Evaluation of the cooking power in three different solar cookers box-type

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Abstract. In the present work calculations for the cooking power in three different solar cookers are shown. The designs considered for the solar cookers are square, rectangular and octagonal. Agree to the results, a solar cooker with larger area for the solar radiation inlet has the biggest cooking power. The cooking powers obtained for the solar cookers are 4.04 W (0.49 m²), 2.06 W (0.15 m²) and 0.88 W (0.19 m²) which correspond to square, rectangular and octagonal designs respectively. For the evaluation, the standard ASAE S580 JAN03 was considered to evaluate the cooking power in the solar cookers. Following the method established in this standard was possible to calculate the cooking power and evaluate the solar cookers at the same time. This activity except for what has been done in the standard, have not been done in other works.

1. Introduction
In the evaluation of solar cookers, different parameters are considered to establish their yield and operation. Among those parameters, the geometry and materials are evaluated frequently. However, in many cases, the cooking power has not been used as the major indicator. Among authors that have considered the cooking power, highlights the followings.

Funk [1] worked on standard presented at the Third World Conference on Solar Cooking (Coimbatore, India, January, 1997). His evaluation was aimed to determine the practical uses for solar cookers designs and possible differences when it used in variable conditions as locations and geometry or the solar cookers.

El-Sebaii and Ibrahim [2] present results for the experimental tests on a solar cooker box-type considering the cooking power standard procedure. Their results allow to establish the cooking power related to the temperature and solar radiation. This work was done for a one case of solar box cooker.

Sethi et al. [3] did a study about qualitative and quantitative variables that intervene in the operation of a solar cooker with parallelepiped cooking vessel design. Their results are identified with figures called figures of merit F₁ and F₂. Also, they developed a mathematical model to compute the effect of the solar radiation in the solar cooker.

Harmin et al. [4] evaluated a design for a optogeometrical arrangement in a solar cooker box-type. Their device was built using local materials in Alegian Sahara. Agree to their results, its effectiveness allow
to cook meals for a family of four persons. In their experimental tests the cooking power was considered as the principal parameter for the results. Purohit and Purohit [5] studied a paraboloid concentrator type solar cooker. In this study they consider parameters as efficiency factor, heat loss factor, overall heat loss coefficient and cooking power for their experimental tests and results. They highlighted the importance of the cooking power due to it indicates the real behavior and yield in a solar cooker. Esteves et al. [6] presented a study for a solar furnace considering qualitative and quantitative parameters for the same one. The solar furnace operates in Nacunan Mendoza, Argentina. The solar absorber, reflectors, gate, interior chamber and cooking power were evaluated and their results allow to establish if the use time could have impact on them. Servin et al. [7] determined the cooking power in a solar cooker called Jorhejpatarantskua. According to their results, the cooking power obtained is very important due to the value of 136 W is maximum value reached for a solar box cooker in similar designs. Gonzalez and Servin [8] presents a mathematical model, which is adjusted with data obtained from an experimental design. This model is useful to estimate some parameters and allows comparing the performance of solar cookers considering testing protocols and international standards such as: standardized cooking power and thermal efficiency. In this work, a comparative of the cooking power for three different solar cookers are shown. This work in difference of other previous works, takes in account three solar cooker in operation at the same time, which have not been done for other authors.

2. Experimental procedure

In the experimental tests three solar cookers box-type were used. These devices are integrated by the following elements: 1. A cover with two flat glasses (which are identified as $T_{g1}$ (external glass) and $T_{g2}$ (internal glass)) 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 cookers are locked tightly; this allows reaching considerable temperatures in the water. In figure 1, the solar cookers are shown in figure 1. In figures 2, 3 and 4 the solar cookers: Square, Rectangular and Octagonal are presented respectively. The solar cooker with octagon design does not have external reflectors as the other cookers evaluated. It was selected to calculate the effect of the reflectors in the heating process. In the tests, 1.5 liters of water were used as the fluid to be heating. The general dimensions for the solar cookers are 0.7 x 0.7 x 0.40 m (square), 0.5 x 0.3 x 0.35 m (rectangular) and 0.5-diameter m (octagonal) with 0.4-high m. A radiometer Eppley model 8-49 was used for measure the solar radiation in horizontal plane. 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 tests. The tests were done on April 1, 2016 and the place Mexico City. The interval considered was 4 hours and 10 minutes (10:00 to 14:10).
3. Experimental results

To measure temperatures, thermocouples in specific points on glass covers were placed. The temperatures measured are: 1. glasses of the cover \( T_{g1_{upper}}, T_{g2_{bottom}} \), 2. lid of the recipient \( T_{lid} \), 3. body of the recipient \( T_{b} \), 4. Water \( T_{w} \), 5. internal environment \( T_{int_{env}} \), 6. external environment \( T_{ext_{env}} \). In figures 5, 6 and 7 the temperature distributions values for the solar cookers: square, rectangular and octagonal are shown respectively. In figure 8, a comparative of the temperature water for the solar cookers is shown.
4. Determination of cooking power

For the cooking power calculation, the standard ASAE S580 JAN03 was considered. According to this standard some conditions must be controlled: 1. Wind velocity. During tests, the velocity should be less than 1.0 m/s. This happened in the test. 2. Ambient temperature. Tests should be conducted when ambient temperatures are between 20 and 35 °C. As one can see, the test reports this interval. 3. Insolation. Available solar energy over the solar cooker must be measured using a radiation pyranometer. The device to measure solar radiation was an Eppley pyranometer. Some equations are considered

\[ P_i = mC(P_2 - P_1) \]  

Where, \( P_i \) = cooking power (W), \( P_2 \) = final water temperature, \( P_1 \) = initial water temperature, \( m \) = water mass (kg), \( C \) = heat capacity (4186 J/[kg·K]). The time, 600 seconds represent a ten-minute interval.

\[ P_s = P_i \left(\frac{700}{I_i}\right) \]  

Where, \( P_s \) = standardized cooking power (W), \( P_i \) = interval cooking power (W), calculated in (1), \( I_i \) = interval average solar insolation (W/m²).

\[ T_d = T_w - T_a \]  

Where, \( T_d \) = difference in temperature, \( T_w \) = water temperature, \( T_a \) = ambient temperature.
Where, $T_d$ = temperature difference (°C), $T_w$ = water temperature (°C), $T_a$ = ambient air temperature (°C). After to apply equations (1), (2) and (3) to the experimental data, $P_s$ is plotted against $T_d$ for each time interval. A linear regression of the plotted points is used to find the relationship between cooking power and temperature difference in terms of intercept $a$ (W) and slope $b$ (W/°C) or $P_s = (a + b) T_d$. In figures 8, 9 and 10 the plotted for the solar cookers square, rectangular and octagonal are shown respectively.

Figure 8. $T_d$ vs $P_s$ and regression for Solar cooker Square

Figure 9. $T_d$ vs $P_s$ and regression for Solar cooker Rectangular

Figure 10. $T_d$ vs $P_s$ and regression for Solar cooker Octagonal

5. Discussion
Agree to the results, the maximum reached temperature for the water correspond to the solar cooker with square design, its value is 92.9 °C, while the minimum temperature for the water is for the solar cooker with octagonal design with 60.4 °C. These results can be associated to the external reflector, which is present in the square design, which augment the solar radiation toward to the cooker. In addition, the reflexion area inside of the square design is bigger than the octagonal cooker. The solar radiation that impacts over the solar cookers is 1050 W/m² which is very important for April, due to May is the month with biggest radiation in Mexico City. Considering the equations by regression for the
solar cookers showed in figures 8, 9 and 10 and evaluating for a temperature of 50 °C (what is required by the standard), the cooking powers are 4.04 W (0.49 m²), 2.06 W (0.15 m²) and 0.88 W(0.19 m²) for the solar cookers: square, rectangular and octagonal respectively. These results must be evaluated taking in account the area for each case. As one can see, when the area increases, the cooking power increases. However, the cooker with octagonal design has a cooking power bigger than the cooker with rectangular form. In this case, it is explained because the reflection area inside of the octagonal cooker is bigger than the rectangular cooker. By other hand, it is very important to point out, that the values reported by other authors for the cooking power in solar cookers is near to 50 W, but the areas considered for those cases is bigger than 2.5 m². According to the obtained results, the solar cooker with better cooking power is the solar cooker with square design.

6. Conclusions
Calculations for the cooking power in three different solar cookers were determined. According to results, the solar cooker with larger area has the biggest cooking power. In this case, a solar cooker with a square design showed the biggest cooking power. The method used in this work can be useful to determine different solar cookers working at the same time. Searching improve the results obtained in this work, new configurations for solar cookers will be considered. It will allow to establish a complete study for several cases of solar cookers.

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