

# Design of Parabolic Solar Cooker: As Alternative Cooker Trough Go Green In Medan, Indonesia

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## Abstract

**Objectives:** One of clean technology applications in daily human life activity is the use of solar thermal energy, such as for rice cooking. As a country where most of its territory is on the equator, this environmentally friendly solar cooker can be reversed due to the high intensity of radiation received throughout the day. Therefore, design and trial run of solar cooker with parabolic collector has been done. **Methods and Analysis:** The collector produced has a diameter of 150 cm, depth 60 cm and the length of the focal point of 23.44 cm. The parabolic equation resulted is  $X^2 = 93.76 Y$  or  $Y = 0.01067 X^2$ . The collector is made of aluminum plates coated with aluminum foil on the surface and isolated with Rockwool at the bottom. While the cooking pot (absorber) is made of aluminum with a diameter of 20 cm and a height of 14 cm. **Findings:** From this dimension a concentration ratio of 56.25 is obtained. The trial results on cooking 400 grams of rice (ratio of rice: water = 1: 1) showed that cooking time and thermal efficiency were strongly influenced by solar irradiation. **Applications:** The optimum condition was achieved at an average solar irradiation of 520 W/m<sup>2</sup>, which obtained 90 minutes of cooking time with 56% thermal efficiency.

**Keywords:** Design, Parabolic, Performance, Solar Cooker

## 1. Introduction

Solar Cookers (SC) are devices that change the intensity of solar radiation into heat in order to cook or pasteurize food and beverages. The principle of SC is by concentrating direct sunlight to increase the temperature of cooking food or water. The cooking temperature starts around 65° C even though the temperature from 120° C to 200° C is preferred. Various solar stove designs are studied to optimize tool performance. This design varies according to geometric shapes and cooking pan places. There are two effective SC designs, namely the box type and the parabolic focus reflector type<sup>1</sup>.

The box type basically converts solar energy into heat energy which will be used to cook food placed in the cooker<sup>2</sup>. The optimum temperature achieved at cooking is around 100°C. The weakness of this type is known to be located in the process of temperature rise which runs slowly so it requires a longer cooking time<sup>1</sup>.

The parabolic type is operated to focus solar radiation at a certain point so that at that point there is a faster temperature increase than the box type. Therefore, parabolic type SC is suitable for foods that require high temperatures or cooking levels<sup>3</sup>. The parabolic type SC relies on the principle of sunlight being received. In order for the parallel file from the received sunlight to be reflected by the surface of the satellite dish at the focal point optimally, the reflector material has a high reflectance such as glass and aluminum mirrors. If a focal point / container are placed at the focal point, the light beam will release energy in the form of heat<sup>4</sup>.

Various SC parabolic designs have been developed to optimize its performance. This design varies according to the geometric shape and place of the pan for cooking (absorbent). In order for heat to accumulate better without having to let fresh air pass, it is necessary to prepare cross parabola. Parabolic collectors are very important to avoid thermal losses. One or more transparent covers are

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used to reduce convection heat and radiation from the absorber to the environment.

This study aims to design, manufacture and test parabolic collector type solar cookers. The following is the basis of the design carried out starting from the design relationship, selection of satellite dish collector and cooking pot (absorber), simulation of parabolic dimension calculation, manufacture and trial.

## 2. Materials and Methods

Determination of the basic parameters of a parabolic reflector the initial specification for designing a parabolic type SC reflector is to use the parabolic equation as follows:

$$X^2 = 4fY \quad (1)$$

Parabolic symmetry dimensions are calculated based on the following equation<sup>5</sup>:

$$h = \frac{R^2}{4.f} \text{ atau } f = \frac{D_{ap}^2}{16.h} \quad (2)$$

Calculate the area of parabolic openings and the surface area of the cooking pot (absorber):

$$A_{ap} = \frac{\pi D_{ap}^2}{4} \text{ dan}$$

$$A_{ab} = \frac{\pi D_{ab}^2}{4} \quad (3)$$

The width of the parabolic surface is calculated based on the following equation<sup>5</sup>:

$$A_s = \frac{8.\pi.f^2}{3} \left[ \left[ \left( \frac{D_{ap}}{4.f} \right)^2 + 1 \right]^{3/2} - 1 \right] \quad (4)$$

The concentration ratio is calculated based on the following equation<sup>5</sup>:

$$C_R = \frac{A_{ap}}{A_{ab}} \quad (5)$$

By using the Parabolic Calculator 2.0 simulation program, calculations are made to get the focal length in order that the focal point is inside the parabolic.

### 2.1 Material Selection

The selected of material is based on the following four basic factors:

1. Material resource,
2. Suitability materials for equipment conditions,
3. Materials Value, and
4. Material properties.

The materials used in the manufacture of Parabolic Type Solar Cookers are presented in Table 1 as follows.

Base on parabolic calculating parabolic simulation and material selected and then making parabolic solar cooker with specification such as Figure 1.

Technical Drawing of parabolic solar cooker design is shown in Figure 2, and then fabricated. And it is conducted with trial to cook rice 400 grams with a water ratio: rice = 1:1. Trial were carried out for 3 repetitions (28th – 30th July 2018) and during the trial, temperature profiles T1, T2, T3, T4 and T5 and the intensity of solar radiation (Figure 1) measured by using the digital thermometer and pyranometer, respectively.

### 2.2 Performance Test

This test is conducted to determine the thermal efficiency of a satellite dish collector by involving an energy balance equation (incoming heat and heat lost by convection, conduction and radiation). The dimensions of the solar power cooker used to calculate heat loss can be seen in Table 2 and Figure 2. Diameter (D), height (L), thickness and area (A) of each collector (inside surface, outside surface, cover glass in a row A1, A2 and A3.

Heat loss is calculated base on the equation below:

$$Q_{\text{convection-conduction}} = (T_a - T_u) / [(1 / (h_1 \cdot A_1) + t_1 / (k_{rw} \cdot A_1) + t_2 / (k_{\text{al-foil}} \cdot A_2) + 1 / (h_2 \cdot A_2))] \quad (6)$$

$$Q_{\text{radiation}} = [A \cdot \sigma \cdot (T_a^4 - (T_k)^4)] / ((1 / \varepsilon_p + 1 / \varepsilon_k - 1) + (1 / \varepsilon_k + 1 / \varepsilon_k - 1)) \quad (7)$$

$$Q_{\text{losses}} = Q_{\text{convection-conduction}} + Q_{\text{radiation}} \quad (8)$$

$$\eta = \left[ \frac{(F' \cdot ((I \cdot A \cdot \tau \cdot a) - Q_{\text{losses}}))}{I \cdot A} \right] \quad (9)$$

Heat Convection Coefficient is calculated by using the equations below:

$$h = (N_u \cdot k) / l \quad (10)$$

**Table 1.** Properties and material selected for manufacturing

Sl. No.	Material	Properties	Remarks
1.	Carbon/Mild Steel Pipe	- Ductility and formability - Maximum carbon content of 0.35% - Strong and capable of absorbing shocks - Easy for casting or welding - Used for all types of manufacturing (frames, building bridges)	Used as a buffer for satellite dish collectors
2.	Aluminum Sheet	- 4 mm thickness - Light and stretchy metals - High thermal conductivity - Easy for casting - Cheaper price	Used as a base for a satellite dish collector
3.	Aluminum foil	- High compatibility. - Impermeability to steam and gas. - High thermal insulator and reflection. - Thermal conductivity: 0.032 W / m.K	Used as a parabolic reflector it is coated to an aluminum sheet
4.	Rockwool	- Light and heat resistant - Easy to find in the market - Easy to form - Thermal conductivity: 0.042 W / m.K	Used as an insulator on a satellite dish collector
5.	Glass Sheet	- Has very low absorption so it is transparent - Colorless - Glass can transmit 80% of solar radiation - 5 mm thickness	Used as a satellite dish cover to maintain heat loss from the absorber (Cooker container).

$$Nu = 0,59 Ra_L^{0,25} \quad (11)$$

$$Ra_L = Gr \cdot Pr \quad (12)$$

$$Gr_L = \frac{\rho^2 \cdot g \cdot \beta \cdot (T_p - T_1) \cdot L^3}{\mu^2} \cdot \cos \theta \quad (13)$$

During the test measurements of radiation intensity were measured using a pyranometer and temperature data (air, outside of wall, inside of wall and parabolic room and glass cover) using a digital thermometer connected to a thermocouple, the environmental air velocity was measured using an anemometer, as shown in Figure 1.

### 3. Results and Discussion

#### 3.1 Parabolic Collector Design Simulation Results

From the simulation results that vary the diameter (200, 150 and 100 cm) and the fixed depth of 60 cm, the focal point lengths are 41.67 cm; 23.44 cm and 10.42 cm. Simulation results show that the larger the diameter, the greater the surface area of the parabolic.

The results of the first simulation (diameter 200 cm) is shown in Figure 3, it can be seen in a parabolic with a height of 60 cm it will produce a focal point that is too high (41.67 cm). With increasing focus position, select absorber (cooking pan) also higher. This position causes the satellite dish collector to not be closed to minimize heat. The smaller the parabolic opening, the smaller the thermal energy that can be received by the parabolic collector. By being approved by both (diameter 150 cm) as in Figure 4 is the most optimal if reviewed of the surface area aperture.

By using eq. (3), (4) and (5), for the design of a satellite dish collector with a diameter of 150 cm and a depth of 60 cm, the surface area aperture ( $A_{ap}$ ) is obtained, and the surface area of parabolic ( $A_s$ ), cooking pan surface area ( $A_{ab}$ ) and Concentration Ratio (CR) respectively as below:

$$A_{ap} = 17671.46 \text{ cm}^2$$

$$A_s = 26294.44 \text{ cm}^2$$

$$A_{ab} = 314 \text{ cm}^2$$

$$CR = 56.25$$

Another reason for choosing variations as shown in Figure 4, besides the high concentration ratio, is that it

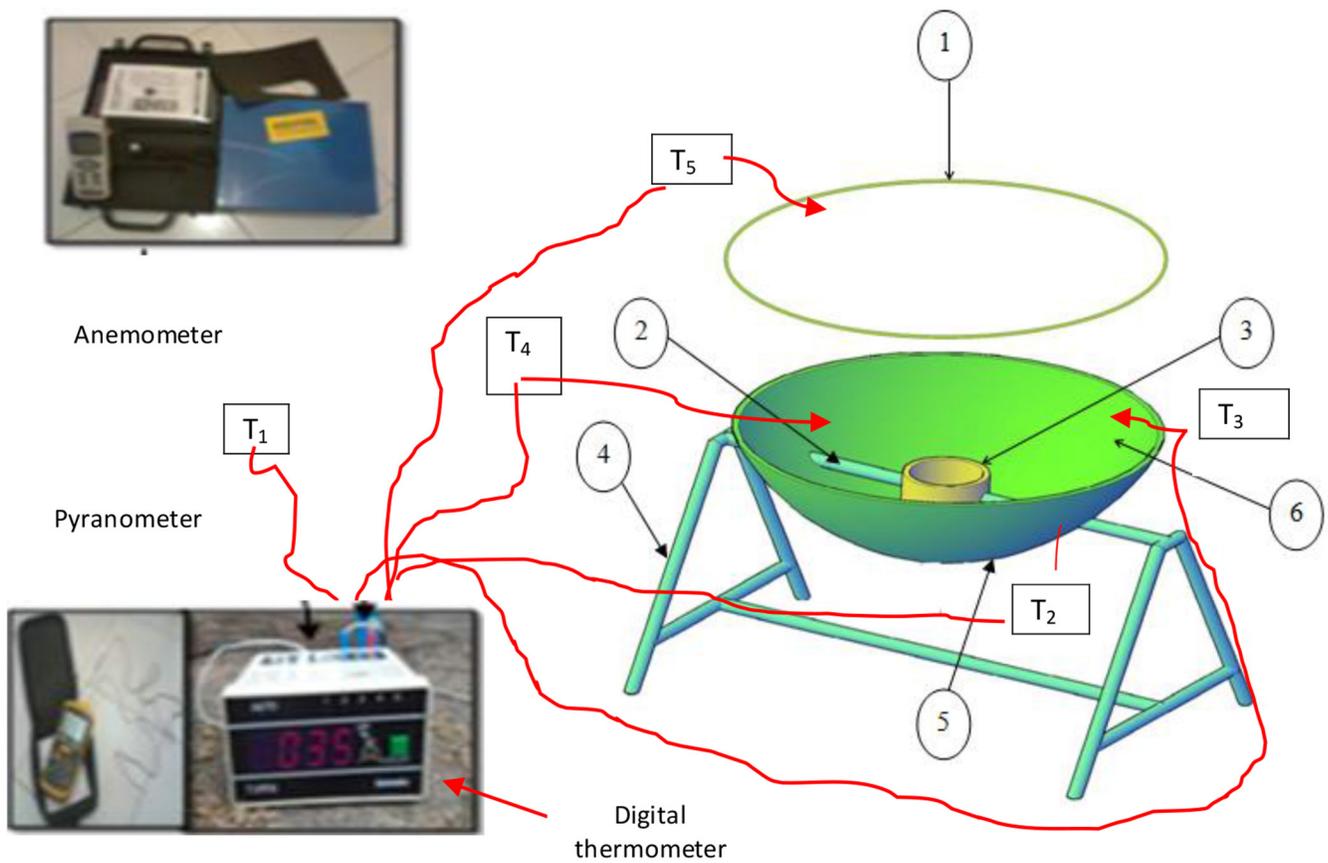


Figure 1. Design of parabolic solar cooker<sup>6</sup>.

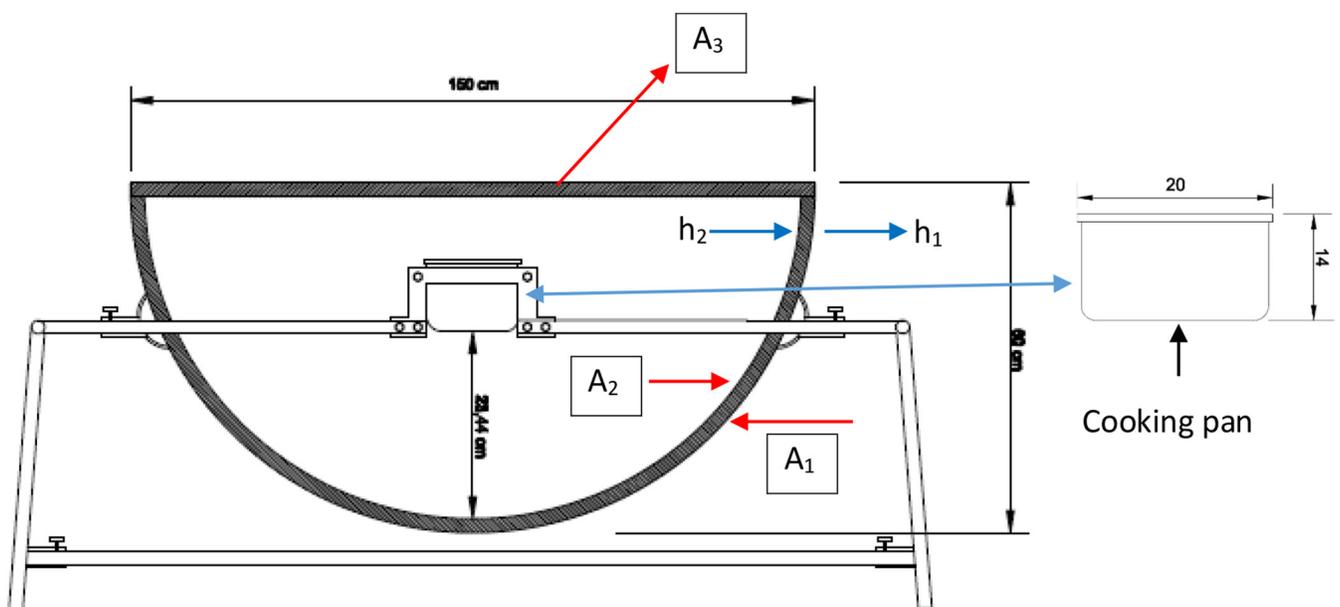


Figure 2. Technical drawing of parabolic solar cooker<sup>2</sup>.

**Table 2.** Dimensions of Collector

Material	D (m)	L (m)	Thickness (m)	A (m <sup>2</sup> )
A <sub>1</sub> (rock wool)	1,508	0,6	0,004	3,5702
A <sub>2</sub> (aluminum)	1,5	0,6	0,004	3,5325
A <sub>3</sub> (glass cover)	1,5	0,6	0,005	1,7662

is possible to use collector cover so that it can minimize heat loss. This design also variations the position of the cooking pan on, above or below the focal point. Whereas the variation in Figure 5 a lower concentration ratio due to the area of the lowest parabolic opening (the smallest diameter). The concentration ratio will affect the amount of heat collected at the focal point. The higher the CR value, the more energy is received by the absorber (cooking pan) so that the cooking rate is higher.

By using the equation 1 is obtained parabolic equation for diameter 150 cm and depth 60 cm below:

$$X^2 = 93,76 Y \text{ atau } Y = 0,01067 X^2$$

### 3.2 Temperature Profile for Solar Thermal Cooking Trial

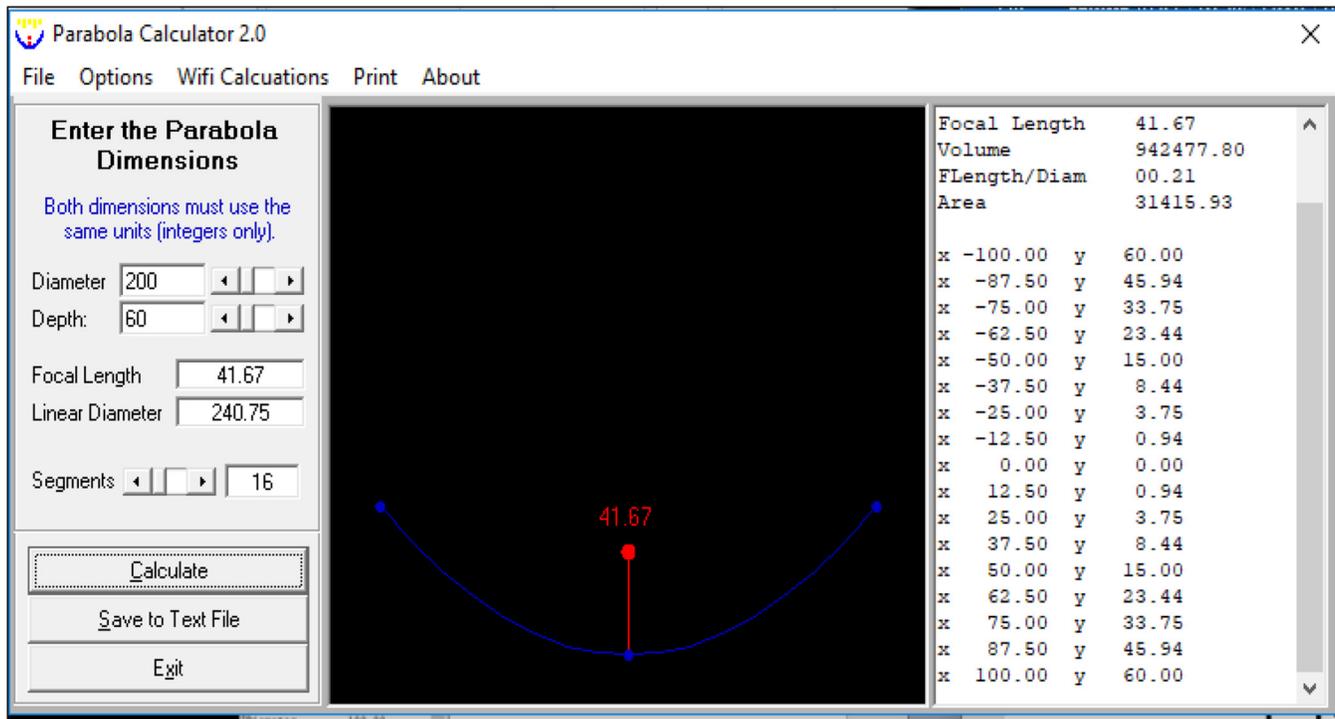
Temperature profile and radiation intensity are measured during the trial of parabolic solar cookers are presented in Figures 6-8. The first trial as shown in Figure 6 shows

that the trial of rice cooking takes time from 12:00 am to 02:40 pm. During the trial, the outside temperature of the satellite dish is in the range of 27°C to 72°C; the temperature inside of parabolic is in the range of 27°C to 73°C; the temperature of the cover glass is 27°C to 56°C and the average radiation intensity is 357 Watt/m<sup>2</sup>. In this condition, the cooking time is took time as long as 160 minutes.

The second trial as shown in Figure 7, that the trial of rice cooking and runs from 11:50 am to 01:20 pm. During the trial, the outside temperature of the parabolic is in the range of 27°C to 67°C; inside temperature is 27°C to 69°C; the temperature of the glass cover is 27°C to 56°C; the average radiation intensity is 469 Watt / m<sup>2</sup>. Cooking time is took time as long as 90 minutes.

The third trial as shown in Figure 8, that the trial of rice cooking and runs from 11:30 am to 12:50 pm. During the trial, the outside temperature of the parabolic is in the range of 27°C to 65°C; inside temperature is 27°C to 73°C; the temperature of the glass cover is 27°C to 57°C; the average radiation intensity is 519 Watt / m<sup>2</sup>. Cooking time is took time as long as 90 minutes.

From the experiments that have been conducted, it is generally seen that cooking time is strongly influenced by the intensity of radiation. The trial in the first day (Figure 6) the weather conditions are cloudy so the radiation intensity is below 500 W/m<sup>2</sup>, whereas in the second

**Figure 3.** Simulation result for diameter 200 cm and depth 60 cm.

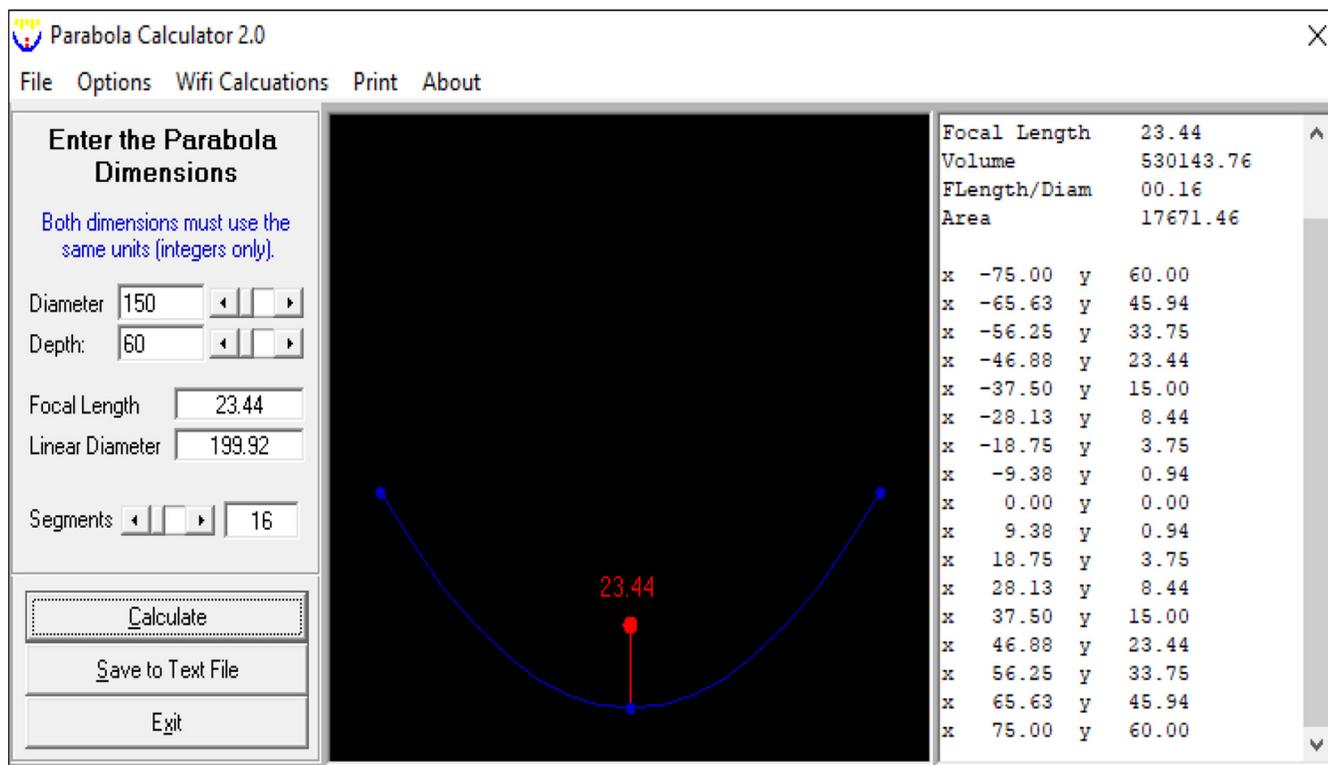


Figure 4. Simulation results for diameter 150 cm and depth 60 cm.

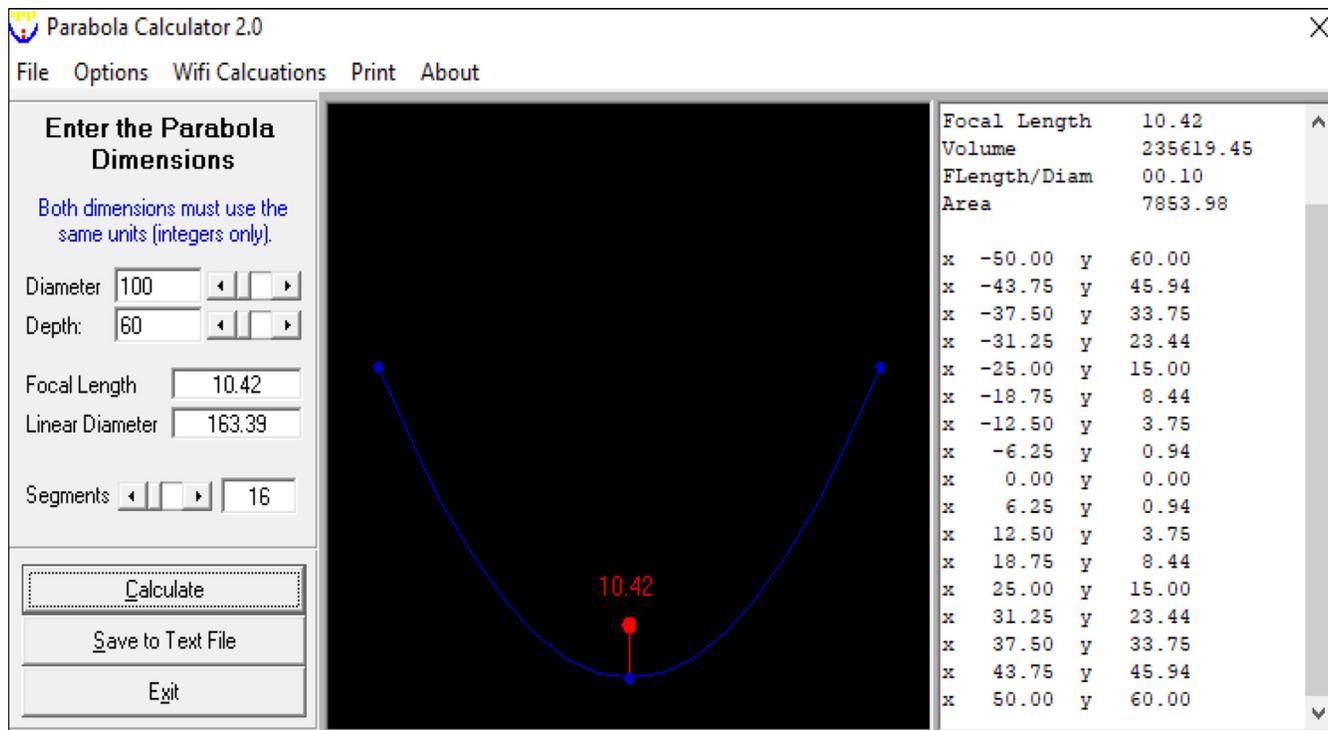


Figure 5. Simulation result for diameter 100 cm and depth 60 cm.

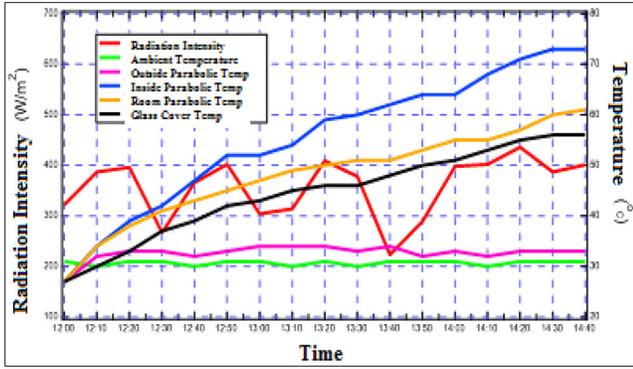


Figure 6. Radiation intensity and temperature profile in rice cooking trial at 400 g (28th July 2018).

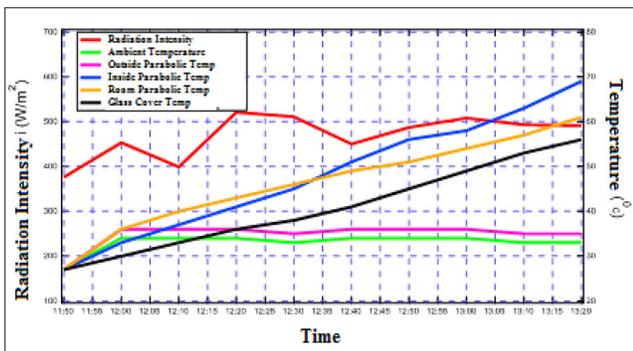


Figure 7. Radiation intensity and temperature profile in rice cooking trial at 400 g (29th July 2018).

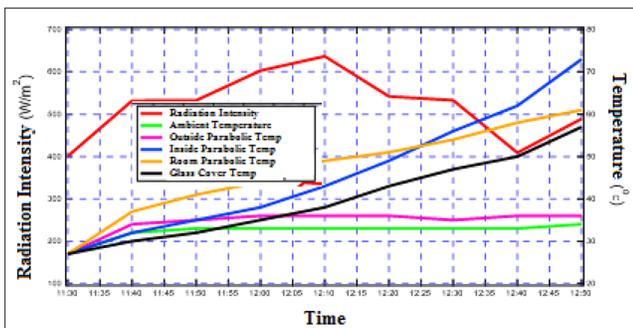


Figure 8. Radiation intensity and temperature profile in rice cooking trial at 400 g (30th July 2018).

and third tests the weather conditions are relatively brighter (radiation intensity above 500 W/m<sup>2</sup>).

### 3.3 Evaluated of Performance

Based on the data of radiation intensity and temperature are measured during the trial, it was then used to calculate the performance of the satellite dish solar collector which was designed by calculating thermal efficiency.

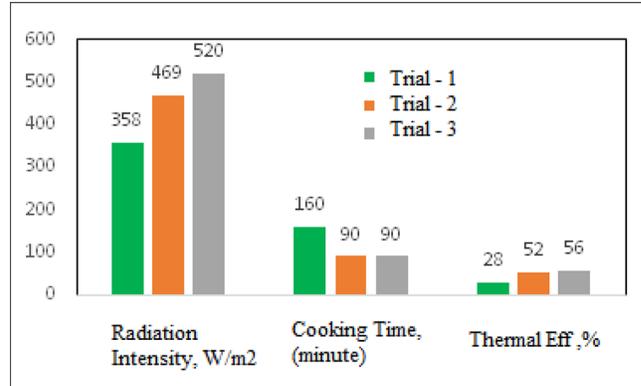


Figure 9. Performance of collector parabolic solar cooker<sup>8</sup>.

The parabolic type solar collector that is designed is made of aluminum plate and the bottom (base) is coated with an insulator (Rockwool). To increase the reflectivity, the surface is coated with aluminum foil with their respective dimensions as presented in Table 2. Calculation of convection naturally by heat loss, conduction and radiation used to determine total heat loss and thermal efficiency is to use equation 6 through equation 13. Results the calculation of efficiency, cooking time and radiation intensity during the trial of the designed solar power cooker is shown in Figure 9. Based on this relationship it can be seen that thermal efficiency is positively correlated with radiation intensity and cooking time is shown in Figure 10. The third trial gives the highest thermal efficiency value is in line with the highest radiation intensity value at the time of the trial. However, overall, this parabolic collector type solar cooker cooks 400 grams of rice for 90 minutes if the average radiation intensity is above 469 W/m<sup>2</sup>.

## 4. Conclusion

From the results of design activities and trials of parabolic type solar cookers, it can be concluded:

The parabolic collector produced by the design has a diameter of 150 cm, depth 60 cm and the length of the focal point 23.44 cm obtained parabolic equation  $X^2 = 93.76 Y$  or  $Y = 0.01067 X^2$ . The collector material is made of aluminum plates coated with aluminum foil on the surface and isolated with Rockwool at the bottom. While the cooking pot (absorber) is made of aluminum with a diameter of 20 cm and a height of 14 cm. From this dimension a concentration ratio of 56.25 is obtained. The results of the trial of cooking 400 grams of rice (ratio of



**Figure 10.** View of parabolic solar cooker eco-friendly.

rice: water = 1: 1) showed that cooking time and thermal efficiency were strongly influenced by radiation intensity. The optimum condition was achieved at an average radiation intensity of 520 W/m<sup>2</sup>, which obtained 90 minutes of cooking time with 56% thermal efficiency.

**Nomenclature:**

- Y is the distance along the vertical axis,
- F focal length
- X distance along the horizontal axis
- H depth of parabolic
- D<sub>ap</sub> The aperture diameter of the parabolic
- A<sub>ap</sub> The aperture area of parabolic
- A<sub>s</sub> The aperture surface of parabolic
- C<sub>R</sub> concentration ratio between the aperture widths of the parabolic to the surface area of the absorber (cooking-pan):

1. Glass cover
2. Cooker Handling
3. Cooker (absorber)
4. Stand support
5. Outside parabolic
6. Inside parabolic

**Nomenclature**

- T1 Ambient
- T1 Ambient temperature, °C

- T2 Outside parabolic temperature, °C
- T3 Inside parabolic temperature, °C
- T4 Room temperature Parabolic, °C
- T5 Glass cover temperature, °C
- h Coefficient of heat transfer by convection, W/m<sup>2</sup> K
- t thickness,m
- ρ Air density at Tf, kg / m<sup>3</sup>
- g Gravity, m/det<sup>2</sup>
- β Air coefficient = 1 / Tf
- μ Air viscosity on Tf, (N.det / m<sup>2</sup>)
- q Slope of the satellite dish collector

Boltzmann constant = 5.67E-08 W/m<sup>2</sup>.K

- L Depth, m
- A Area, m<sup>2</sup>
- I Radiation intensity, Watt / m<sup>2</sup>
- ε<sub>k</sub> Glass emissivity = 0.88
- ε<sub>p</sub> Reflectoremissivity = 0.98e
- T<sub>f</sub> Film temperature, C = (Environment + Wall) / 2
- T<sub>a</sub> Inside wall temperature, K
- T<sub>u</sub> Environment air temperature, K
- T<sub>k</sub> Glass Temperature, K
- L Depth, m

A	Area, m <sup>2</sup>
I	Radiation intensity, Watt / m <sup>2</sup>
$\epsilon_k$	Glass emissivity = 0.88
$\epsilon_p$	Reflectoremissivity = 0.98e
T <sub>f</sub>	Film temperature, C = (Environment + Wall) / 2
T <sub>a</sub>	Inside wall temperature, K
T <sub>u</sub>	Environment air temperature, K
T <sub>k</sub>	Glass Temperature, K
kal-foil	Heat conductivity aluminum foil = 0.032 W.m / K
krockwool	Heat conductivity rock wool = 0.042 W.m / K
v	Environmental air velocity, m / sec
Gr	Grashof number
Nu	Nusselt's number
RL	Rayleigh numbers
Pr	Prandtl number

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