Experimental Study on Performance of a Box Solar Cooker with Flat Plate Collector to Boil Water

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Abstract. In this study, a flat plate type solar cooker is tested by exposing in solar irradiation. The objective is to examine the performance of solar cooker in boiling water. The solar cooker is a box type with collector area and height are 100 × 100 cm and 40 cm, respectively. Vessel for water is made of aluminum plate with diameter and height of 22 cm and 15 cm. The experiments are performed by varying mass of the water. It is 2 kg and 4 kg, respectively. Every experiment starts from 10:00 AM until the boiling temperature is reached. The parameters measured are radiance intensity, ambient and solar box cooker temperatures, and wind speed. The results show that the duration of water heating up to 100°C with water mass 2 kg within 2 hours 45 minutes and water mass 4 kg within 3 hours 17 minutes. The maximum temperature of solar box cooker is 117°C at 12:56 PM and maximum efficiency is 46.30%. The main conclusion can be drawn here is that a simple solar box cooker can be used to boil water.

1. Introduction
The use of solar energy by converting into thermal energy for cooking, drying agricultural products, and heat water has been growing rapidly in tropical and subtropical regions of the world. One of the possible application of thermal solar energy is the solar cooker. Solar cooker is an equipment used to collect solar energy and use it for cooking [1]. The solar cooker is classified into two types of solar cookers using storage media heat and solar cookers without storage medium heat.

Various designs of solar cookers have been studied theoretically as the combined of mirrors as a reflector to optimize the performance of solar cooker. Starting from conventional solar cooker type box states that the performance of a solar cooker is strongly influenced by the design and manufacture as shown in Fig. 1. The temperature of the solar collectors has been tested it was between 140°C to 160°C. The parameters are: (a) conventional solar cooker box type by using the mirror as a reflector...
facing the South, (b) a conventional solar cooker box type with a surface sloping towards the South and the mirror facing the South, (c) a conventional solar cooker box type surfaces tilted toward the South and the mirror facing the North, (d) a solar cooker conventional box type with surfaces sloping toward the South and mirror overlooking the North as well as vertical mirror facing the South, and (e) a conventional solar cooker box type with using mirrors as reflector mounted vertically and sideways-facing South and mirror overlooking the North [2].

Researchers have examined several aspects of solar cookers and classify solar cookers broadly into categories: (a) the design, manufacture, and testing of new designs solar cookers, (b) methods of increasing the intensity of solar energy by using mirrors, (c) the type of energy storage solar cell using PCM for use indoors and during the sun does not shine, and (d) test type solar cookers that depend on cooking, engineering models and simulations [3,4].

The analysis of energy storage process of a solar flat-plate collector with an integrated aluminum foam porous structure filled with paraffin as the phase-change medium is reported in this paper. The momentum conservation of liquid paraffin is modeled with Darcy’s law with the Brinkman-Forchheimer’s extension, while heat transfer between the metal foams and paraffin in solid and liquid phases is modeled with a two-temperature model [5].

![Various designs of solar cookers](image)

**Figure 1.** Various designs of solar cookers

In order to improve the performance of solar cookers, Reddy and Rao [4] suggested that the performance of the solar cooker can also be increased with a vessel design that refers to a material good heat transfer, and by providing support to the vessel being used as latent heat storage media. The same was described [6] that there is heat transfer to the bottom surface of the vessel will be more
effective when placed lug below the surface because it can improve the heat transfer rate on the lower surface of the vessel [7].

The bottom surface of the cooking vessel and the lid are ineffective in the heat transfer process to the food. Raising the vessel by providing a few lugs will make the bottom of the vessel a heat transfer surface. This change improves the performance of the system by improving the heat transfer rates in both heating and cooling modes [8]. Mohammed said that performed for three days from 8:30 h to 16:30 h in the year 2008 – showed that the water temperature inside the cooker’s tube reached 90°C in typical summer days, when the maximum registered ambient temperature was 36°C. It was also noticed that the water temperature increases when the ambient temperature gets higher or when the solar intensity is abundant [9].

The performance of conventional box type solar cookers can be improved by better designs of cooking vessels with proper understanding of the heat flow to the material to be cooked. An attempt has been made in this article to arrive at a mathematical model to understand the heat flow process to the cooking vessel and thereby to the food material. The mathematical model considers a double glazed hot box type solar cooker loaded with two different types of vessels, kept either on the floor of the cooker or on lugs. The performance of the cooking vessel with a central cylindrical cavity is compared with that of a conventional cylindrical cooking vessel. It is found from the experiments and modeling that the cooking vessel with a central cylindrical cavity on lugs results in a higher temperature of the thermic fluid than that of a conventional vessel on the floor or on lugs [10].

From the above it can be concluded that the performance of the solar cooker is strongly influenced by the design, methods, and the position of the vessel used in box solar cooker. It makes researchers want to design and construct a solar cooker that is used to boil water to a boil. Based on studies that have examined above, the researchers chose conventional box solar cooker type using mirrors as reflectors are installed vertically and sideways-facing south and overlooking the North to be checked, because the design is a design with maximum performance. In this study, performance of a box solar cooker will be studied experimentally. To improve the performance, two mirrors are used. The objective is to examine the performance of solar cooker in boiling water.

2. Methods

2.1. Experimental Apparatus

In the implementation of the experiment, a box-type solar cooker with a size of 1000 × 1000 × 500 (mm) has been designed and manufactured. The main components are a box solar cookers, water container vessel, and a reflector as shown in Fig. 2. The measured parameters are the ambient temperature ($T_{ambient}$), temperature of glass 1 ($T_{K1}$), temperature gap 1 ($T_{G1}$), temperature glass 2 ($T_{K2}$), room temperature collectors ($T_{G2}$), temperature plate collectors ($T_{pa}$), water temperature ($T_{water}$), the radiation intensity sun ($I_{rad}$) and wind speed ($w$). The measuring instrument for measuring temperature used Agilent, the intensity of the radiation used micro hobo station, and the wind speed measured using DT-8880 Hot wire anemometer with speed measuring range 0.3-30 m/s with an accuracy of 3%.
2.2. Cooking and boiling method
The experiments have been carried out in Medan city by heating water from 10:00 AM until the water boiled. The water is heated to various mass of water, 2 kg and 4 kg. Water vessels containers made of aluminum plate with maximum volume of water until 6 kg.

2.3. Performance parameters
It has been mentioned that the temperature in the box solar cooker, the intensity of the radiation, and wind speed measured acquisition and used to obtain performance parameters. Thus, the results in measuring parameters as shown in Fig. 3 (a-b). Performance parameters measurement is used to analyze as followed:

Illustration loses heat at box solar collector can be calculated by the equation:

\[ q_a = U_a \times A_a \times (T_F - T_L) \]  

(1)

Where \( U_a \) in units of W/m\(^2\).K and can be calculated by the equation:

\[ U_a = \frac{1}{\frac{1}{h_c} + \frac{1}{h_f} + \frac{1}{h_k} + \frac{1}{h_c} + \frac{1}{h_p} + \frac{1}{h_c}} \]  

(2)

The amount of heat energy collected by the solar collector (\( Q_{rad} \)) in Watts can be calculated equation:

\[ Q_{rad} = \alpha_p \times \tau_k \times A_K \times P_{rad} \]  

(3)
The thermal efficiency of solar collectors can be formulated by the equation:

\[ \eta_K = \frac{\Sigma q_{fr} - \Sigma q_{ll}}{\Sigma q_{fr}} \]  

(4)

**Figure 3.** Measurement results

- a. Water mass 2kg
- b. Water mass 4kg
3. Results and discussion
Two variations of the water masses have been tested in this study. The results obtained by heating the water until boiled in the box of solar cookers, and the efficiency of solar collectors.

3.1. Energy of radiation intensity
In calculating the heat loss that occurs in the box solar cookers, can be done by measuring temperature inside of box and surround of the box cooker. The increasing temperature depends on the radiation intensity. The maximum radiation is 871 W/m² at 12:41 PM as shown in Fig. 4.

3.2. Efficiency solar cooker
The efficiency of a solar cooker in heating water by the water mass of 2 kg and 4 kg is 46.30% and 41.35%, respectively.

Figure 4. Solar radiation in heating water
4. Conclusion
A solar cooker with an area of 1 m$^2$ has been designed and manufactured. The test starts with a 28°C of ambient temperature water and water mass difference of 2 kg and 4 kg each test. The purpose of this study is the cooking water to a boil using a box-type solar cooker. The results show that the duration of water heating up to 100°C with water mass 2 kg within 2 hours 45 minutes and water mass 4 kg within 3 hours 17 minutes. The maximum temperature of solar box cooker is 117°C at 12:56 PM and maximum efficiency is 46.30%. The main conclusion can be drawn here is that a simple solar box cooker can be used to boil water.

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