

Influence of the Incident Solar Flux on the Temperature Variation of the Hot-Box Cooker

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Abstract: In rural areas, families do not often have access to butane gas and women are looking for wood to cook. Forests are often threatened by the production of charcoal. Housewives are exposed to the emissions of these fuels. Thus a problem of public health arises. The aim of our work is a part of the development and popularization of solar cooking as an alternative to the abusive use of fossil fuels. On the other hand, it allows to protect the environment and contributes to improving the living conditions of housewives. A prototype was developed at the Center of Studies and Researches on Renewable Energies (CERER) in Dakar, Senegal. This is a solar cooker box double glazed and inclined lateral faces, provided with a flat reflector. In this paper we present the results of testing of the prototype. The climatic data in this study are obtained at the CERER weather station. Several series of tests were carried out under natural sunlight. They concern empty tests of the cooker and tests of water boiling and cooking. During these tests the temperatures at different points of the cooker were measured at different sunshine and at different times of the year. The results obtained by different tests are satisfactory and encouraging especially as solar cookers are easy to build and test prototype gets to reach temperatures favorable for healthy cooking different food products and dishes.

Keywords: Experimentation, Collector, Reflectors Shots, Solar Cooker, Stove, Side Panels Inclined

1. Introduction

Successive energy crises in the world have led people to reflect on the fate of man without the fossil energy resources (oil, gas, coal, etc.) that are becoming increasingly scarce as energy demand grows. Developing countries are the first to be affected by these multiple crises.

Since the 90s, Senegal is facing an energy crisis that never ends [1]. Companies are often confronted with fluctuations in the price of oil, fuel shortages, and shortfalls in production, distribution problems and control of the electrical network (SENELEC) causing cuts and load shedding. At the same time people are facing shortages of butane gas resulting from increases in the price of wood and charcoal... The impact of this crisis has very important consequences for the economy (agriculture, industry, SMEs, domestic electrification,...) These crises have resulted in extremely high cost of living, paralysis of the economic system but also to advancement of

rural deforestation. This leads to increasing desertification, also a degradation of the environment: change of climate, soil erosion, floods in the cities causing displacements of populations by the public services is the case of the Diakhaye plan in 2006 and Noflaye in 2012 where whole districts are lost in the waters.... [2] In some remote areas, the Fouta in North, often desert where wood is somewhat rare, the use of cow dung for cooking is the main source of sickness for housewives because they contain harmful gases (methane, CO₂,...). Moreover, due to the scarcity of fossil resources, most of the population's survival strategies are based on natural resources such as the wood of a few rare shrubs, leading to an alarming state of environmental degradation.

The sunlight is a natural source of energy, free and inexhaustible [3]. Although unknown to most people, solar cooking is one of the simplest domestic uses of solar energy [4]. This application is one that can be an alternative to limit deforestation and misuse of fossil fuels whose emissions of greenhouse gases could jeopardize the future of humanity.

Indeed, for citizens living in several remote areas, cooking food is very costly when using conventional energy sources and causing disastrous consequences on the ecosystem. The first solar cooker called "hot box" was invented by Horace de Saussure, a Swiss naturalist who already experimented in 1767. However, solar cooking actually appeared in the 1970s in a context of profound energy crisis [5].

The solar cooker is a device for cooking food directly through sunlight converted into heat. It achieves average temperatures to cook, boil, and roast. Almost everything that could be done with other traditional methods of cooking (wood, coal, electricity, gas...).

Our work of evaluating the performance of the hot-box solar cooker is part of the development and popularization of this application that is solar cooking. Indeed a prototype has been realized, it is a solar cooker of the box type with lateral inclined faces. Our objective is to study its use in the climatic conditions of Senegal and possibly to make improvements.

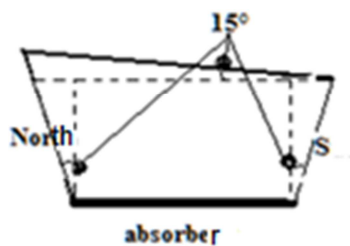
After a complete description of our cooker, we will undertake a study Theoretical study of our system before starting the experimental study which passes through various tests carried out at the Center of Study and Research on Renewable Energies (CERER).

In this document, we present the results obtained from the experimentation of this prototype. Several series of tests were carried out under natural sunlight. They involve empty tests of the cooker and of the boiling and cooking tests. During these tests the temperatures at different points of the cooker were measured at different sunshine and at different times of the year. The results obtained by the various tests are satisfactory and encouraging, especially since solar cookers are simple to build and the prototype tested reaches temperatures favorable to the healthy cooking of various food products and dishes. The average temperatures reached allow us to cook, boil, almost anything we could do with other traditional cooking methods (wood, coal, electricity, gas...).

2. Description and Modeling

The studied system is a solar cooker box with a flat reflector [6].

It is a wooden box (cons-plated) thermally insulated (glass



wool between the inner and outer boxes) and closed by a double glazing (two panes of 4mm thick, spaced 3 mm from each another) inclined at an angle of 15 ° South relative to the horizontal. This inclination allows the cooker to receive the maximum of radiation because solar oven only works with direct radiation so it is necessary to orient the solar oven correctly in relation to the sun



Figure 1. Solar cooker hot-box inclined lateral faces.

Its lateral faces are covered with mirrors and arranged as follows: the North faces, South and East are inclined at an angle of 15 ° relative to the vertical. This allows us to reduce the shadows cast by these faces on the absorber at sunrise. The west side is inclined at an angle of 30° to the vertical in order to increase the daily cooking periods without shading the absorber. These faces are lined with flat mirrors to favor the reflection of the rays in the cooker enclosure.

The inside bottom is covered with a painted black aluminum plate that serves as an absorber. It converts light energy into thermal energy.

A wooden door is opened on the north side of the cooker. It is covered with mirror to reflect radiation on the absorber. It is such a medium sized pot to pass through. To avoid as much heat as possible, avoid opening the oven too much during cooking! The best is still to put all the necessary ingredients from the beginning.

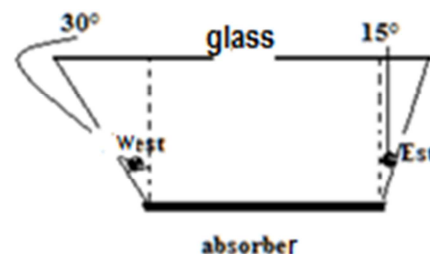


Figure 2. Diagram of hot-box cooker.

The reflector, north opening is made against-plated wood supported by thin tassets. Reflection is ensured by aluminum paper lining the surface of the reflector. It serves cooker cover after hours of use.

2.1. Theoretical Study

A solar cooker is a cooking appliance based on the conversion into heat of the light radiation emitted by the sun.

It is a complex energy system where most of the modes of heat transfer are involved. It has several types of solar cookers all operating according to the principle of conversion of light energy into thermal energy. However there are different processing methods of that energy that characterize each cooker. A solar cooker is a box receiving cash from sunlight. It allows cooking food at temperatures from 80 to 170°C. The infrared rays from the sun are trapped in the cooker with the glass which causes a sharp rise in temperature within the box by greenhouse effect. The system that generates heat energy in some stores and in exchange with the other with its environment, (which we translate by equation (1)) provides thermal balance equations on the various oven components systems [7, 8].

$$Production = Storages + Exchanges \quad (1)$$

$$m_{vex} C_{p_{vex}} \frac{\partial T_{vex}}{\partial t} = \alpha_{vex} S_v (T_{ciel} - T_{vex})$$

$$+ h_{vex} S_v (T_{amb} - T_{vex}) + h_{cn1} S_v (T_{vex} - T_{vin}) + h_{r,vin-vex} S_v (T_{vex} - T_{vin}) \quad (2)$$

$$m_{vin} C_{p_{vin}} \frac{\partial T_{vin}}{\partial t} = \tau_{vex} \alpha_{vin} S_v \Phi_i + h_{r,ab-vin} S_v (T_{vin} - T_{ab}) + h_{r,vin-vex} S_v (T_{vex} - T_{vin}) + h_{cn2} S_v (T_{vin} - T_{ac}) + h_{cn1} S_v (T_{vex} - T_{vin}) \quad (3)$$

The energy balance of the air cooker and the absorber are given respectively by equations 4 and 5.

$$m_{ac} C_{p_{air}} \frac{\partial T_{ac}}{\partial t} = h_{cn3} S_v (T_{ab} - T_{ac}) + h_{cn2} S_v (T_{vin} - T_{ac}) \quad (4)$$

$$m_{ab} C_{p_{ab}} \frac{\partial T_{ab}}{\partial t} = \tau_v^2 \alpha_{ab} S_{ab} \Phi_i + 4\tau_v^2 R_m S_{ab} \Phi_i + h_{r,ab-vin} S_{ab} (T_{vin} - T_{ab}) + h_{cn3} S_v (T_{ac} - T_{ab}) + h_{ab-is} (T_{amb} - T_{ab}) \quad (5)$$

2.3. Experimental Study

The experimental study concerns the performance testing under natural sunlight at the CERER in different periods of the year.

For each of these tests measuring the global radiation there are: the average wind speed, ambient temperature, the temperature at the absorbing plate, the outer pane, the inner pane, of the atmosphere of the cooker. In the case of cooking or boiling tests, it also measures the temperature of the kitchen appliance and the temperature of the water to boil.

The equipment used to study the cooker consists essentially of kitchen utensils and measuring instruments.

As kitchen utensils we used aluminum cooking pots painted in black paste (on the external side only). Shorter cooking times are achieved with thin-walled aluminum cooking pots, distributing the food on several cooking pots and kitchen gloves.

The measuring instruments consist of:

- A pyranometer (KIPP & ZONEN model CM11) which measures the solar flux (global) on a flat surface from a solid angle of 2°.

- Platinum resistance thermometers to measure the absorber temperature and the surface of the inner glass.

- A probe (+ 200°C) to measure the ambient air temperature of the cooker.

- A laser camera thermometer that measures surface temperatures. Thanks to the latter we can measure the

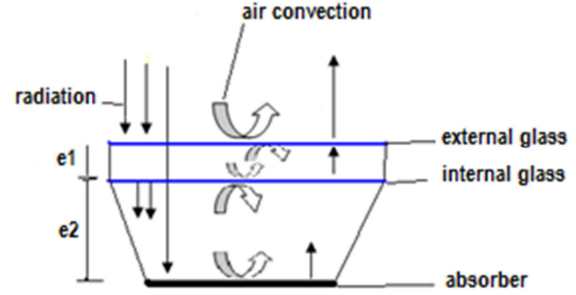


Figure 3. Total energy exchanges within the cooker.

2.2. Heat Balance Equation

Equation on the external glass:

The heat balance of external and internal glass are given respectively by equations 2 and 3.

temperatures of all external surfaces.

- Mercury thermometers to measure the temperatures in volume (boiling water...)

- A digital anemometer that instantly gives the speed and the orientation of the wind at the site but also the ambient temperature.

- A multimeter for measurements of current, voltage, resistances...

2.3.1. Stagnation Tests

During these tests, the cooker is sun-exposed without charge: one tests the vacuum cooker performance [4, 9 and 15].

2.3.2. Tests with Load

This water heating ranges from to boiling tests and to preparation of some local dishes [10].

3. Results and Discussion

Several series of tests were carried out at different insolation. To study the performance of the hot-box cooker, we will exploit the thermal capacity of the cooker during the sunniest periods but also those of lower sun exposure.

3.1. Stagnation Tests

The hot-box exposed to the sun without load; we make a

vacuum performance test.

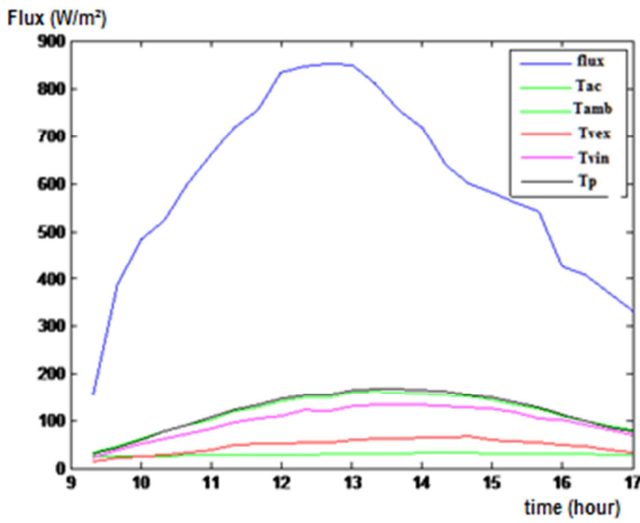


Figure 4. Influence of the incident flux on the temperature variation during 04/01/2015.

These tests were carried out during the day of Monday, January 4, 2015. The day was very sunny; the solar flux exceeds 850 W/m^2 to 12. There is also a lack of wind [10]. These same atmospheric conditions were used to validate theoretical results. However there is an evolution of the cooker temperature is strongly dependent on the solar flux incident. It rises and decreases with the solar flux incident [2, 4, 9, 11, and 15].

These discrepancies are due to insufficient thermal sunny exposure at the double glazing; heat losses are significant at the windows.

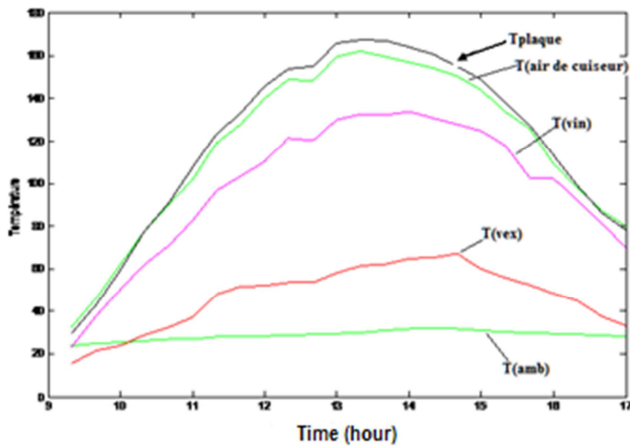


Figure 5. Evolution of temperatures (T_a , T_{ve} , T_{vi} , T_{ac} , T_p) as a function of time during 04/01/2015.

The graphic shows the evolution of the temperature of the absorbing plate, glass (internal and external), air from the cooker and the environment. His study has two stage: A first stage where temperatures grow to reach a peak between 13h and 14h when the variation of flux is also rising. The exposure unit is warmed by the absorption of radiation; temperature rises continuously leading the air from the cooker and

windows.

Later than 14h, there was a decrease, the cooker temperature dropped dramatically at about 17h when it reached temperatures below 100°C unlike the theoretical observations. These temperature drops are due firstly to the fact that the solar flux decreases, as well as the energy generating thermal energy. On the other hand the double glazing is not a good thermal warm exposure. Apparently it can trap infrared radiation but not the heat energy that is generated.

The absorber cools while the temperature of the glass continues to grow. That's a reversal of the direction of heat exchange at the two windows beyond the solar setting. The cooker gives more heat to the environment than it can receive through the windows and it tends towards a state of thermodynamic equilibrium with it [8].

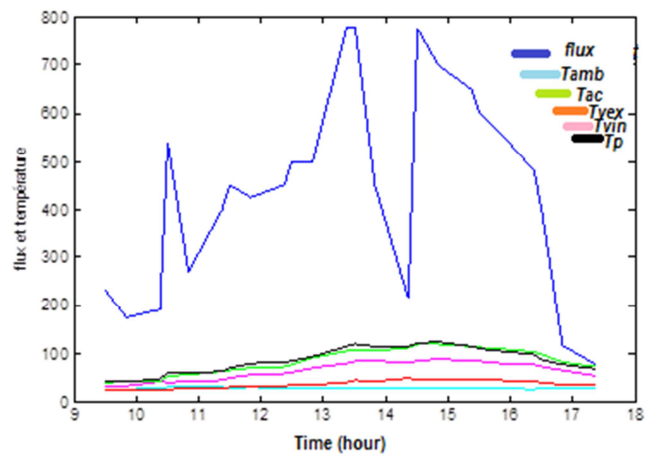


Figure 6. Influence of the incident flux on the temperature variation during 02/02/2015.

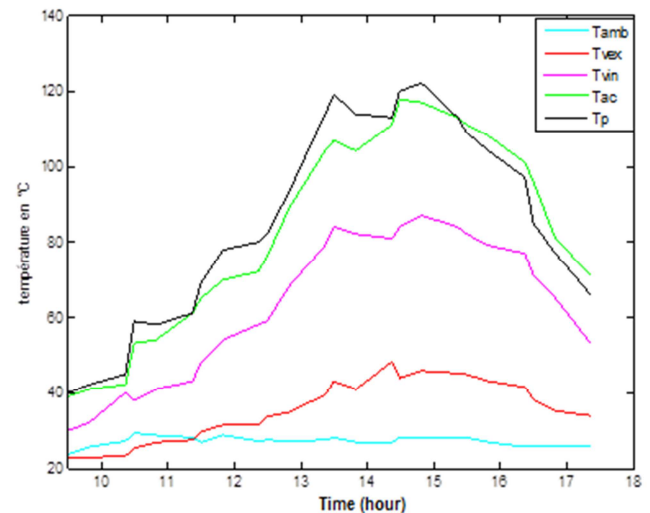


Figure 7. Evolution of temperatures (T_a , T_{ve} , T_{vi} , T_{ac} , T_p) as a function of time during 02/02/2015.

These tests were performed on February 2, 2015 in order to test the performance of the cooker during non-sunny periods. That was a cloudy sky with strong winds. The 100°C was reached around 13h unlike the days of strong sunlight.

However the temperature peaked above 120°C between 13h and 14h. This reflects the fact that the conversion of light flow into thermal energy is selective, the live stream is concerned. The default storage is so important because of notorious decreases during cloudy periods.

3.2. Tests with Load

These tests are related to water boil tests and cooking some local dishes. Water boiling tests were carried out by measuring the change of the water temperature, the absorber, the air from the cooker and the incident solar flux.

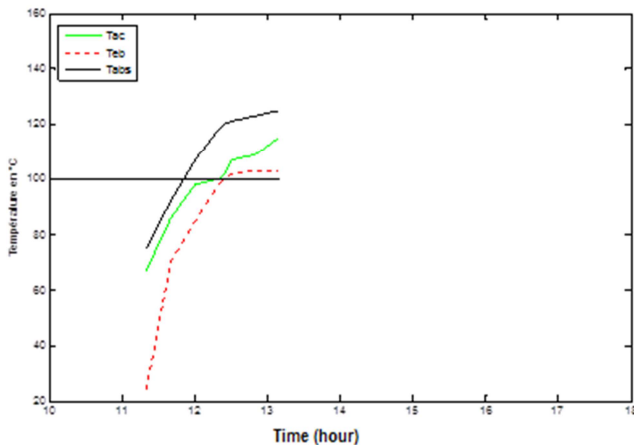


Figure 8. Water boiling test.

This boiling test of a liter of water was performed on Feb 07th, 2015 where the ambient temperature varied between 22° and 26°C along the duration of the tests. The maximum flux density incident was 812W / m² and the average wind speed of 1.6m/s.

After 1 hour of pre-heating, the duration of boiling water was 1h 05mn and the absorber temperature was 120°C.

A temperature of 120°C is more than sufficient for all kinds of cooking. Since the water does not reach more than 100°C, a water-based food cooking will not therefore reach a higher temperature than this one.

It is found that the water temperature is relatively lower than that of the air from the cooker and absorber.

Cooking time depends on the dish to be cooked, the amount and intensity of the sun. It varies from 2 to 4 hours. The cooking is not very fast (120 to 170°C are reached), the dishes can, without risk, be left unattended. Similarly, you can grill walnuts, peanuts or confit fruits, cook eggs (without water), bread, pastries...

4. Conclusion

The solar "hot-box" prototype cooker was designed and tested under natural sunlight at the CERER. Various tests have shown that the system can reach temperatures sufficient for cooking and pasteurization of water even during periods of low sunlight. The arrangement of the side faces permits to reduce the shadow effects on the absorber, which allows the cooker to heat rapidly enough and at a due time of day. It has an exposure time that is improved enough.

The comparative study between theoretical and experimental results that is observed allowed us to move forward on the prospects for improvement of hot-box. The study of the adiabatic transparent materials radiates clearly. The design of thermal storage systems is to improve the daily operating time of the solar cooker.

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Nomenclature

- α_{ab} : Absorption coefficient of absorber
- α_{vin} : Coefficient of absorption of the glass
- c_p : Mass calorific capacity (J.kg⁻¹.K⁻¹)
- ϵ : Emissivity of the material
- h : Convective exchange coefficient (W.m⁻².K⁻¹)
- k : Thermal conductivity (W.m⁻¹.K⁻¹)
- λ : Wave length (m)
- μ : Dynamic viscosity (kg.m⁻¹.s⁻¹)
- m_{vin} : Mass of the glass (kg)
- ρ : Density (kg.m⁻³)
- σ : Stefan-Boltzmann constant (W.m⁻².K⁻⁴)
- τ : Coefficient of transmission of the glass
- R_m : Reflection coefficient of mirrors
- S_{ab} : Surface of the absorber (m²)
- S_{vi} : Surface of the glass (m²)
- T_{ab} : Temperature of the absorber (K)
- T_{ac} : Room temperature of the cooker (K)
- T_{amb} : Ambient temperature (K)
- T_{ciel} : Temperature of the sky (K)
- T_{vin} : Temperature of internal glass (K)
- T_{vex} : Temperature of external glass (K)
- Φ_e : The incoming heat flux (W)
- Φ_g : The generated heat flux (W)
- Φ_s : Outgoing heat flow (W)
- Φ_{st} : Stored flow (W)
- Φ_{th} : Thermal flux (W)
- ϕ_i : Density of incident flux on the surface of the glass (W.m⁻²)
- ϕ_M : Thermal flux density vector (W.m⁻²)
- U : Enthalpy (J)
- V_v : Average wind speed

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