Effect of the position of the internal reflectors on the thermal operation of a solar cooker box-type

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Abstract. The results of the effect that five internal reflectors have on the operation of a box-type solar cooker are shown. Variations in the angular position of the reflectors generate new dimensions for the cooker. For this reason, in order to carry out the comparison of four solar cookers with different dimensions under the same operating conditions, it is used the numerical simulation that allows obtaining the representative temperatures that describe the thermal operation of the solar cooker. The temperature values achieved and expressly referred to the heating of 1 liter of water are obtained from the numerical solution of a mathematical model under initial conditions. The results show that for a tilt of the reflector angles with respect to the horizontal of 40°, 50°, 60°, 70° and 81° the highest values of the water temperature are obtained, specifically, the highest value among these is 98.1 °C. While for reflector inclinations of 13°, 18°, 21°, 24° and 30°, there are the lowest temperature values and among these, the highest value is 83.9 °C. The results, together with their discussion, contribute to the knowledge of the behavior of the components of box-type solar cookers.

1. Introduction

Solar cookers are energy devices used in various applications, among the diverse variety of studies of these, one can see topics as economic and environmental aspects, Amal Hereza et al. [1]. Improvements through technological design, Saxena, and Agarwal [2]. And theoretical analyses of the use of solar energy in solar cookers, Cuce [3].

Harmim. et al. [4] showed in their work an experimental comparison for a box-type solar cooker with two cooking vessels equal in shape and volume with the specific difference that one of them has fins attached. The fins are added to improve heat transfer from the hot air inside the kitchen to the container. Their results showed a considerable reduction in cooking time. The tests were carried out on an experimental platform at the renewable energy research unit in the Sahara, located at 27° 53'O and 0° 17 'W in Algeria.

Aramesh et al. [5] show work on the different designs of solar cookers, focusing on the box type, concentration, and panels. They analyse the modes of heat transfer and the process of the solar cooking process in them. Yettou et al. [6] evaluates the mathematical modelling and experimental validation of two types of solar cookers: 1. Box type with its inclined intercept area and 2. Parabolic disk design. Their results show consistencies between theoretical values and experimental data.

To learn about the advantages and uses of solar cookers research has been carried out to promote their usefulness in the varied communities of the world [7, 8, 9, 10]. Their results, although highly relevant, have points that have not yet been addressed with the specific depth for the varied cases of solar cookers.
The present work shows the effect produced by the position of the internal reflectors in the thermal functioning of a solar box-type during the water heating process. Variations in the position and areas of the reflectors modify the dimensions of the cooker. The results obtained contribute to the knowledge and improvements of cookers box-type.

2. Solar cooker box-type and data generation

The solar cooker box-type (SCBT) with internal reflectors typically is integrated by the following elements:
1. A cover with two flat glasses with a clearance between them.
2. Internal reflectors made in a commercial aluminum sheet placed to different tilt angles.
3. Thermal insulator placed in the lateral part of the same one.
4. Recipient contains the product to cook.

The solar cooker is locked air tightly; this allows reaching considerable temperatures in the test fluid, which is 1 liter water. The dimensional characteristics of a solar cooker are shown in figure 1. Table 1 shows the values corresponding to the most representative general dimensions of solar cookers.

![Figure 1. Solar cooker box-type.](image)

**Table 1** General dimension of the solar cookers evaluated

| Solar cooker | Angle reflector | Length (m) | Width (m) | Height (m) | Area of glass 1 (m²) |
|--------------|-----------------|------------|-----------|------------|----------------------|
| SCBT-I       | b= 40°, g= 50°, m= 60°, z= 70°, F= 81° | 0.9        | 0.9       | 0.52       | 0.19                 |
| SCBT-II      | b= 25°, g= 35°, m= 45°, z= 53°, F= 63° | 1.11       | 1.11      | 0.44       | 1.02                 |
| SCBT-III     | b= 15°, g= 25°, m= 35°, z= 40°, F= 44° | 1.25       | 1.25      | 0.36       | 1.32                 |
| SCBT-IV      | b= 13°, g= 18°, m= 21°, z= 24°, F= 30° | 1.34       | 1.34      | 0.28       | 1.54                 |

Figures 2, 3, 4, and 5 show correspondingly the solar cookers of the cases SBCT-I, SBCT-II, SBCT-III, SBCT-IV, and that are considered in this work.

![Figure 2. SBCT-I: b= 40°, g= 50°, m= 60°, z= 70°, F= 81°.](image)

![Figure 3. SBCT-II: b= 25°, g= 35°, m= 45°, z= 53°, F= 63°.](image)
To generate the data that allows comparing solar cookers under similar operating conditions, a mathematical model of the solar cooker is used, which has already been validated and used in various application cases [11, 12]. Validation of the results achieved using the mathematical model generates a maximum difference of 10% between the theoretical values of the model and the experimental values in the field. This model considers the energy gains and losses for the components that have the greatest effect on the operation of the solar cooker. Appendix A shows the nomenclature that identifies the variables of the model. The solution of this model is obtained by the fourth order Runge-Kutta's method which permits to estimate the temperatures evolution using initial conditions. The explicit mathematical model is:

\[ m_C \frac{dT}{dt} = A_C \sigma (T^4 - T_{amb}^4) \]  
(1)

\[ m_C \frac{dT}{dt} = \frac{\nabla x}{h_{TA} A_T} + A_C \sigma (T^4 - T_{amb}^4) \]  
(2)

\[ m_C \frac{dT}{dt} = -A_C \sigma (T^4 - T_{amb}^4) + A_C \sigma (T^4 - T_{amb}^4) \]  
(3)

\[ m_C \frac{dT}{dt} = -A_C \sigma (T^4 - T_{amb}^4) + A_C \sigma (T^4 - T_{amb}^4) \]  
(4)

\[ m_C \frac{dT}{dt} = A_C \sigma (T^4 - T_{amb}^4) + A_C \sigma (T^4 - T_{amb}^4) \]  
(5)

The convection coefficients values used in the mathematical model have been estimated according to the data from Thulas et al. [14]. The values considered as conditions in the model solution are the solar radiation and the ambient temperature data for the average February day in Mexico City (19.4 N, 99.1 W). Appendix B shows the numerical values used in the model solution including convection values.

### 3. Numerical results

Figures 6, 7, 8, and 9 graphically show the results obtained for container body temperatures, water, outdoor ambient temperature, and global solar radiation for the cases considered. The values of the other temperatures considered in the model are not presented given the objective of this work.
4. Discussion

According to figures 6 to 9, the maximum temperatures for water are 98.1, 92.9, 88.9, and 83.9 °C corresponding to the SBCT-I, SBCT-II, SBCT-III, and SBCT-IV cases, respectively.

The water temperatures reached are due to the hermetic seal of both the cooker and the container that contains the water, which avoids reaching the boiling temperature for the test site, which in this case corresponds to Mexico City where the saturation temperature is approximately 94 °C.

The simulation time considered was 7 hours, which is a long time, however, the outdoor ambient temperature and global solar radiation data used corresponds to one of the least favorable days of solar radiation in the year for Mexico City, which is associated with the results for the worst operating conditions of the solar cooker.

According to these results, the solar cooker has the highest temperature in the case of 40°, 50°, 60°, 70° and 81° in the inclination of its reflectors (SBCT-I), while the lowest temperature values occur in the case where the inclinations are 13°, 18°, 21°, 24°, and 30° (SBCT-II).

This happens due to the increase in the effective reflector-area, which increases with higher values of the inclination of the same ones.

With high values in the inclined of the reflectors, the concentration of solar radiation increases over the container surface and this affects directly the water temperature.

According to the results, the best solar cooker would be the SBCT-I. However, it should be taken into account the dimensional characteristics which can have a significant impact on the size of the container. For the case of the SBCT-IV, the area of their cover glasses has the highest area, and due to this, the solar radiation input inside the solar cooker augment, but the effective area-reflection decreases and this impacts the effective energy received for the surface container, which modifies the temperature of the water. This is the reason why this cooker has smaller values for the water temperature.

5. Conclusions

In this work, the results of the effects produced by the variation in the position of the internal reflectors of a box-type solar cooker were shown. Changes in the inclination of the reflectors modify the dimensioning of the solar cooker. These modifications indicate that high values in the inclination of the reflector increase the water temperature. The results contribute to the knowledge of the behaviour of the components of box-type solar cookers.
Appendix A. Nomenclature used in the mathematical model

| Symbol | Description                   | Unit            |
|--------|-------------------------------|-----------------|
| A      | Area                          | m²              |
| h      | Heat transfer convection coefficient | W/m²°C     |
| T      | Temperature                    | °C              |
| m      | Mass                          | kg              |
| t      | Time                          | sec             |
| C      | Specific heat                  | kJ/kg °C        |
| G      | Incidental solar radiation    | W/m²           |

Subindex
- g: Glass
- r: Recipient
- ref: Reflector
- amb: Ambient
- e: Mirror
- w: Water
- fl: Lateral fluid
- S: Water surface

Greek letters
- σ: Steffan-Boltzman constant
- ρ: Reflectivity
- ε: Emittance
- 𝛼: Absorptance
- θ: Reflector angle
- τ: Transmitti

Appendix B. Numerical data used in the mathematical model.

| Variable | Magnitude / Quantity | Unit       |
|----------|----------------------|------------|
| m_r      | 0.2                  | kg         |
| m_t      | 0.1                  | kg         |
| m_f      | 2.0                  | kg         |
| ρ_v      | 2730.0               | kg/m³      |
| ρ_f      | 1030.0               | kg/m³      |
| c_v      | 800.0                | J/kg·K     |
| c_t, c_r (aluminum) | 900.0 | J/kg·K     |
| c_f (water) | 3900.0 | J/kg·K     |
| A_t, A_h | 0.0201               | m²         |
| A_r      | 0.0804               | m²         |
| ε_g      | 0.35                 | Adimensional |
| ε_t      | 0.85                 | Adimensional |
| α_g      | 0.17                 | Adimensional |
| α_t, α_r | 0.9                  | Adimensional |
| α_w      | 0.5                  | Adimensional |
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