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HEATING OF BEE HONEY, OLIVE OIL, MILK AND WATER IN A SOLAR COOKER BOX TYPE WITH INTERNAL REFLECTORS

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KEYWORDS

Solar cooker, temperature, numeric solution, heating

ABSTRACT

Numerical simulation results are shown to determine the heating in liquids when a solar cooker box type with internal reflector is used to this end.

The data evaluated correspond to temperature values from bee honey, olive oil, milk and water when they are heated in the solar cooker.

The maximum simulation temperatures reached are 91.8, 91.6, 86.2 and 85.3 ºC that correspond to bee honey, olive oil, milk and water respectively. A comparative between simulation and experimental results also are shown.

The values presented evidence the influence of the specific heat in each fluid considered.

In the numerical simulation were used solar radiation and environment temperature values for February 26, 2006 in Mexico City.

The experimental data were acquired using an Eppley piranometer and a Field Point device and were used as initial numerical conditions in the simulation. The processing information acquired was made using the LabView 7.0 software.

INTRODUCTION

At the present, the numerical simulation is important to predict or to evaluate if any project or design is feasibility.

However, some mathematical models present a great difficulty, due to climatic variations and its consequent effects in the heat transfer processes implicated.

In this work is studied the behavior in a solar cooker box type with internal reflector when it is used to heat bee honey, olive oil, milk and water.

The numerical values obtained are based on a mathematical model that describes the thermal behavior in the cooker.

Also, are shown a comparative of simulation and experimental results for each liquid used.

There are different types of solar cooker box type: with internal reflectors and external reflectors; these can be viewed in the figures 1 and 2

Figure 1 Solar cooker box type with internal reflectors

Figure 2 Solar cooker box type with external reflectors

Ibrahim A. Olwi and Adel M. A. Khalifa [1], showed results when the concept of a portable solar oven using a vapor-tight pot is introduced and theoretically investigated. The mathematical model involved uses the lumped analysis approach where the whole system is broken up into several elements, each of which is treated as a lumped system by itself. The governing equations of these elements resulting from the heat balance equations were solved on the computer using the fourth-order Runge-Kutta method. The oven performance was predicted for olive oil heating and water boiling tests. The comparison with published experimental results revealed that a considerable improvement of the oven performance can be achieved if the oven is made air tight.

El-Sebaii and Domanski [2], presented analytical expressions for temperatures on a solar cooker to predict their functioning, it was constructed in Tanta, Egypt.

Thulasi, et al. [3], obtained a mathematical model for a solar cooker box type; they showed the problems for the great quantity of parameters that intervene in the operation processes of the same one.

Funk and Larson [4], presented a parametrical model of operation for a solar cooker to predict their cooking power based on three controlled parameters (area of solar interception, overall heat loss coefficient and thermal conductivity of the plateful base's absorber) and three not controlled variables (heatstroke, temperature difference and load distribution). The model was fundamentally an energy balance equation. This model was validated utilizing solar commercial cookers of the fellows of box and concentrators.

Kariuki, et al. [5], used an explicit finite-difference method to simulate the thermal performance of short-term thermal storage for a focusing, indoor, they were shown the simulations for a pot of cold water that was placed on a hot storage block and the time then estimated until the water either boils or the temperature of the water reaches a maximum value. Simulations were made for a given pot capacity with the storage block made from either cast iron or granite (rock). The effects on cooker performance were compared for a variety of height to diameter ratios of the storage block and size of the area of solar input zone.

Martínez [6], designed and constructed a solar cooker with multi-step inner reflectors and he accomplished a study on the same one, obtaining a mathematical model to predict his functioning, highlighting the importance to look for models that they cater to the bigger quantity of possible variables.

NOMENCLATURE

A : Area (m^2)
h : heat transfer convection coefficient (W/ m^2 °C)
T : Temperature (°C)
m : Mass (kg)
t : Time (sec)
C : Specific heat to constant pressure (kJ/kg °C)
G : Incidental solar radiation (W/m^2)

Subindex

g : Glass
r : Recipient or reflector
c : Convection or sky
amb: Ambient
e : Mirror
f : Fluid
fl : lateral fluid
m : Wet
t : Lid
int-1: Inner 1
int-2: Inner 2
int-3: Inner 3

Greek letters

σ : Steffan-Boltzman constant ($5.669X10^{-8}$ W/m^2 K^4)
ρ : Reflectivity
ε : Emittance
α : Absorptance
θ : Reflector angle
τ : Transmittivity

MATHEMATICAL MODEL OF THE SOLAR COOKER

The mathematical model used in this work was obtained by Terres and Quinto [7], it allows to predict temperatures in a solar box cooker box type with internal reflectors.

This mathematical model takes into account the earnings and losses of heat in each component part of the same one.

The solution of the mathematical model has been resolved using the fourth order Runge-Kutta's method which permits to estimate temperatures evolution around the different parts of the cooker, using initial conditions.

The numerical solution of the mathematical model was obtained using no commercial software called ESCRIM (Estufa Solar Con Reflectores Interiores multipasos) [8].

This software was developed in C++, and permits to study different cases of application for solar box cookers with multi-step inner reflectors. The validation of this software presents a maximum difference of 10% regarding the experimental values.

The explicit mathematical model is

$$m_v\, c_v \frac{dT_{v1}}{dt} = A_v G\alpha_v + A_v\sigma\varepsilon_v(T_{v2}^4 - T_{v1}^4) - A_v h_{v1-\text{int}1}(T_{v2} - T_{v1}) - A_v\sigma\varepsilon_v(T_{v1}^4 - \left(0.0552T_{amb}^{1.5}\right)^4) - A_v h_{v1-amb}(T_{v1} - T_{amb}) \quad (1)$$

$$m_v\, c_v \frac{dT_{v2}}{dt} = \tau_v A_v G\alpha_v - A_v\sigma\varepsilon_v(T_{v2}^4 - T_{v1}^4) - A_v h_{v2-\text{int}1}(T_{v2} - T_{v1}) + A_t\sigma\varepsilon_t(T_t^4 - T_{v2}^4) + A_v h_{v2-\text{int}2}\left[\frac{T_{v2} + T_t + T_r}{3} - T_{v2}\right] + A_r\sigma\varepsilon_r(T_r^4 - T_{v2}^4) \quad (2)$$

$$m_t\, c_t \frac{dT_t}{dt} = -A_t\sigma\varepsilon_t(T_t^4 - T_{v2}^4) + A_t h_{t-\text{int}2}(T_t - T_{\text{int}2}) + A_t G\tau_v^2\alpha_t - A_t h_{t-\text{int}3}(T_t - T_f) - A_t\sigma\varepsilon_t(T_t^4 - T_f^4) \quad (3)$$

$$m_r\, c_r \frac{dT_r}{dt} = A_r h_{t-\text{int}2}\left[\frac{T_{v2} + T_t + T_r}{3}\right] + 4\sum_{i=1}^{n=5}\rho A_{ref,n} G\tau_v^2 \cos\left(90 - \theta_{ref,n}\right) - A_r\sigma\varepsilon_r\left(T_r^4 - T_{v2}^4\right) - A_r\sigma\varepsilon_r\left(T_r^4 - T_f^4\right) - A_m h_{r-fl}\left(T_r - T_f\right) \quad (4)$$

$$m_f\, c_f \frac{dT_f}{dt} = A_t h_{t-\text{int}3}(T_t - T_f) + A_t\sigma\varepsilon_t(T_t^4 - T_f^4) + A_r\sigma\varepsilon_r(T_r^4 - T_f^4) + A_m h_{r-fl}(T_r - T_f) \quad (5)$$

This mathematical model takes in count the parts showed in the figure 3

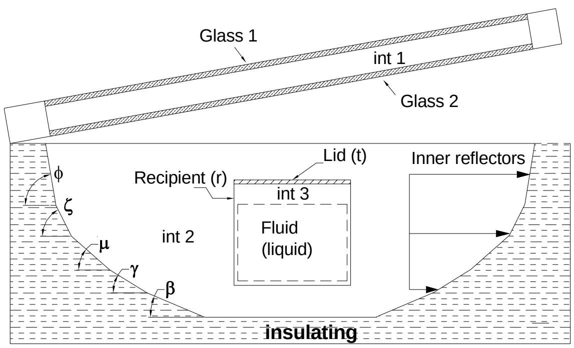

Figure 3 Parts considered in the mathematical model of the solar cooker with 5 inner reflectors

NUMERIC SOLUTION

The numerical solution of mathematical model was carried out by means of the software ESCRIM.

This software was developed in C++, in order to go into different cases of application for solar box cooker with multi-step inner reflectors. Using data of solar radiation, ambient temperature, fluid characteristics and geometry in the solar cooker, is possible to determine the temperature distributions for different parts of the same one.

The numeric parameters values contained in the mathematical model are shown in the table 1.

The convection coefficients values used in the mathematical model have been estimated according to the data from Thulasi et al. [3].

The numerical simulation values take in count the solar radiation data and environment temperature to February 26, 2006 for Mexico City.

Table 1. Numerical values parameters used in the ESCRIM software.

Variable	Amount	Units
m_r	0.2	Kg
m_t	0.1	
m_f	1.5	
ρ_v	2730	kg/m^3
ρ_f	1000	
$C_{bee\ honey}$	800	J/kg-K
$C_{olive\ oil}$	900	
C_{milk}	900	
C_{water}	4190	
A_{fs}	0.020	m^2
ε_v	0.35	Dimensionless
ε_t	0.85	
α_v	0.17	
α_r	0.9	
α_t	0.9	
α_e	0.5	
τ_v	0.48	
$h_{v1\text{-}amb}$ [3]	13.3	W/m^2-K
$h_{v1\text{-}int1}$ [3]	3.8	
$h_{v2\text{-}int2}$ [3]	4.4	
$h_{r\text{-}int2}$ [3]	4.4	
$h_{r\text{-}int2}$ [3]	4.4	
$h_{tapa\text{-}int2}$ [3]	4.4	
$h_{tapa\text{-}int3}$ [3]	4	
$h_{f\text{-}int3}$ [3]	4	
$h_{r\text{-}Am}$ [3]	4	
θ_{r1}	30	degrees
θ_{r2}	45	
θ_{r3}	75	

The solar cooker studied has the geometric dimensions showed in the table 2. To a better viewed of this data see figure 3.

Table 2. Geometrical dimensions of the solar cooker studied

Variable		Amount
Reflector Angle (deg)	β	40
	γ	50
	μ	60
	ζ	70
	ϕ	80
Reflector area (m^2)	A_{r1}	0.0391
	A_{r2}	0.0532
	A_{r3}	0.0646
	A_{r4}	0.0731
	A_{r5}	0.0782
Glasses Area, A_v, (m^2)		0.64
Glasses thicknesses 1 y 2, v1 and v2 (m)		0.005
Area of lid recipient, A_t, (m^2)		0.0314
Area of recipient, (lateral+base), A_r, (m^2)		0.0942
Mass of fluid, m_f, (kg)		2.0

RESULTS

Applying the ESCRIM software to the values considered, allowing to determinate temperature values to each fluid evaluated.

In figures 4 to 7 are shown the cases considered. Comparatives of simulated and experimental values for bee honey, olive oil, milk and water are shown in figures 8 to 11

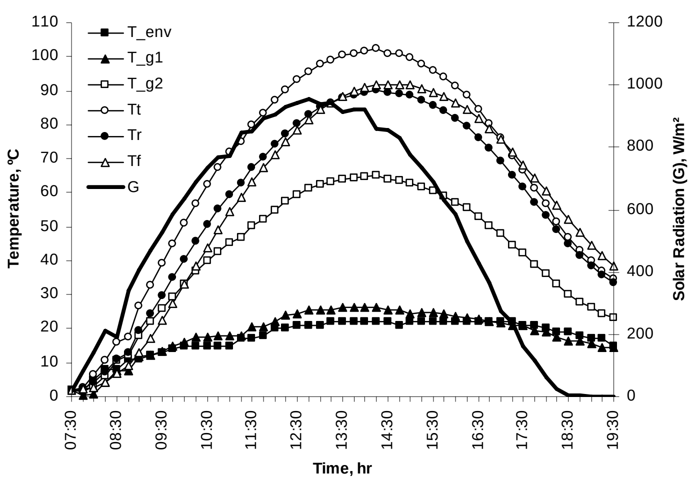

Figure 4 Temperatures distribution in bee honey heating

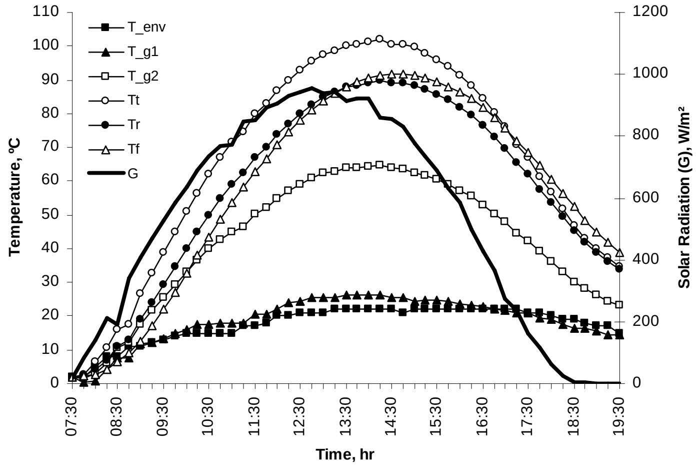

Figure 5 Temperatures distribution in the olive oil heating

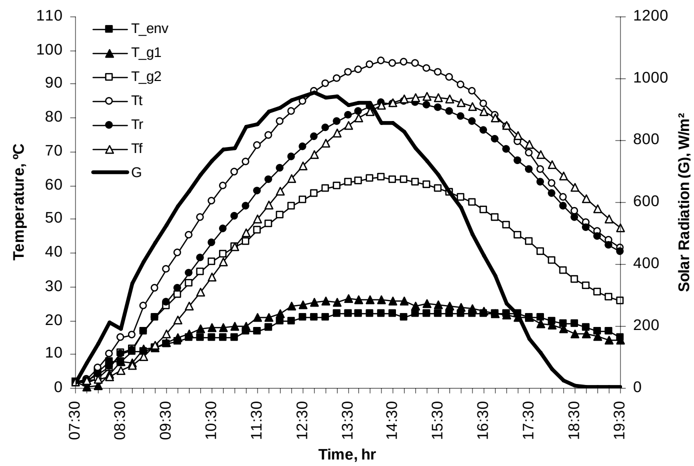

Figure 6 Temperatures distribution in the milk heating

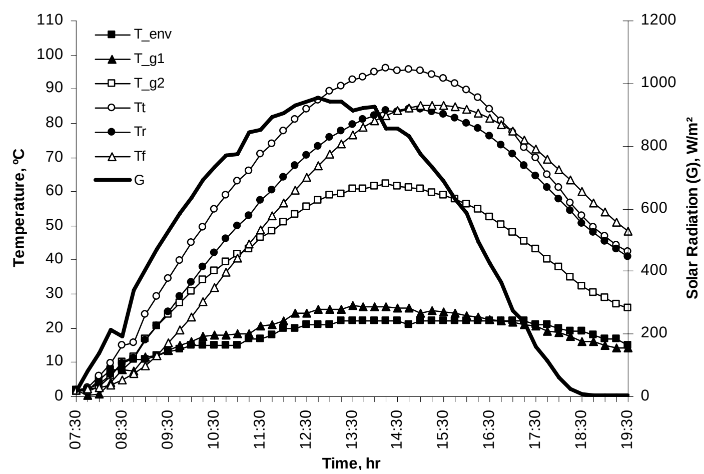

Figure 7 Temperatures distribution in the water heating

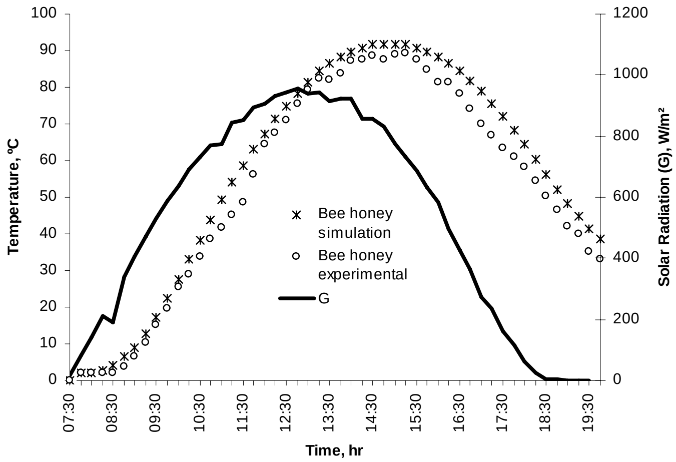

Figure 8 Comparative of simulation and experimental values: Bee Honey

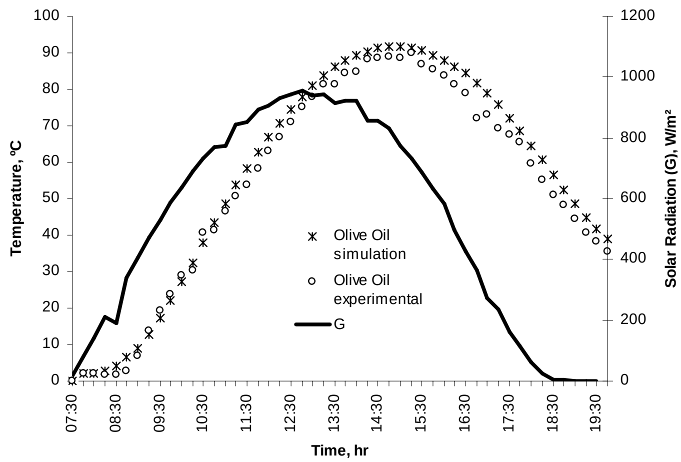

Figure 9 Comparative of simulation and experimental values: Olive Oil.

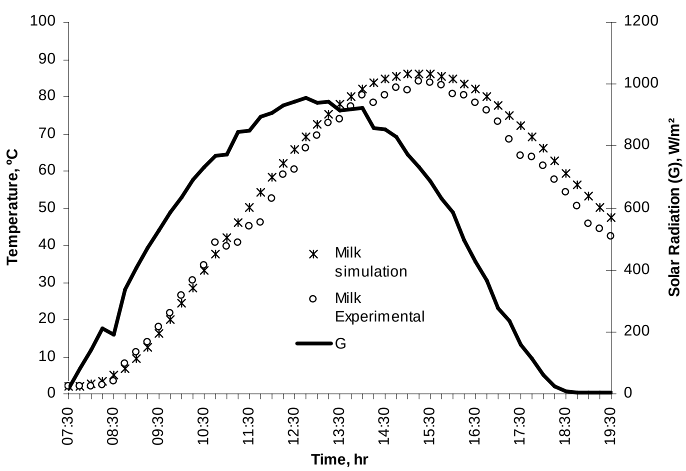

Figure 10 Comparative of simulation and experimental values: Milk.

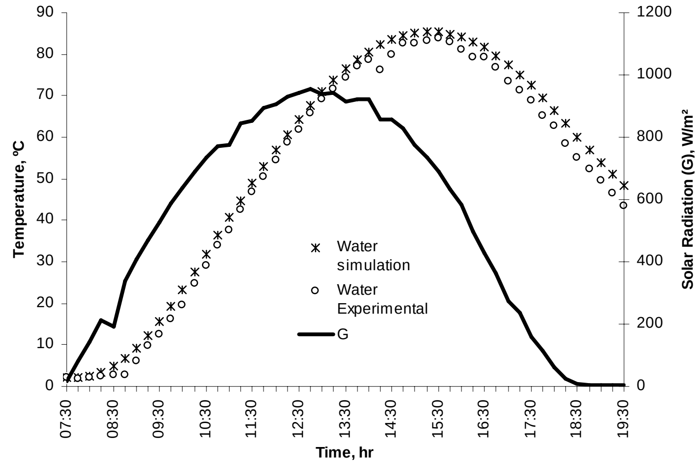

Figure 11 Comparative of simulation and experimental values: Water.

The maximum simulation temperatures reached are 91.8, 91.6, 86.2 and 85.3 ºC, that correspond to bee honey, olive oil, milk and water respectively.

For these fluids their maximum experimental temperature values are 87.6, 88.6, 84.0 and 83.3 ºC respectively.

The maximum values differences are respectively for bee honey, olive oil, milk and water 10.06, 9.71, 8.36 and 6.16 ºC.

According to these differences it is possible to say that for water the mathematical model presented allow obtaining the better results.

The differences in the values are explained because the mathematical model was validated using water as fluid.

However, the numerical values should be interpreted in their behavior, if precision in the values are needed, the experimental values must be considered to this end.

The behaviors in the fluids heated are according to specific heat of the same ones. When the specific heat is high the temperature value is low. It occurs for bee honey and water when they are compared in terms of their values.

The solar radiation influences on the heating processes, this can be seeing it in the experimental data, but it not occurs in the numerical values.

This happen due to the mathematical model doesn't evaluate these variations.

The numeric results obtained shown that for 7:30 to 12:45 h. approximately, the cooker has the following behavior in its distribution of temperatures: $T_{v1} < T_{v2} < T_f < T_r < T_t$.

After this time, for 17:00 to 19:30 h. approximately, the behavior in the distribution of temperatures changes to: $T_{v1} < T_{v2} < T_r < T_t < T_f$.

The behavior study on different liquids used in heating processes by numerical simulation, allows comparing the thermal process of different liquids for similar conditions.

CONCLUSIONS

The data showed, allow seeing the relation between solar radiation and the increases of temperature on the liquids used.

This type of solar cooker, according to the results, can be used in different applications. For example to break the crystallization in the bee honey, just as it has been promoted in areas rural producers of honey in the center of Mexico.

However, the heating time is important, is necessary 5 or 6 hours to reach the maximum temperatures, and this is real trouble.

On the other hand, this work can be of great utility in the taking of decisions for the design of new cookers, if the model is used for different geometries.

This form of analyzing the transitory aspects of the radiation and their corresponding use, avoid having to build many solar cookers, being had a saving of time and the advantage of enlarging the aspects that are implied in the heating process in an outstanding way.

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