First and Second Law Efficiencies in the Cooking Process of Eggplant using a Solar Cooker Box-Type

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Abstract. In this work an experimental procedure and the determination of first and second law efficiencies for the cooking process of eggplant using a solar cooker box-type are shown. The eggplant was modelled as cylinder. In the experimental process a NI Compact Field Point was used as acquisition data system which allows measure temperatures in simultaneous form. The temperatures evolution was defined using thermocouples located at water, surface and central point of the eggplant. After to measure the evolution temperatures in a solar cooker thermodynamics principles were applied to determine the first and second laws. The results obtained indicates what is the numerical difference between the first and second laws in the cooking process of eggplant. The results allow to understand how the inlet energy that impacts on solar cooker is converted in energy useful in the cooking process of eggplant. This work be used in future designs of solar cookers.

1. Introduction

In the solar energy field is important determine which is the real value or magnitude that is used for the several solar devices. For this reason, useful parameters are the first and second laws, which are obtained in the thermodynamics analysis and they are aimed to the different processes where heat or work have an important contribution. Some references are cited to illustrate applications of the exergy and efficiency in solar energy.

Petela [1], works in equations for heat transfer between three surfaces: cooking pot, reflector and imagined surface making up the system, were derived. He obtained a model which allowed for theoretical estimation of the energy and exergy losses: unabsorbed insolation, convective and radiative heat transfer to the ambient, and additionally, for the exergy losses: the radiative irreversibilities on the surfaces, and the irreversibility of the useful heat transferred to the water. The exergy efficiency of a solar parabolic cooker, was found to be relatively very low (1% aprox.), and to be about 10 times smaller than the respective energy efficiency which is in agreement with experimental data from the literature.

Kamthania et al. [2] In their paper an attempt to analyze the performance of semi-transparent hybrid PVT double pass air collector is shown. Considering a quasi-steady state condition, analytical

expression for air temperature at the outlet in a hybrid PVT air collector was obtained. Energy balance equations applying the thermodynamical first law were formulated.
Their paper shows a detailed analysis of energy and exergy for a semi-transparent hybrid with double pass air collector. This device is compared with a single pass air collector.

Different conditions of weather for five different cities (New Delhi, Bangalore, Mumbai, Srinagar, and Jodhpur) of India were condidered. When the compare is done, is possible to see that hybrid double pass air collector have better performance than the single pass air collector.

Candau [3] proposes a derivation of the exergy of radiation, based solely on classical thermodynamics notions, making thus possible a ready check of the validity of the results. Results are given first for the blackbody case, then extended to a radiation with arbitrary spectrum. Finally, application of the notion of radiation entropy to a few simple examples shows the consistency of this notion with some well-known physical laws, and can even give some insight into the real signification of these laws.

Fudholi et al. [4] designed, constructed and tested a solar drying system for drying of seaweed. Seaweed is a potential source of renewable energy, and it can be converted into energy such as biofuel oil, biodiesel and gas. Drying kinetics of red seaweed were investigated and obtained. The nonlinear regression procedure was used to fit three different drying models. The Page's model clearly showed a better fit to the experimental data between Newton's model and Henderson and Pabis model. The Page's model was resulted in the highest value of R^2 and lowest values of MBE and RMSE. At average solar radiation of about 500 W/m^2 and air flow rate 0.05 kg/s, the collector, drying system and pick-up efficiencies were found about 35, 27 and 95%, respectively. This study was performed with energy analysis and exergy analyses of the solar drying process of red seaweed. The specific energy consumption (SEC) of 2.62 kWh/kg was obtained. Moreover, the exergy efficiency of solar drying ranged from 1% to 93%, with an average of 30%.

Gunerhan and Arif Hepbasli [5] worked on a solar water heating. In Izmir, Turkey, the device was evaluated. Exergy destructions as well as exergy efficiency relations are determined for the Solar heating system. Exergy efficiency values on a product/fuel basis are found to range between from 2.0 to 3.3 %, and 3.2 to 4.3 % at a dead state temperature of 32.7 C.

In this work, a study for first and second law applied to the cooking process of eggplant using a solar cooker box-type is shown. The results obtained can be used to evaluate the process and they indicate what is the real energy quantity used in the cooking process of eggplant.
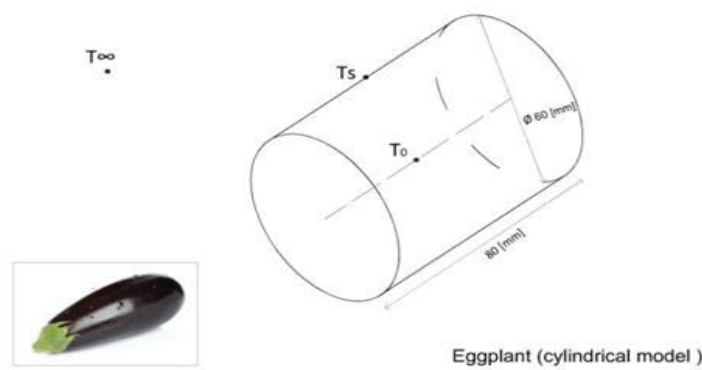
2. Experimentation
In the experiment a solar cooker box-type as energy source is used. The solar cooker is integrated by the following elements: 1. a cover with two flat glasses with a clearance between them. 2. Reflectors placed on the cover outer of the cooker 3. Internal reflectors made in commercial aluminium paper placed to different tilt angles, 4. Thermal insulator placed in the lateral part of the same one, and 5. Recipient contains the product to cook. The solar cooker is locked tightly; this allows reaching considerable temperatures in the water. In figure 1 the solar cooker is shown.

The solar radiation (total) was measured using an Eppley piranometer model 8-48. Multimeters were used to measure the temperature. Thermocouples k-type at surface, central point of the eggplant and water were placed. The temperature measuring was realized each 5 minutes. The time cooking process considered was 2.5 hours. The average value of the mass in the eggplant was 250 g. The average value for the water was 250 ml. The geometrical characteristics and the thermocouples colocation at eggplant, are shown in figures 2.

Figure 1 Solar cooker box-type: with exterior reflectors and interior reflectors

Figure 2 Thermocouples position and geometry for eggplant

Once temperature data is obtained, first and second law are defined to calculate the values for the process. For this purpose, some considerations were done: 1. Thermal conductivity constant. 2. One-dimensional flow. 3. Without heat generation. 4. Cylindrical coordinates.
According to thermodynamics theory states [6]

First law Efficiency

$$\eta_I = \frac{Q_{out}}{Q_{in}} = \frac{m(u_{f-}u_i)}{\frac{A_vG(t_f-t_i)}{1000}} \tag{1}$$

Second law Efficiency

$$\eta_{II} = \frac{\psi_{out}}{Q_{in}} = \frac{mcT_0\left[\frac{T_f}{T_0}-1-ln\left(\frac{T_f}{T_0}\right)\right]}{\frac{A_vG(t_f-t_i)}{1000}} \tag{2}$$

The heat specific was determined using correlations in function of temperature [7].

$$C = C_{H_2O}x_i + C_{protein}x_i + C_{fat}x_i + C_{carbohidrates}x_i + C_{fiber}x_i \tag{3}$$

Where

$$x_i = Mass\ component\ of\ the\ product\ (eggplant) \tag{4}$$
$$C_{H_2O} = 4176.2 - 0.090864T - 0.0054731T^2 \tag{5}$$

$$C_{protein} = 2008.2 + 1.2089T - 0.0013129T^2 \tag{6}$$
$$C_{fat} = 1984.2 - 1.4733T - 0.0048008T^2 \tag{7}$$
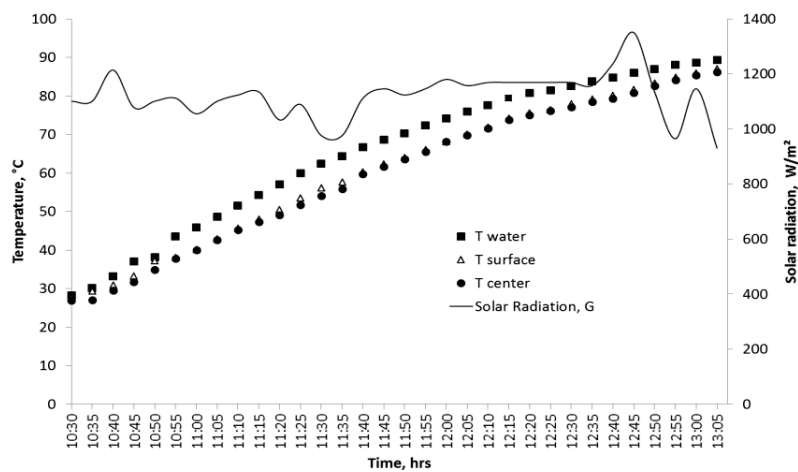$$C_{carbohidrates} = 1548.8 + 1.9625T - 0.0059399T^2 \tag{8}$$
$$C_{fiber} = 1845.9 + 1.8306T - 0.0046509T^2 \tag{9}$$

Q is the heat in kJ, m is the mass of the eggplant in kg, u is the internal energy kJ/kgK, T is the absolute temperature, in K, A_v is area of the cover glass in m^2, G is the solar radiation in W/m^2, t is the time in seconds. In subscripts, *out* represents the out energy, *in* is the out energy and *f*, *i* and *0* correspond to final, initial and dead state respectively.
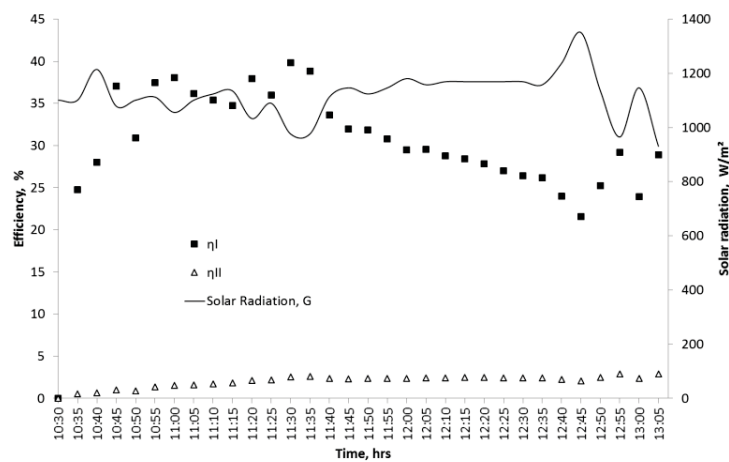
3. Results and discusion

After the experimental procedure, results for the thermal process are obtained. In figure 3, temperatures for water, surface and centre of the eggplant are shown.

Figure 3 Thermocouples position and geometry for eggplant

With this data and using equations (1) and (2) first and second law efficiencies are determined, in figure 4 are shown.

Figure 4 Thermocouples position and geometry for eggplant

The experimental data allow to appreciate the temperature behavior in the cooking process which is consistent for the heating process of eggplant, this is $T_{water} > T_{surface} > T_{center}$.

According to the efficiencies data, the second law values are not bigger than 5 % while the first law values reaches 40 %. Those results allow to evaluate the quantity of energy not used in the cooking of eggplant.

The first law efficiency indicates the cooking process in an ideal interpretation.

By other hand, the second law efficiency shows how the inlet energy is really used during the cooking process. This efficiency is called real efficiency because it allows to view the irreversibility in a process like this case.

It is identified in other works [8] the loss of energy occurs in the cover of the solar cooker and it is associated to the conduction and convection heat transfer.

This work can be useful to identify what is thermal behavior in the cooking process of eggplant. The results also can be useful to establish how and where the solar cooker could be improved.

4. Conclusions

Experimental procedure to determine the evolution of temperatures was shown. The implement of instrumentation in solar energy was illustrated. Thermodynamics principles were applied to determine the first and second laws. The results obtained indicates what is the numerical difference between the first and second laws in the cooking process of eggplant. The results obtained can be used in future designs of solar cookers

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