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Exergy applied to the heat conduction analysis in glass covers of a solar cooker box-type with internal and external reflectors

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Abstract. In this work, an exergy evaluation to determine the energy availability across to glass covers, place where the solar radiation enters toward a solar cooker box-type is done. Considering the heating process of water, the energy not used is quantified by means of exergy. The results allow identifying the glasses in the cover as the zone where the solar cooker could be improved. The conduction heat transfer losses for the glasses is most big than 75%. Because the values for the conduction heat losses are around 90%, which are very important, this allows to identify the cover glass as the area where improvements could be made in this type of solar cookers.

1. Introduction

When solar cookers are constructed, is very important to consider the heat losses in the same ones. The conduction, convection and radiation mechanisms happen when a solar cooker is operating during the heating process of water. According to previous works by Terres et al. [1, 2, 3], the conduction is the most important because of their losses are bigger than convection and radiation in the heating process in a solar cooker box-type. Pandey et al. [4] realized an experimental study of solar cookers based on the exergy analysis. They showed that for a solar cooker box-type when the volume of water used in tests increases, the exergy efficiency increases too. However, for a solar cooker paraboloid-type, the exergy efficiency is higher than the solar cooker box-type for the same increment in the volume of water. Panwar [5] present a study for an animal feed solar cooker. He shows a thermal model and an experimental validation for the same one. He considered an experiment for 9 months. Agree to his model, it is capable of predicting the water temperature close to experimental values. Also in his work energy and exergy assessment for the cooker was also carried out. Nemati and Javanmardi [6] considered the exergy theory to study a domestic solar cylindrical-parabolic cooker, they determined the 1st and 2nd law efficiencies for the cooker. They establish that the 1st law efficiency is very low and the 2nd law efficiency is even lower. Taking in account these results, the authors considered necessary the performance optimization in domestic solar cylindrical-parabolic cookers. Kumar et al. [7] proposed parameters based in exergy to study solar cookers. Their results are shown by graphs between exergy output power and temperature difference. They determined the exergy power with variation of the temperature difference. The slope of the straight line obtained through curve fitting represents the heat loss coefficient of the cooker. In this work, the exergy is applied to determine the useful energy across the glasses inside of the cover of a solar cooker box-type. The results are important for improve designs and studies in solar cooker cookers box-type.

2. Experimental procedure and experimental results

For the experiment, the solar cooker box-type used consists of 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, which is used as test fluid. 2 liters of water were used. The general dimensions of the solar cookers 0.7 x 0.7 x 0.35 m. In addition, a radiometer Eppley model 8-49 was used for the solar radiation and thermocouples type-k were used for the temperature measures. An acquisition system data integrated by a compact Field Point of National Instruments and Lab View software were instrumented for the test. The interval considered was 4 hours (10:00 to 14:00) and the day was April 10, 2016. The test was done in Mexico City. In figures 1 and 2, the solar cooker evaluated is shown.

Figure 1. Solar cooker box-type with exterior and external

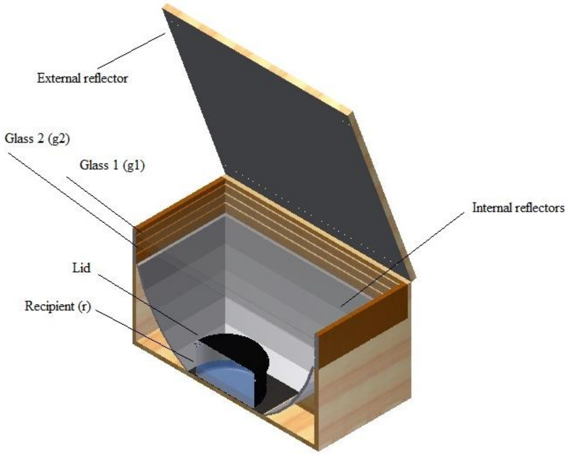

Figure 2. Solar cooker box-type with exterior and external (cut presentation)

Thermocouples k-type were placed in the cooker to measure: 1. Temperatures in glass covers (T_{g1_upper}, T_{g1_bottom}, T_{g2_upper}, T_{g2_bottom}), 2. lid of the recipient (T_{lid}), 3. body of the recipient (T_r), 4. Water (T_w), 5. internal environment (T_{int_env}), 6. external environment (T_{ext_env}). In figures 3, the values for the temperature distribution are shown.

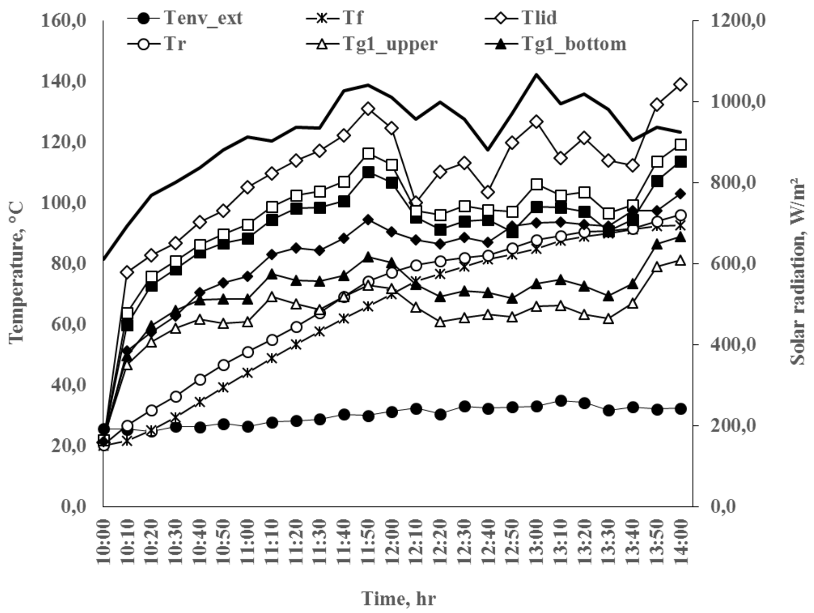

Figure 3. Temperatures for the solar cooker

3. Conduction heat transfer and destroyed exergy in the cover glasses

To evaluate the heat transfer and the destroyed exergy across the cover glasses in the solar cooker, the conduction heat transfer and the exergy for each glass is determined. For this, next equations are applied [8]

Conduction heat transfer in glasses

$$\dot{Q}_{g1} = \frac{kA_{g1}}{e}\left[T_{\text{g1\_bottom}} - T_{\text{g1\_upper}}\right] \quad [\text{W}] \tag{1}$$

$$\dot{Q}_{g2} = \frac{kA_{g2}}{e}\left[T_{\text{g2\_bottom}} - T_{\text{g2\_upper}}\right] \quad [\text{W}] \tag{2}$$

Destroyed Exergy

$$\dot{X}_{g1} = \dot{Q}_{g1}\left[1 - \frac{T_{\text{o}}}{T_{\text{g1\_bottom}}}\right] - \dot{Q}_{g1}\left[1 - \frac{T_{\text{o}}}{T_{\text{g1\_upper}}}\right] \quad [\text{W}] \tag{3}$$

$$\dot{X}_{g2} = \dot{Q}_{g2}\left[1 - \frac{T_{\text{o}}}{T_{\text{g2\_bottom}}}\right] - \dot{Q}_{g2}\left[1 - \frac{T_{\text{o}}}{T_{\text{g2\_upper}}}\right] \quad [\text{W}] \tag{4}$$

Where, k is thermal conductivity, W/m K; T_o is temperature in dead state, K in this case, this temperature correspond to the environment temperature. In figures, 4 and 5 the conduction heat transfer and the destroyed exergy are shown.

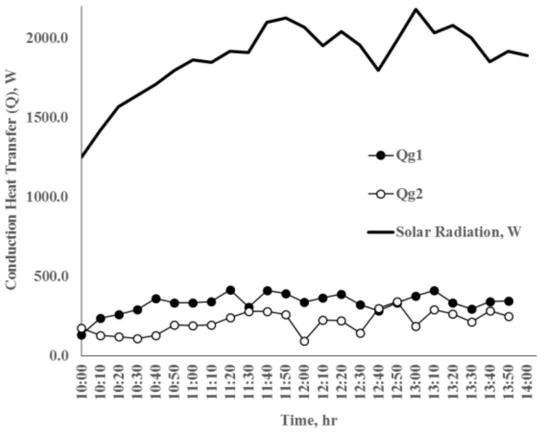

Figure 4. Conduction heat transfer for glasses *g1* and *g2* in the cover of the solar cooker

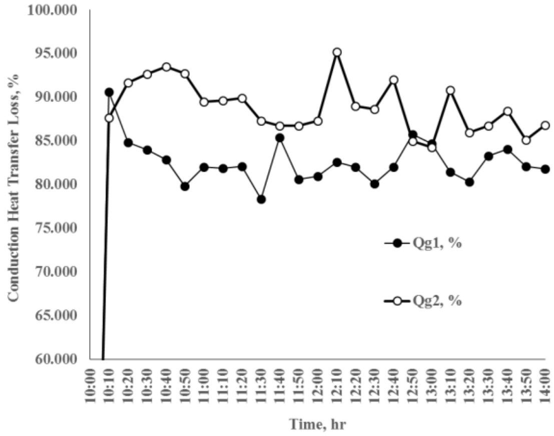

Figure 5. Conduction heat transfer losses for glasses *g1* and *g2* in the cover of the solar cooker

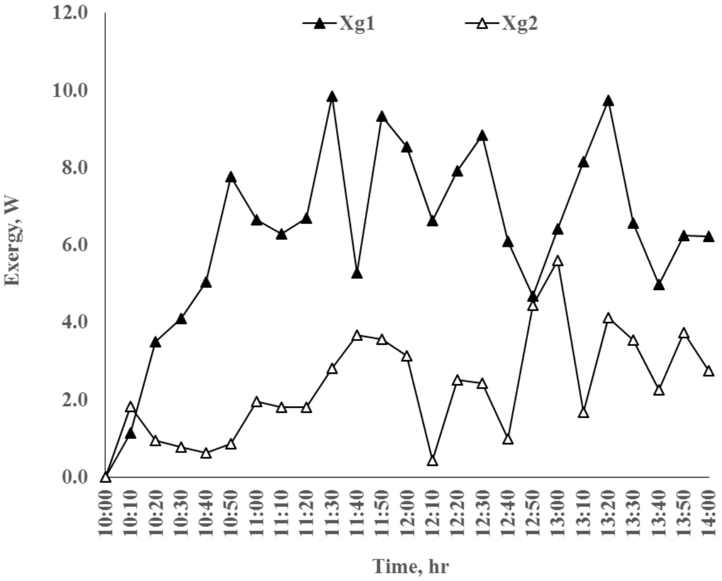

Figure 6. Exergy for the glasses *g1* and *g2* in the cover of the solar cooker

5. Discussion

As one can see in figure 3, temperatures for the glasses in the cover are high; 81.3°C, 89.0 °C, 113.7 °C and 119.2 °C that correspond to T_{g1_upper}, T_{g1_bottom}, T_{g2_upper} and T_{g2_bottom} respectively. This is the reason why the cover is identified as the zone where the heat losses is the most important. However, for the reached temperatures in the cover glass covers, the temperature for the water was 92.7 °C near to saturation temperature in Mexico City. This temperature could be enough for domestic proposes, but is necessary to establish how much of the energy is not used in the heating process.

Considering figure 4, the comparative between conduction heat transfer in the glasses and the solar radiation in Watts (Solar Radiation/Ag) shows the glass 1 is where the conduction heat loss is biggest. This is explained due to glass 1 is exposed directly to the external environment and here the temperature is affected for the convection heat transfer.

As one can see in figure 5, the conduction heat transfer losses for the glasses is most big than 75%. For the glass 1, the conduction heat losses values are around to 90 %, which is very important and shows this is the zone where improvements for the solar cooker could be made. Here, it should be noted that the temperature inside the solar cooker is increasing during the heating process. This situation is important to take into account, since otherwise; this might be misinterpreted under the second law's concept and establish that the inlet energy in the cooker must be equal to what comes out of it. Thus, the heat energy outlet is the energy inlet plus the energy cumulated and released during the heating process.

Figure 6 indicates the quantity of useful energy, which is represented by the exergy. Their values are consistent with the conduction heat transfer losses in the glasses.

The results allow identifying the glasses as the zone where the solar cooker could be improved. In a first approximation, the thickness could be a parameter to study; because it has an important impact in the thermic resistance of the conduction heat transfer.

6. Conclusions

An evaluation of exergy considering the conduction heat transfer in glass covers of a solar cooker box-type was done. Results show that a great quantity of the entering energy to solar cooker during the heating process is not used. With the results is possible to identify how the cover glasses is the zone where the solar cooker could be improved. Almost 90% of the energy is not used during the heating process. The results can be useful in design or improvements of solar cooker box-type.

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