Thermal and Exergy Evaluation of a Parabolic Solar Cooker for Domestic use at Home

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Abstract. The results of the thermal behavior and exergy efficiency of a prototype of a parabolic solar cooker are shown. The design and construction of the prototype consider aspects that have not been addressed in other devices of the same nature, such as easy construction and low cost. The results of the temperature reached approximately 96 °C can be useful for use in domestic applications of cooking and heating food in homes. The evaluation of the efficiencies both first and second law show values less than 45% and 5% respectively and these generate the possibility of carrying out improvements in the solar cooker, which would allow significant improvements to be made in the times required for cooking and food heating. If the construction-cost relationship of the device is considered, the analysis presented in this work can contribute to its promotion and use in the society that demands alternatives to current and future energy problems.

1. Introduction
The design of new solar energy devices represents a constant challenge in innovation and operation. This fact has become, the reason to look for improvements that allow us to take advantage of solar energy in the best possible way. However, technological advance has also become a problem due to the investment costs that must be made and the final impact that can be achieved with the new energy devices. In this way, considering functional and cost-effective designs for those who use them are now variables that must be taken into account for the proposed new designs.
Among the wide range of research carried out in the specialized field on parabolic solar cookers, the costs and easy design have not come variables that contribute to the new designs.

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In the diversity of the research work, models have been carried out to make estimates of energy losses and exergy, which have allowed improvements to be made to the performance of parabolic solar cookers [1]. Other studies, work has been done on the design of folding solar cookers with improvements using compound concentrators and the results that have been achieved under the exergy analysis have been reported [2, 3, 4]. Other authors have highlighted the relevance of the study of parabolic designs under the analysis of energy and exergy, given the great difference between values that can be achieved in both cases [5, 6]. Osueke et al. [7] oriented his studies to the impact that meteorological conditions have on solar devices, highlighting their performance according to the conditions of the environment in which they are found. In this work, the results of the evaluation of a prototype of a parabolic solar cooker are shown. This device features both a simple design as well as an uncomplicated construction. Its low cost can promote its manufacture and use to serve basic domestic food cooking services in a home.

2. Parabolic solar cooker and experimental operation process
The parabolic solar cooker was built considering fundamental elements both its easy design as well as its simple construction. A part already made for a sound horn was used as a support. The orientation mechanism was designed keeping in mind that its manufacture was simple. The reflectors were made with stainless steel after generating their profile of revolution. Figure 1 shows the solar cooker with a basic description of its components and table 1 shows their general dimensions.

For experimental development, a hermetically sealed container was used in which water was deposited. The tests were carried out for 0.5, 1.0, and 1.5 liters of water. Global solar radiation was measured using a radiometer Epjley model 8-49. For data acquisition, an Arduino system was used that measured the temperature delivered by thermocouples k-type. The experimental test was done on February in Mexico City (19.4 N, 99.1 W). Measurements were made every 5 minutes for an interval of 10:00 to 12:00 in official time. This time interval was sufficient to achieve that the temperature difference between the last least penultimate value was less than 1 °C. In figure 2 experimental arrangement is shown.

![Figure 1. Parabolic solar cooker: Parts of the prototype](image1)

![Figure 2. Experimental arrangement](image2)

| Variable                | Length/Diameter (m) | Width (m) | Height (m) | Area (m²) |
|-------------------------|--------------------|-----------|------------|----------|
| Diameter                | 0.98               | -         | -          | -        |
| Reflection area         | -                  | -         | -          | 0.88     |
| Height to disc centre   | 1.0                | -         | -          | 0.49     |
| Container               | 0.18               | -         | 0.2        | -        |
3. Experimental results
Figures 3, 4 and 5 show the experimental results of water temperature, global solar radiation and environmental temperature for cases of 0.5, 1.0 and 1.5 liters.

![Figure 3. Water temperatures](image)

![Figure 4. Global solar radiation](image)

![Figure 5. Environmental temperature](image)
4. Determination of Heat transfer ratio and first and second law efficiencies

The heat transfer ratio is determined considering the heat gained per unit time [8]

\[ \dot{Q} = \frac{Q}{\Delta t} = \frac{mC\Delta T}{\Delta t} = \frac{m(T_{n+1} - T_{n})}{\Delta t} \]  

(1)

Where, \( \dot{Q} \) heat transfer ratio in W, \( m \) the amount of water deposited in the container in kg, \( C \) is the specific heat of the water, \( T_{n+1} - T_{i} \) is the final temperature after 5 minutes minus the temperature in the initial state before 5 minutes and \( \Delta t \) is the time interval between each state, which corresponds to 5 minutes.

The first-law efficiency is defined by [9]

\[ I = \frac{m(T_{i+1} - T_{i})}{GA} \]  

(2)

Where \( G \) is the global solar radiation in W/m², \( A \) is parabolic solar cooker reflector area in m² and \( \Delta t \) is the time interval between each state, which corresponds to 5 minutes (300 seconds).

The second-law efficiency will be [9]

\[ \eta_{II} = \frac{x_{outlet}GTA}{CT_{i}} = \frac{mCT_{0}(\frac{T}{T_{0}} - 1 - ln(\frac{T}{T_{0}}))}{GATA} \]  

(3)

Where \( T_{0} \) is the temperature in the dead state during the heating process, \( T \) is the temperature of the water in the defined state every 5 minutes. Figures 6, 7 and 8 show the results obtained after applying equations (1), (2) and (3).

**Figure 6.** Experimental heat transfer ratio
5. Discussion
According to figure 3, the water temperatures for the three cases of the amount of water used is 96 °C, which is more than enough for the conventional cases of use in a house [10]. The time required to achieve the maximum temperature was 1 hour. If it is considered that the tests were carried out in February, when the global solar radiation is the lowest of the year for Mexico City, the prototype will achieve shorter times in months where the radiation is greater, for example May.
The obtained temperature value can be reached since the container is hermetically closed. Otherwise, the temperature value would be the one corresponding to the saturation pressure at the test site, this is approximately 94 °C for Mexico City.

Figures 4 and 5 show the results of global solar radiation and ambient temperature respectively, and as can be seen, they do not have a noticeable effect during the heating process. However, it is important to highlight that variations in solar radiation can affect heating processes since for, parabolic solar cookers, the direct radiation component is the one that defines the most important variable in the heating process.

In figure 6, which corresponds to the rate of heat transfer, it is shown that its behavior tends to decrease as time passes, this occurs due to the difference in temperatures that become lower as the maximum temperature of each test is reached. The highest values of the heat transfer ratio are held for 1.5 liters while the lowest values correspond to the volume 0.5 liters.
The efficiency of the first-law that can be seen in figure 7, indicates that the highest values are for a volume of 1.5 liters, while for the volume of 0.5 liters, the smallest values are found. This shows that
the device is more efficient with a higher volume. However, it must be taken into account that the solar radiation for the evaluated days shows for 0.5 liters the lowest radiation values also were obtained. First-law efficiency values decrease as a consequence of the decrease in the temperature difference throughout the water heating process.

On the other hand, the efficiency of the second Law shown in figure 7 indicates a different behavior of the efficiency of the first Law. The values obtained do not exceed 5% while in the efficiency of the first Law they decrease from a value of 45%.

The efficiency of the second law takes into account the irreversibility effects, and is associated with the amount of useful energy that is not used. In the equation that defines this efficiency, the term exergy is the one in charge of evidencing this situation.

The increase in the efficiency of the second law after 11:50 is explained by the effect of the thermal inertia of the water during the heating process. That is, after the aforementioned time, the amount of useful energy begins to be used but it is not the maximum that could be achieved. The behavior of the device is subject to the Clausius statement.

6. Conclusions
Based on the results achieved, the prototype can be proposed for basic domestic uses such as cooking food and heating water.

The second law efficiency values should encourage research on improvements, since it will be possible to obtain higher temperatures and shorter times than those achieved if attention is paid to the irreversibility of the process and other participatory variants, such as the heat transfer mechanism by convection on the outside of the container.

The analysis presented in this work can contribute to its promotion and use in the society that demands alternatives to current and future energy problems.

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