials and Solar Cells, vol 208, pp. 110394, 2020

[13] A. Regattieri, F. Piana, M. Bortolini, M. Gamberi, and E. Ferrari, "Innovative portable solar cooker using the packaging waste of humanitarian supplies", Renewable and Sustainable Energy Reviews, vol. 57, pp. 319-326, 2016

[14] A. Regattieri, F. Piana, M. Bortolini, M. Gamberi and E. Ferrari, "Innovative portable solar cooker using the packaging waste of humanitarian supplies", Renewable and Sustainable Energy Reviews, vol. 57, pp. 319-326, 2016

[15] K. Lentswe, A. Mawire, P. Owusu, and A. Shobo, "A review of parabolic solar cookers with thermal energy storage", Heliyon, Vol. 7, No. 10, p. e08226, 2021

[16] A. Mawire, K. Lentswe, P. Owusu, A. Shobo, J. Darkwa, J. Calautit, and M. Worall, "Performance comparison of two solar cooking storage pots combined with wonderbag slow cookers for off-sunshine cooking", Solar Energy, vol. 208, pp. 1166-1180, 2020

[17] K. Schwarzer and M. E. V. da Silva, "Characterisation and design methods of solar cookers", Solar Energy, Vol. 82, No. 2, pp. 157-163, 2008

[18] Q. Chen and Y. Wang, "Research Status and Development Trend of Concentrating Solar Power", 9th International Conference on Renewable Energy Research and Application (ICRERA), Glasgow, pp. 390-393, 27-30 September 2020.

[19] A. Murat, E. DOKUR, and R. BAYINDIR, "Energy Management for EV Charging Based on Solar Energy in an Industrial Microgrid", 9th International Conference on Renewable Energy Research and Application (ICRERA), Glasgow, pp. 489-493, 27-30 September 2020.

[20] R. Wang, O. T. Tai, and K. W. Tam, “Solar radiation reduction monitoring of macao world heritage district photovoltaic system using GIS and UHF RFID obstacle detection approach”, 9th International Conference on Smart Grid (icSmartGrid), Setubal, pp. 154-157, 29 June-01 July 2021.

[21] L. Nkhonjera, T. Bello-Ochende, G. John, and C. K. King’ondu, “A review of thermal energy storage designs, heat storage materials and cooking performance of solar cookers with heat storage”, Renewable and Sustainable Energy Reviews, vol. 75, pp. 157-167, 2017

[22] K. Schwarzer and M. E. Vieira da Silva, “Solar cooking system with or without heat storage for families and institutions”, Solar Energy, Vol. 75, No. 1, pp. 35-41, 2003

[23] M. Silva, L. L. P. Santana, R. D. B. Alves, and K. Schwarzer, “Comperative Study of two Solar Cookers: Parabolic Reflector and Flate Plate Collector Indirect Heating”, RIO 5 World Climate and Energy Event, Rio de Janeiro, pp 257-263, 15-17 February 2005.

[24] M. Da Silva, M. Eugenia, K. Schwarzer, Q. Medeiros, M. Ricardo, and E. Event, “Experimental results of a solar cooker with heat storage," Proceedings of Rio 02 World Climate, pp. 89-93, 2002

[25] B. DIANDA and T. S. Maurice, “KY. parabolic trough cooker”, International Journal of Current Resear Key Words, Vol. 11, No. 03, pp. 1869–1874, 2019

[26] H. Asmelash, M. Bayray, C. Kimambo, P. Gebray, and A. M. Sebbit, “Performance test of parabolic trough solar cooker for indoor cooking”, Momona Ethiopian Journal of Science, Vol. 6, No. 2, pp. 39-54, 2014.

[27] J. M. Arenas, “Design, development and testing of a portable parabolic solar kitchen”, Renewable Energy, Vol. 32, No. 2, pp. 257-266, 2007

[28] O. O. Craig, R. T. Dobson, and W. Van Niekerk, “A novel indirect parabolic solar cooker”, Journal of Electrical Engineering, vol. 5, pp. 137-142, 2017

[29] N. El Moussaoui, S. Talbi, I. Atmane, K. Kassmi, K. Schwarzer, H. Chayeb and N. Bachiri, “Feasibility of a new design of a Parabolic Trough Solar Thermal Cooker (PSTC) ”, Solar Energy, vol. 201, pp. 866-871, 2020

[30] S. M. Ebersviller and J. J. Jetter, “Evaluation of performance of household solar cookers”, Solar Energy, vol. 208, pp. 166-172, 2020.

[31] J. Folaranmi, “Performance evaluation of a double-glazed box-type solar oven with reflector”, Journal of Renewable Energy, vol. 2013, pp. 1-8, 2013

[32] I. Edmonds, “Low cost realisation of a high temperature solar cooker”, Renewable Energy, vol. 121, pp. 94-101, 2018

[33] M. Amin, F. Amir, N. A. Abdullah, A. P. A. Samad, H. Umar, and A. O. T. Y. Sirait, “Experimental Research of Solar Cooker with High Solar Energy Concentration Using Parabolic Dish”, 2nd International Conference on Experimental and Computational Mechanics in Engineering. Springer, Singapore, pp. 179-188, 13–14 October 2021.

[34] A. G. Bhave and K. A. Thakare, “ Development of a solar thermal storage cum cooking device using salt hydrate. Solar Energy”, vol. 171, pp. 784-789, 2018

[35] Z. Guidara, M. Souissi, A. Morgenstern, and A. Maalej, “Thermal performance of a solar box cooker with outer reflectors: Numerical study and experimental investigation”, Solar Energy, vol. 158, pp. 347-359, 2017

[36] O. K. Singh, “Development of a solar cooking system suitable for indoor cooking and its exergy and enviroeconomic analyses”, Solar Energy, vol. 217, pp. 223-234, 2021