Original Research Article

Enhancing box type solar cookers by using Jatropha oil as sensible heat storage medium

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ABSTRACT

This research evaluates the performance of a box-type solar cooker insulated with kapok wool and incorporating a thermal heat storage unit. The heat storage material used in this work is Jatropha Curcas seed oil which is available locally as well as kapok wool. The constructed solar cooker from locally accessible materials can offer an economically viable alternative while avoiding environmental deterioration caused by the significant use of biomass and conventional energy sources for culinary purposes. The different tests based on existing standards permitted to determine the thermal performance parameters of the cooker such as the first figure of merit (F_1) and the second figure of merit (F_2) which were determined to be F_1= 0.13 and F_2= 0.31. The cooker efficiency η = 47.07 %. The American Society of Agricultural Engineers for Solar Cooking (ASAE S580.1) was used to determine the cooking power and it was found to be P =123.2 W.

Keywords: Solar cooker; Solar energy; Jatropha Curcas seeds; Heat storage; Performance

1. INTRODUCTION

Cooking food is an indispensable process that requires energy resources of all nature. However, in developing countries and particularly in rural areas, these sources are mainly from biomass (i.e. wood, agricultural wastes, etc.) with harmful consequences for environment and human beings [1]. Fortunately, solar cookers offer an economical and environmentally friendly way to cut back on energy use [2],[3]. Thus, solar cooking system has gained more attention and has become a popular cooking system around the world [4],[5]. The primary reason limiting the use of solar energy for cooking is its intermittence [6]. To overcome this issue, solar cooking systems require energy storage for a proper use and overcast periods and several solar cooking systems have been proposed [7], [8],[9]. These works have always highlighted problems of complexity and costs [10]. A good sensible heat storage material available locally is a viable option to enhance solar cookers performance and strengthen their autonomy [10].

Jatropha Curca crude oil is an inedible oil presenting interesting properties to be a good heat transfer oil and sensible heat storage material [11], which is available and accessible locally.

In this work, a solar cooker fabricated by using optimal conception parameters presented in our previously works [12], equipped with a heat storage system.

The experimental performance of a box type solar cooker using Jatropha Curcas seed oil as heat storage medium is the main emphasis of this work.

2. MATERIAL AND METHODS

2.1. Material

The solar cooker developed consists of two trapezoidal boxes separated by kapok wool used as thermal insulation. The opening surface is double-glazed to minimise heat loss by convection between the inside of the cooker and the surrounding environment.The dimensions of the cooker were determined taking into account the optimal design parameters determined in our previous works [12]. Fins on the storage unit facilitate better heat transfer from the absorber to the storage material. The upper side of the storage unit is the cooker absorber. Fig. 1 shows the scheme of the device. The storage material is Jatropha oil which is an inedible oil produced by pressing the seeds of Jatropha Curcas which is available locally thanks to its virtues [13].

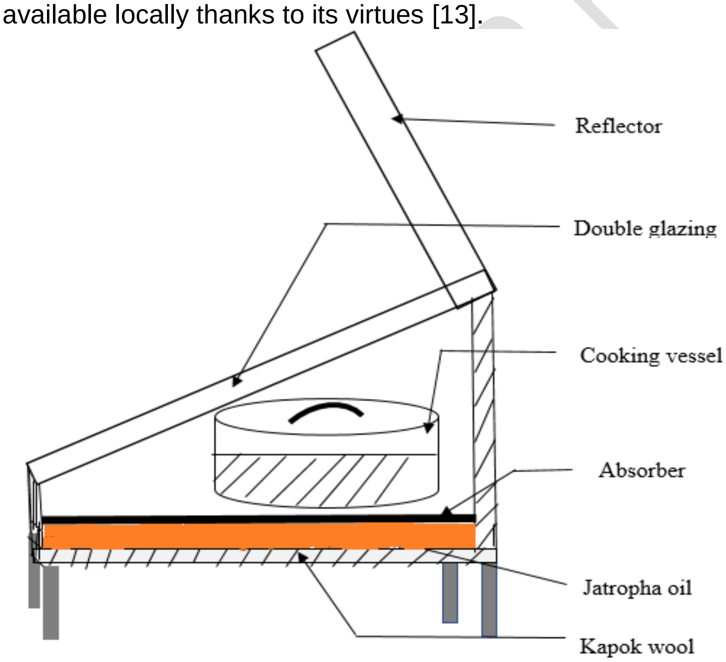

Fig. 1. Scheme of the device

2.2. Methods

The performance of the cooker with a heat storage material integrated has been evaluated using both a no-load test and a load test. The performance parameters, first and second figure of merit were calculated.

- Equation 1 is used to determine the first figure of merit F_1, which is the ratio of optical efficiency to heat loss factor [14].

$$F_1 = \frac{\eta_0}{U_L} = \frac{T_{ps} - T_{as}}{I_G} \quad (1)$$

Where η_0; U_L; F_1, T_{ps}, T_{as}, I_G are, in that order, the optical efficiency, the global heat loss coefficient, the absorber plate's stagnation temperature (°C), the ambient temperature (for stagnation), and the sun global irradiation (W/m²).

- The Second figure of merit F_2 allowing the assessment of heat transfer between the vessel and its content equation is given by Equation 2 [14], [15].

$$F_2 = F'\eta_0 C_R = \frac{F_1(mc)_W}{A_C t} \ln\left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{W_i} - \overline{T_a}}{\overline{I_G}}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{W_f} - \overline{T_a}}{\overline{I_G}}\right)}\right] \quad (2)$$

where F', C_R, c_w, m_w, T_{W_i}, T_{W_f}, $\overline{T_a}$, $\overline{I_G}$ are heat exchange factor, ratio of thermal capacities, water specific heat, mass of water, water initial and final temperature, the ambient average temperature and the average solar global radiation.

To evaluate the performance, the cooking power P is also considered. Funk showed that this figure is among the finest at illustrating the thermal performance for various cooker sizes and rates of heat gain. [16]. It is calculated using equation 3 [17]:

$$P = \frac{m_w c_W (T_{W_f} - T_{W_i})}{\Delta t} = \frac{m_w c_W (T_{W_f} - T_{W_i})}{600} \quad (3)$$

- The cooker thermal efficiency (η) is given by equation 4 [7]:

$$\eta = \frac{m_w c_w \left(T_{wf} - T_{wi}\right)}{A_c I_G \Delta t} \quad (4)$$

3. RESULTS AND DISCUSSION

The stagnation test results are shown in Fig. 2, together with the changes in the storage oil temperature, absorber temperature, ambient temperature, and solar global radiation. Between 9:04 a.m. and 3:24 p.m., the absorber's temperature ranges from 77 °C to 158.3 °C, while the storage temperature ranges from 61.6 °C to 150 °C. At 12:34 p.m., the maximum solar radiation value of 923.95 W/m² is obtained, while the maximum storage temperature is reached at 1:54 p.m., or one hour and twenty minutes later. This test makes it possible to determine the first figure merit. According to [18], parameters used for the calculation of F_1 are: T_{ps}=158.3 °C; T_{as}=48.4 °C et I_G=830 W/m². Thus, first figure of merit is calculated to be F_1=0.13, which shows that the cooker constructed is a higher grade solar cookers according to the Bureau of Indian Standard [19].

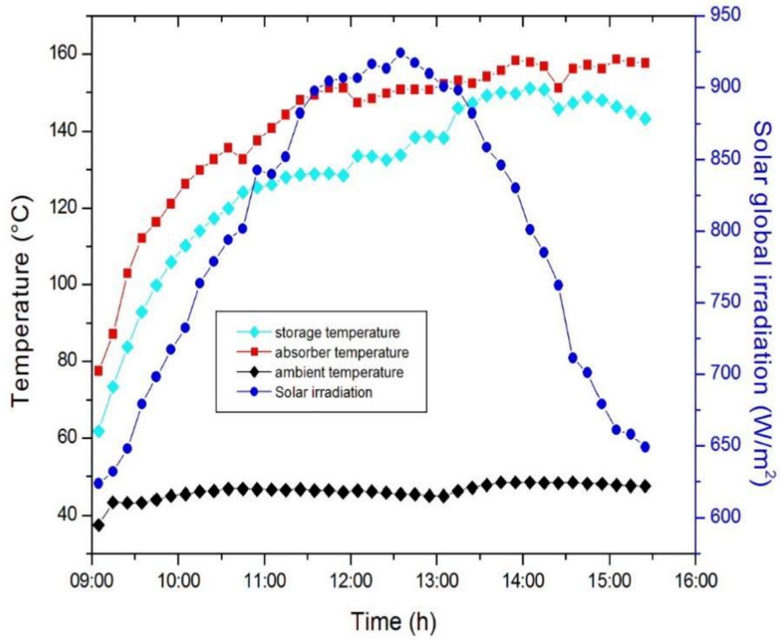

Fig. 2. No-load test

Fig. 3 shows the results of water heating test. This experiment is marked by cloudy disturbance at the beginning of the day. After the cooker is exposed to the sun until the absorber reaches a temperature of 101.3 °C and a maximum solar radiation of 886.65 W.m^{-2}, the load is introduced at 11:38 a.m. While, the storage oil temperature varies between 50 et 103.8°C during the experience. An abrupt drop in the absorber temperature is observed due to the high convective and radiative heat losses caused by the radiation during the loading process. This sudden drop is also observed with the storage oil, showing a transfer of thermal energy from the storage oil to the absorber. The second figure of merit obtained is F_2=0.31 by using equation 2, that indicates a good heat exchange in the solar cooker [15],[7].

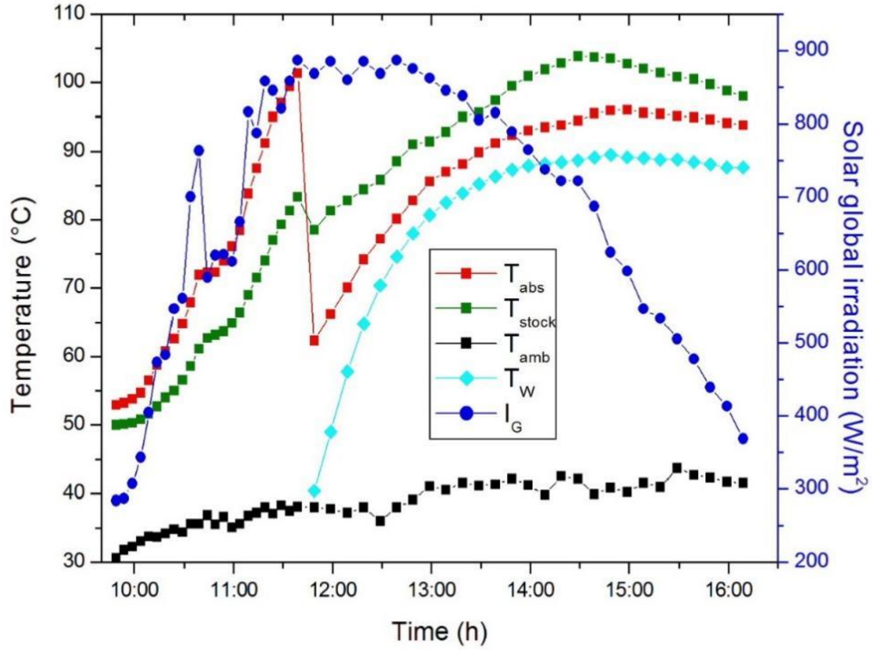

Fig.3. Water heating test

These values of F_1=0.13 et F_2=0.31 indicates good insulation and efficient thermal exchange inside the cooker thanks to the increasing of the cooker thermal inertia due to the storage system [20]. This outcome demonstrates that cooking a variety of dishes in a reasonable amount of time is possible with the proposed box-type solar cooker that integrates sensible heat storage material. [21],[22].

Fig. 4 shows the temporal variation of the cooker power and thermal efficiency. The highest power and efficiency are 47.07% and 123.2 W, respectively.
According to [23], the efficiency of the box-type solar cookers without storage material varies between 3.05 % and 35.2 %. In addition, an experimental study conducted with this same cooker without storage gave a maximum power of 87.5 W with a maximum efficiency of 35.45 % [3]. This interesting result is due to the sensible heat storage as a back-up heat source and proves the contribution of that heat source to the enhancement of the box type solar cooker performances.

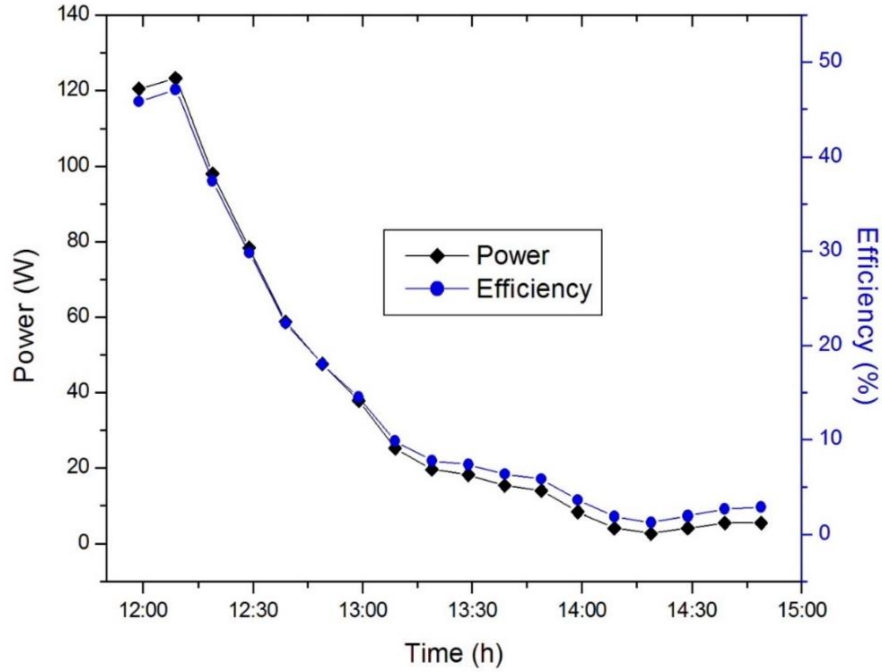

Fig. 4. Instantaneous power and efficiency

- **Testing during cloudy weather**

Fig. 5 shows the thermal behaviour of the cooker integrating a heat storage unit during a cloudy weather condition. Fluctuations in the solar radiation curve indicate a cloudy period. The low intensity of solar radiation due to clouds poses a significant obstacle to the proper operation of solar cookers [24]. Despite this permanent cloud disturbance, the temperature of the absorber is almost stable. Moreover, this temperature reaches 103 °C at 11:54 p.m. and the stagnation temperature of 126.4 °C at 2:24 p.m. The achievement of these performances demonstrates that the cooker is really capable of cooking, although under poor weather conditions [25]. This proves that heat storage in solar cooker contributes to the cooker's energy independence and autonomy which is its main attraction [5].

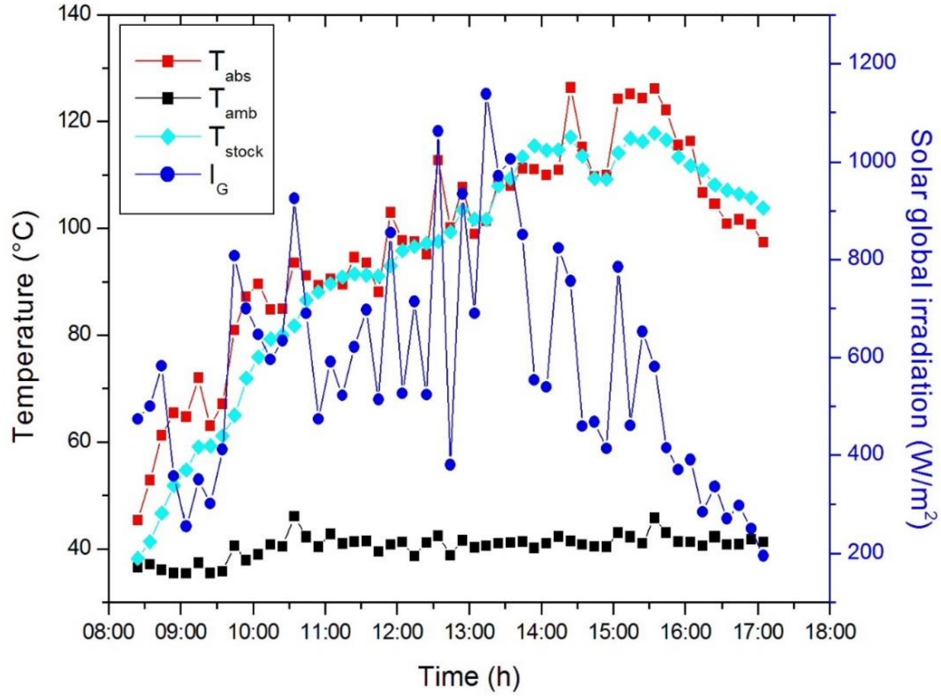

Fig. 5. Operation of the cooker in cloudy weather

- **Cooking test**

Fig. 6 shows the evolution of temperatures during the cooking of 0.5 kg of beans.
The cooker is exposed to the sun at 9 am, so that the absorber temperature reaches 100 °C by 10 am. It is then opened for the introduction of food. When the cooker is opened, the temperature of the absorber drops significantly, falling below the storage temperature, which continues to charge as shown by its growing temperature.
After 2 h 55 min of operation (i.e. at 12:55 p.m.), the cooker is opened to check the cooking of the bean. The figure shows that this causes a drop in the temperature of both the absorber and the air. A considerable drop in the temperature of the heat storage material is also noted. This demonstrates that thermal energy is moved from the storage material to the absorber to compensate for the heat losses caused by the opening of the cooker.
The check-up indicates that, the beans were almost cooked at a temperature of 92.6 °C.
After closing the cooker, the temperature of the bean quickly rises to the temperature just before opening in 25 minutes, while solar irradiation decreases. These results obtained show the advantage of storage for this solar cooker. In particular, in mitigating the effects of disturbances (clouds, opening of pots for stirring or introducing spices) during the cooking process.

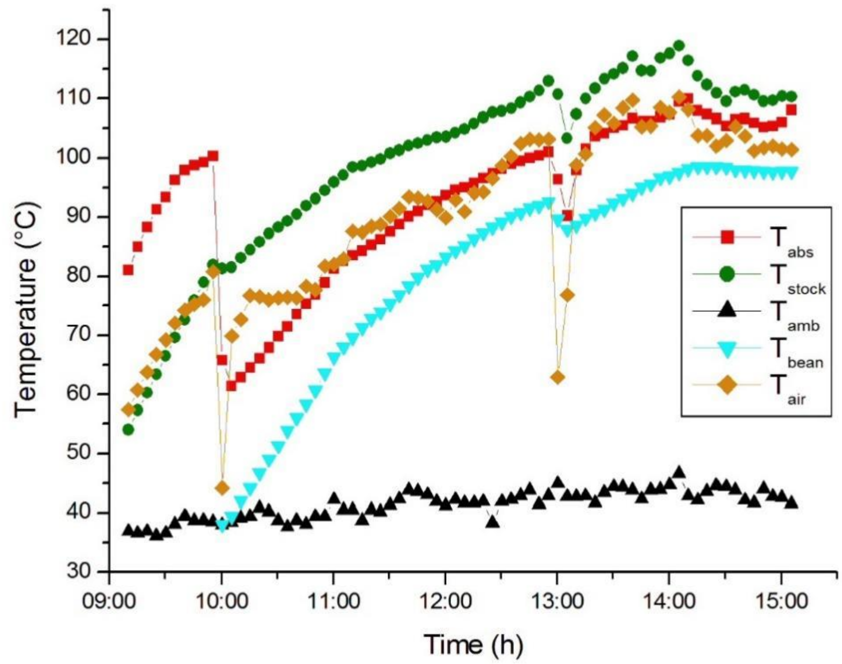

Fig. 6. Cooking test

4. CONCLUSION

A box type solar cooker integrating heat storage system with Jatropha Curcas seeds raw oil as heat storage material was studied. The assessment of performance parameters according to international standards clearly showed the improvement of locally made box type solar cooker. In fact, the results showed that it is a cooker of grade A with cooking power P=123.2 W and thermal efficiency η = 47.07 %. The cooking test and test during cloudy weather showed the ability of the cooker integrating heat storage to attenuate the solar energy intermittence effects on the solar cooker operation. From this result, it can be concluded easily that the use of sensible heat storage can remove limits of using solar cookers due to solar energy intermittence. However, the introduction of a storage system to solar cookers could increase their cost. Hence the need to look for locally available heat storage materials.

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