Jurnal Polimesin
Department of Mechanical Engineering
State Polytechnic of Lhokseumawe
http://e-jurnal.pnl.ac.id/polimesin

e-ISSN	: 2549-1999	No.	: 5	Month	: October
p-ISSN	: 1693-5462	Volume	: 21	Year	: 2023

Article Processing Dates: Received on 2023-10-06, Reviewed on 2023-10-08, Revised on 2023-10-24, Accepted on 2023-10-28 and Available online on 2023-10-29

An Experimental Study On Parabolic Trough Solar Cookers With Materials Collector Of Chrome Stickers And Glass Mirrors

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Abstract

Cooking,a fundamental human necessity, frequently relies on environmentally harmful energy sources. Concentrated solar power offers a promising solution through solar cookers to address this issue. This study assesses a Parabolic Trough Collector (PTC) solar cooker's performance with two reflector materials: chrome stickers and glass mirrors. The PTC-type solar cooker comprises essential components, including an absorber tube, a flexible conduit, and a spiral-shaped cooking container holder that accommodates a diverse range of cooking vessels. In the configuration of the PTC collector, reflectors fabricated from chrome stickers and glass mirrors are strategically employed to harness and concentrate solar radiation effectively. The absorber tube, crafted from copper, is filled with a heat-transfer fluid consisting of soya oil. Experimental investigations were conducted in a two-stage process, encompassing trials without any applied load and subsequently with varying loads. In the no-load experiments, alterations were made to the PTC collector's inclination angle, spanning the ranges of 15º, 20º, 25º, and 30º. In contrast, the load-bearing tests encompassed the assessment of the PTC solar cooker's performance under a diverse array of cooking scenarios, including boiling water, heating oil, frying eggs, and crisping crackers. The evaluated parameters encompassed key metrics such as incident solar radiation (I_r), ambient temperature (T_a), receiver temperature (T_r), fluid temperature (T_f), spiral furnace temperature (T_{sf}), and load temperature (T_o). Subsequently, the outcomes of the experiments were employed to determine the efficiency of the solar cooker. Analysis of the no-load test results indicates that the most favorable performance, as observed in the parameters T_r, T_f, and T_{sf}, is achieved at a collector inclination angle of 15º for both chrome sticker and glass mirror reflector materials. The solar cooker demonstrated commendable proficiency in boiling water, heating oil, frying eggs, and crisping crackers, accomplishing these tasks within a time frame ranging from 5 to 20 minutes. Notably, the solar cooker featuring the glass mirror reflector exhibited a superior thermal efficiency of 33.7%, surpassing the efficiency of the counterpart with the chrome sticker reflector, which registered an efficiency of 30.9%. These findings underscore the efficacy of the glass mirror reflector in harnessing solar energy for enhanced cooking performance within this solar cooker configuration.

Keywords:
Parabolic trough, Solar cooker, Collector, Sticker chrome, Glass mirror

1 Introduction

Culinary art, a quintessential facet of human existence globally, holds a significant role in the daily life of the Indonesian populace. Historically, the cooking process in Indonesia, like in many other regions, has been predominantly reliant on traditional fossil fuel sources, such as kerosene and firewood. Nevertheless, in recent times, there has been a discernible shift away from this traditional reliance on kerosene and firewood within the Indonesian culinary landscape. This transformation can be attributed to a series of policy initiatives undertaken by the Indonesian government aimed at incentivizing the adoption of LPG (Liquefied Petroleum Gas) as a more sustainable and environmentally responsible alternative for cooking purposes [1].

Notwithstanding the observable reduction in the utilization of traditional fossil fuels for culinary purposes, it is imperative to acknowledge that the consequential carbon dioxide (CO_2) emissions continue to bear notable significance. Specifically, the combustion of kerosene, firewood, and LPG gives rise to CO_2 emissions in the order of approximately 179 grams of CO_2 equivalent per megajoule (g CO_2 eq./MJ), 70 g CO_2 eq./MJ, and 160 g CO_2 eq./MJ, respectively. These figures underscore the persistent environmental implications associated with cooking practices despite transitioning away from specific fossil fuel sources [2]. The overconsumption of firewood has substantially exacerbated deforestation and environmental degradation in the Indonesian context [3].

Adopting renewable energy sources has emerged as a compelling and viable solutionto addressing this challenge. The Indonesian government, in line with its commitment to combat these issues, has undertaken a strategic initiative to elevate the utilization of renewable energy. As part of this initiative, the government has set ambitious targets, aiming to achieve a renewable energy contribution of 23% by the year 2025 and further escalate this to 30% by 2030, with a specific focus on integrating 5% of solar energy into the national energy matrix [4]. Due to its strategic equatorial location, Indonesia presents substantial promise in harnessing solar energy. The nation benefits from an ample solar resource, with solar radiation intensity ranging between 4.5 to 5.1 kilowatt-hours per square meter per day ($kWh/m^2/day$), featuring monthly variations typically within the range of 9% to 10% [5]. Consequently, solar energy stands out as one of the most auspicious renewable alternatives to supplant fossil fuels in culinary applications.

Solar Energy holds significant promise in fulfilling thermal energy needs for cooking. A prominent example of its practical application is the solar cooker, a technology that has seen progressive development since the 18th century. This journey of evolution traces back to pioneers such as Tschirnhausen (1651-1708), followed by Swiss scientist Horace de Saussure in 1767. Subsequent advancements in solar cooker technology were driven by the work of Sir John Herschel (1830), AugustinMouchot (1860), W. Adams (1876), Mouchot (1877), Clarence Kemp (1891), and Xiao in Sichuan (1894). These contributions collectively mark significant milestones in the historical development of solar cooking technology [6]. Furthermore, it is essential to note that the evolution of solar cookers continues, with numerous contemporary innovations and developments in the field [7]. Solar cookers operate on the fundamental principle of harnessing sunlight to generate elevated temperatures suitable for culinary purposes. These solar cookers can be categorized into three primary types: the box-type, the concentration-type, and the panel-type solar cookers [8]. The concentration-type solar cooker distinguishes itself by its capacity to generate a more intense and higher heat source compared to the other solar cooker types [9][10].

Several subtypes exist within the concentration-type solar cooker category, such as the parabolic trough type, parabolic dish, and fresnel lens, each offering distinct design and performance characteristics [11]. All three of these solar cooker types share the advantage of concentrating sunlight to attain temperatures of up to 220°C, particularly during the time frame from 11 a.m. to 2 p.m. However, inherent challenges, such as variations in the focal point due to the sun's movement and the potential discomfort caused by solar radiation during cooking, have led to the proposal of adopting parabolic trough-type solar cookers in various studies. These cookers offer excellent stability despite solar radiation intensity fluctuations, ensuring a more consistent cooking experience[12].

The parabolic trough-type solar cooker is an apparatus designed to harness sunlight or thermal energy through a focused system. Its operational principle revolves around the reflection of solar radiation, which impinges upon the collector's surface, converging at a specific focal point or area. This concentration of solar thermal energy results in the generation of exceedingly high temperatures conducive to cooking and other applications [9].

The parabolic trough-type solar cooker primarily comprises seven key components: the solar collector, reflector, receiver, tilt mechanism, cooking container holder, cooking pot, and frame. These elements collaboratively contribute to the functionality and performance of the solar cooker. [13]. A solar collector is a specialized device engineered for the purpose of capturing and converting sunlight into thermal energy, which can subsequently be harnessed for various practical applications [14]. The solar collector requires a reflector, serving as a component that redirects and focuses incoming solar radiation onto the receiver [15]. The efficacy of a solar collector is intricately tied to the quality and characteristics of its reflector. Reflectors typically feature surfaces crafted from a range of materials, including polished aluminum, aluminized plastic, stainless steel mirrors, chrome stickers, chrome nickel, glass, and acrylic mirrors. The choice of reflector material is a critical factor that significantly influences the overall performance of the solar collector [13,15,16]. Numerous research endeavors have been undertaken to assess the efficacy of reflectors in the context of concentrated solar power. Among these investigations, a notable study was conducted by Kenneth Ritter III and colleagues. Their research findings demonstrated that the solar mirror film material, specifically the type of 3M SMF 2020 (commonly known as sticker chrome), exhibited superior effectiveness on sunny days compared to the glass mirror material of the yellow glass-colored silver type. This comparison highlights the distinctive performance attributes of these two reflector materials under varying environmental conditions [17]. The receiver component within the parabolic trough structure serves as an absorber of concentrated solar energy. Typically, it is designed with a copper tube enveloped by a protective cover of either glass or plastic [18,19]. Contained within the tube is a working fluid, which serves as a heat conductor, facilitating the transfer of thermal energy to the cooking container holder. Various sources and references have cited multiple working fluids suitable for this purpose, including but not limited to vegetable oil, sunflower oil, olive oil, engine oil, soybean oil, coconut oil, and *mobiltherm* 605. These working fluids play a critical role in the overall functionality of the solar cooker [20][21][22][23][24].

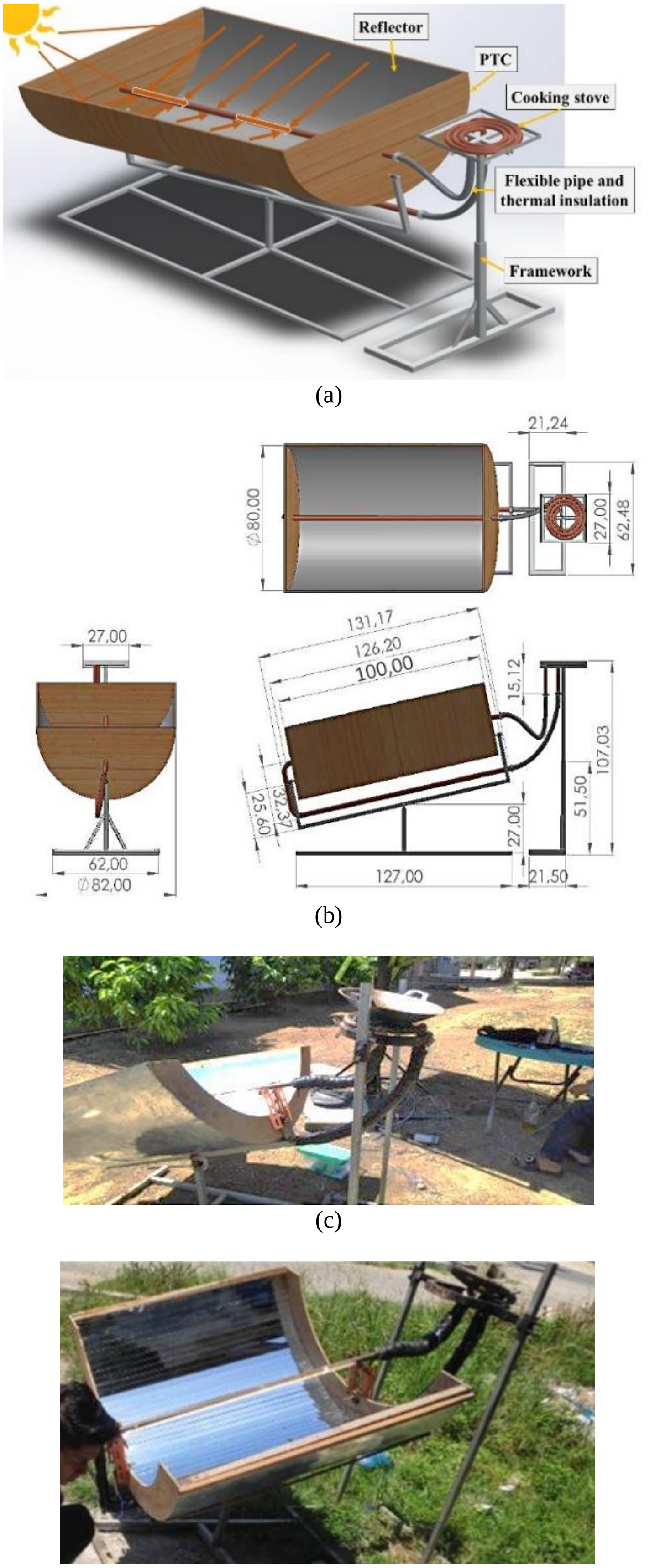
The tilt mechanism incorporated into a parabolic trough-type solar cooker is meticulously engineered to align with the sun's trajectory as it moves across the sky. Typically, two prevalent types of tilt mechanisms are employed: manual mechanisms, which require human intervention to adjust, and automatic sun tracking systems, which autonomously orient the solar cooker to follow the sun's path. These mechanisms ensure the cooker optimally captures solar radiation throughout the day, enhancing its efficiency [25],[26]. Furthermore, the cooking vessel holder is pivotal in dictating the solar cooker's cooking capabilities. Diverse designs exist for these holders, ranging from distinct and detached from the cooking vessel (pot) to integrated units that combine both functionalities. Each design bears its unique set of advantages and drawbacks. For instance, in the study by Asmelash and colleagues, a separate cooking vessel holder was devised, featuring an additional box-shaped oil storage serving as a heating vessel. One limitation of this design is the necessity for the cooking pot to be compatible and adjustable to the holder, introducing an element of constraint into its practical use [21]. Kumaresan et al. designed a solar cooker stand separate from the cooking container of the tava type [23]. Moussaoui and colleagues devised a cooking vessel holder with an integrated design that seamlessly doubles as the cooking container. In this context, the cooking container is engineered as a pressurized apparatus akin to a pressure cooker [27]. In the work by Saini and collaborators, the solar cooker stand is distinct and separate from the cylindrical cooking vessel, reflecting a separation in design between the stand and the cooking container [28].

Studies pertaining to parabolic trough-type solar cookers are typically conducted using a combination of experimental methodologies and numerical analyses. These investigations encompass a range of tests aimed at assessing key performance indicators such as efficiency, exergy, and the cooker's capacity to facilitate practical cooking experiments. Despite the substantial potential for solar cookers in Indonesia, the body of literature ondeploying parabolic trough-type solar cookers equipped with various reflector materials remains somewhat limited.Hence, this research endeavors to bridge this knowledge gap by conducting experimental tests involving parabolic trough-type solar cookers configured with two distinct reflector materials. The anticipated outcomes of this study hold the potential to enhance our comprehension of the viable integration of renewable energy sources, particularly within the Indonesian context. Moreover, the findings are poised to shed light on the practical applications that can foster sustainability and offer tangible benefits to the local community.

This research's primary objective is to comprehensively evaluate the operational performance of a parabolic trough-type solar cooker utilizing two distinct reflector materials. This assessment will encompass an in-depth analysis of the solar cooker's efficiency and capability to facilitate various cooking experiments effectively.

2 Research Methods

Figure 1 depicts the solar cooker system utilized in this study. The constructed solar cooker comprises several integral components, notably the Parabolic Trough Collector (PTC), absorber tube, flexible pipe, and cooking container holder. The PTC in use has dimensions with a trough length of 100 cm and an aperture width of 82 cm, resulting in a collector area of 1.58 m². Positioned on the collector are reflectors, exemplified in Figure 1c as a chrome sticker and Figure 1d as a glass mirror. The copper absorber tube features specific dimensions, including a length of 131.17 cm and a diameter of 2 in. The cooking vessel holder is designed in a spiral configuration, ensuring compatibility with various cooking vessels. This holder is also crafted from copper. A flexible pipe enhances the mobility and flexibility of the solar cooker system by being strategically positioned between the copper stand and the absorber tube. Rockwool insulation material was applied to the flexible pipe to enhance thermal insulation. The comprehensive specifications and dimensions of the solar cooker apparatus and its constituent materials are documented in Table 1. Subsequently, 2 liters of soya oil was introduced into the absorber tube, serving as a heat transfer medium to facilitate heat transfer to the cooking container. The choice of soybean oil as the heat transfer medium is consistent with previous research by Kalbande and colleagues, affirming its suitability owing to its suitable boiling point for solar cooker applications and widespread accessibility[20]. Experimental trials involving water and palm oil samples were conducted using adaptable cooking containers. Detailed property data for both soya and palm oil can be found in Table 2.



(a)

(b)

(c)

(d)

Fig 1. illustrates the design of the parabolic trough-type solar cooker, including. (a) its components, (b) the dimensions of the solar cooker, (c) the presence of a chrome sticker as a reflector, and (d) the incorporation of a glass mirror as an alternative reflector.

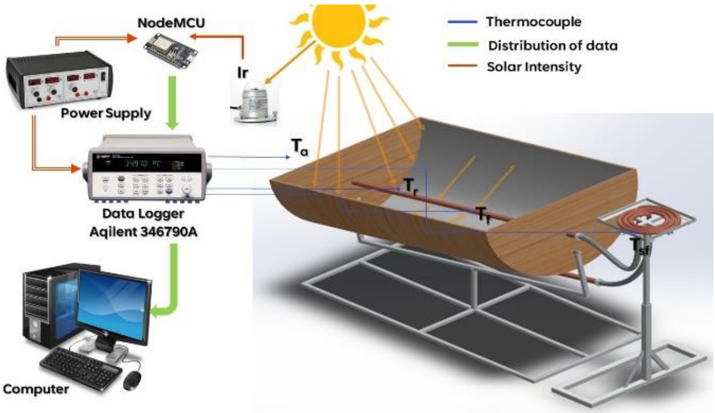


Fig 2. The schematic diagram is used for testing purposes.

This research constitutes an experimental investigation conducted at the Faculty of Engineering, Universitas Samudra, located in Aceh, Indonesia, at a latitude of 4°27'31.4" N and 97°58'14.0" E. The tests were meticulously scheduled according to the sun's trajectory, commencing at 06.18 WIB in Langsa City and concluding at sunset at 18.41 WIB. The solar cooker trials were executed on separate days featuring hot weather conditions, and the tests involved the deployment of solar cookers equipped with reflectors made from chrome stickers and glass mirrors. These assessments encompassed two phases: one without any applied load and the other with a specified load.

Table 1. The key components are integral to the parabolic trough-type solar cooker.

The item	Type of material	Parameters	Description
PTC	-	Aperture width (W) Depth (D) Trough Length (L) Focal length (f) Rim angle (ϕ_R) Concentration ratio (CR) PTC area	82 cm 32.37 cm 100 cm 12.98 cm 115.31° 24.62 1.1 m^2
Reflector	Sticker chrome Glass mirror	Reflectivity Reflectivity	91% 91%
Absorber tube	Cooper	Inner Diameter (D_i) Outside Diameter (D_o) Length (L) Total Area Absorber Thermal conductivity	4.67 cm 5.08 cm 99.6 cm 0.016 m^2 380 $W/m^2.K$
Cooker Furnace (spiral pipe)	Cooper	Diameter Thickness Area Thermal conductivity	5.08 cm 0.2 cm 0.13 m^2 380 W/m.K
Thermal insulation	Rockwool	Thermal conductivity	0.04 W/m.K

In the no-load test, the tilt angle of the Parabolic Trough Collector (PTC) was systematically adjusted at four different angles: 15°, 20°, 25°, and 30°. The measured parameters encompass solar radiation intensity (I_r), ambient temperature (T_a), fluid temperature (T_f), Receiver Temperature (T_r), and furnace temperature (T_{sf}). Subsequently, the optimal PTC tilt angle, determined through the no-load test, was selected in the test involving a load. Once the most suitable PTC angle was identified in the no-load test, the evaluation extended to additional parameters, focusing on measuring the oil temperature (T_o) in the test with load. Temperature measurements were conducted utilizing K-type thermocouples characterized by a high precision level with an accuracy of ±0.1% and a broad temperature range from -270 to 1260 °C. These thermocouples were linked to an Agilent 346790A type Data Acquisition System (DAQ) data recording system, featuring an accuracy level of ±0.2%. Data acquired from the DAQ system was subsequently processed utilizing a computer. The outcomes of the experiments were meticulously collated and presented in the form of tables and graphs, thereby facilitating a comprehensive comprehension and analytical assessment of the research findings.

ASentec model pyranometer (SEM228A) was employed to measure solar radiation intensity, offering an accuracy of ±2% and an expansive measurement range from 0 to 1800 W/m². The experimental procedure is visually depicted in Figure 2.Upon the completion of parameter measurements, the subsequent phase entailed the practical application of the solar cooker for cooking, boiling, and frying various samples, including boiling water, frying eggs, and crisping crackers. The assessments were directed towards quantifying water boiling time (measured in minutes) and frying time (also in minutes), alongside a qualitative evaluation of the resultant food products.

Table 2. Specification of soybean oil and palm oil [20][29].

Fluids	**Boiling temperature (ºC)**	**Density (kg/m³)**	**Specific heat (kJ/kg.K)**
Soybean oil	257 ºC	903.3 – 807.4	1.692 – 2.149 kJ/kg.K
Palm oil	302.2 ºC	800 kg/m³	2.081 kJ/kg.K

Lastly, the efficiency of the tested parabolic trough-type solar cooker (η) was computed employing the following equation:
The calculation of energy input (E_i) for the solar cooker involves the use of the equation (1) [30].

$$E_i = I_r . A_{sf} . t \tag{1}$$

Energy output (E_o) for the solar cooker is computed using the equation (2) [31].

$$E_o = m_f C_{pf} \left(T_{f2} - T_{f1} \right) \tag{2}$$

The efficiency (η) of the solar cooker can be determined using equations (3) and (4)[32].

$$\eta = \frac{E_o}{E_i} \tag{3}$$

$$\eta = \frac{m_f C_p (T_{o2} - T_{o1})}{I_r A_{sf} t} \tag{4}$$

In the given equation, the variables are defined as follows:

- m represents the mass of water or oil.
- C_p denotes the specific heat capacity of water (4118 kJ/kg·°C) or the specific heat capacity of oil (2.1 kJ/kg·°C).
- T_{o1} signifies the initial temperature of water or oil (in °C).
- T_{o2}signifies the initial temperature of water or oil (in °C).
- I_r indicates the solar radiation intensity (in W/m²).
- A_{sf} stands for the area of the spiral furnace (in m²).
- t corresponds to the time required for cooking (in seconds)

3 Results and Discussion

This experiment delves into the influence of employing parabolic reflectors constructed from chrome stickers and glass mirrors within the context of solar cooker applications. The research encompasses multiple phases: investigations without any load, with applied load, practical assessments involving boiling water and frying various food products, and the subsequent computation of the solar cooker's efficiency. The experiments were executed from 10:00 a.m. to 4:00 p.m. on specific sunlit days. The initial test sequence involved the solar cooker employing chrome sticker reflectors, progressing through phases commencing with no load, followed by load application, practical cooking exercises, and culminating in efficiency calculations. Subsequently, an analogous series of tests was conducted employing a solar cooker equipped with glass mirror reflectors, mirroring the stages employed with the chrome sticker reflector solar cooker.

The initial phase of research without any load was conducted to ascertain and achieve spiral furnace temperatures surpassing 100°C, which is a prerequisite for advancing to tests involving a load. The trials involving a load were intended to validate the practical application of solar cookers and subsequently compute their performance. During the no-load test, the angle of the Parabolic Trough Collector (PTC) was systematically altered, spanning angles of 15°, 20°, 25°, and 30°. In contrast, for the load-bearing tests, the PTC angle was determined by selecting the specific angle variation that yielded the highest furnace temperature.

3.1 The no-load testing was carried out in two variants: one utilizing reflectors constructed from chrome stickers and the other employing reflectors made from glass mirrors.

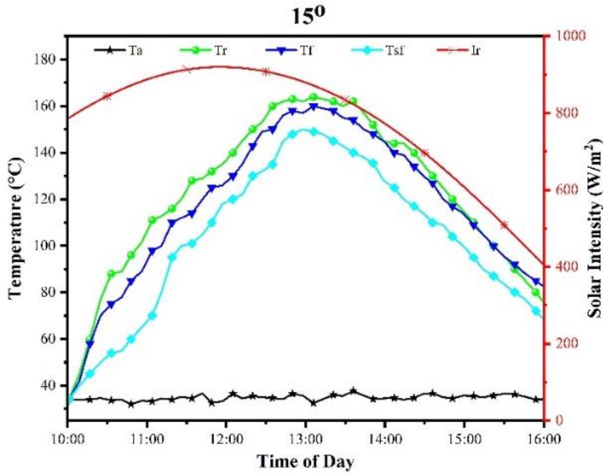
Figure 3 presents the results obtained from the no-load testing involving reflectors crafted from chrome stickers, considering four distinct Parabolic Trough Collector (PTC) angles: 15°, 20°, 25°, and 30°. The average solar radiation (I_r) and ambient temperature (T_a) measured between 10:00 and 16:00 WIB for these angles were recorded at 508 W/m² and 35.46°C. Meanwhile, the peak solar radiation (I_r) reached values of 913, 805, 897, and 765 W/m² for PTC angles of 15°, 20°, 25°, and 30°, respectively. The temperature progression exhibited a consistent pattern, commencing at 10:00 a.m. and peaking around 13:00, followed by a decline until 16:00. This pattern was observed in critical temperatures such as T_r (receiver temperature), T_f (fluid temperature), and T_{sf} (spiral furnace temperature) for all PTC angles, namely 15°, 20°, 25°, and 30°.

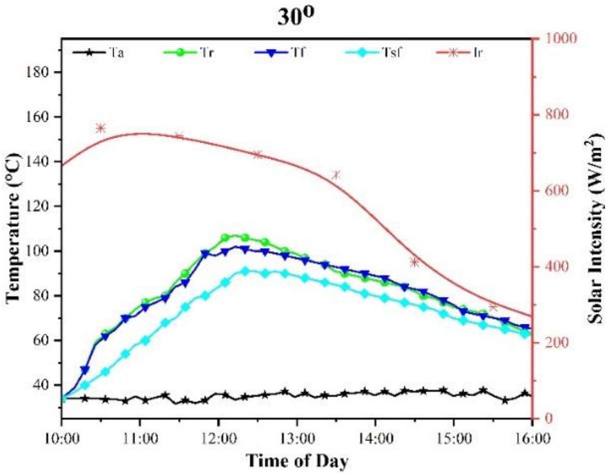
In the test employing a chrome sticker reflector at a PTC angle of 15°, the most substantial increase in fluid temperature was observed. The highest recorded fluid temperature (T_f) at a PTC angle of 15° reached 160°C, with an average of 117°C. Subsequently, the heat was transferred to the spiral furnace, resulting in the highest furnace temperature (T_{sf}) of 150°C, with an average of 102°C. Moreover, for PTC angles of 20°, 25°, and 30°, the average T_f and T_{sf} temperatures obtained were as follows: 108°C and 84.3°C, 84.8°C and 71.1°C, and 80.9°C and 72.2°C, respectively. In the tests conducted with the chrome sticker reflector, a reduction in T_{sf} temperature was observed as solar radiation diminished. The decline in T_{sf} occurred in the PTC angles of 15°, 20°, 25°, and 30°, commencing from 13:00 WIB and lasting until 14:00 WIB. Among the tests using the chrome sticker reflector, the highest gain in fluid temperature was observed at a PTC angle of 15°, where the highest fluid temperature (T_f) reached 160°C, with an average of 117°C. Subsequently, the spiral furnace temperature (T_{sf}) achieved its highest point at 150°C, with an average of 102°C. As for PTC angles of 20°, 25°, and 30°, the respective average T_f and T_{sf} temperatures recorded were 108°C and 84.3°C, 84.8°C and 71.1°C, and 80.9°C and 72.2°C.

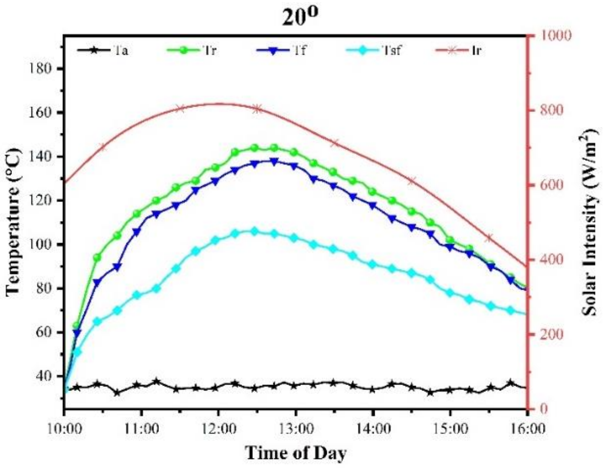
Notably, in the tests employing the chrome sticker reflector, the T_{sf} temperature exhibited a decline in correspondence with decreasing solar radiation. This decrease in $T_{sf}$was observed at PTC angles of 15°, 20°, 25°, and 30°, starting around 1:00 p.m. and continuing until 2:00 p.m. The final T_{sf} temperatures at these angles were 68°C, 68°C, 67°C, and 62°C, respectively. The ultimate T_{sf} temperatures at the respective angles of 15°, 20°, 25°, and 30° are 68°C, 68°C, 67°C, and 62°C.The data presented in all the graphs from Fig. 3 has been consolidated and summarized in Table 3.

Table 3. Summary of the test results obtained for the no-load experiments using reflectors constructed from chrome stickers at four distinct Parabolic Trough Collector (PTC) tilt angles.

Types of solar cooker collectors	PTC angle	T_a average	I_r average	I_r Max	T_r average	T_r maks	T_f average	T_f maks	The average T_{sf}	T_{sf} maks
Sticker Chrome	15°	34,8	522,38	913 W/m^2 at 11.30 a.m.	122,2	164 at 1.06 p.m.	117,1	160 at 1.06 p.m.	102,9	150 at 12.58 p.m.
	20°	35,2	450,84	805 W/m^2 at 11.30 a.m.	113,9	144 at 12.27 p.m.	108,0	138 at 12.35 p.m.	84,3	106 at 12.20 p.m.
	25°	35,5	427	897 W/m^2 at 12.30 p.m.	91,1	120 at 1.06 p.m.	84,8	109 at 1.28 p.m.	71,1	92 at 1.21 p.m.
	30°	35,18	411,38	765 W/m^2 at 10.30 a.m.	81,63	107 at 12.12 p.m.	80,90	102 at 12.12 p.m.	72,02	91 at 12.20 p.m.







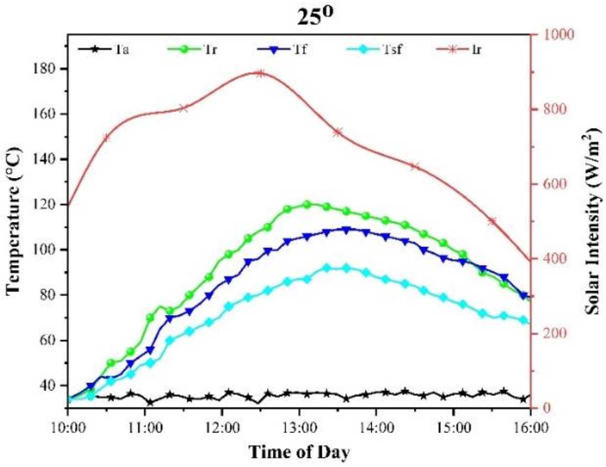


Fig 3. Illustrates the outcomes of the no-load testing conducted with chrome sticker reflectors at each of the specified Parabolic Trough Collector (PTC) angles.

The results obtained using glass mirror reflectors closely resemble those achieved with chrome sticker reflectors. In Figure 4, it is evident that the no-load tests performed at PTC angles of 15°, 20°, 25°, and 30° exhibit a consistent pattern of temperature increase commencing at 10:00 a.m. and reaching its zenith at 13:00, followed by a gradual decline until 16:00. The average values for solar radiation (I_r) and ambient temperature (T_a) recorded for PTC angles of 15°, 20°, 25°, and 30° are 478 W/m² and 35.73°C within the timeframe of 10:00 a.m. to 4:00 p.m.

In the tests employing glass mirror PTC, the 15° angle continues to yield the highest T_f and T_{sf} temperatures, reaching 160°C and 150°C, with respective averages of 117°C and 104.1°C. As for PTC angles of 20°, 25°, and 30°, the average T_f and T_{sf} temperatures recorded were 106.8°C and 90.3°C, 86.8°C and 70.5°C, and 79.3°C and 71.1°C, respectively. The ultimate T_{sf} temperatures in the glass mirror tests are similar to those obtained with chrome stickers. The final T_{sf} temperatures at angles of 15°, 20°, 25°, and 30° are 68°C, 65°C, 47°C, and 54°C, respectively.

The obtained T_{sf} values signify that the testing can proceed to the phase involving load application since the furnace temperature meets the requisite threshold for cooking, exceeding 100°C. As depicted in all the graphs from Fig 4, these results have been condensed and presented in summary form in Table 4.

3.2 The subsequent stage encompassed tests involving loads, utilizing both chrome sticker reflectors and glass mirror reflectors.

During the testing phase with loads, water and coconut oil were employed as the sample loads. The experiments were conducted on July 30, 2023, for the solar cooker equipped with chrome sticker reflectors and on August 06, 2023, for the solar cooker featuring glass mirror reflectors. Figure 5 portrays the outcomes of the load tests for these two distinct scenarios, conducted at a PTC angle of 15° due to the significantly high T_{sf}values achieved at this angle.

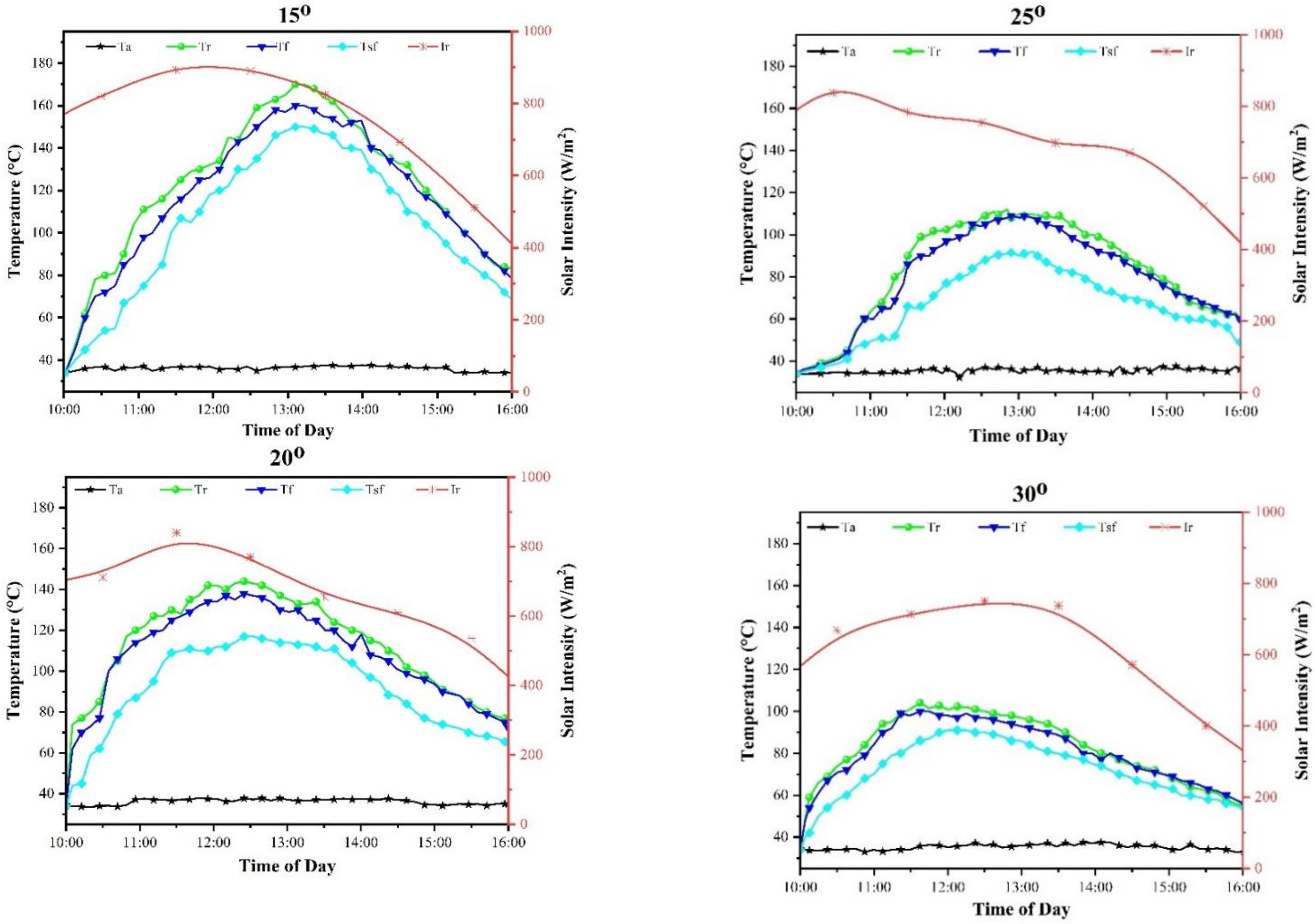


Fig 4. Test results were obtained without load, utilizing glass mirror reflectors at various Parabolic Trough Collector (PTC) angles.

Table 4. Summary of test results derived from the no-load experiments conducted using glass mirror reflectors at four distinct Parabolic Trough Collector (PTC) tilt angles.

Types of solar cooker collectors	PTC angle	T_a average	I_r average	I_r Max	T_r average	T_r maks	T_f average	T_f maks	The average T_{sf}	T_{sf} maks
Glass mirror	15°	36,1	501,53	893 W/m² at 11.30 a.m.	122,0	170 at 1.06 p.m.	117,0	160 at 1.06 p.m.	104,1	150 at 1.06 p.m.
	20°	36,1	478,46	840 W/m² at 11300 hrs.	111,5	144 at 12.24 p.m.	106,8	138 at 12.24 p.m.	90,3	117 at 12.24 p.m.
	25°	35,5	488,53	838 W/m² at 10.30 a.m.	89,7	109 at 12.33 p.m.	86,8	109 at 12.54 p.m.	70,5	92 at 1.11 p.m.
	30°	35,2	401,92	751 W/m² at 12.30 p.m.	81,3	104 at 11.37 a.m.	79,3	100 at 11.37 a.m.	71,1	91 at noon.

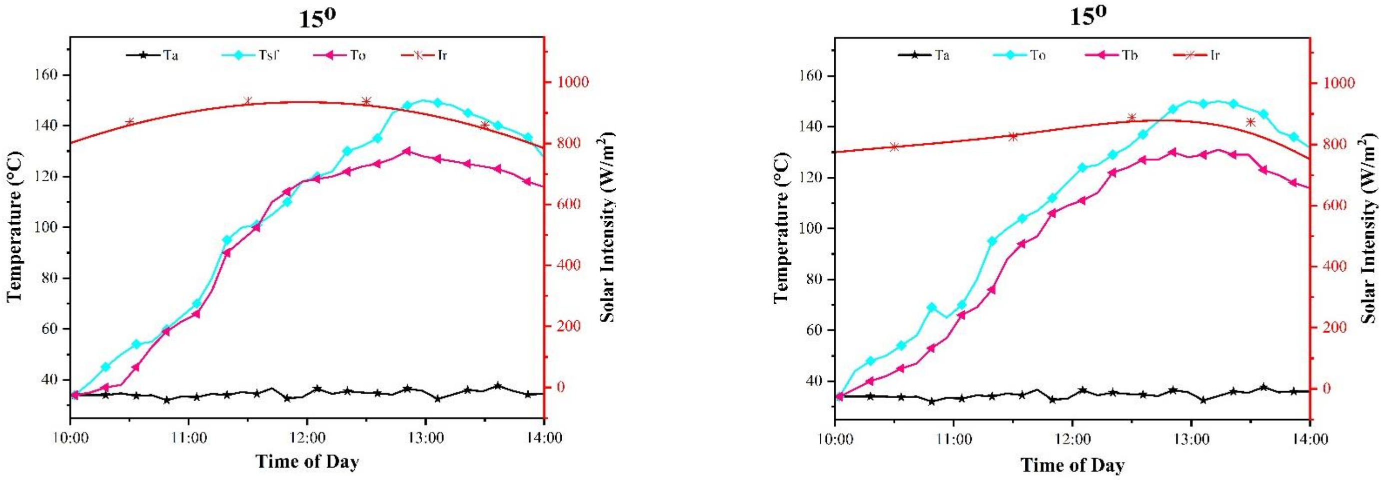


Fig 5. The test results obtained with a load for two different scenarios, (a) Sticker chrome; (b) Glass mirror

Fig 5a shows the results of load testing with a solar cooker employing chrome sticker reflectors. The average ambient temperature (T_a) recorded is approximately 35°C, while the average solar radiation (I_r) measures around 540.76 W/m², reaching its peak value of 939 W/m² at 11:30 a.m. During the load tests using the large chrome sticker, the furnace temperature (T_{sf}) achieved a maximum of 150°C at 12:58 p.m., with an average T_{sf} of 102.92°C. Subsequently, the heat from the furnace was employed to heat the load in oil, with the highest oil temperature (T_o) recorded at 130°C at 12:50 p.m. and an average T_o of 92.97°C.

Similarly, in the load testing with glass mirrors, as depicted in Fig 5b, the maximum solar radiation intensity reached 888 W/m² at 12:30 p.m., with an average I_r of 592.53 W/m². The received radiation generated averages of T_o and T_{sf}, measuring 89.98°C and 102.92°C, respectively, in the context of an average ambient temperature (T_a) of 35°C. The highest T_o and T_{sf} temperatures recorded were 131°C at 13:13 and 150°C at 13:13.

3.3 Cooking experiments utilize solar cookers equipped with reflectors constructed from chrome stickers and glass mirrors.

The cooking experiments were conducted using solar cookers with reflectors constructed from chrome stickers and glass mirrors, involving boiling water, heating oil, and frying eggs. For both scenarios, the experiments were carried out over 2 hours, commencing at 11 a.m. and concluding at 2 p.m., during hot weather conditions. At the outset of the cooking experiments with chrome sticker reflectors, the radiation level at 11 a.m. was measured at 939 W/m². In contrast, the radiation at 11 a.m. was recorded at 826 W/m² for the cooking experiments with glass mirror reflectors.

Figure 6 shows a cooking experiment using solar cookers equipped with chrome sticker reflectors, focusing on boiling water. A wok pan was employed as the container for boiling the water, utilizing a volume of 200 mL, equivalent to a mass of water of 0.2 kg. The water was boiled for approximately 14 minutes, utilizing a furnace temperature of 120°C.

Fig 6. Experiment with boiling water using reflectors made from chrome stickers.

Figure 7 portrays a cooking experiment involving solar cookers equipped with chrome sticker reflectors for heating oil. A wok pan served as the container for heating the oil, utilizing 200 mL of coconut oil, equivalent to a mass of 0.18 kg. It took approximately 19 minutes to heat the coconut oil to boiling, with the furnace temperature maintained at 149°C.

In Fig 8, a cooking experiment is depicted, which involves frying eggs using a solar cooker equipped with chrome sticker reflectors. The process required approximately 17 minutes to thoroughly cook the egg, with the furnace temperature maintained at 128 °C.

Fig 7. Illustration of the experiment involving the heating of coconut oil using a solar cooker equipped with chrome sticker reflectors.

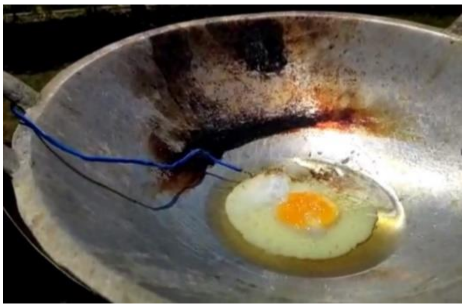


Fig8. The experiment involved frying an egg using a solar cooker equipped with chrome sticker reflectors.

Figure 9 illustrates a cooking experiment with a glass mirror collector focusing on boiling water. A wok pan was utilized as the container for boiling the water, with a volume of 200 mL, equivalent to a mass of water of 0.2 kg. The experiment took approximately 15 minutes to bring the water to a boil, with the furnace temperature maintained at 120°C. During the cooking experiments employing solar cookers equipped with glass mirror reflectors, the focus was on heating oil. A wok pan was used to heat the oil, with 200 mL of coconut oil corresponding to a mass of 0.18 kg. It took approximately 19 minutes to heat the coconut oil to boiling, with the furnace temperature maintained at 149°C.

Fig 9. The experiment in which water was boiled using a solar cooker equipped with a glass mirror reflector.

Figure 10 presents a cooking experiment conducted using a solar cooker equipped with a glass mirror reflector, focusing on frying an egg. A wok pan served as the container for heating the oil, which was 200 mL of coconut oil, corresponding to a mass of 0.18 kg. The experiment involved heating the coconut oil for approximately 20 minutes, with the furnace temperature maintained at 150°C. Subsequently, it took around 10 minutes to fry the eggs until they were fully cooked, with the furnace temperature remaining at 150°C.

Fig 10. Illustration of the experiment involving egg frying using a solar cooker equipped with a glass mirror reflector.

Figure 11 showcases a cooking experiment involving frying crackers using a solar cooker equipped with a glass mirror reflector. The process required approximately 10 minutes to cook the crackers thoroughly, with the furnace temperature at 150°C.

Fig 11. The experiment involved frying crackers using a solar cooker equipped with a glass mirror reflector.

Table 5 summarizes the results of all cooking experiments conducted with parabolic trough-type solar cookers utilizing two different reflector materials.

Table 5. Summary of cooking experiments on two different reflector types

Solar cooker solar reflector material	**Cookery test**	**Total cookery time**
Sticker chrome	Boiling water at 200 mL volume, T_{sf} 120°C	14 minutes
	Heating oil at 200 mL, T_{sf} 149°C	19 minutes
	Frying eggs at T_{sf} 128°C	17 minutes
Glass mirror	Boiling water at 200 mL, T_{sf} 120°C	15 minutes
	Heating oil at 200 mL, T_{sf} 150°C	20 minutes
	Frying eggs at T_{sf}150˚C	10 minutes
	Frying at T_{sf} crackers, 150˚C	5 minutes

According to equation 4, the efficiency of a well-performing solar cooker with a chrome sticker reflector is determined to be 30.9%, requiring 19 minutes for cooking. On the other hand, the efficiency of the solar cooker with a glass mirror reflector is measured at 33.7%, with a cooking time of 20 minutes.

4 Conclusion

The parabolic trough-type solar cooker has been successfully designed, tested, and employed using both chrome sticker and glass mirror reflectors. These solar cookers consistently achieve furnace temperatures exceeding 100°C when set at a PTC angle of 15°. Extensive testing has demonstrated the solar cookers' capability to boil water, heat oil, and fry eggs and crackers. Remarkably, both types of solar cookers exhibit strong performance, with reflectors made of sticker chrome achieving an efficiency of 30.9% and those made of glass mirrors reaching an efficiency of 33.7%.

Acknowledgments

Our deepest gratitude to all those who have helped successfully implement this research, especially *Lembaga Penelitian Pengabdian kepada Masyarakat dan Penjaminan Mutu* (LPPM and PM) Universitas Samudra scheme *Penelitian Lektor* 611/UN54.6/PG/2023, which already invested trust in our capability to conduct this research.

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