Influence of Adding a Convex Lens as a Solar Concentrator on the Performance of Solar Cooker with an Octagonal Panel

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Abstact: Currently, the two most popular renewable energy is solar power and wind power. However, solar power can be harvested almost in every region for a whole year during the day because Indonesia is located at the equator with average daily radiation of 4,8 kWh/m^2. One way to use solar power is used in a solar cooker. The octagonal solar cooker is combine of box type solar cooker and panel type solar cooker. The box part is made of a zincalume with a half-cylinder shape as a reflector from the octagonal reflector to the cooking tray. An addition of convex lens put under the cooking tray. In each cooking tray, 500 mL of water was placed, and the sun's radiation heated the water. Performance of solar cooker tested at 09.00 in the morning for two hour or 120 minute. The results show that adding four convex lenses improved the solar cooker's performance, allowing the highest temperature to rise to 86°C and increasing efficiency to 22,3%. In comparison to an addition, only one convex lens raises the temperature to 84,3°C with a 21,5% efficiency, while the temperature without the lens rises to 70°C with an 16% efficiency.

Keywords: Solar Cooker, Convex Lens, Renewable Energy, Octagonal Reflector, Solar Power.

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I. INTRODUCTION

A recent study showed that fossil fuels will run out around 2088, that's why many people research renewable energy to find sustainability for energy without compromising future generation demand [1]. Currently, the two most popular renewable energy is solar power and wind power [2]. However, solar power can be harvested almost in every region for a whole year during the day because Indonesia is located at the equator with average daily radiation of 4,8 kWh/m^2[3]. One way to use solar power is used in a solar cooker. In addition, cooking is an activity that used a large amount of energy consumption because almost everybody on this planet eats and cooks three times a day [4].

Solar cooker had many benefits as an alternative to cooking because its safe, pollution-free, and low-cost [5]. Despite all of that, not many people use it to cook because it's inconvenient due to strong radiation, a large space, and need a long time to cook. That is why many researchers invent many types of solar cookers to fill people's demand [6]. The three main designs of solar cookers are box type or solar oven, parabola type, and panel type. Box type work like oven, it is cooked food in an enclosed chamber. The parabolic type can achieve high temperatures but it's inconvenient because of strong radiation from sun ray reflection. Meanwhile, the panel type can modify the reflector to achieve high temperatures without too much blinding [7].

Strong radiation from the reflector and long time to cooked became the main reasons why people are still reluctant to use solar cookers [8]. That is why, in this study, we attempt to reduce strong radiation by combining a panel reflector and a box type with the addition of a convex lens to enhance solar radiation and direct the sunray into the cooking plate, thereby increasing temperatures and decreasing cooking time. The design of solar cookers used in this research has been modified so that it can protect our eyes from strong radiation, while a convex lens is used to converge sunrays and focus the light on tray cooking in order to enhance heat.

Several studies have used fresnel lenses as solar concentrators in solar cookers [9,10]. The function of the fresnel lens itself is to strengthen or collect light in a solar cooker, this function is quite similar to the nature of a convex lens, which is why Singhy, et al. [11] used the fresnel lens and convex lenss optic element in PVT to concentrated the sunray. Meanwhile A study about convex lens used in solar cooking is still limited, which is why we selected convex lens in this research to know more about the influence of convex lens in solar cooking. The use of a convex lens in solar cooking is adjusted to the design that has been made and is expected to improve the performance of the solar cooker.

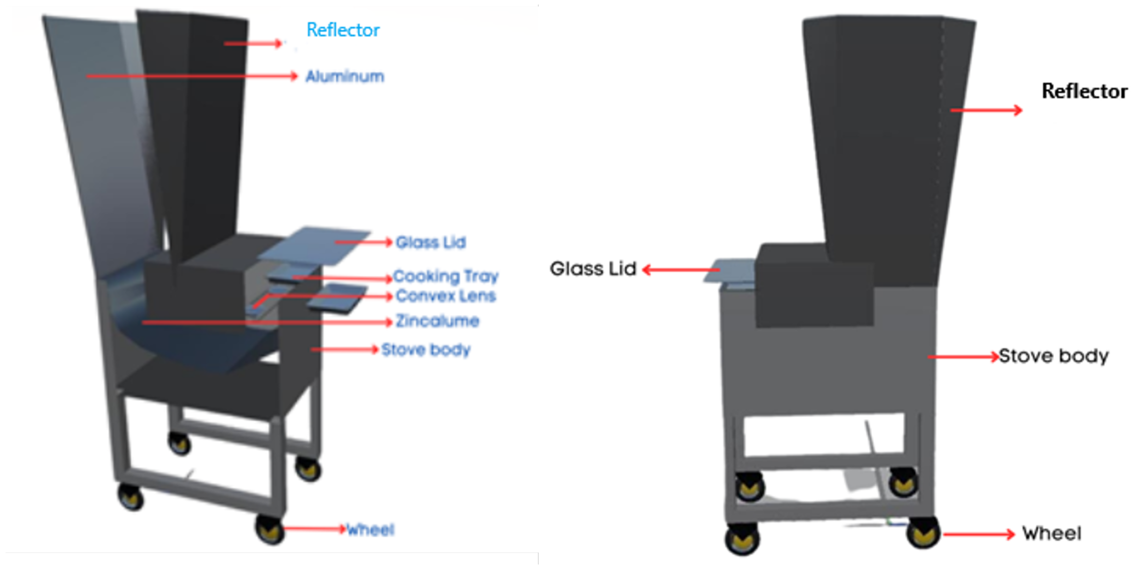

FIG. 1: Solar cookers with convex lens addition.

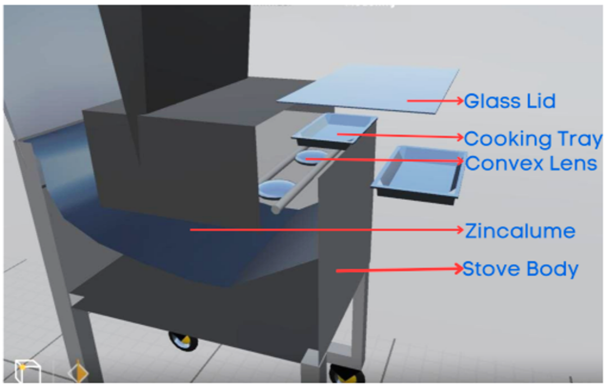

FIG. 2: Inside the box part of solar cooking.

II. DESIGN AND METHOD

A. Design of Solar Cookers

The aim of this solar cooker was to reach high temperature,which usually we get from parabolic-type solar cookers and comfortable to use without strong radiation, which can be found in box-type solar cookers. Therefore, we combine these two types of solar cookers to get solar cookers with high temperature and comfortable to use. The panel reflector used an octagonal shape with the hope of reflecting sunlight from many angle, similar to a parabolic reflector. This panel connects with tray cooking, which is put in a box through zincalume reflector. Beneath the cooking tray there are convex lenses to collect the scattered sunray and focus on tray cooking so that we can get a higher temperature. Meanwhile, the lid covers the tray cooking to prevent heat loss and there is a shade above the tray cooking to keep out the sunray from our eyes.

The octagonal solar cooker is combine of box type solar cooker and panel type solar cooker The framework is made from plywood. The box is made of 15-mm plywood, and the octagonal structure is made of 9-mm plywood covered in black paint. The octagonal panel was covered with aluminum tape for reflection. The silinder aluminum is placed in the connection between the box and the panel.

There are two cooking tray in the cooker, beneath the trays, a convex lens is placed; on one side, there is no convex lens, and on the other, there are one or four convex lenses (see Fig. 1). The box part is made of a zincalume with a half-cylinder shape as a reflector from the octagonal reflector to the cooking tray. In each cooking tray, 500 mL of water was placed, and the sun's radiation heated the water (see Fig. 2).

The main reason why this research used many material with light weight (ex:plywood, aluminum tape, etc) is to make a solar cookers with a panel big enough so that it can capture/reflect many sunlight but it also can be moved easily to search where the place with the best sunlight. Because the aim is to create solar cooker that can easily used in household, that why we added a whells to make the user move this big solar cooker easily.

B. Experiment Method

The method to see the performa of solar cooker can be seen step by step in Fig. 3. First, the new design of solar cooker has been explain in previous paper [12], the first experiment is to see the performa of solar cooking one tray without adding a convex lens and beneath another tray adding one lens. On the following day, the second experiment used in the same time and the same place with no addition of convex lens on the left tray and four convex lenses on the right tray. The solar cookers test with load a 500 ml of water into a cooking tray.

Performance of solar cooker tested at 09.00 in the morning

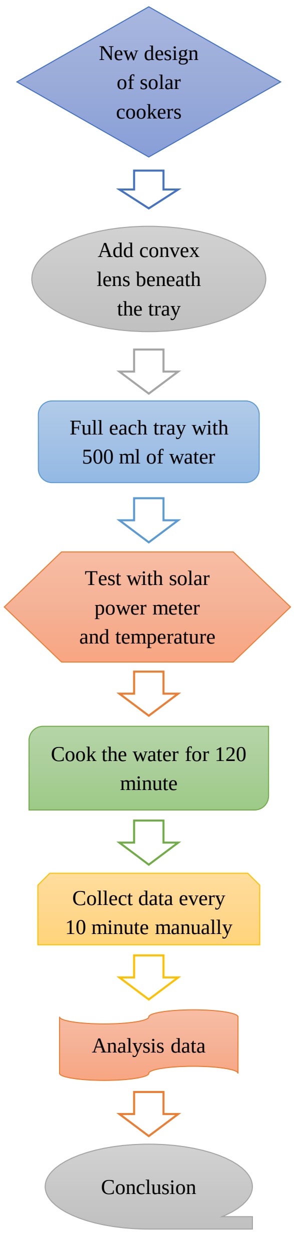

FIG. 3: Flowchart of experimental method.

for two hour or 120 minute. The tools used to test the performance of the solar cooker are a thermometer to check the water temperature and a solar meter to see the power radiation in W/m^2. Temperature and radiation are checked gradually and manually every 10 minutes. The location used to test the performance of solar cooker is the backyard with many tree surrounding area and enclosed with wall. This location was purposefully chosen to test the solar cooker's performance in a real household where, due to the surrounding area, not many sun rays can get through.

Efficiency of a solar cooker with an octagonal panel can be

FIG. 4: (a) Solar radiation in solar cooker without cooking tray, (b) Water heating with solar cooker

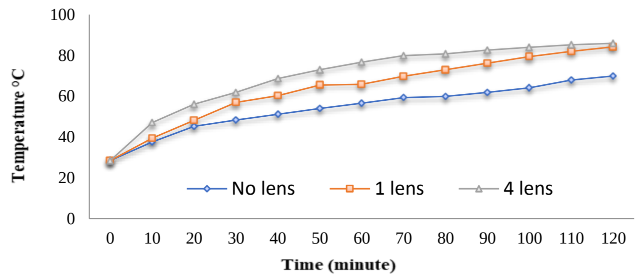

FIG. 5: Temperature difference in solar cooker with different number of convex lens.

calculated by using:

$$\eta = \frac{Q_w}{Q_{in}} \times 100\% \tag{1}$$

In Eq. (1), efficiency can be calculated by dividing power heating in water and power radiation. Power radiaton can be calculated with mutiple refractive of aluminum tape, sectional area and solar radiation incident.

$$Q_{in} = \varepsilon A_r I_{in} \tag{2}$$

Whereas power heating in water calculated by multiply mass of 500 ml water which is approximately 0,5 kg, heat capacity of water and temperature rise [13,14].

$$Q_w = mC_p(T_1 - T_2)/\Delta t \tag{3}$$

III. RESULTS AND DISCUSSION

A solar cooker was successfully constructed using a box and a panel reflector. Solar radiation is collected with the octagonal panel layered with aluminum tape, whereas the box part layered with a half silinder zinccalume is used to reflect the incoming solar radiation from the octagonal panel that goes through the convex lens and is accepted by the cooking tray. The experiment included three variables: no lens, one

TABLE I: Temperature of solar cooking with different number of lens.

Time	Temperature No lens (°C)	Solar Power (W/m^2)	Temperature one Lens (°C)	Temperature No lens (°C)	Solar Power (W/m^2)	Temperature Four lenses (°C)
0	28,5	1096	28,5	27,8	1096	28,5
10	37,6	1172,7	39,5	40,5	1075	47,2
20	45,3	1191,5	48,3	48,7	1191,5	56,1
30	48,4	1097,3	57	51,3	1210,1	62
40	51,2	1052,4	60,4	56,5	1079,3	68,7
50	54	1211	65,5	58	1143	73,1
60	56,7	1081,2	65,9	59,3	1028	76,7
70	59,3	1079,3	69,8	60,4	1216,5	80
80	60	1132,8	73,1	62	1038,6	80,8
90	62	1018	76,2	64,7	1014	82,7
100	64,2	1099,6	79,4	66	1170,3	84
110	68	1067,5	82	68,2	1034	85,2
120	70	1126,5	84,3	70,1	1046	86

lens, and four lenses. The convex lens collects and focuses incoming solar radiation, allowing the cooking tray to receive more heat than it would without the lens.

The result of collected and reflected solar radiation in an octagonal solar cooker can be seen in Fig. 4(a). From the figure, we can see the strong radiation coming out of the solar cooker, which means this radiation can be strong enough to heat the cooking tray and cook the food. Fig. 4(b) depicts an experiment in which 500 ml of water was loaded into a cooking tray. The cooking tray was covered with 10-mm thick transparent glass to prevent heat loss. The transparent glass is used for easy checking to see the state of food so that it won't be overcooked. Above the cover lid, there is an additional cover used to protect the user's hand so that it won't burn because of strong radiation from direct sunlight when dealing with the food.

TABLE II: Efficiency of solar cooking with different number of lens.

Lens	Average I_{in} (W/m^2)	Efficiency
No lens	1109	16 %
One lens	1103	21,5 %
Four lens	1103	22,3 %

The performance of solar cooking with an octagonal panel can be seen in Fig. 5 and Table I, the test was done with 500 ml of water heated for 120 minute or 2 hours. The temperature of ambient around 30°C test with a digital thermometer gun, meanwhile to measure the incoming solar radiation (I_{in}) used solar power meter. Begin with a water temperature at 28,5°C the no lens highest performance was increase the temperature up to 70°C, while the one lens heating the water up to 84,3 C and the four lens rose up to 86°C. This result proved that convex lenses can be used to increase solar cooker performance up to 15°C.

The efficiency of a solar cooker with different numbers of convex lenses can be calculated with Eq. (1) and the result can be seen in Table I. Power radiation (Q_{in}) Eq. (2) results from the coefficient reflectivity of aluminum (0,88) times tray area (0,31 × 0,25) m^2 times incoming solar radiation. The amount of Q_{in} in Table I with 1103 W/m^2 of incoming solar radiation was 75,225 W. Meanwhile, power heating water (Q_w) from Eq. (3) with a heat capacity of 4200 J/kg.K times a temperature difference of 55,8°C and a cooking time of 7200 seconds was 16,275 J. Therefore, the efficiency from Eq. (1) with Q_w divided by Q_{in} was 21,5%.

From Table I, we can see the solar cooker without a lens achived an efficiency of 16% with 1109 W/m^2 of incoming solar radiation. An additional one lens in the solar cooker received 21,6 percent of the 1103 W/m^2 incoming solar radiation, and four additional lenses received 22,3%. According to Table I, an addition with four convex lenses has the highest efficiency (22,3%), while an addition with one lens has a higher efficiency (21,5%) than a solar cooker with no convex lenses (16%). It is shown that an adition of convex lenses can increase the efficiency of solar cookers.

The overall result show that an addition of convex lenses can increased the performance of solar cooker, though it may not increase that much, in comparison with the work of Zhao [10] an addition of fresnel lenses can increase temperature up to 99°C and receive 12,2% efficiency. According to Salima and Ali [15], there might be absorption and reflectivity loss from the convex lens causing a decreased in efficiency. Rihui Jin et al. [16] explained that the angle of the convex lens can determine the efficiency of absorption and reflectivity loss, with the right angle we can achieve the best reflectivity, thus the incoming radiation can go through all the lens and heat the cooking tray. In this work, we put the lens about 10 cm under the cooking tray in the hope that the upcoming radiation can be accepted and focusing solely on the cooking tray. Setting a lens at the right angle will be a little difficult since the angle of incidence of sunlight changes every minute. Based on this analysis, the placement of the aluminum cylinder should also be reconsidered, and the addition of a solar tracker can help get a higher amount of incoming radiation thus it increasing the temperature of the solar cooker.

Elamin and Abdalla [17] in their research showed different results from three different solar cookers, they showed that box-type solar cookers reach temperatures up to 52.36°C with 77,4% efficiency and the panel type 43.5°C with 67.4% efficiency, whereas the maximum result from a parabolic type solar cooker was 86,5°C with 31,53% efficiency. Even though parabolic-type solar cookers get the highest temperature, they have the lowest efficiency. The lowest efficiency in parabolic solar cookers is due to heat loss caused by design. It can be compared with the solar cooker in this research, which can reach high temperatures but has low efficiency. The result of this experiment showed that the new design of solar cooker got a better result than the regular box-type and panel-type solar cookers. Meanwhile, it shows similar results with parabolic solar cookers. It means the design cannot prevent much heat loss caused by low efficiency, but unlike parabolic-type solar cookers, this new design makes the user more comfortable because the sunlight does not hurt the eyes.

IV. CONCLUSION

A solar cooker was successfully constructed using a box and a panel reflector. An addition of convex lenses was used to increase the performance of the solar cooker. The results show that adding four convex lenses improved the solar cooker's performance, allowing the highest temperature to rise to 86°C and increasing efficiency to 22,3%. In comparison to an addition, only one convex lens raises the temperature to 84,3°C with a 21,5% efficiency, while the temperature without the lens rises to 70°C with an 16% efficiency. This result is still far from perfect because we ignored the importance of optic angle, absorption, and reflectivity loss from incoming solar radiation. Thus, from in the future we hope this study can be continued to get a better result from a solar cooker.

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