Experimental Results of a Solar Cooker with Heat Storage

Maria Eugênia Vieira da Silva, Klemens Schwarzer*, and Marcelo Ricardo Queiroz Medeiros.
Universidade Federal do Ceara, Laboratório de Energia Solar Aplicada
Bloco 714, Campus do Pici s/n, Pici, Fortaleza 60190-080 BRAZIL
E-mail: eugenia@les.ufc.br
*Ingenieurbüro für Energie und Umwelttechnik
Tuchbleich 12, Juelich, GEMANY

Abstract

This research article determines the experimental efficiency of a solar cooker with storage system. This system is composed of flat plate collectors, a cooking unity, control valves and a heat storage tank. In its operation, the working fluid is heated in the solar collectors and moves in a thermal siphon circuit. The control valves direct the fluid flux to the cooking unity or to the storage tank for later use. In the experiments, the gathered data are measured by precision instruments and are stored in a data-logger. These data are used to determinate the heat sensible and boiling thermal efficiencies. The results show the good system performance, with the sensible efficiency varying from 0,34 to 0,38. The results also show that when the same tests are made with the heat stored into the tank, the heating time intervals for direct and indirect cooking are very closed. The latent efficiency varied around 0,30.

1. INTRODUCTION

The use of solar energy, friendly to the environment and economical in various applications, in residential and industrial processes is becoming a reality in various countries. In spite of that, the destruction of forests without control has been occurring in other regions. Wood burning has been widely used for cooking in many places, such as in Africa, because it is the only affordable and/or available energy source.

Food processing is a practical solar energy application that can be used in regions with limited vegetation resources and with good solar radiation intensity. The working fluid temperature, in good quality flat plate solar collectors, can reach values around 200°C, which makes possible the use of these collectors in solar cooking systems. The purpose of this work is to present the experimental results, the thermal efficiencies, and the operational experience with a solar cooking system with heat storage, tested in the city of Fortaleza, located in the Northeast coast of Brazil. The original system was developed by a private city firma in Germany and in the last years it has been further adjusted and tested by two research institutions, one in Germany and the other in Brazil. Various systems, with and without heat storage, have been installed in different countries, such as Germany, India, South Africa, Mali, Chile, and Argentina, among others (Schwarzer and Krings, 1996; Vieira *et al.*, 1997). The addition of a baking oven and other components, operational adjustments and specification of the working fluid, and the identification of new application are among the themes being currently studied.

1.1 System Description

A photo of the solar cooking system is shown in Figure 1. The photo shows the flat plate collectors, the cooking unit with the storage tank inside, and a baking oven. In operation, the working fluid is heated up in the solar collectors and flows in a thermal siphon circuit due to the difference in density between the hot and cooler parts of the system. As the hot fluid leaves the solar collector, control valves direct the flow either to the cooking unit or to the top of the storage tank. After use, the cooler fluid returns to the collector inlet. The most important advantages of this system are the possibility of indoors cooking, very safe operation when compared to the more popular 'butterfly' cookers, and the unnecessary use of an external electrical source to pump the working fluid though the system. The disadvantage is the higher first cost when compared with the low cost concentrator cookers.

The system shown in Figure 1 is installed in Fortaleza and its basis characteristics are: high quality flat plate collectors ($4m^2$); one storage tank (50 L); one cooking unit with 3 pots and 1 oven; 5 control valves.

Picture 1. Photo of the solar cooker tested in Fortaleza - outdoors model with heat storage tank and oven.

2. APPROACH

To study the thermal performance of the solar cooking system, experimental measurements and analytical calculation have been made. The measured values are: the global solar radiation intensity on the tilted collector plane, wind speed, ambient temperature, and temperature in various points of the system. The experimental data are read and stored in data logger. The thermal sensible and boiling efficiencies are determined using the definition of the sensible and boiling powers, as defined below.

2.1 Analytical Approach

The thermal sensible efficiency, Equation 1, is defined as the ratio of the energy used to sensibly heat a certain mass of water contained in a pot of the cooker from the ambient temperature to 95°C and the global solar energy incident on the time interval. This end temperature value is used to avoid the uncertainly in the start of boiling.

$$\eta_{95} = \frac{m_w \, . \, c_p \, . \, \Delta T_{amb-95}}{A_c \int_0^t G.dt} \tag{1}$$

In this equation, m_w is the mass of the water in [kg], c_p is the specific heat at constant pressure in [J/(kg.K)], ΔT is the temperature difference in [C], and Δt is the time elapsed in the heating process in [s],

A_c is the collector area in $[m^2]$, and G is the instantaneous global solar radiation flux on the tilted plane in $[W/m^2]$. The thermal sensible power is the rate of sensible energy used to heat up the water, as in Equation (2).

$$\dot{Q}_h = \frac{m_w . c_p . \Delta T_{amb-95}}{\Delta t} \tag{2}$$

To estimate the boiling efficiency and power, the numerator in the above equations are replaced by the corresponding latent heat expressions. The boiling power, Equation 3, is the rate of the energy used to boil a certain mass of water in the elapsed time interval.

$$\dot{Q}_b = \frac{m_w . h_{fg}}{\Delta t} \tag{3}$$

In Equation 3, h_{fg} is the water latent heat in [J/(kg)], and Δt is the time elapsed in the boiling process in [s]. The average latent efficiency is determined as the ratio of the energy used in the boiling process to the integrated global radiation in the time interval, as expressed in Equation (4).

$$\bar{\eta}_{boiling} = \frac{m_w . h_{fg}}{A_c . \int_0^t G.dt} \tag{4}$$

2.2 Experimental Measurements

To measure temperature in the cooking system, on the outside walls of the copper piping, type-K thermocouples are used. Ambient temperature is measured with a PT-100 and the wind speed with an anemometer. The global solar radiation flux on the tilted plane is measured with a pv-cell type sensor, which has an error of 1% when the values are compared with those from a precision pyranometer, The solar flux on the horizontal plane is measured by a precision pyranometer. The instruments are scanned every 2 seconds and the average values stored at every minute.

In the experiments, 8 liters of water were used in the 10-liter pot to determine the sensible energy needed to raise the water temperature from ambient to 95^oC. Three thermocouples are use to determine the water temperature in the pot. The pot is also calibrated to allow the visual determination of the water evaporated during the boiling process.

3. RESULTS

Figure 2 shows the variation of the water temperature and the global solar flux during a sensible heating experiment. The measuring started as 12:00 o'clock noon and lasted 32 minutes. The average value of the thermal sensible efficiency, as determined using Equation (1), using the measured data is 0,38. Other values of the thermal sensible efficiency presented in literature vary from 0,30 to 0,34 and this small difference can be associated with the different kind of oil used in this experiment. In this case, synthetic thermal oil was used instead of vegetable oils due to problems associated with dissociation at temperatures near 200^oC. The vegetable oils available were produced in pressing process and presented this dissociation phenomenon. The average flux of global radiation on the inclined plane was 786,1 W/m^2. The heating process lasted 32 minutes to heat up 8 kg of water. The same process with the heat from the storage tank lasted 37 minutes.

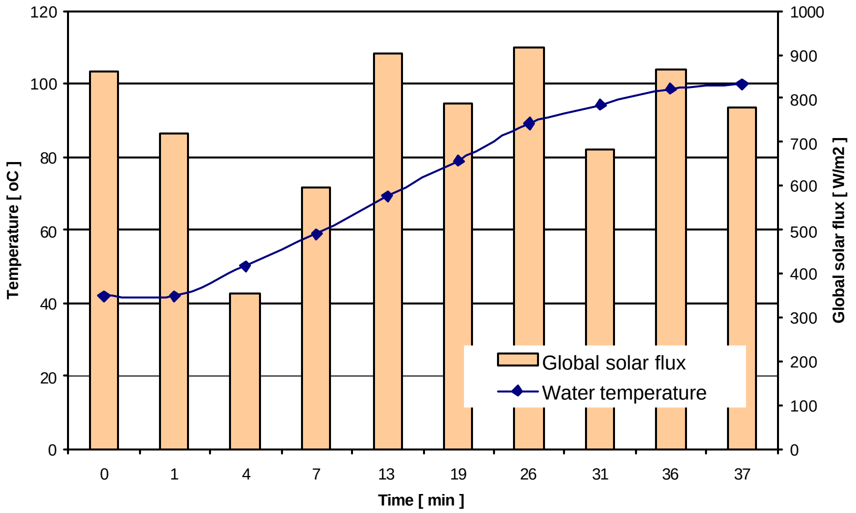

Figure 2. Temperature of the water and solar global radiation flux during a sensible heating experiment

Figure 3 shows the experimental data gathered during a heat charging (storage tank) experiment. This plot shows the temperature fields from sunrise to sunset time. The storage tank is 50L in size and has a spherical shape. The location of the temperature sensors is: inlet and outlet of the solar collectors, and at two positions of the storage tank. These data are to be used in the calculation of the accumulated energy in the system and the temperature distribution in the tank. It is also shown the global solar flux.

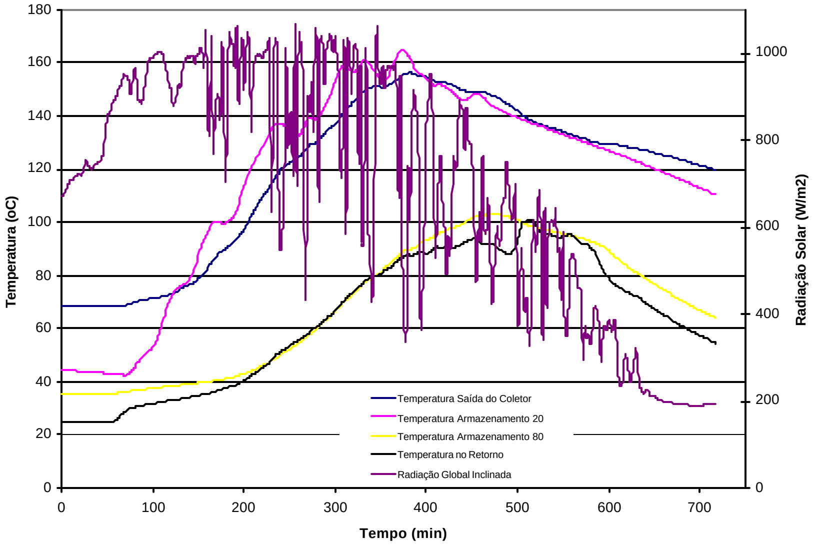

Figure 3. Temperature data in the system during a heat storage charging experiment (24.03.2001)

The results presented in these initial tests show the good performance of the solar cooker system in the conditions in Fortaleza. The thermal sensible efficiency reached a slightly higher value than expected because of the adequate thermal properties of the oil used in the system. The latent efficiency was somewhat more difficult to estimate. A new pot cover was made to perform the tests and the latent efficiency value was 0,30 for an average global radiation on the horizontal plane of 664 W/m^2. In summary, the tests showed that the system can and should be used to prepare meal in institutions, schools, among others, because of its very safe operation, capacity to cook large meals and keep them warm a whole day, and its use of a much needed and environmentally friendly energy source.

4. ACKNOWLEDGEMENTS

The support from the Brazilian institutions SECITECE for financing most of the equipment, and from CNPq for a research fellowship has been much appreciated. Also, thanks to FUNCAP (Brazil) and BMBF (Germany) for supporting travel expenses.

5. REFERENCES

Vieira, M. E., Gomes, C. A. S., Teixeira, R. N. P., 1997, *“ Thermal Efficiency of a Solar Cooking System with Storage”.* COBEM, São Paulo, Brazil

Schwarzer, K., Krings, T., 1996, “*Demonstration- und Feldtest von Solarkochern mit temporärem Speicher in Indien und Mali*“. Shaker Verlag, Germany.