

THE SPECIFIC CHARACTERISTICS OF TIME AND TEMPERATURE INSIDE A VACUUM GLASS TUBE FOR COOKING RAW INGREDIENTS BY ADJUSTING THE ANGLE OF SOLAR RADIATION AND TYPE OF REFLECTOR

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ABSTRACT

This research reports the design and construction of a solar oven for the cooking of raw ingredients with reduced gas consumption. There are three main components to the solar oven: an adjustable angle base, a parabolic rail, and an ingredient tray. The designed components are used together with a vacuum tube to cook raw ingredients. The performance testing process of the constructed solar oven was separated into two conditions. First, the improvement of the temperature inside the solar oven was measured with a tilt angle of 0° using foil, aluminum, and stainless steel as the base materials of the parabolic rail. Second, the temperature inside the solar oven was measured using a stainless-steel parabolic rail at 0°, 15°, and 30°. After one hour of testing, the solar oven produced an inside temperature in the vacuum tube of 116.6 °C, 118.1 °C, 100.5 °C, and 84.4 °C for the parabolic rail with foil, aluminum, stainless steel, and solar without a parabolic rail. The ingredients weighing 50 grams were reduced to around 20 grams after testing. With the angle adjustment of the parabolic rail condition, the temperature inside the vacuum tube reached maximum values at a tilt angle of 15°, with the inside temperature ranging from 90 to 120 °C. The weight of the ingredients after testing was reduced to around 33 grams without the reflector and to between 25 and 28 grams with the reflector

attached. The results suggested that solar oven equipped with aluminum reflector below the vacuum glass tube and when tilting at 15° produce the most heat to cook the raw ingredients.

Keywords: Solar oven, Parabolic rail, Solar energy, Cooking, Reflection angle

I. INTRODUCTION

Sunlight is a clean and abundant natural energy source. Over the decades, humans have developed various technologies to utilize solar energy a source for both heat and electricity conversion. These technologies have gathered increasing interest and usage because of their low investment cost and non-pollutive properties. As for the use of solar heat energy in particular, humans have developed technologies for various applications such as water heaters, dryers, solar cooking stoves, etc (Department of Alternative Energy Development and Efficiency, 2010, pp. 23-25; Sonsaree et al., 2014, pp. 105-121; Dasin et al., 2011, pp. 43-51; Al-Soud et al., 2010, pp. 463-470).

Base on literature, a solar oven is a low-cost instrument that heats the contents of a container, and it can be used for cooking and drying, based on the materials used to construct the oven. A solar oven concentrates solar radiation and converts it into heat energy. When used for cooking, ramping time is needed to raise the temperature until it reaches the appropriate cooking point. Concentrated sunlight needs to be distributed across the solar oven for it to operate (Al-Soud et al., 2010, pp. 463-470; SLiCK Solar Stove UK, 2017, Online; Rathore & Chopra, 2012, pp. 2277-9477). In the case of a solar oven with a parabolic reflector, solar rays are concentrated on a singular focal point. The material commonly used to construct the reflector is either polished aluminum or stainless steel (Rathore & Chopra, 2012, pp. 2277-9477). The advantage of this variant of solar oven is that it has faster temperature ramping compared to box-type ovens (Coccia et al., 2012, p. 023110; Öztürk, 2004, pp. 67-71; Ayompe et al., 2011, pp. 3370-3378).

A further review of the literature also reveals that the design and construction of a vacuum glass tube solar oven with a parabolic reflector is still very rare in Thailand. Therefore, this study proposes the design and construction of this variant of solar oven to heat raw ingredients using solar thermal energy. In addition, the characteristics of time and temperature inside the vacuum glass tube when cooking and the effect of solar radiation intensity on the temperature inside the vacuum tube are determined by adjusting the solar radiation angle and the type of reflector (Al-Soud et al., 2010, pp. 463-470; Coccia et al., 2012, p. 023110; Öztürk, 2004, pp. 67-71; Ayompe et al., 2011, pp. 3370-3378). This solar oven with a parabolic reflector has the potential to be viable for practical use, with the temperature inside the vacuum glass tube being sufficient to cook raw ingredients within the appropriate time (Clean Heat Energy Saving Solutions (Pty) Ltd, 2018, Online). However, there are sparsely amount of report regarding comparative study of multiple materials of parabolic rail in combination of tilting angle for solar cooker applied in Thailand.



The reflected light from the parabolic reflector with appropriate types of materials and tilt angles converging on the vacuum glass tube coated with a substance that can absorb heat well should allow the temperature inside the glass tube to increase to a level sufficient to cook raw ingredients. In addition, this study proposes the application of solar thermal energy for cooking to replace the use of gas and reduce pollution by using clean energy.

II. LITERATURE REVIEW

A parabola is a conic section originating from an intersection between the cone surface and a plane parallel to the original line of the cone surface. The parabola can be defined by the points in a two-dimensional plane that are equidistant from a fixed focal point, while the fixed line is the directrix line (Alkhaldi, 2014, p. 64). For an analysis to find the size of the parabolic rail, the equation of an upward-opening parabola has the vertex at the origin (0,0) is as display in Equation (1) (Abdulhamed, 2020, pp. 47-65). The design for the vertical distance or depth of the parabolic rail equals the focus length, are as shown in the Equation (2) to (4). For the design of a parabolic rail, the suitable ratio of the focus per aperture should be equal to 0.25. Meanwhile, the reflection of light is a phenomenon in which light travels from the medium of one density to another, causing the incident light to bounce off the new medium and be reflected back to the original one. For example, the reflection of light from air to the surface of a mirror causes the light to reflect off the surface of the flat mirror and return to the air (He et al., 1991, pp. 175-186). When light hits the surface of any medium, the intensity and direction of reflection depend on the nature of the surface of that medium. If a parallel beam of light hits a smooth surface, the light reflects as a parallel beam in the same manner as the incident beam. This may result in a possibly perfect reflection or an incomplete reflection with a distorted physical image while still conserving energy, depending on the type of opaque medium in which the light is reflected (He et al., 1991, pp. 175-186). The two laws of reflection are presented in Figure 1 (Fitzpatrick, 2007, Online): (1) The incident ray that hits the medium, the reflected ray that bounces off the medium, and the normal line that divides the two exist in the same plane. (2) The incident angle is equal to the reflecting angle.

$$x = \frac{x^2}{4f} \quad (1)$$

$$y = f ; x = w^2 \quad (2)$$

$$y = \frac{\left(\frac{w}{2}\right)^2}{4f} \quad (3)$$



$$\frac{f}{w} = 0.25 \quad (4)$$

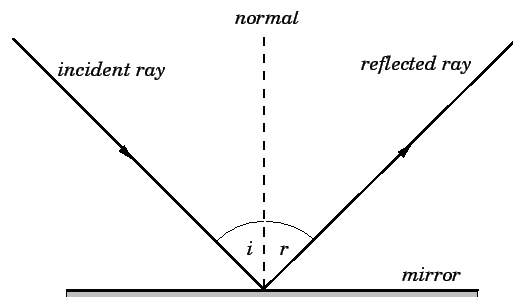


Figure 1: Light reflection
Source: Fitzpatrick (2007, Online)

Parabolic solar ovens have been studied by international researchers such as Öztürk et al. (2004, pp. 67-71), who designed and built a low-cost parabolic solar oven and evaluated the energy efficiency and energy usage of the constructed device. The energy efficiency and energy usage were found to range from 2.8 to 15.7 and 0.4 to 1.25, respectively. Al-Soud et al. (2010, pp. 463-470) designed and built a parabolic solar oven with a two-axis solar tracking system. A three-day test showed that the temperature of the water inside the glass tube used for heating can reach 90 °C on a hot summer's day when the ambient temperature is at its maximum of 36 °C. Hence, the water temperature increases when the ambient temperature is higher or the light intensity is higher. Ayompe et al. (2011, pp. 3370-3378) reported that a vacuum tube solar collector for a solar oven showed remarkable efficiency at low temperatures compared to a flat plate solar collector. In the same study, the thermal efficiency of the vacuum tube and flat plate solar furnaces when heating water under the same environmental conditions was 60.7 and 46.1, respectively. Under a fixed angle, the capability of parabolic rail materials to heat the thermally insulated glass tube should rely on their UV reflectivity. Based on study of Hussain et al. (2017, pp. 44-52), aluminum has noticeably higher capability to reflect large number of solar radiations to absorber resulting in higher thermal efficiency. Their paper report two identical conical solar collectors systems for water heating having different reflector materials under similar operating conditions where maximum thermal efficiency of aluminum reflector at 45° was 73% in comparison to 65% of stainless steeler reflector. As for comparison of aluminum and aluminum foil, the morphology of reflector plays a crucial role on specular reflection of the solar radiation as the more polished surface will has higher specular reflectivity not just in UV but in board wavelength due to lower dispersion as reported by Pozzobon et al. (2020, p. e00399). In their report, both bright side and matte side of foil result in similar total reflection but the polished bright side yielded 52.5% for specular reflection and 41.5% for diffused reflection while rough matte side yield 19.8% and 76.2%, respectively. Since specular reflection was key to control direction of solar radiation toward solar collector, the more polished aluminum surface would be more suitable as reflector. Therefore, the parabolic rail created from polished aluminum



should possess superior heating capability comparing to aluminum foil and stainless steel made ones due to its high UV reflectivity in board range. Regardless, the study to compare the performance of this cost-effective reflector material relative to each other for cooking need to be studied. To take advantage of Thailand where the country is sunny all years, the solar oven could reduce reliance on natural gas for cooking to help people who live on countryside and cut down budget for One Tambon One Product (OTOP) as well (Sanboonrat, 2001, pp. 1-2; Thipwong et al., 2022, pp. 167-180). With these knowledges in mind, the use of highly UV-reflective material as a rail combined with an appropriate tilting angle for the location (Thailand in our case study) should improve the ramp up time and temperature inside a thermally insulated glass tube for cooking purpose. As a result, chicken meat should lose its weight when properly cooked by solar oven.

III. RESEARCH METHODOLOGY

Design of the Solar Oven

Solar oven was designed through Solid Works 2017 software. Each component was design around the purchased solar collector and assembled into solar oven. Model detailing each component of the solar oven was shown in Figure 2 indicated by corresponding number as following:

1. Solar collector
2. Food tray
3. Parabolic rail
4. Ring for securing the closed end of a solar collector.
5. Ring for securing the open end of a solar collector.
6. Tilttable base



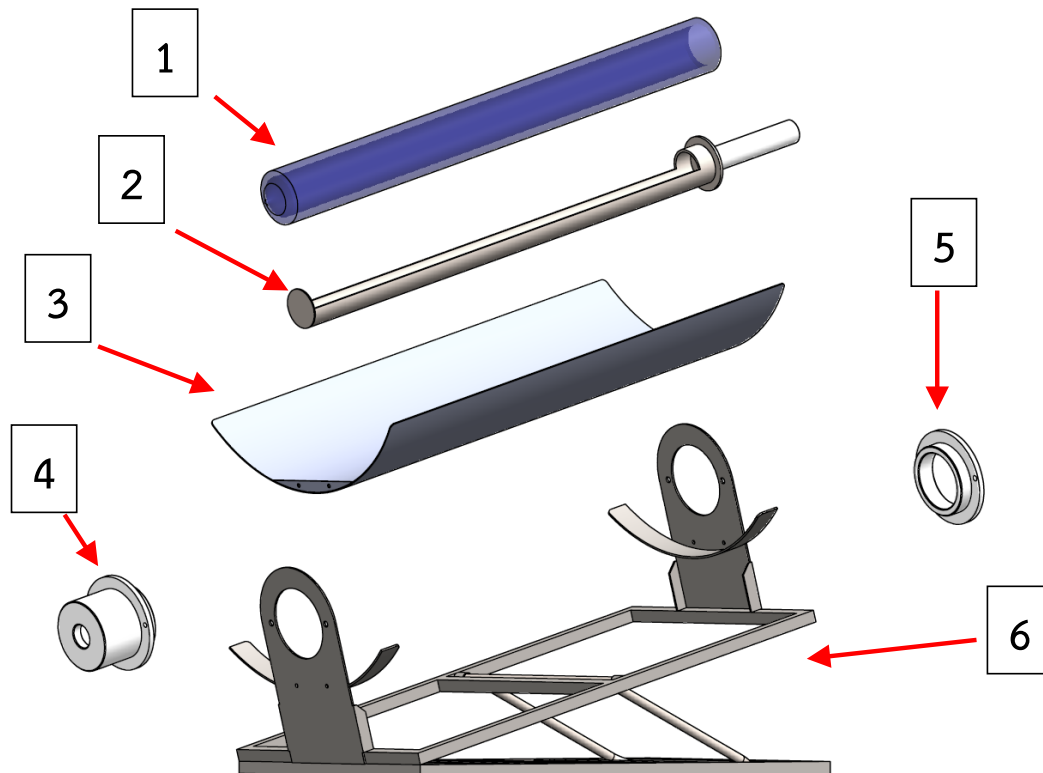


Figure 2: Model detailing each component of the solar oven

Food tray

The food tray is a component designed and constructed to hold experimental ingredients inside a vacuum glass tube of solar collector. The design details are as follows: a hollow cylindrical structure of 550 mm long, with an outer radius of 21 mm and a thickness of 2.7 mm. Both ends are sealed with circular plates of 42 mm in diameter and 1.5 mm in thickness. A 10-mm diameter hole was drilled on one of the sealed ends to insert a temperature probe of thermocouple. A handle with a 24-mm diameter and 120-mm length was attached to one end of the food tray. The main materials used in its construction are stainless steel and Teflon for the food tray and the handle, respectively.

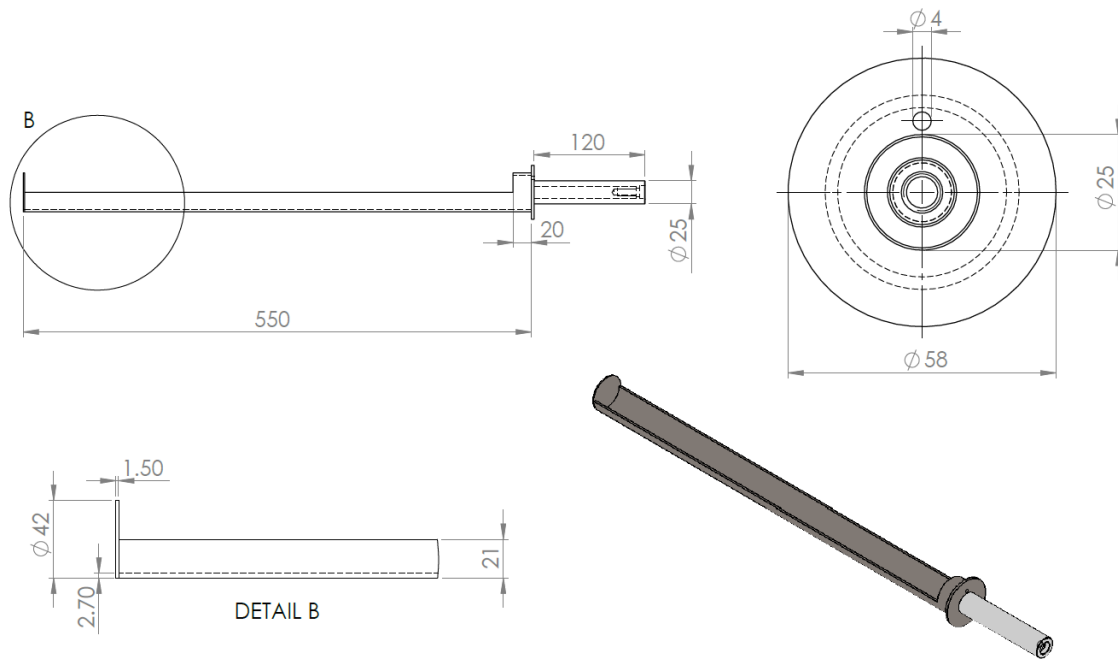


Figure 3: Schematics of food tray

Parabolic rail

The parabolic rail is a component designed to reflect solar radiation onto a vacuum glass tube, converting solar rays into thermal energy, thus increasing the temperature inside the tube. The design specifications included a width of 300 mm and a length of 540 mm, constructed primarily from stainless steel to create a curved shape with a focal length of 75 mm. The focal point was calculated using the equation $W = f / 0.25$, where f is the focal length, and W is the width of the curved base. Figures 4 and 5 show the ratio of the width and focal point of the parabolic rail and a detailed schematic of the parabolic rail, respectively. After design and construction, the parabolic rail is mounted on a tiltable base.

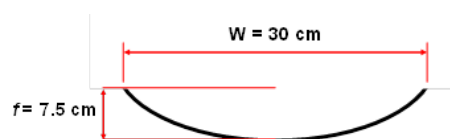


Figure 4: Ratio of the width and focal point of the parabolic rail

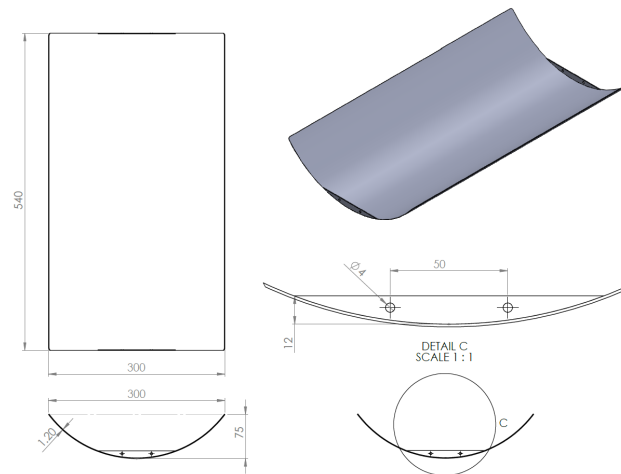


Figure 5: Detailed schematic of the parabolic rail

Ring for securing the closed end and open end of a solar collector

The clamping rings for vacuum glass tubes were designed in two directions to secure the vacuum solar collector to the main frame at both the closed and open ends of the tube, which were made of Teflon material. The design details for the closed-end securing ring of the vacuum glass tube are as follows: a hollow cylinder with an outer diameter of 100 mm and an inner diameter of 60 mm, connected to a cylinder with an outer diameter of 75 mm and an inner diameter of 60 mm, as shown in Figure 6. The design details for the open-end securing ring are as follows: a hollow cylinder with an outer diameter of 75 mm and an inner diameter of 60 mm, and a thickness of 6 mm, connected to a long cylindrical tube with an outer diameter of 100 mm and an inner diameter of 60 mm at a distance of 14 mm from one end of the long cylindrical tube, as shown in Figure 7.

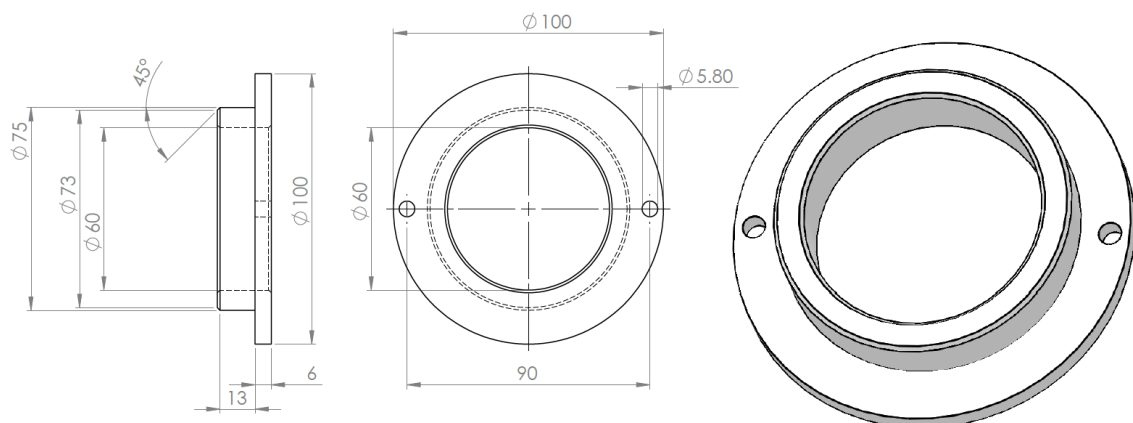


Figure 6: Schematics of ring for securing the closed end of a solar collector

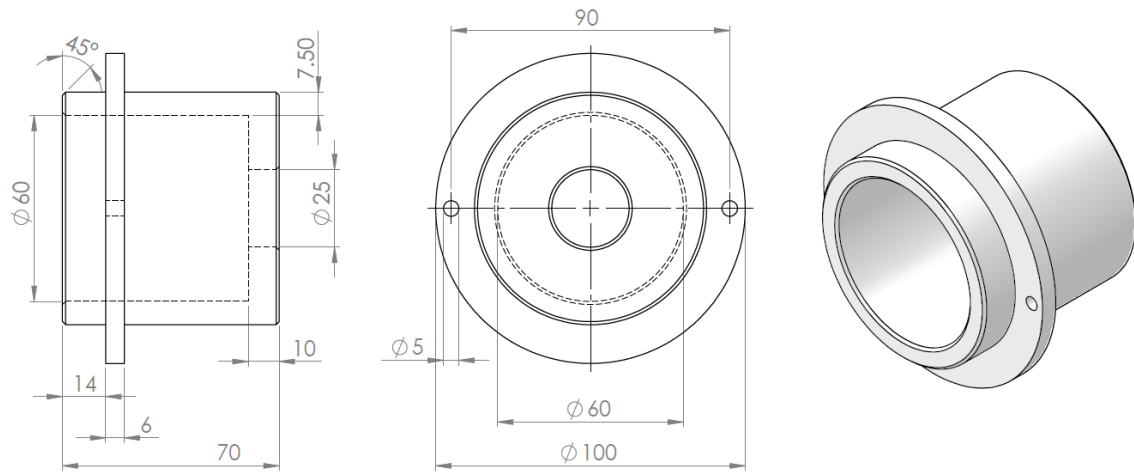


Figure 7: Schematics of ring for securing the open end of a solar collector

Tiltable base

The tiltable base is a component designed to support all the assembled parts of the solar furnace. The researchers designed this base to allow adjustment of the parabolic rail's tilting angle relative to the horizontal axis, ranging from 0, 15, to 30 degrees. The base consists of three main parts: the vacuum solar collector holder, the angular stand, and the base itself. All parts are constructed from stainless steel. The vacuum solar collector holder was designed as a frame for connection to the parabolic rail, with an overall height of 220 mm and an overall width of 120 mm. Both ends of the holder were designed for connection of the vacuum solar collector and its end-securing rings. A 76-mm diameter hole is drilled, centered at 150 mm from the horizontal base for inserting the ring and vacuum solar collector. The central section of the frame, with curved ends on both sides, was designed for connecting the parabolic rails. The width of the curve is 250 mm, and the frame panel is 2 mm thick, as shown in Figure 8.

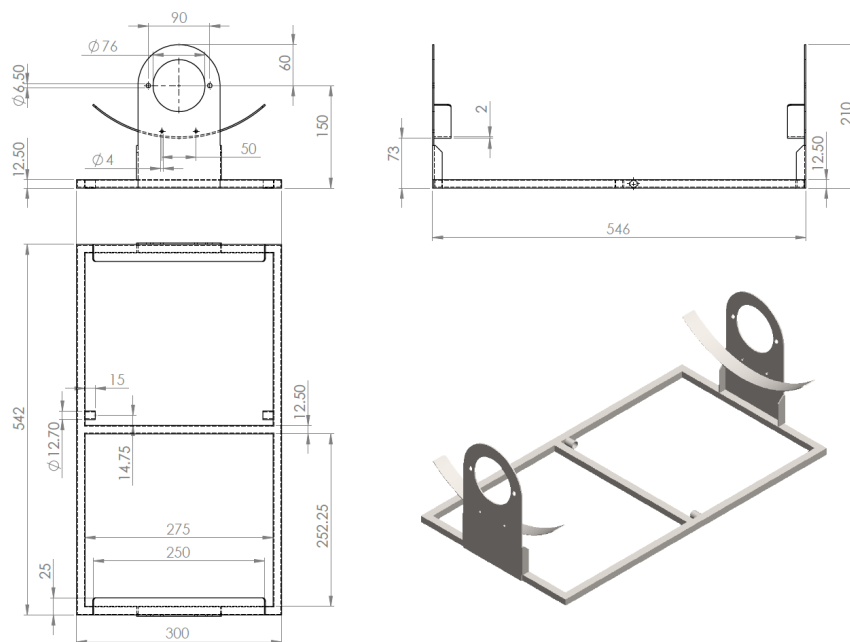


Figure 8: Schematics of holder for solar collector



The angular stand is a component that holds the tiltable base when adjusts the angular position of the system's plane. The angular stand was designed as a rectangular frame with rounded section made from a 9.50 mm diameter stainless steel cylinder welded to a 274 mm long cylindrical shaft. The combined longitudinal and transversal dimensions of the section are 274 mm and 216 mm, respectively, as shown in Figure 9.

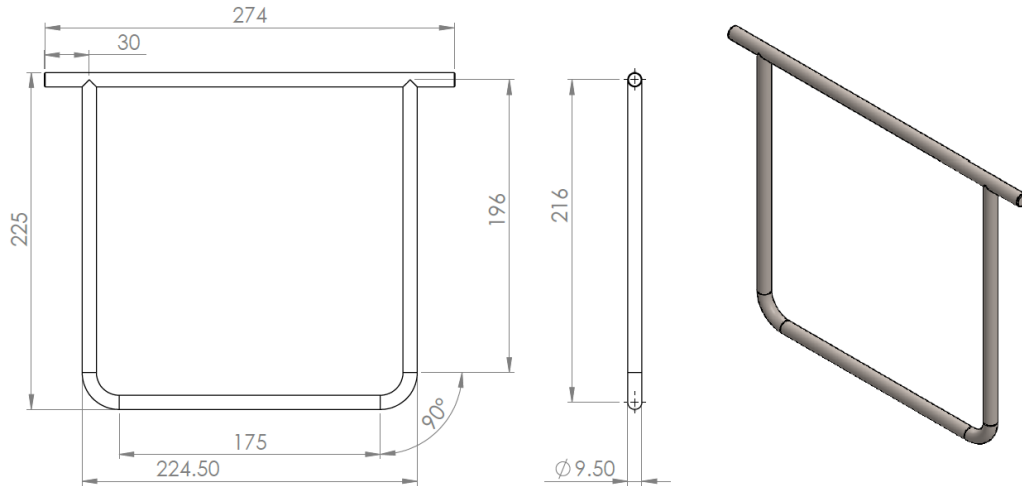


Figure 9: Schematics of angular stand

The angle-fixing base is a component that adjusts the tilting angle of the parabolic rail by adjusting the position of the angular stand according to the position of the secondary perpendicular alignment of the base. The angle-fixing base was designed as a rectangular frame with a width of 300 mm and a length of 542 mm, constructed from 12.50 mm-wide stainless steel box sections. The secondary perpendicular alignment positions were specified at distances of 390 mm and 482 mm from the bottom end of the angle-fixing base, which allows for the determination of the parabolic rail's tilting angle in respect to the horizontal axis at values of 30 and 15°, respectively. The design diagram of the angle-fixing base is shown in Figure 10.

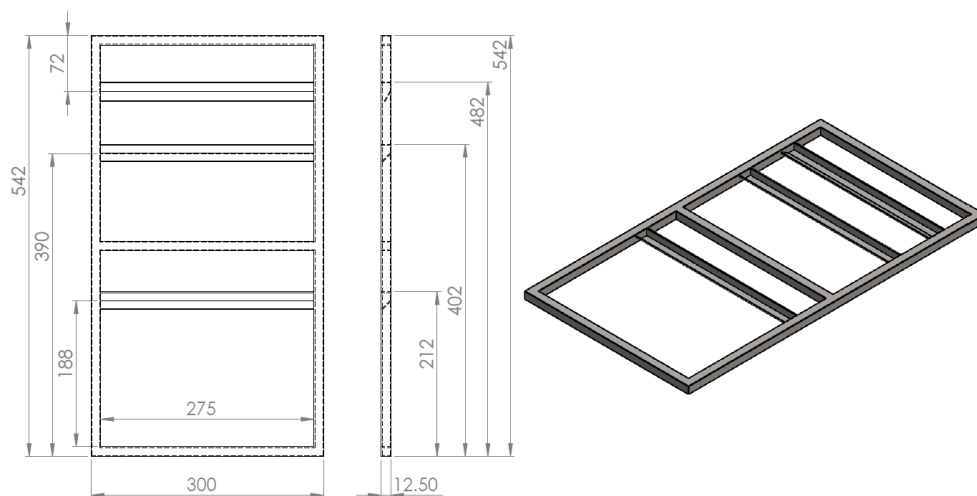


Figure 10: Schematics of angle-fixing base



Each adjustable tilting angle achievable by the tiltable base were portrayed in Figure 11.

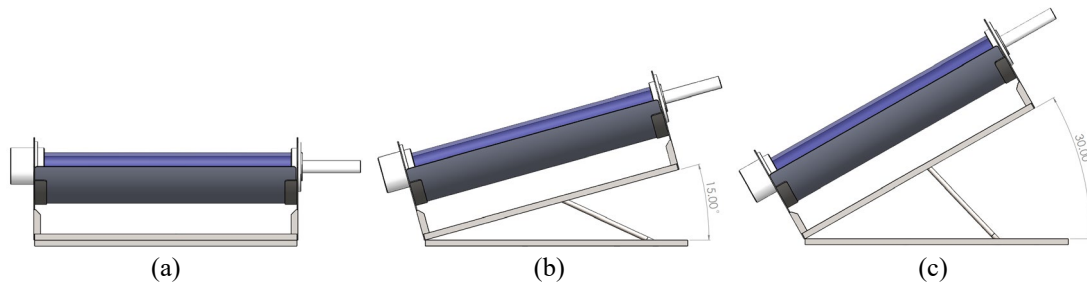


Figure 11: Tilting angle of solar oven (a) 0° , (b) 15° , and (c) 30°

The heating efficiency of the solar oven was tested under two experimental conditions. First, the experiment involved a parabolic rail made from different reflector materials fixed at a 0° angle horizontally. Next, the experiment involved a stainless-steel parabolic rail at various tilting angles of 0° , 15° , and 30° . The purpose of the experiment was to assess the heating efficiency inside the vacuum glass tube based on different reflector materials and reflector angles.

Testing of the Solar Oven Under Different Reflector Conditions

The research group set up a solar oven connected to a thermocouple inside the vacuum glass tube without a parabolic rail and with a parabolic rail of stainless steel, aluminum foil, and aluminum plate. The raw chicken weighing around 50 grams was prepared and inserted into the four trays inside the solar oven. Four solar ovens were then set in a clear location, and the light intensity and temperature inside the oven were recorded every minute for a 60-minute period in total. Figure 12 shows the solar oven under four conditions, namely (a) without parabolic rail, (b) stainless steel, (c) aluminum foil, and (d) aluminum plate.



(a)



(b)

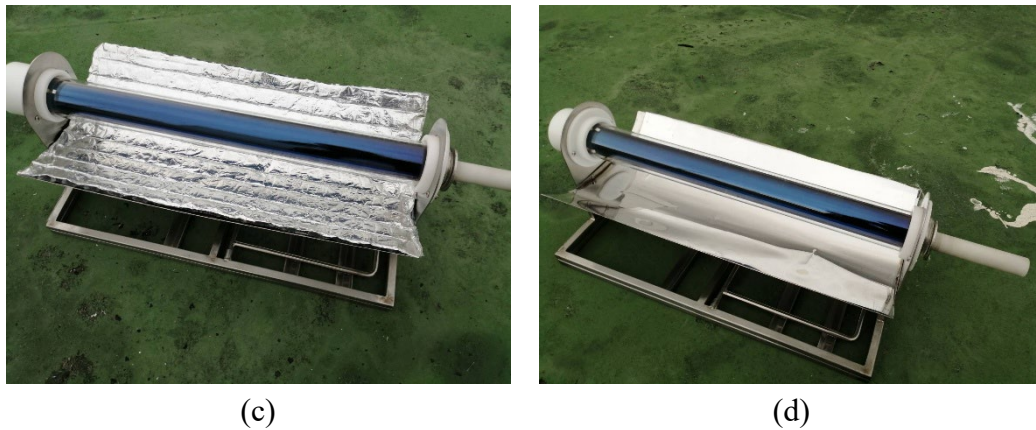


Figure 12: Solar oven together with parabolic rail material consisting of (a) without parabolic rail, (b) stainless steel, (c) aluminum foil, and (d) aluminum plate

Testing the Solar Oven Under Different Reflector Angle Conditions

The research team set up a solar oven with a thermocouple inside the vacuum glass tube. The stainless-steel plate was selected for this experiment. The angle between the reflector and base was set at (a) 0° , (b) 15° , and (c) 30° as shown in Figure 13.

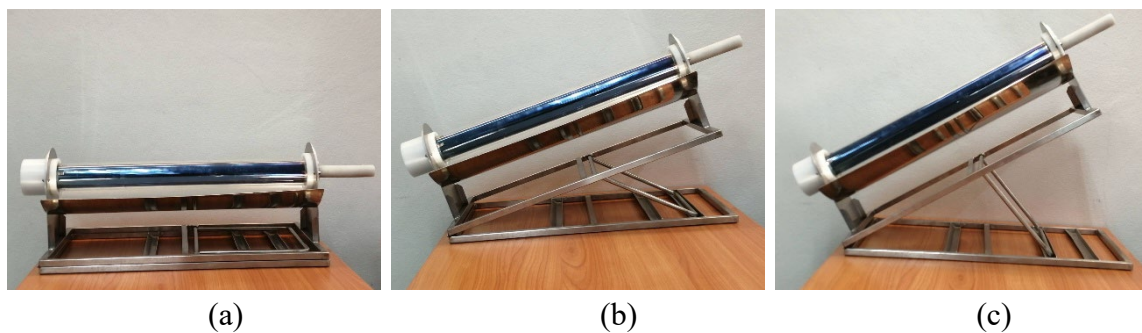


Figure 13: Solar oven at different angles: (a) 0° , (b) 15° , and (c) 30°

IV. RESULTS

Table 1: Experimental data for heating efficiency at an angle of 0° under various reflector materials

Experimental details	Results
Date of experiment	June 20, 2019
Experiment duration	12.30–13.30 p.m.
Heating duration	60 minutes
Location	In front of Amazon (SC08 building, KMITL)
Type of reflector material	1. Without a reflector 2. Stainless steel 3. Aluminum foil 4. Aluminum plate
Angle between the reflector and base	0°
Light intensity	115–1150 W/m ²
Weather conditions	Cloudy



Figure 14 shows the relationship between temperature and time based on experimental data for temperature generation inside a vacuum glass tube. The temperature-time relationship reveals that the highest temperature was achieved in the range of 100 to 106 °C. Comparing the temperature throughout 30 minutes of heating, the bare oven without a parabolic rail showed the lowest trend in temperature increase inside the vacuum glass tube at approximately 65.3 °C at 30 minutes. Meanwhile, the solar ovens with parabolic rails for radiation concentration showed internal temperatures of 86.5, 97.0, and 100.5 °C, depending on the reflector material, namely foil, stainless steel, and aluminum, respectively. Afterward, the temperature in the vacuum tube were around 84.4 °C for solar oven without a parabolic rail then 116.6 °C, 100.5 °C, and 118.1 °C for solar oven with the parabolic rail made of stainless steel, aluminum, and aluminum foil at one hour. The temperatures achieved were within a suitable range for cooking raw ingredients.

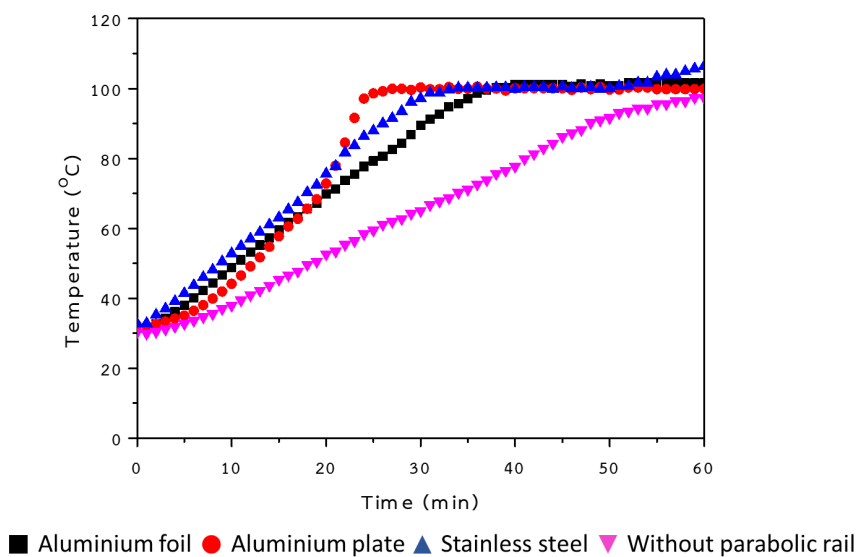


Figure 14: The graph represents the relationship between time and temperature inside ovens constructed using a parabolic rail made of aluminum foil, aluminum plate, and stainless steel, compared to a bare oven on June 20, 2019

Figure 15 shows the relationship between solar radiation intensity and time of the experimental data for the temperature accumulated inside a vacuum glass tube. The graph shows a trend of intensity values ranging from 800 to 1000 W/m² throughout the experiment, except for the period from the 21st to the 24th minute, when the intensity decreases due to a transient change occurring in the environment.

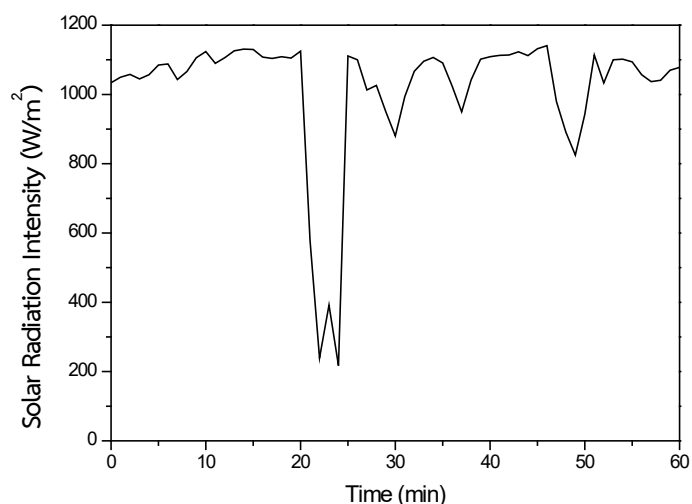


Figure 15: The graph represents the relationship between time and solar radiation intensity measured on June 20, 2019

Table 2: Weight of ingredients before and after heating at an angle of 0° under various reflector materials

Reflector material	Weight of ingredients before the experiment	Weight of ingredients after the experiment
Without a reflector	50.5513 g	33.1366 g
Stainless steel	50.7233 g	25.6328 g
Aluminum foil	50.5247 g	27.6663 g
Aluminum plate	50.7420 g	25.3301 g



(a)



(b)



(c)



(d)

Figure 16: Weight of chicken meat before heating by a solar oven constructed without a parabolic rail and with a parabolic rail made from (b) stainless steel, (c) aluminum foil, and (d) aluminum plate



(a)



(b)



(c)



(d)

Figure 17: Weight of chicken meat after by a solar oven constructed without a parabolic rail and with a parabolic rail made from (b) stainless steel, (c) aluminum foil, and (d) aluminum plate

Table 3: Experimental parameters for determining the performance of a solar oven using a stainless-steel rail at different tilting angles

Parameters	Results
Date	July 4, 2019
Time	11.00 a.m.–12.00 p.m.
Heating duration	60 minutes
Location	Roof of SC04 building, KMITL
Reflector material	Stainless steel
Tilting angle compared to the base	0°, 15°, and 30°
Radiation intensity 0°	400–930 W/m ²
Radiation intensity 15°	260–410 W/m ²
Radiation intensity 30°	250–370 W/m ²
Weather conditions	Slightly cloudy

Figure 18 represents the relationship between time and temperature inside the solar oven at different tilting angles of 0°, 15°, and 30°. According to the experiment to measure the temperature inside a vacuum glass tube, the highest temperature was 120.9 °C measured at 15°. By tilting the reflector to 0° and 30°, the maximum measured temperatures were 100.8 and 100.1 °C, respectively.

Figure 19 represents the relationship between time and solar radiation intensity at different tilting angles. The intensity ranged from 290 to 408 W/m² in the experiment where the tilting angles were 15° and 30°. At a tilting angle of 0°, the system exhibited an initial intensity of 605 W/m², rising to a maximum intensity of 922 W/m² after 29 minutes.

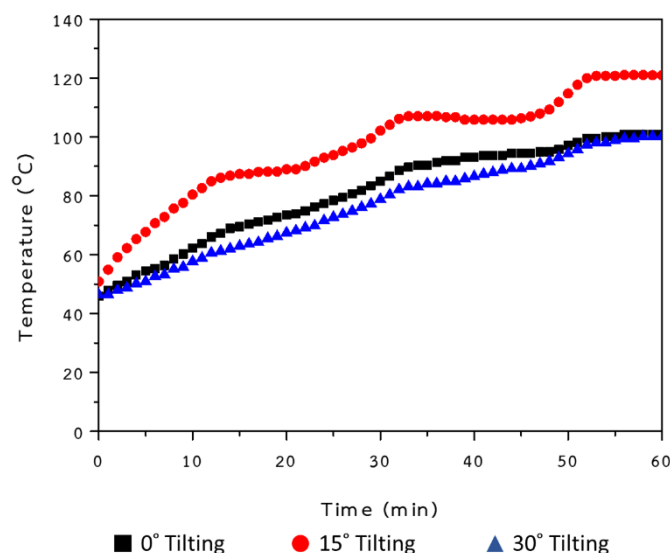


Figure 18: The graph represents the relationship between time and temperature inside the solar oven measured on July 4, 2019, at different tilting angles



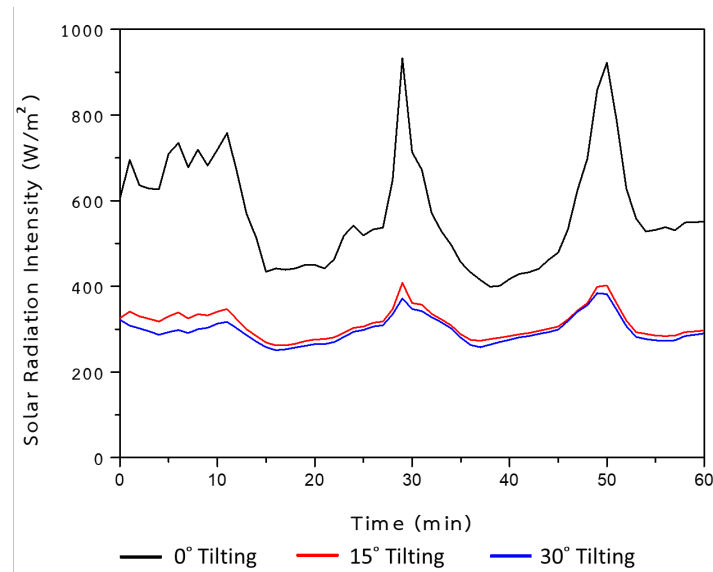


Figure 19: The graph represents the relationship between time and solar radiation intensity measured on July 4, 2019, at different tilting angles

Table 4: Weight of the chicken meat before and after heating in the solar oven at different angles

Tilting angle	Weight before the experiment	Weight after the experiment
0°	50.6244 g	20.5780 g
15°	50.4363 g	20.9683 g
30°	50.8899 g	20.7203 g

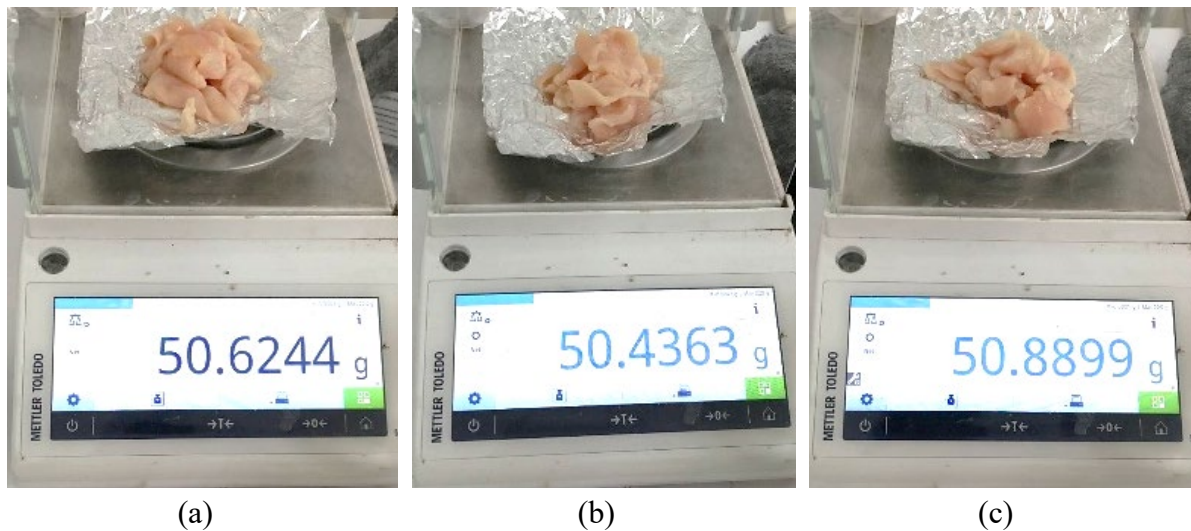


Figure 20: Weight of the chicken meat before heating by the solar oven at different angles: (a) 0°, (b) 15°, and (c) 30°

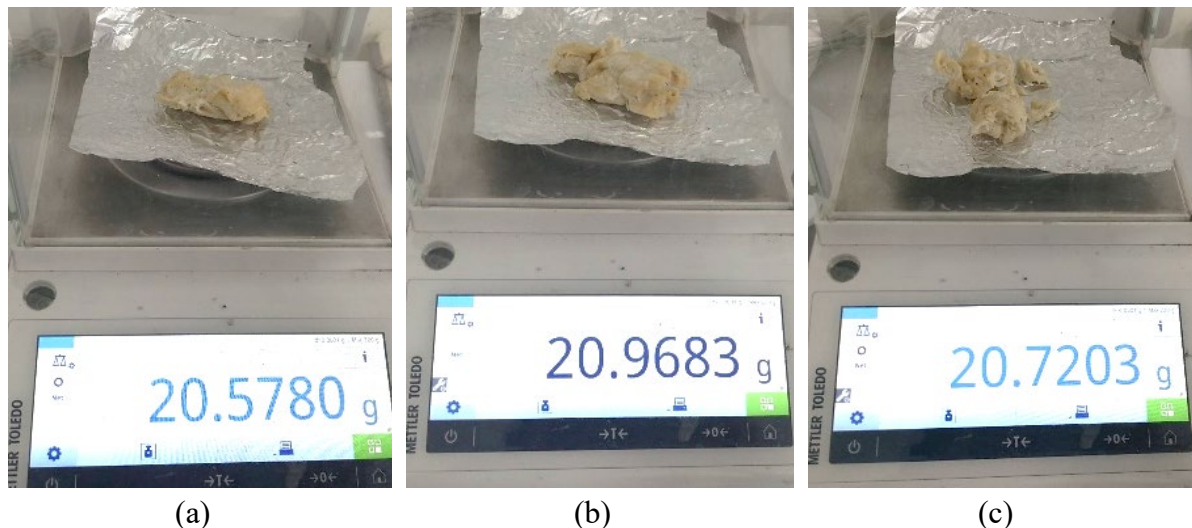


Figure 21: Weight of the chicken meat after heating by the solar oven at different angles: (a) 0°, (b) 15°, and (c) 30°

V. CONCLUSION AND DISCUSSION

The aim of this research was to study and design a solar oven with the purpose of applying solar energy to cook raw ingredients. A parabolic rail was designed for a solar oven with the capability to adjust the angle of light reflection into the vacuum glass tube and the reflector material to study the temperature inside the vacuum glass tube under two different conditions. For the first case, a myriad of materials was used, such as aluminum plate, aluminum foil, and stainless steel as the reflector material. In the second case, the light reflection angle was adjusted to 0°, 15°, and 30°. The researchers designed and constructed all the main components, including the food tray, parabolic rail, rings for securing the closed ends of the vacuum glass tube, rings for securing the open ends of the vacuum glass tube, and the adjustable tilt base. These were assembled with purchased equipment, comprising a vacuum glass tube, a thermocouple, a K-type temperature probe, and a solar irradiance meter. The heat values tested in the case involving the parabolic rail material showed that polished aluminum plate could ramp up to a maximum temperature of 100 °C faster than the other materials. The weight of the raw material was found to have decreased by approximately 20 to 30 grams after the experiment. Thermal testing in the case where the tilt angle of a stainless-steel parabolic rail was changed revealed that the maximum temperature ranged from 60 to 120 °C, with the highest temperature observed at a tilt angle of 15° relative to the horizontal of the base. The weight reduction in the raw material after the experiment was approximately 30 grams.

The thermal gain efficiency over time of the design is around 2.5 °C/minutes allowing it to reach 100 °C in less than 30 minutes for the solar oven with parabolic rail and able to sustain temperature of 100 °C or beyond throughout cooking time of chicken which is 20-30 minutes. This result in cooking time under time frame of 60 minutes which is the typical range for cooking of commercial solar oven (Prompuge and Sirisamphanwong, 2018, pp. 1-15; Silva et al., 2025, p. 428). The result of variation of materials under fixed angle showed that aluminum plate yielded highest heating rate implying highest amount of solar radiation reflected to the

solar collector following by stainless steel then aluminum foil. For the result of the experiment on tilting angle, the 15° yield the best result in our case, as this angle was the closest to the estimated optimal tilt angle for Bangkok of approximately 13.5° (Jacobson & Jadhav, 2018, pp. 55-66). The weight loss from cooking using our solar oven is roughly half compared to the result from a commercial cooker that would yield the weight loss of 64.93 g/100g as per calculation from a formula derived in a study of Barbantia and Pasquini (2005, pp. 895-901). Regardless, the doneness of chickens was examined by split through the cooked chicken which revealed fully opaque white with no on pink area. This indicate there is no raw part inside and safe to eat as the chickens was cooked at temperature exceed that of typical cooking temperature (Nisbet, 2025, Online). As for recommendation of the research, the dimension and type of solar collector could be redesign and study for further improvement of the solar oven.

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