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Numerical, Modeling of a Solar Cooker of Box Type to Solar Concentrator

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Abstract: A numerical computer code simulating the operation of a solar cooker of box type to solar concentrator was established. The computer code was used to study the effect of the thermal performance of the cooker. The aim of this work is to present a mathematical model of this solar cooker model in comparison with other models, and to analyze the various parameters that influence the cooker's thermal performance. The equations governing heat transfer in this solar cooker are deduced from the analogy between heat transfer and electrical transfer. These equations are discretized and solved by an implicit finite-difference method, using Gauss' algorithm coupled with an iterative procedure. he results show that an optimum solar flux of 900W/m² was used to determine the various optimum parameters. We deduce that the mirror is a good reflector, and for optimal dimensions of the parallelepiped enclosure [60cm*50cm*50cm], the thermal efficiency of the cooker varies from 42 to 45%. The influence of different pot wall materials shows that copper is a good conductor, and the influence of pot wall dimensions shows that a thin wall (3mm) increases thermal conductivity.

Keywords: Model, Numerical, Solar Cooker, Solar Concentrator

1. Introduction

To promote renewable energies, the Central African Republic, with a population of 4.5 million, has been trying for some years to raise awareness of a policy to protect the environment against deforestation, based on the development of solar energy, which is abundant and well distributed throughout its 623km² territory. Indeed, the average daily global solar flux density in Central Africa is 6.6 GJ.m²/year (5 kWh/m²/day), for an average sunshine duration of 2,600 hours/year, or 7.1 hours/day. The highest temperatures are recorded in March [1]. The country has only one main energy source, wood, which does not meet the energy needs of the entire population. Electricity consumption remains very low at national level, at 5.1% of households [2]. Faced with this problem, 91.6% of households rely on firewood and charcoal [2] to meet their vital needs, leading to massive destruction of wood, with the deplorable consequences of deforestation. Wood is a primary energy resource that still plays an important role in cooking, with wood consumption in urban areas at 89% and 92.9% in rural areas [2] in the Central African Republic. Faced with these investment difficulties on the part of the government, it has become necessary to turn to renewable energies such as solar power to modernize current electricity production structures. Solar energy, one of the most readily exploitable forms of energy, has enjoyed a boom in recent years, thanks to the diversity of its applications and the interest it has aroused worldwide.

Thus, the solar systems with concentration can contribute to the contribution of thermal energy for the cooking of food. It was conceived in 1767 by Switzerland Horace BENEDICT [3] and allowed him to cook vegetables in parallelipipedic of which one of the walls is made up of a pane. Thereafter, French engineer Augustin Bernard MOUCHOT worked out a solar concave solar concentrator cooker in 1860 in Algerie [4].

The aim of this study is to present a mathematical model compared to other existing models [5]. The numerical code of this model will be validated against other existing models in the literature. A numerical analysis will be carried out in order to justify the influence of the different parameters of the cooker. This seemed a viable compromise, avoiding the cost and scarcity of the electrical grid; and of course an alternative to the elimination of our rich forests, preserving our climate in the face of CO_2 emissions due to the combustion of firewood. Numerical analyses of the cooker's operation were carried out. Then, in view of its thermal performance, its use would be recommended and encouraged. The solar cooker consists of a parallelepiped enclosure and a parabolic concentrator. The use of this cooker, one of the interests of this thesis, not only helps to reduce our household energy bills, but also cooking times.

Several year after, various models of solar cooker were the subject of many numerical work and that experimental and various projects have also been carried out.

With regard to the numerical work carried out, several researchers have carried out these studies in a scientific manner. For studies carried out with SIMUSOL software, the objectives are to analyze the influence of solar irradiance and the angle of aperture of the concentrator on the temperature reached at its hearth and the cooking time of various foods (corn, rice, eggs, meat). The results show that the temperature at the focus of the concentrator can reach 150 to 300°C, depending on the size of the concentrator. In addition, the cooking time depends on the type of food and the intensity of the solar flux. Energy efficiency reaches 60%, and cooking times range from 35 to 120 minutes [6-14]. Modeling and simulation of this type of cooker are generally carried out using MATLAB and TRNSYS. 15TM software. Their purpose is to determine the thermal efficiency, the temperature of the heat transfer fluid at the outlet of the tube positioned at the concentrator's hearth, and the overall heat loss coefficient [15-17]. The results show that the outlet temperature of the heat transfer fluid varies from 135 to 185°C, depending on the size of the concentrator, and that thermal efficiency can be as high as 60.5%. For a low overall heat loss coefficient, optical efficiency can exceed 61%. Other studies have analyzed the influence of solar concentrator absorber tube diameter and the angle of inclination of the parabolic trough on energy efficiency and fluid temperature at the focus of the parabolic trough concentrator [18-21]. It has been shown that water temperatures can reach values in excess of 106°C. In addition, energy efficiency and thermal performance decrease significantly as the angle of inclination of the parabolic trough increases.

Numerical work has also been carried out on a number of box-type cookers with solar reflectors, based on the numerical solution of transfer equations obtained using the nodal method and MATLAB software [22-25]. Analysis of the influence of the reflector's angle of inclination on the thermal efficiency, the temperature of the water, the absorber and the air inside the cooker, and the cooking time, has shown that, for a reflector angle of inclination to the horizontal equal to 17°, the boiling time for 3.5 liters of water is 118 minutes, and the thermal efficiency reaches 32.5%. In addition, thermal efficiency and maximum air temperature inside the cooker are equal to 33.9% and 140°C respectively. Box-type systems without reflectors, on the other hand, are based on the numerical resolution of transfer equations [26-33]. One of the aims of this work is to analyze the transient behavior of the solar cooker. The fluids considered in the cooker are water and oil. The duration of these fluids, their temperature and thermal efficiency are the parameters analyzed. The results show that for 2.4 liters of fluid (water, oil), the final temperature of the water reaches 100°C in 50 minutes, and that of the oil 149°C in 60 minutes. Thermal efficiency is 33% for water and 20% for oil.

A synthesis of this documentary resource, shows that the concentration of solar flow is one of the alternatives most promising in the current energy context for the solar cookers. It is viable long-term, it does not produce a gas for purpose of greenhouse. The solar cookers of box type are, share their simple design and construction and their handinesses, adapted well to the zones deprived of traditional sources of energies. They do not present a particular disadvantage (burn). This bibliographical study, shows that the two basic models of the most used solar cookers are of box type and with parabolic concentrator. The cooker of the box type can be used directly or indirectly. The duration of cooking is higher than that obtained by using wood like fuel, the maximum temperature of the air inside the cooker can reach 140°C. For the parabolic cooker the temperature is higher, until 250°C and the duration of cooking is lower than that of the cooker of the box type. However, it presents a particular disadvantage (burn) and the design is complex. Moreover, it requires a regular monitoring during its operation. The duration of the cooking of a solar cooker of box type lies between 2 and 3 hours; it is reduced by 1 to 2 hours for the concentration cooker with a temperature of the air ranging between 82°C and 140°C according to the type of the coker. For this cooker, the energetic efficiency varies between 8,5 and 55%.

Thus these data will be used to us as references in simulation, in order to compare the thermal performance of the solar model of cooker proposed with other what exists in the literature.

2. Description and Principle of Operation of the Cooker

2.1. Description

The solar model of cooker selected is based on the analysis of the various existing solar cookers. This solar cooker is composed of a solar concentrator and a parallelepipedic enclosure in which the pot containing food to be cooked is laid out. The pot in which the food is laid out is a semi-spherical tank whose external face is painted black. The walls of the parallelepipedic enclosure, except for that opposite the concentrator are out of wood of dimension $0{,}65 \times 0{,}50 \times 0{,}50\text{m}$ and 3 cm thickness and a layer of glass wool thickness 2 cm for the insulation. A 4 mm thickness pane ensures the transmission of part of the solar flow reflected by the concentrator on the pot laid out in this enclosure. The access inside the enclosure is ensured by one of the adjacent vertical walls the wall of the pane, designed as a door.

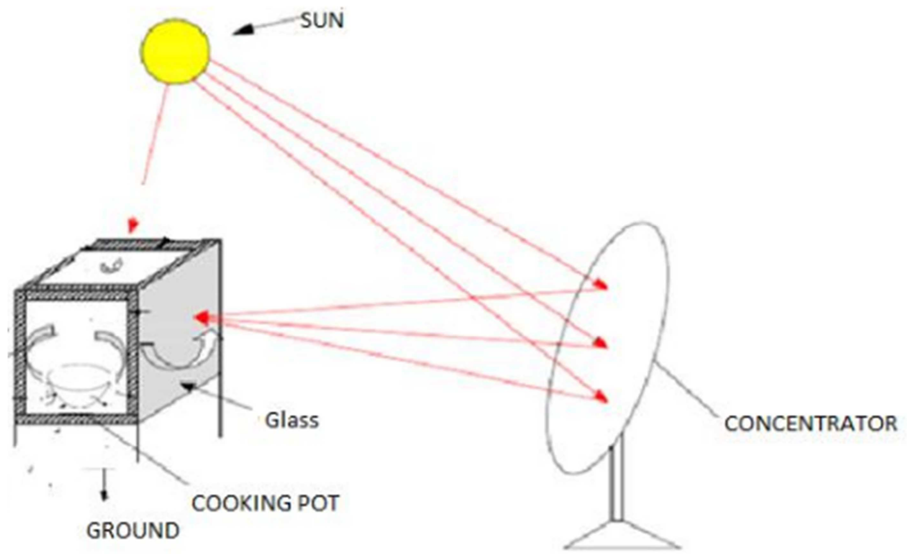

Figure 1. *Synoptic Diagram of the Solar Concentrator Cooker.*

2.2. Operation

The solar flow reflected by the concentrator is transmitted inside the enclosure through the pane and a part is absorbed by the wall of the pot. It follows a heat flow by conduction through the wall of the semi-spherical tank towards the interior of the pot and, consequently a contribution of heat to the fluid and food contained in the pot.

3. Mathematical Model

3.1. Mathematical Formulation

In order to circumvent certain difficulties of solution of equations which proves sometimes very delicate, the following assumptions are registered.

Simplifying Hypothesis

the sky is compared to a black body, the temperature of the ground is taken equal to the ambient temperature, the properties of materials are constant, the walls on each side of the box are thermically insulated, the temperatures of the components of the solar cooker and that of the fluid in the pot are uniform the various elements (walls) constituent the system are at uniform temperatures. the speed of the fluids in the parallelepipedic enclosure and the pot are supposed very weak the solar flow collected by the concentrator uniformly set out again the optical properties (reflectivity, absorptivity) are uniform on all reflective surface; At the ends of the concentrator, the heat losses per radiation are negligible; the heat losses by convection and radiation between the concentrator and environment are negligible; the heat losses by conduction through the walls of the concentrator are neglected.

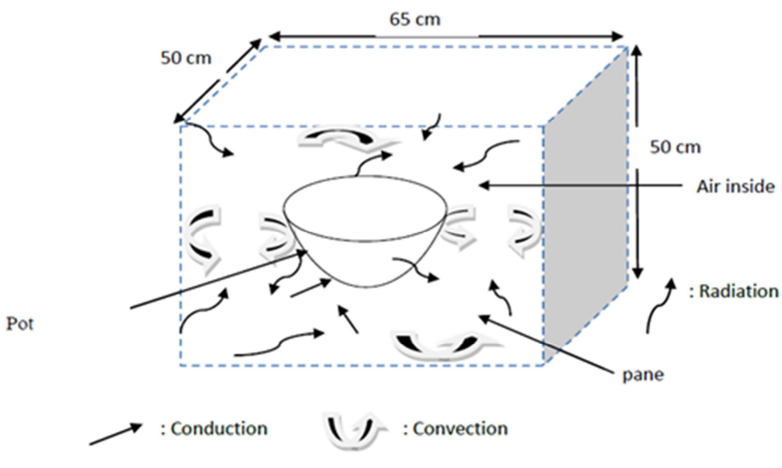

Figure 2. *Synoptic Diagram of the Box with Cooking.*

So, the transfers of heat in the solar cooker can be represented by a thermal resistance network.

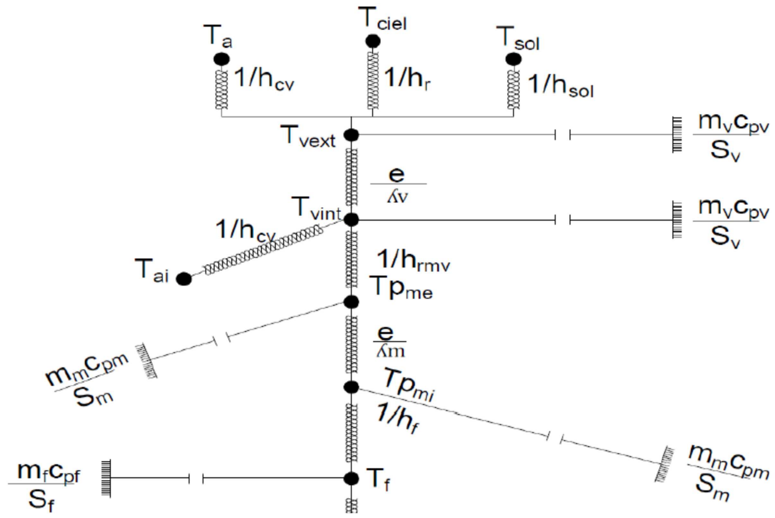

Figure 3. *Diagram of the Thermal Resistance Network in the Cooker.*

Concerning the role of each term in the thermal network we have:

The mass which allows to attenuate the surplus of heat for stabilization of the temperature.

The condenser allows to release the stored heat in case of absence of heat or sun.

The resistance allows to regulate the heat between two nodes and each node must give back all that it receives, this is the principle of conservation allowing to establish the expression of the law of nodes.

3.2. Equation of Transfer

The equations which govern the transfers of heat in the parallelepipedic enclosure and the pots are based on the analogy between the transfers of heat and the transfers electric. Thus, the energy balance, on the level of each component of the solar cooker, is equal to the algebraic sum of the densities of the heat flows exchanged between the various components.

The general equation of this assessment checks the expression:

$$M_iC_{pi}\frac{\partial T_i}{\partial t} = \varphi_{sol}\times S_i + \sum_{k=1}^{m}\sum_{j=1}^{n}\left(h_{r,j-k}+h_{cv,j-k}+h_{cond,j-k}\right)(T_k-T_j) \qquad (1)$$

Or

$h_{r,j-k}$: Coefficient de transfert de chaleur par rayonnement entre les composants j et k

$h_{cv,j-k}$: Coefficient de transfert de chaleur par convection entre les composants j et k

$h_{cond,j-k}$: Coefficient de transfert de chaleur par conduction entre les composants j et k.

Let us apply the equation (1) to the various components of the cooker.

Glaze

External face

$$mC_p\frac{\partial T_{ve}}{\partial t} = I\alpha_vS_v + h_{rv}S_v(T_{ciel}-T_{ve}) + h_{rvsol}S_v(T_{sol}-T_{ve}) + h_{cv}S_v(T_{amb}-T_{ve}) + \frac{\lambda_vS_v}{e}(T_{vi}-T_{ve}) \qquad (2)$$

Internal face

$$mC_p\frac{\partial T_{vi}}{\partial t} = I\alpha_vS_v + h_{rmv}S_m\left(T_{pme}-T_{vi}\right) + h_{cvv}S_v(T_{ai}-T_{vi}) + \frac{\lambda_vS_v}{e}(T_{ve}-T_{vi}) \qquad (3)$$

Air inside

$$m_{ai}\,C_{pai}\frac{\partial T_{ai}}{\partial t} + m_{ai}C_PV_{ai}\frac{dT_{ai}}{\partial x} = h_{cvai}\,S_v(T_{vi}-T_{ai}) + h_{cvm}\,S_m\left(T_{pme}-T_{ai}\right) \qquad (4)$$

Absorber

External face

$$mC_p\frac{\partial T_{pme}}{\partial t} = I\tau_v\alpha_m + h_{cvm}\,S_m\left(T_{ai}-T_{pme}\right) + h_rS_m\left(T_{vi}-T_{pme}\right) + 2\pi\lambda_m\left(\frac{R_2-R_1}{R_2.R_1}\right)\left(T_{pmi}-T_{pme}\right) \qquad (5)$$

Internal face

$$mC_p\frac{\partial T_{pmi}}{\partial t} = 2\pi\lambda_m\left(\frac{R_2-R_1}{R_2.R_1}\right)\left(T_{pme}-T_{pmi}\right) + h_fS_m\left(T_f-T_{pmi}\right) \qquad (6)$$

Fluid

$$m_fC_{Pf}\frac{\partial T_f}{\partial t} + m_fC_{Pf}V_f\frac{\partial T_f}{\partial x} = h_fS_m\left(T_{pmi}-T_f\right) \qquad (7)$$

Thermal performance

$$p_{th} = \frac{m_e\times C_p(T_{fe}-T_{ie})}{\Delta t} \qquad (8)$$

The thermal efficiency is deduced from the expression:

$$\eta = \frac{(M.C_p)_{water}.[T_{f(water)}-T_{in(water)}}{A_c\int I(t)dt} \qquad (9)$$

4. Methodology of the Numerical Resolution

The system of equations (2-7) is solved by the method of Gauss coupled to an iterative procedure because the coefficients of transfer of heat by convection and radiation depend on the temperatures of the various mediums which are unknown factors. Thus for a step of time given, we allot an arbitrary value to the temperatures of the various mediums by the calculation of the coefficients of transfer of heat by natural convection and by radiation and the resolution of the algebraic system of equations, the values of the calculated temperatures are compared with the arbitrary values; if the variation is higher than the desired precision (0,5°C), the arbitrary values are replaced by the computed values and the procedure of calculation described above is taken again until the precision is reached. In this case, calculations are taken again with the step of next time and this procedure continues in the course of time until the operation life wished is reached.

Calculations were carried out by the values of the parameters deferred in the following table:

The thermal power of cooking of a solar cooker can be calculated when a well defined water mass is maintained inside the utensil of cooking and the solar cooker is brought into service according to certain conditions described in the Standard of Funk [2].

5. Results and Discussions

Validation of the Numerical Code

In order to validate our numerical code, we then applied our numerical code to the problem treated numerically and experimentally by Soria et al [2015]. The cooker built by Soria is of box type with wooden walls of dimension 0.22×0.52×0.70 m consisting of a double glazing in front of the solar concentrator. The walls are insulated with 2cm thick cork sheets placed on their inner sides. This comparison shows a perfect agreement between our numerical results and those of Soria et al., with regard to the correlation coefficient R^2=0.9020 and the maximum relative deviation obtained, of the order of 2%.

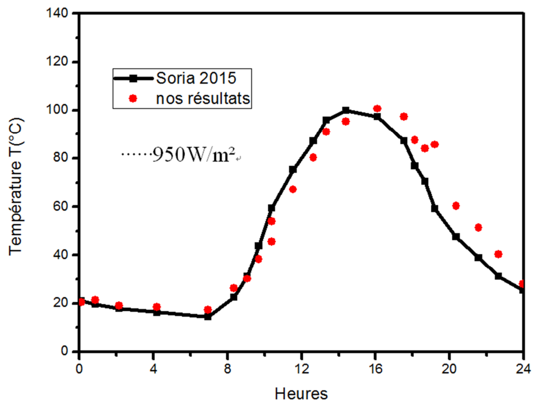

Figure 4. *Evolution Horaire de Température de l'air intérieur de la boîte à cuisson.*

6. Modelling of the Solar Cooker

6.1. Influence of Solar Flux

The knowledge of the evolution of the solar irradiance, the main source of energy for cooking, is necessary to determine the optimal dimensions of the solar cooker. For this purpose, we analyse the influence of the solar flux on the temperature distribution inside the solar cooker, with the diameter of the concentrator opening. For a solar irradiance between 900 and 1000 W/m², the temperature inside the cooker can reach 100°C and its thermal efficiency can increase up to 80%.

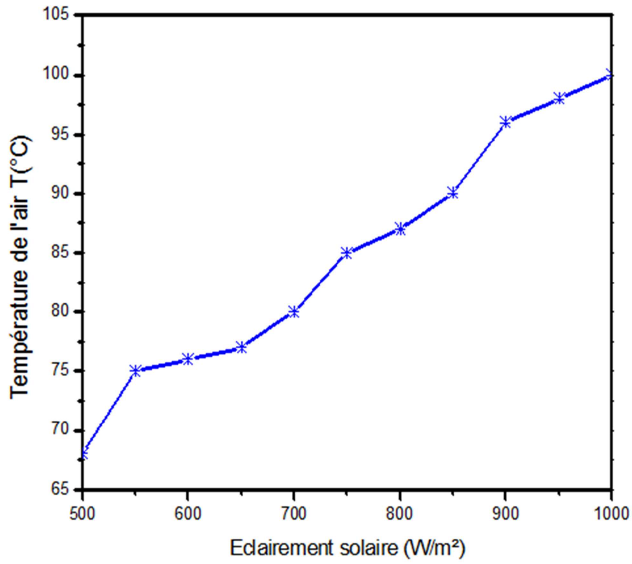

Figure 5. *Evolution of the Temperature Inside.*

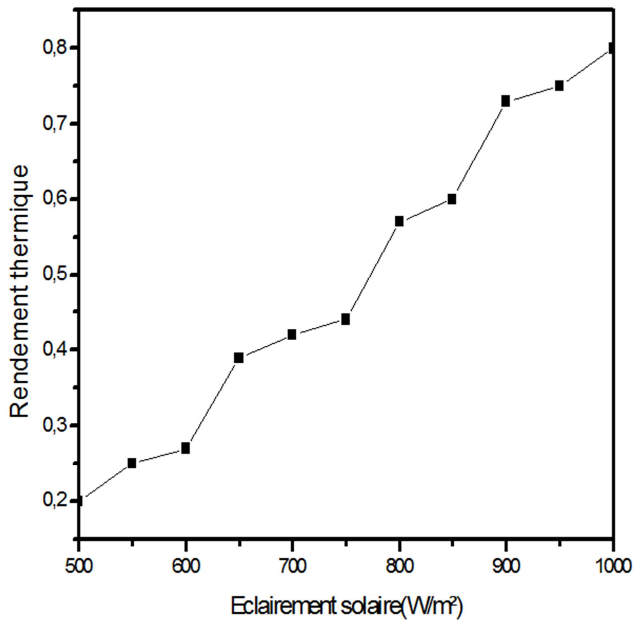

Figure 6. *Thermal efficiency in of the solar cooker under consideration as a function of the solar irradiance for the cooker under consideration.*

6.2. Influence of the Concentrator Opening Diameter

Figures 7-8 illustrate the evolution of the temperature of the fluid in the kettle and its thermal efficiency as a function of the opening diameter of the concentrator. These figures show that the higher the temperature of the fluid, the larger the opening diameter of the concentrator.

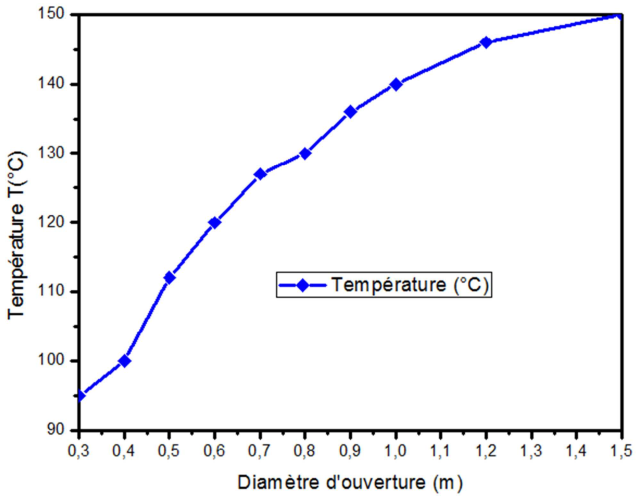

Figure7. *Evolution of the Fluid Temperatures in the Kettle as a Function of the Opening Diameter.*

In fact, the solar flux captured by the concentrator increases with its capture area, and therefore with its diameter. The temperature of the fluid and the thermal efficiency of the solar cooker increase with the increase in the diameter of the concentrator opening. Thus, for the rest of our calculations, we assume that the opening diameter of our cooker is 65cm.

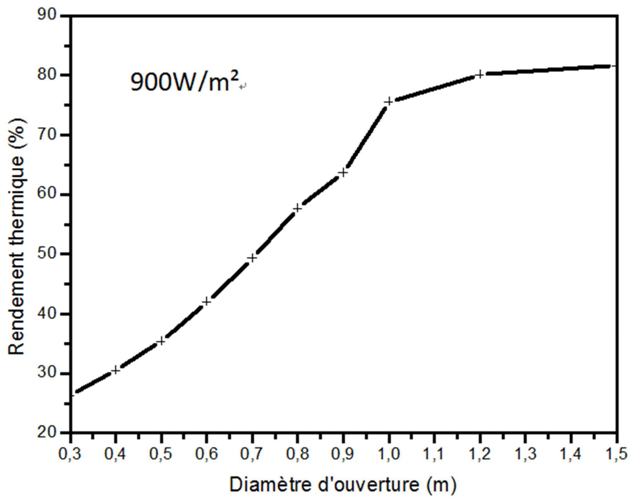

Figure 8. *Thermal Efficiency of Fluid Temperatures in the Kettle as a Function of Opening Diameter.*

6.3. Influence of the Nature of the Concentrator Coating Materials

In this section we present two types of concentrator coated with different materials whose reflectivity and emissivity properties are shown in the table below.

Table 1. *Coefficients Radiatifs Des Matériaux Du Concentrateur.*

Materials	Reflectivity	Emissivity
Aluminium foil	0,65	0.09
Mirror	0,99	0,97

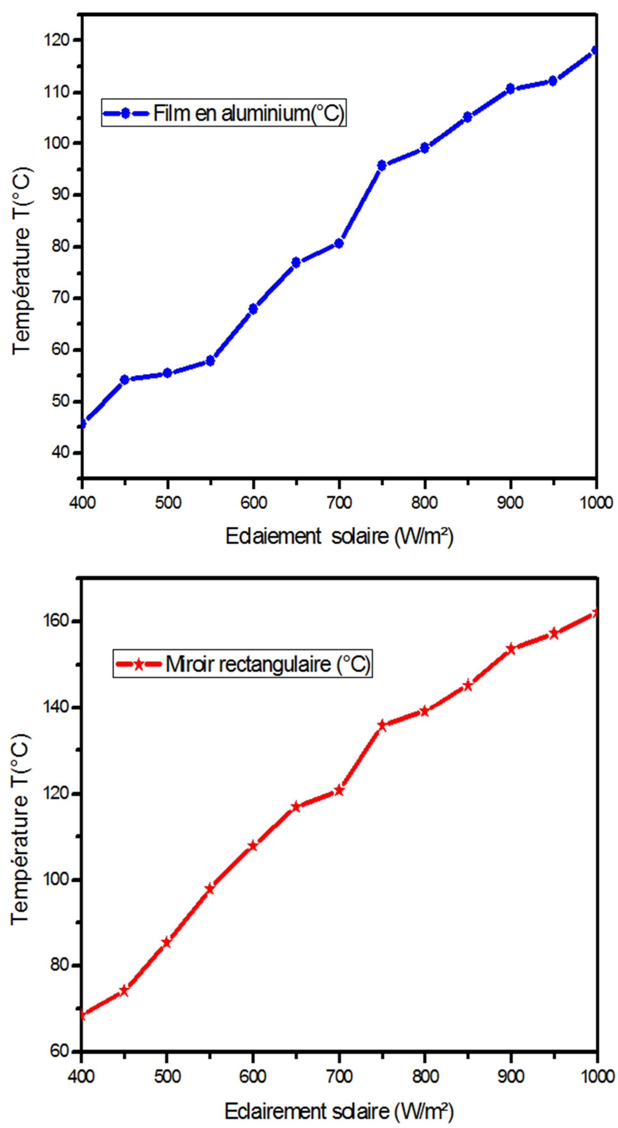

Figure9. *Temperature Evolution at the Focus of the Concentrator.*

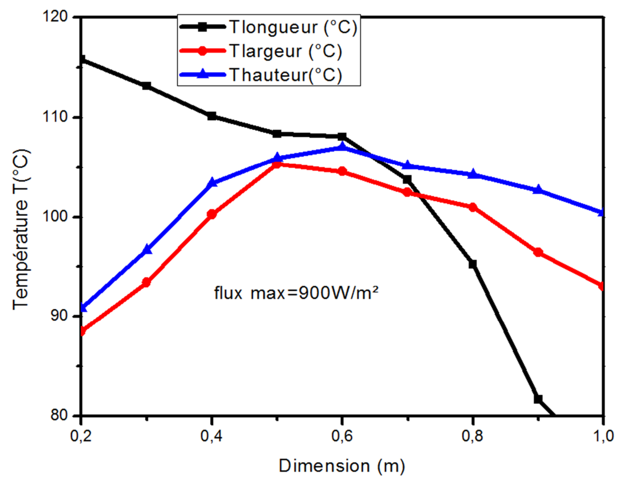

Figure 10. *Evolution of the air Temperature in the Cooker Chamber as a Function of its Dimensions.*

Figures 3-7 shows the hourly change in concentrator focus temperature for the same solar illumination in a single day. It is noted that the surface covered by the mirror pieces has a higher temperature than the aluminum film surface, we obtain a focus temperature equal to 122°C for an opening diameter of 0.60m. However, the focus temperature of the concentrator for an aluminum film is equal to 114°C for the same opening diameter. In addition, the thermo-physical properties of these materials have a very important role in the concentration of the solar flux reflected on the surface of the concentrator. The temperature profiles in figure 1 show that the mirror concentrator model as reflection material can be considered as an optimal configuration for a good temperature inside the cooker enclosure.

In order to define the optimal dimensions of this cooker, the figure below illustrates the evolution of the temperature in the cooker chamber as a function of its dimensions (length, width and height). We notice that the optimal dimensions are located in the ABC zone where the temperature is maximum. Therefore, the optimal height and width are 0.50m and the optimal length is 0.65m.

7. Parameters Change

7.1. Influence of the Opening Diameter

Figure 11 illustrates the time evolution for different values of the concentrator opening diameter of the fluid temperature in the pot positioned inside the cooker. It should be noted that the temperature is higher as the opening diameter of the concentrator is important. Indeed, the solar flux captured by the concentrator increases with the area of the concentrator so with its diameter. Thus, the solar flux received by the kettle and the temperature of the fluid it contains increases with the opening diameter of the concentrator.

We present on figure 11 the change of the temperature for three types of pots made up of various materials (aluminum, stainless steel, copper).

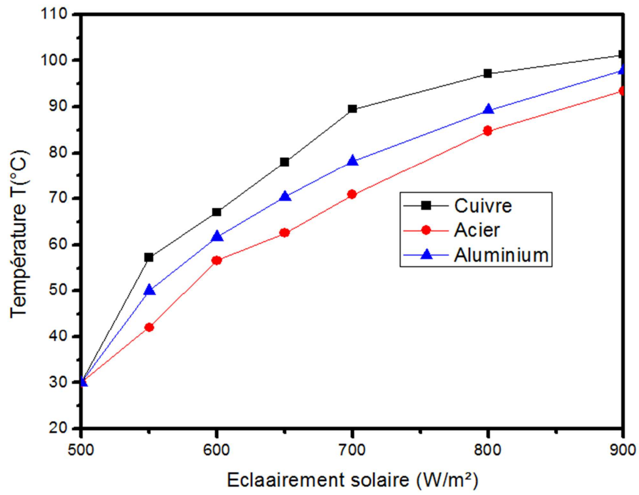

Figure 11. *Evolution of Fluid Temperatures in the Kettle.*

The values of the thermo-physical properties of these materials are deferred in table 2.

Table 2: *Propriété Thermo-Physique des Matériaux Dont est Constituée la Paroi de la Marmite.*

Matériaux	Conductivité thermique (W/m.K)	Chaleur spécifique (J/kg.K)	Masse volumique Kg/m^3	Coefficient d'échange par conduction (W/m².K)
Aluminium	237	896	2700	19010

7.2. Influence of Pot Wall Thickness

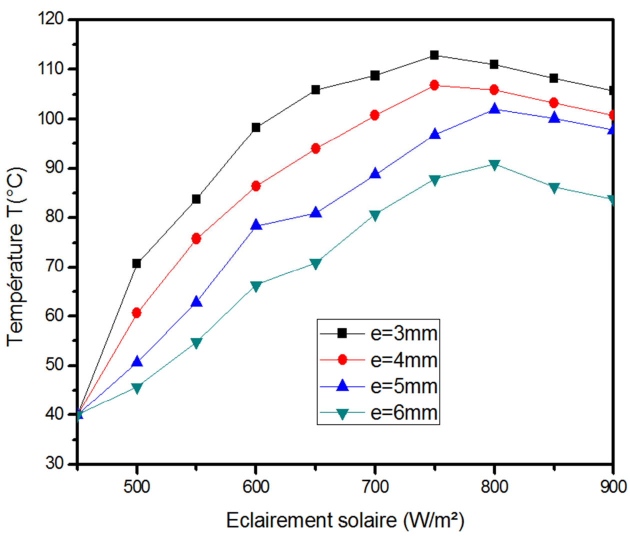

Figure 12. *Hourly temperature trend of the outer surface of the pot wall for different pot thicknesses*

Analysis of the influence of the thickness of the pot wall shows that the thickness of the pot increases the temperature of its inner surface (figure 12).

This result is consistent with the fact that the greater the wall thickness, the greater the thermal resistance between the outer and inner surfaces. The wall thickness is of the order of a few millimetres. Thus, thermal efficiency by conduction through the pot wall becomes significant when the thickness is low. This result is in line with the hourly evolution of the fluid temperature in the kettle.

7.3. Influence of the Load on the Performance of the Cooker

The duration so that water in the copper pot reaches the boiling point is all the more short as the volume of water is low. Indeed for the same value of the solar illumination collected by the pot the quantity the thermal output by conduction through the wall of the pot by convection to water allows the increase in the temperature of the water of its initial value the boiling point. This quantity of heat is all the more high as the volume of water is significant. Also the duration so that water reaches the boiling point increases with the volume of water (figure 13).

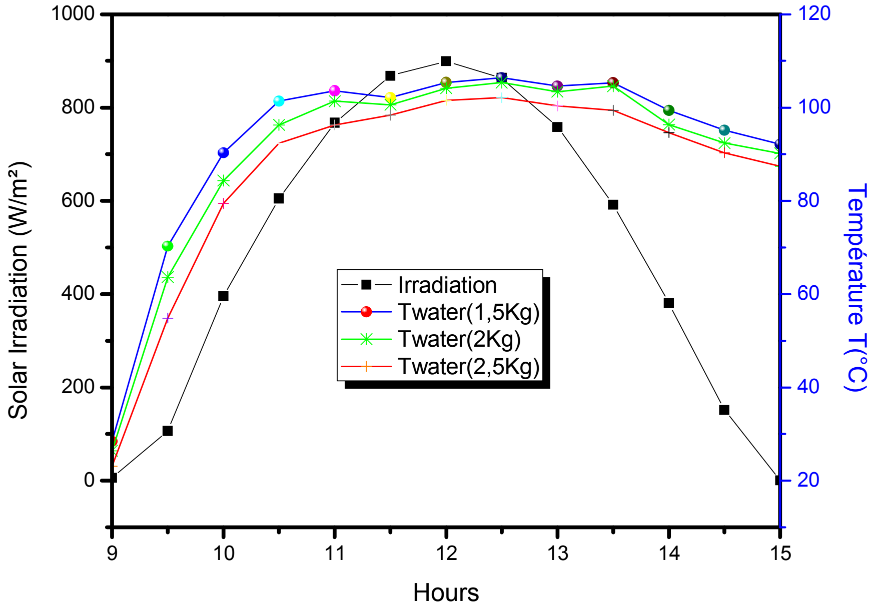

Figure 13. *Variation in the Water Temperature for Various Masses in the Cooker According to Time.*

The thermal performance of a solar cooker depends on its parameters and the solar irradiance. In this analysis, the results show that in order to have a high temperature at the focus of the concentrator, an opening diameter is required that meets the expectation of the cooking box for the different qualities of food to be cooked. The mirror is considered to be the material that reflects the solar radiation incident on the surface of the concentrator. However the type of pot which is in the cooker enclosure is considered as an absorber, obviously for good thermal conductivity the pot component is highlighted. After the simulation, we observe that copper is a better heat conducting material due to its high conductivity coefficient. So for good conductivity, a wall thickness of 3 mm of the pot is needed.

The expected thermal performance of the solar cooker is 38.17%. This is higher than that reported by Nahar [2001], which is 30.5%. The thermal power has a value of 18.24W.

8. Conclusion

The thermal model of transfer is a model based on the temperature. We developed a rather simple algorithm which enables us to predict the transitory thermal behavior of the solar cooker, in order to improve the thermal performances by the increase of heat exchange. The mathematical model is a model of partial derivative equations, we chose the method of resolution numerical to different finished. The resolution of this mathematical model enables us to predict theoretically, the design of the new cooker. This numerical computer code based on the conservation equations of heat, takes account of the variation of the physical properties of the air confined in the enclosure of the cooker according to its temperature, to envisage the time of cooking correctly.

The optimum flux for modeling purposes is 900W/m². The diameter of the concentrator opening is set at 65cm. Rectangular mirrors are used to line the surface of the concentrator because of their better reflectivity. The optimum dimensions for the cooker are 65cm long, 50cm wide and 50cm high, while the thermal conductivities of the materials used for the kettle, namely aluminum, steel and copper, are 237W/m.k, 50W/m.k and 401W/m.k respectively. These values show that copper conducts heat better than aluminum and steel. The simulation shows that the two curves for the inner and outer walls of the kettle are superimposed due to the negligible wall thickness. It appears that thermal efficiency is a proportional function of overall solar irradiation, which plays a predominant role.

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Conflicts Interests

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

References

[1] Atlas de la République Centrafricaine 2010 Site Web: https://www.se4all-africa.org/fileadmin/uploads/se4all/Documents/Country_RAGAs/Central_African_Republic_RAGA_FR_Released.pdf

[2] Luc Marboua Bara, «estimation du gisement solaire de la République centrafricaine et possibilité d'application», 2003.

[3] Saint George Utah 84791-0756, "Solar cooker At Cantina west," 2008-2014. [In ligne]. Available: http://www.solarcooker-At-cantinawest.com/solarcooking-history. [Consulted on August 13, 2015].

[4] Solar David Anderson, Document, "Cookers: how to build, employ and appreciate, "Solar Cooker International (SCI), California, the USA, 2004.

[5] Harmim “Mathematical modeling of a box-type solar cooker employing an asymmetric compound parabolic concentrator”Solar Energy 86(2012) 1673–1682.

[6] José M. Arenas, Design, development and testing of a portable parabolic 2. solar kitchen march 2006.

[7] Judith «Multiple use communal solar cookers» Solar Energy 77(2004) 217–223.

[8] Pohekar S. D, “Utility assessment of parabolic solar cooker as adomestic cooking device in India” Renewable Energy 31(2006) 1827–1838.

[9] Fraser P. “Stirling dish system performance and prediction model. MSc thesis inmechanical engineering”. Madison, USA: University of Wisconsin; 2008.

[10] Rabl A. “Solar concentrators with maximal concentration for cylindrical absorbers”. Applied Optics1976; 15(7): 1871–3.

[11] Mohamed, “Parabolic solar cooker with automatic system tracking two axis”AppliedEenergy 87(2010) 463-470.

[12] Kumar S, Reddy N.”Numerical investigation of natural convection heat loss in modified cavity receiver for fuzzy focal solar dish concentrator”. J Solar Energy 2007; 81: 846–55.

[13] Ali A., Portable solar cooker and water heater, Energy Conversion and Management 51(2010) 1605-1609.

[14] S. Marzougui, M. Bouabid, F. Mebarek-Oudina, N. Abu-Hamdeh, M. Magherbi, and K. Ramesh, International Journal of Numerical Methods for Heat and Fluid Flow 31, 2197 (2021).

[15] A. Gama «Etude et réalisation d’un concentrateur cylindro parabolique avec poursuite solaire aveugle» Revue des Energies RenouvelablesVol. 11 N°3(2008) 437–451 437.

[16] Y. Boukhchana «Theoretical and Experimental Study of a Cylindro-Parabolic Solar Collector» Journal of Environmental Science and Engineering, 5(2011) 1026-1030.

[17] Yasmina Boukhchana «Etudes théorique et expérimentale des performances d’un capteur solaire cylindro- parabolique», (5èCongrès International Energie Renouvelable et Environnement).

[18] E. Sharaf «A new design for an economical, efficient, conical solar Cooker» Renewable Energy, vol. 27, P599-619, 2002.

[19] Yacine Marif, «étude comparative entre les modes de poursuite solaire d’un concentrateur solaire cylindro-parabolique», annales des sciences et technologies vol, 6 N°2 2014.

[20] Al-Soud M. S, «A parabolic solar cooker with automatic two axes sun tracking system,» Applied Energy, vol. 87, p. 463–470, 2010.

[21] KlemensSchwarzer, “Characterisation and design methods of solar cookers”, Solar Energy 82(2008) 157–163.

[22] Olwi, A. “Computer simulation of the solar pressure cooker. Solar Energy” 40(3), 259–268. 1988.

[23] Peajack, E. R., 1991. “Mathematical model of the thermal performance of box-type solar cookers”. Renewable Energy 1(5/6), 609–615.

[24] Soriaverdugo« Experimental analysis and simulation of the performance of a box-type solar cooker»Energy for Sustainable Development 29(2015) 65–71.

[25] El-Sebaii AA. “Thermal performance of a box type solar cooker with outer-inner reflectors”. Energy 1997; 22: 969–78.

[26] Kawthar Dhif, “Thermal Analysis of the Solar Collector Cum Storage System Using a Hybrid-Nanofluids” Journal of Nanofluids Vol. 10, pp. 616–626, 2021 (www.aspbs.com/jon).

[27] Garg HP, “Mathematical modeling of the performance of a solar cooker”. Appl Energy 1983; 14: 233–9.

[28] Binark AK,” Modelling of a hot box solar cooker. Energy Conv Manage” 1996; 37: 303–10.

[29] Ibrahim “Computer Simulation of the Solar Pressure Cooker” Solar Energy Vol. 40 N°3 PP259-268, 1988.

[30] M. Patel “Mathematical modeling hading to a solar cooker design” Proc. National Solar Energy Convention India January, 22-24. 3.036-3.040 (1981) lar Energy THE SOLARRESSURE

[31] Reddy “Prediction and experimental verification of performance of box type solar cooker. Part II: Cooking vessel with depressed lid”.

[32] Sunil “Sunil Geddam, Determination of thermal performance of a box type solar cooker,” Solar Energy 113(2015) 324-331.

[33] Mirdha “Design optimization of solar cooker” Renewable Energy 33(2008) 530–544.