THEORETICAL STUDY AND DESIGN OF A HYBRID SOLAR COOKER

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ABSTRACT

This work presents a new conception of a hybrid solar cooker. The new conception consists mainly of a glass cover, a dark absorber plate exposed to the solar radiation, parabolic reflectors, electrical resistance and thermal insulation. Eelectricity is used only for starting; accelerate the growing temperature, and when the period is lacking insufficient sunshine for cooking. The models of the different sections of the system are developed and numerically simulated to help in predicting the behavior of the system in various climatic changes. The new conception presents a contribution in the development of a hybrid solar system to substitute conventional energy used for cooking. The system is tested and the measuring stagnation temperatures offer a good condition for cooking.

Keywords: *solar thermal energy; modeling; numerical simulation; solar cookers*.

1. INTRODUCTION

The growing demand of electricity, the exhaustion of wood/charcoal consumption and the rapid inflating of fuel price, the environmental degradation, have lead countries to encourage the use of renewable energy. On the whole African continent, 50% of the energy needed for cooking or heating are satisfied from fuel, wood, charcoal, agricultural waste and animal dung. This proportion rises to 90% in sub-Saharan Africa. Today, 6 to 10 African women living in rural areas face the scarcity of wood resources [1]. In Asia, the production of firewood and wood for charcoal region amounted to 375.8 million m3 in 1980. This represents nearly 87% of the forestry production and more than 60% of the total energy consumption [2].
Throughout the world, researches have begun to develop solar cookers using renewable energy sources that will remain in the control of energy needing and minimal adverse impact upon the environment. (Richard Petela, 2005)[3], present the methodology of detailed exergy analysis of a solar parabolic cooker. (S.D. Onekama et al)[4], evaluate the parabolic solar cooker with respect to eight prevalent domestic cooking devices in India. Different criteria categorized under technical, economic, environmental, social, behavioral and commercial aspects are considered for the evaluation based on the additive Multi Attribute Utility Theory model. (B.S Negi et al)[5], present box type solar cooker utilizing non-tracking concentrator optics to enhance the solar energy availability in the box of the cooker for efficient cooking. A model of a box type solar cooker employing a non-tracking concentrator has been designed and fabricated, and its thermal performance has been investigated experimentally. (S.D Sharma et al)[6], present a design and develop of a phase change material storage unit for a solar cooker to store solar energy during sunshine hours. The stored energy was utilized to cook food in the evening. Commercial grade acetamide was used as a latent heat storage material.

This article presents a hybrid solar/electricity system using solar energy for cooking. The production of heat from solar energy is in order to reduce the consumption of firewood or conventional fuel, the electricity is used only for starting, accelerate the growing temperature, and when the period lacking insufficient sunshine for cooking.

2. DESCRIPTION OF THE SOLAR COOKER

The solar cooker prototype, $0.37\ m \times 0.37\ m \times 0.37\ m$ consists mainly of a glass cover, a dark absorber plate exposed to solar radiation, parabolic reflectors, electrical resistance and thermal insulation fig.1 cooker sides consist of a structural member that support the glass covers, the absorber, electrical and layer of polyurethane insulation. The cooking vessel is heated by the fraction of the solar energy flux incident upon the upper glass cover, the heat from the solar energy absorbed by the absorber and the electrical resistance when the period lacking insufficient sunshine for cooking or it is necessary. This hybrid solar cooker is interested in substituting considerable gas, electricity and firewood demand for cooking energy by other less expensive energies, notably those which are renewable and less polluting to the environment and with minimal ecological damages.

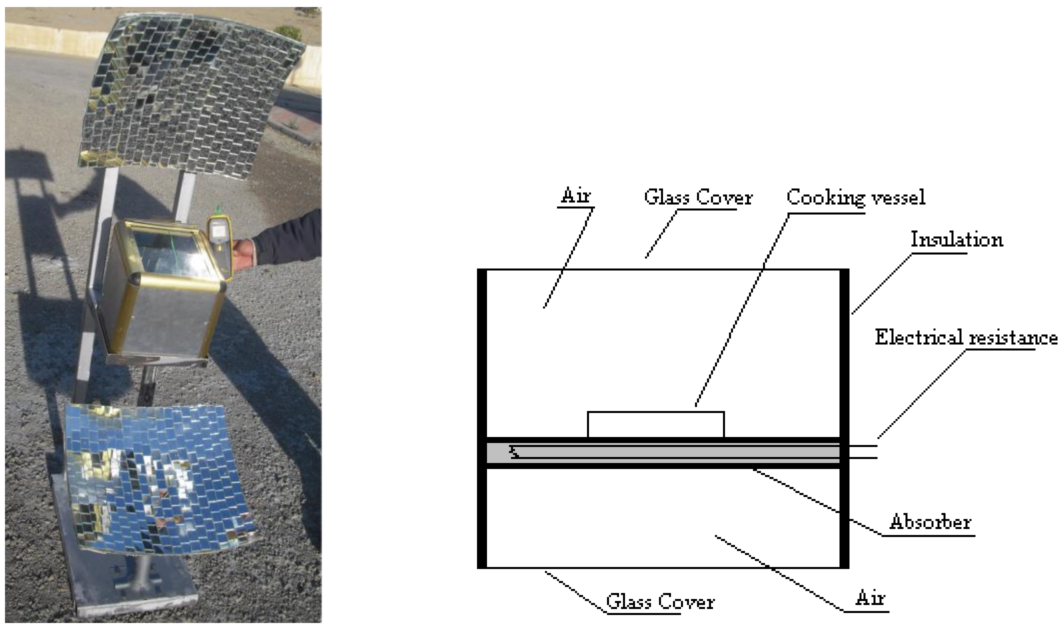

Figure 1: Hybrid solar cooker.

3. MATHEMATICAL MODEL

The energy absorbed from solar radiation and the electricity input energy equals the sum of the energy stored, the total heat losses and the useful energy.

$$q_{sun} + q_{elec} = q_{stored} + q_{useful} + q_{loss} \quad (1)$$

The rate of the solar energy absorbed by the cooker can thus be given by the following expression:

$$q_{s\_ugc} = A_{ugc} I + F_{ref\_ugc} A_{ref\_ugc} I_{ref\_ugc} \quad (2)$$

$$q_{s\_\lg c} = F_{ref\_\lg c} A_{ref\_\lg c} I_{ref\_\lg c} \quad (3)$$

- **Energy balance of the Upper glass cover**

$$m_{ugc} C_{ugc} \frac{dT_{ugc}}{dt} = \alpha_{ugc} q_{s\_ugc} + q_{conv,a1\_ugc} + q_{vap} - q_{conv,ugc\_amb} - q_{r,ugc\_sky} \quad (4)$$

The energy rates $q_{conv,a1\_ugc}$, q_{conv,ugc_amb} and q_{r,ugc_sky} are given by:

$$q_{conv,a1\_ugc} = U_{conv,a1\_ugc} A_{ugc} (T_{a1} - T_{ugc}) \quad (5)$$

$$q_{conv,ugc\_amb} = U_{conv,ugc\_amb} A_{ugc} (T_{ugc} - T_{amb}) \quad (6)$$

$$q_{r,ugc\_sky} = \sigma \varepsilon_{ugc} A_{ugc} (T_{ugc}^4 - T_{sky}^4) \quad (7)$$

$$T_{sky} = T_{amb} - 6 \quad (8)$$

- **Energy balance of the Lower glass cover**

$$m_{\lg c} C_{\lg c} \frac{dT_{\lg c}}{dt} = \alpha_{\lg c} q_{s\_\lg c} + q_{conv,a2\_\lg c} - q_{conv,\lg c\_amb} - q_{r,\lg c\_amb} \quad (9)$$

The energy rates $q_{conv,a2\_lgc}$, q_{conv,lgc_amb} and q_{r,lgc_amb} are given by:

$$q_{conv,a2\_lgc} = U_{conv,a2\_lgc} A_{lgc} (T_{a2} - T_{lgc}) \tag{10}$$

$$q_{conv,lgc\_amb} = U_{conv,lgc\_amb} A_{lgc} (T_{lgc} - T_{amb}) \tag{11}$$

$$q_{r,lgc\_amb} = \sigma\varepsilon_{lgc} A_{lgc} (T_{lgc}^4 - T_{amb}^4) \tag{12}$$

- **Energy balance of the Absorber plate**

$$m_{abs} C_{abs} \frac{dT_{abs}}{dt} = \kappa_{abs\_ugc}.q_{s\_ugc} \frac{A_{abs} - A_f}{A_{ugc}} + \kappa_{abs\_lgc}.q_{s\_lgc} \frac{A_{abs}}{A_{lgc}} + q_{ele} - q_{cond,abs\_f} - q_{conv,abs\_a1} - q_{conv,abs\_vap} - q_{cond,abs\_a2} \tag{13}$$

Where, κ is a product coefficient range between zero to the (glass cover transmittance)-(absorber plate absorptance) products. The energy rates q_{cond,abs_f} , q_{cond,abs_a1} and q_{cond,abs_a2} are given by

$$q_{cond,abs\_f} = U_{cond,abs\_f} A_f (T_{abs} - T_f) \tag{14}$$

$$q_{conv,abs\_a1} = U_{conv,abs\_a1} (A_{abs} - A_f)(T_{abs} - T_{a1}) \tag{15}$$

$$q_{conv,abs\_a2} = U_{conv,abs\_a1} A_{abs} (T_{abs} - T_{a2}) \tag{16}$$

- **Energy balance of the Upper air gap**

$$m_{a1} C_{a1} \frac{dT_{a1}}{dt} = q_{conv,abs\_a1} + q_{conv,a1\_f} - q_{conv,a1\_ugc} - q_{cond,a1\_ambL1} \tag{17}$$

The energy rates q_{conv,abs_a1}, $q_{conv,a1\_f}$, $q_{conv,a1\_ugc}$ and $q_{cond,a1\_ambL1}$ are given by:

$$q_{conv,a1\_f} = U_{conv,a1\_f} A_f (T_f - T_{a1}) \tag{18}$$

$$q_{conv,a1\_ugc} = U_{conv,a1\_ugc} A_{ugc} (T_{a1} - T_{ugc}) \tag{19}$$

$$q_{cond,a1\_ambL1} = \sum_{i=1}^{4} U_{cond,a1\_ambL1i} A_{L1i} (T_{a1} - T_{ambL1i}) \tag{20}$$

- **Energy balance of the Lower air gap**

$$m_{a2} C_{a2} \frac{dT_{a1}}{dt} = q_{conv,abs\_a2} - q_{conv,a2\_lgc} - q_{cond,a2\_ambL2} \tag{21}$$

The energy rates q_{conv,abs_a2}, $q_{conv,a2\_lgc}$ and $q_{cond,a2\_ambL2}$ are given by:

$$q_{conv,a2\_lgc} = U_{conv,a2\_lgc} A_{lgc} (T_{a2} - T_{lgc}) \tag{22}$$

$$q_{cond,a2\_ambL2} = \sum_{i=1}^{4} U_{cond,a2\_ambL2i} A_{L2i} (T_{a2} - T_{ambL2i}) \tag{23}$$

- **Energy balance of the Cooking vessel and food**

$$m_f C_f \frac{dT_f}{dt} = \kappa_f .q_{s\_ugc} \frac{A_f}{A_{ugc}} + q_{cond,abs\_f} - q_{conv,a1\_f} - q_{vap} \tag{24}$$

4. SIMULATION AND RESULTS

The numerical simulations of the developed equations in, section 3, allow predicting the behavior of the solar cooker following variations of the meteorological conditions. The sides have a thin metal clip support the components of the hybrid solar cooker (2 mm glass thick cover, absorber plate, electrical resistance etc.) and 3 cm of polyurethane thermal insulation. The exterior surfaces of the cooker sides are normally exposed to the outside air which is estimated moving at speed of 3 m/s, the ambient temperature and the heat solar flux for simulation is respectively estimated at 30 $^\circ C$ and 300 W/m^2. Principal system specifications and input data are listed in table 1.

Table: 1.

Symbol	Value	Unit
A_{abs}	0.122	$[m^2]$
A_f	0.01	$[m^2]$
A_{L1}	0.28	$[m^2]$
A_{L1}	0.14	$[m^2]$
$A_{\lg c}$	0.122	$[m^2]$
A_{ugc}	0.122	$[m^2]$
$C_{\lg c}$	720	$[J/kg.K]$
C_{ugc}	720	$[J/kg.K]$
C_{a1}	1008	$[J/kg.K]$
C_{a2}	1008	$[J/kg.K]$
m_f	0.5	$[kg]$
q_{elec}	0.	$[W]$
$\kappa_{abs\_\lg c}$	0.4	-
κ_{abs_ugc}	0.3	-
κ_f	0.5	-
$\alpha_{\lg c}$	0.8	-
α_{ugc}	0.8	-
$\varepsilon_{\lg c}$	0.2	-
ε_{ugc}	0.5	-

Table 1: System specifications and input data

Fig.2 and Fig.3 illustrate respectively the result of the simulation of the temperatures variation of the different part of the cooker, after one hour the temperatures of the cooking vessel, food and the absorber plate reach 100°C without using electricity, the measuring temperatures offer a good condition for cooking.

Fig.4 illustrates the average testing solar cooker of 3 days in Gafsa Tunisia from 23 to 25 June 2009 starting at 10h. Moving air, number of cover and insulation thick are very important parameters should be controlled to reduce the heat loss.

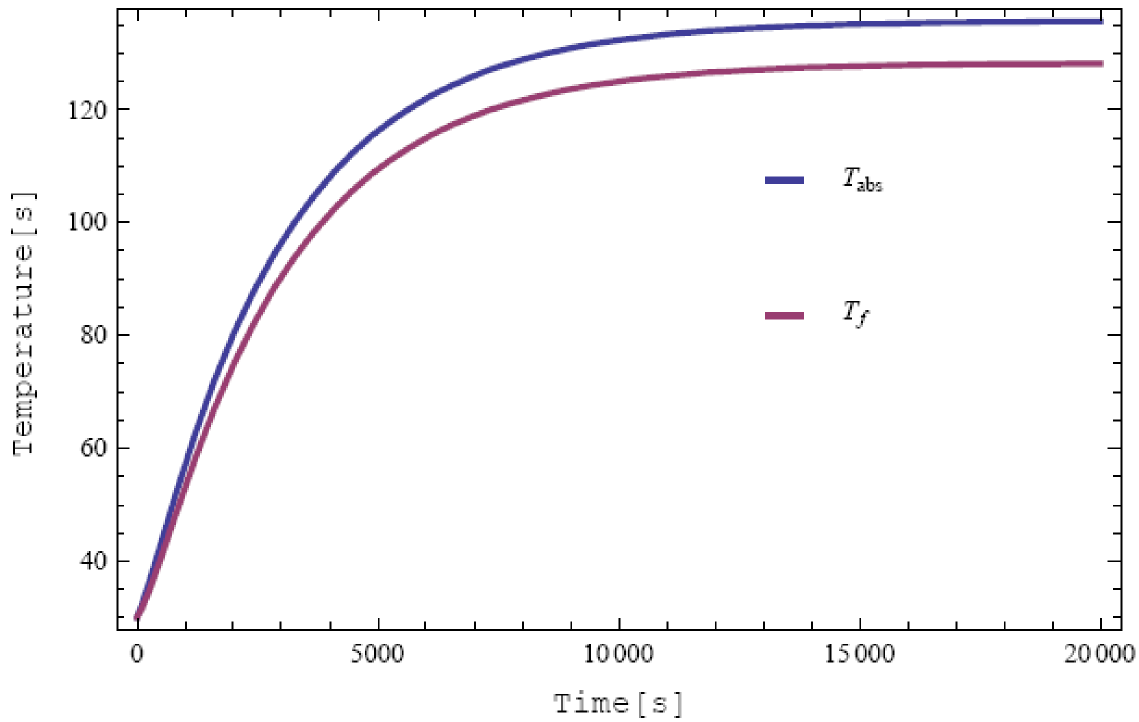

Figure 2 : Absorber plat and the Cooking vessel and food temperature variation

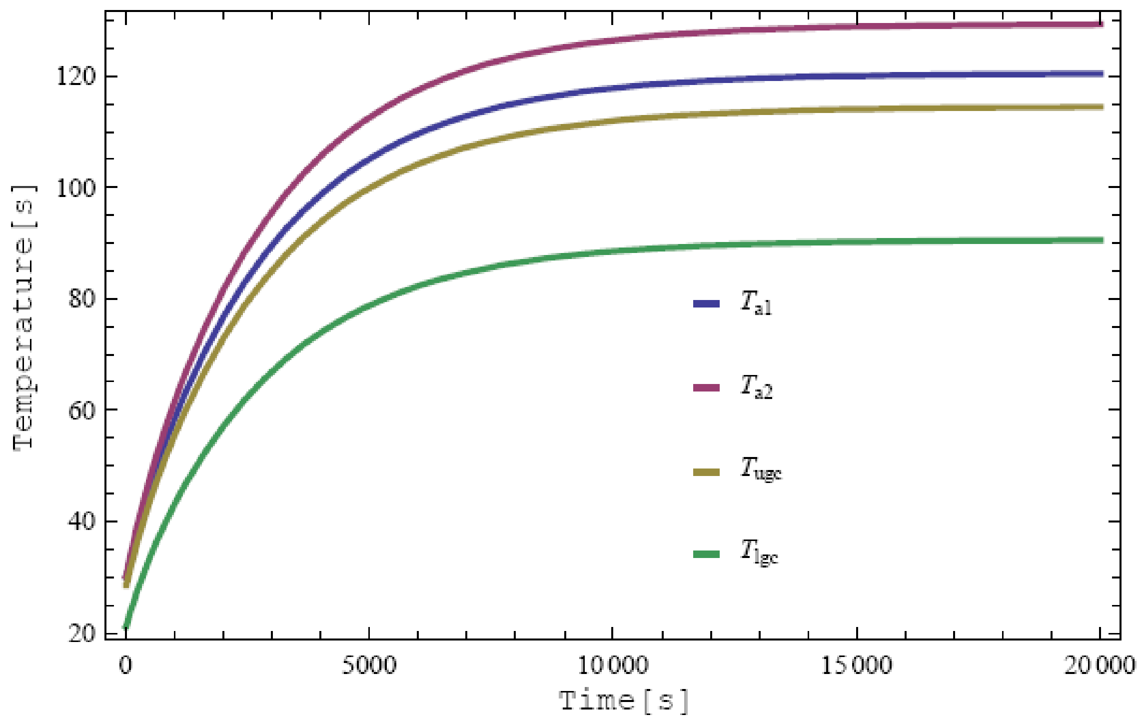

Figure 3 : Upper and Lower air gap and glass cover temperature variation

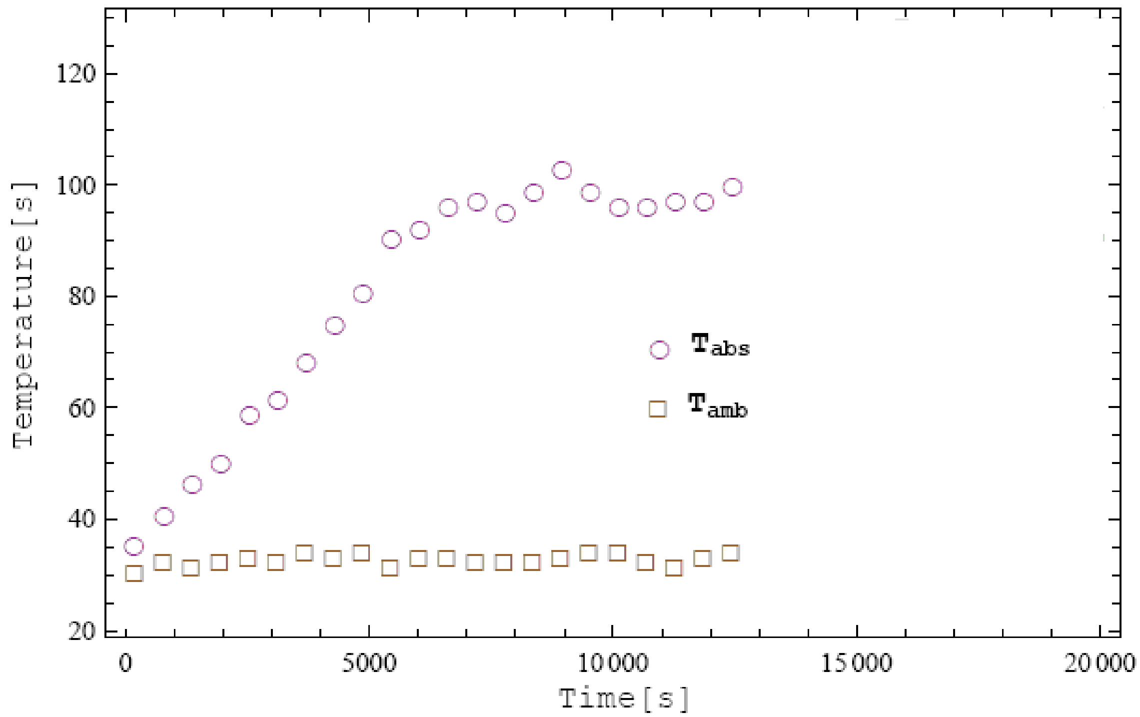

Figure 5 : Absorber plat and ambient temperature variation

5. CONCLUSION

This paper presents a contribution to the development of a hybrid solar system to substitute conventional energy system for cooking. It aims mainly at mastering the solar cooker system and optimizing its performance, which can be widely used in the regions with hot sunshine, and contribute to the reduction of the firewood, charcoal and conventional energy consumption for cooking and have the advantages of environmental protection and low operation cost. The hybrid solar cooker can substitute conventional energy used for cooking by solar energy in order to satisfy the needs of a few number of person. The mathematical modeling and the numerical simulation of the different components of the solar cooker would allow a better knowledge of the system.

6. NOMENCLATURE

A	: Surface Area	m^2
C	: Specific heat	$J/(kg.K)$
F	: View factor	-
I	: Solar radiation on tilted surface	W/m^2
m	: Mass	kg
q	: Rate of heat exchange	W
T	: Temperature	K
t	: Time	second
U	: Heat transfer coefficient	$W/(m^2K)$

Subscripts

$a1$	Upper: air gap
$a2$	: Dawn air gap
abs	: Absorber plate
amb	: Ambient
$conv$	: Convection heat transfer.
$elec$	: Electricity
f	: Cooking vessel (Food)
ugc	: Upper glass cover
ref	: Reflector
$\lg c$	: Lower glass cover
r	: Radiation heat transfer
vap	: Vapor form the food

Greeks

κ	: Product coefficient
σ	: Stefan-Boltsman constant
ε	: Emittance
α	: Absorptance factor

7. ACKNOWLEDGEMENTS

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