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# Assessment on the developed solar thermal processing (STP) system for roasting cashew kernels

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## Abstract

Existing roasting techniques are not adaptable to farmers in developing countries because of high initial investments and rapidly increasing prices for non-renewable energy resources. Many technological efforts have been made to facilitate rural communities by mechanizing the roasting process, however, many of these technologies depend on fuels or electricity. The study aims to assess the viability of a developed Solar Thermal Processor (STP) system for roasting cashew kernels through thermal performance and productivity. The performance evaluation was conducted based on ASAE S580.1 suggested time for testing and reporting solar cooker performance. The process parameters involved in the data gathering are temperature and load manipulation with a drum speed of 10 rpm. Climate-Temperature data profiling shows that the STP's solar concentrator was able to produce a solar flux up to four times the available solar irradiance equal to 396.6°C of temperature. At no-load condition the maximum drum temperature reaches 296°C. For roasting 10 kg of cashew kernels, the recommended temperature is 110°C-120°C for 60 minutes. Furthermore, the collected data shows that the design of the machine was able to reduce roasting time by 30 minutes for a full load of 10 kg with an average moisture reduction of 3.9% per hour. The developed system can be a great help in increasing the monthly income of cashew kernel processors by minimizing operational costs, as well as increasing the market value of their products.

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## Introduction

Mindanao has abundant natural resources. It is considered the Philippines food basket, producing 40 percent of the country's food needs, and contributing more than 30 percent to the country's food trade. Agriculture accounts for one-third of its land area. Northern Mindanao is an agro-industrial region with one of the highest concentrations of coconut, mango, cashew, coffee and other crops (Akoy, 2015). According to the 2015 Philippine Statistics Authority report, 11.29 million people depended on agriculture as a means of subsistence.

This represented 29.2% of the country's total employment, with many of these farmers in the micro, small and medium-sized enterprises (MSME) category. MSMEs make up 99.6% of the 900,914 business enterprises in the Philippines, based on 2015 Philippine Statistics Authority figures, less than 8,195 or below 1% are in the agriculture, forestry, and fishing industries.

There is still a need to emphasize the importance of establishing more MSMEs in the agriculture sector, especially if we will consider that rural poverty is still extremely high in the Philippines. One of the reasons why agricultural MSMEs are outnumbered by other industries is because of the lack of technical support to the farmers, many are discouraged to venture into agriculture while others have shifted to other industries. Local food processors especially MSMEs faced with challenges like maintaining market share; a wide variety of imported processed foods readily enter the market due to increased trade liberalization and innovating or introducing new products. High capital investment and acquisition of state-of-the-art equipment deprived our local manufacturers of the opportunity to expand product lines to meet a diverse range of customer requirements and become globally competitive. Consequently, there is the priority need of the food processors for affordable equipment to increase production efficiency and compliance to standard requirements that will enable MSMEs to become more competitive in both local and foreign markets.

However, the conventional methods of roasting are inefficient, uncontrollable, laborious, tedious, energy and time consuming. These practices also provide a very un-hygienic environment to farmers/operators such as direct exposure to heat radiations and smoke. Many technological efforts have been made to facilitate the rural communities by mechanizing the roasting process (Olaniyan *et al*., 2017), but all rely on fuels or electric energy. This scenario creates a tremendous need to discover such alternate resources for heat generation which are non-depleting and environment-friendly, i.e., solar thermal energy. The solar concentrators offer an alternative use for fossil fuels. It can produce thermal energy at high temperature without environmental emission by concentrating solar irradiance. Some of the major drawbacks of fossil fuels are avoided by solar concentrator.

The system will help to identify the maximum solar irradiance at a given time to improve its solar tracking and solar cooking. Data from PAGASA shows that the Philippines particularly Region X, receives an average of 5,500 W/m2 on an average of 7.8 solar hours every day see Table 1 for reference. This abundance of solar energy is enough for solar technologies and to process agricultural products. This study will be taken up for the enhancement of existing post-harvest processing facilities using renewable energy by developing a Concentrated Solar Thermal Processing (STP) for roasting cashew nuts. Existing roasting techniques are not adaptable for the growers of developing countries due to high initial investment and rapidly escalating prices of non-renewable energy resources. The innovation is expected to lessen energy poverty in far flung agricultural communities that is out of reach of government infrastructure because small scale farmers will have the capacity to process their surplus harvest and sell more valuable products. Farmers will have economic freedom from traders because their products would have a longer shelf life, light weight and commands better prices than raw agricultural products. A Concentrated Solar cashew roaster will be fabricated and will be tested for energy efficiency and economic benefits to the farmers and compare it with existing technology. The outcome is that it would give chance for small and medium-sized enterprises farmers to become entrepreneurs and give inclusive and sustainable growth in the countryside. This will have a big impact on the quality of life of the farmers, not just increasing income but also creating healthier working conditions, safer foods, less wastage, more inclusive growth and less exploitation from traders. The Development of Concentrated Solar processor offers an alternative for fossil fuels. Through concentrating solar irradiance thermal energy is produced at high temperature without carbon footprints. Some of the major drawbacks of fossil fuels are avoided by solar concentrator. Further, the solar data generated from this study as to the concentrated solar irradiance will help identify the ideal conditions for solar technology and improve solar tracking and solar cooking in the region.

## Methodology

*A. Experimental set-up and site location*

The solar concentrator plays an important role in the system (Fig. 1). It supplies the heat needed for processing the agricultural commodities thus assessment is necessary to identify how much solar flux can be generated from the solar concentrator as shown in Table 2. Site validation is one of the key variables in evaluating the solar concentrator's performance. Selecting the right location boosts the efficiency of solar technologies.

The experimentation is conducted at the rooftop of LRC building 23 inside the campus of the University of Science and Technology of Southern Philippines located at CM Recto Avenue Lapasan, Cagayan de Oro City (Latitude: 8.4855°N, Longitude: 124.6564°E). The oven solar cooker is a drum-type rotating at a speed of 10 rpm, recommended speed for the roasting process. The solar flux will be reflected into the oven aperture allowing the drum as the receiver to absorb the heat.

*B. Experimental materials*

Cashew kernels from a local supplier were used as a test sample. Before conducting the experiment, cashew kernels were evaluated first in terms of the moisture content, color, and size.

This is to classify the quality of the cashew before it undergoes the process of roasting. After the test, cashew kernels were pack and sealed for analysis.

*C. Experimental parameters*

The following are the parameters considered for the evaluation of the STP's performance.

*Available Solar Irradiance*

The available solar irradiance is an essential element to produce solar thermal energy using the Linear Fresnel Concentrator. A pyranometer is used to measure the available solar irradiance.

*Concentrated Solar Irradiance*

Using the linear Fresnel concentrator will convert the available solar irradiance into concentrated solar irradiance. Which produces a higher amount of solar flux pyranometer is used to measure the concentrated solar irradiance.

*Temperature*

This refers to how much is the temperature produced by the solar concentrator which available for heating. A thermal gun and thermometer are used to measure the temperature.

*Humidity*

It is the amount of water vapor in the air. If there is a lot of water vapor in the air, it will take more heat making roasting or drying time to be slower.

*Cloudiness*

Cloud cover (also known as cloudiness, cloudage, or cloud amount) refers to the fraction of the sky obscured by clouds when observed from a particular location.

The cloud cover is correlated to the sunshine duration as the least cloudy locales are the sunniest ones while the cloudiest areas are the least sunny places. It is categorized as the following shown in Table 3.

*D. Experimental procedure*

To determine the thermal efficiency and cooking power of the solar concentrator, the performance testing procedure will adopt the method of water boiling test and time requirement to attain maximum temperature. Data of solar irradiance will be gathered from 8:00 am-5:00 pm using a manual data collection table. The roasting of cashew kernels was conducted based on ASAE S580.1 (suggested time for testing and reporting solar cooker performance) (Ebersviller and Jetter, 2020). Testing is done in no-load condition and with a full load of 10 kg. Time, temperature, and moisture content are the key parameters in this performance analysis.

*E. Data analysis*

The amount of solar flux varies depending on the weather condition. This will affect the duration of the roasting process. The data gathered for analysis includes the amount of Solar Flux, Thermal Efficiency Cooking power and moisture reduction.

*F. Thermal performance of the solar concentrator*

*Solar flux*

The Solar Flux is measured using a pyranometer. It is the amount of solar irradiance concentrated in a specific area. This parameter will determine how much heat is available for heating.

*Thermal efficiency*

Overall thermal efficiency was calculated by the following equation as shown in Equation 1 below (El-Sebaii and Ibrahim, 2005).

Legend under Equation 1 (insert below the equation 1)

$$n_u = \frac{M_f C_f \Delta T_f}{I_{av} A_c \Delta t}$$

Equation 1

Where:

$n_u$ overall thermal efficiency (%)

$M_t$ mass of cooking fluid (kg)

$C_t$ specific heat of cooking fluid (J/kg. K)

$\Delta T_f$ difference between the maximum and ambient air temperature

$I_{av}$ average solar intensity (W/m$^2$) during the time interval.

$A_c$ is the aperture area (m$^2$) of the cooker.

$\Delta t$ time required to achieve the maximum temperature of the cooking fluid (s).

*Cooking power*

The cooking power of the different solar cookers was calculated using equation 2 below given by Kundapur and Sudhir (2009) as follows:

Legend under Equation 2 (insert below the equation 2)

$$P = \frac{Tw_2 - Tw_1}{t} m_w C_{pw}$$

Equation 2

Where:

$P$ cooking power (W)

Twz final water temperature caC)

Twı initial water temperature caC)

t time (s)

mw mass of water (kg)

$C_{pw}$ water heat capacity (4.168 kJ/kg. K)

*G. Solar oven roasters productivity*

The initial test was conducted to evaluate the productivity of the roaster.

A comparison between the methods used by Best Agri Products Processing Cooperative (BAPCO) of Lumbia, Cagayan de Oro City a local cashew processor was the benchmark validating the roaster's productivity.

According to them a 10 kg of cashew kernels was processed for 1 hour and 30 minutes using manual roasting.

*H. Energy consumption*

The energy consumption is calculated using equation 3 shown below:

Legend under Equation 3 (insert below the equation 3)

$$E_t = VIt$$

Equation 3

Where:

$E_t$ Total energy consumed, (kWh)

*V* Voltage, (V)

*I* Current, (A)

*t* operating time, (hour)

## Results and discussion

*A. No-load experiment*

The results no-load experiment show that the STP's solar concentrator was able to produce a solar flux up to four to six times the available solar irradiance amounting to 165.2°C to 396.6°C. At no-load condition the maximum drum temperature reaches 296°C. Shown in Fig. 2 is the solar flux recorded on February 2, 2021. Its equivalent temperature was shown in Fig. 3.

**Table 1.** Solar Radiation from the National Solar Radiation Center of DOST PAGASA in El Salvador, Misamis Oriental Station for the period January 1, 2013, to March 2016 (Latitude: 8° 32' N, longitude: 124° 33' E).

| Months | 2013 | | 2014 | | 2015 | | 2016 | |
|---|---|---|---|---|---|---|---|---|
| | Total (W/m²) | Average (W/m²) | Total (W/m²) | Average (W/m²) | Total (W/m²) | Average (W/m²) | Total (W/m²) | Average (W/m²) |
| January | 113371 | 3818 | 97828 | 3156 | 139806 | 4660 | 12617 | |
| February | 149841 | 5351 | 151942 | 5627 | 171423 | 5714 | 23292 | |
| March | 205412 | 6626 | 181946 | 5869 | 189573 | 6115 | | 27240 |
| April | 201450 | 6498 | 183406 | 6114 | 186841 | 6228 | | |
| May | 206425 | 6659 | 209822 | 6768 | 200158 | 6456 | | |
| June | 158763 | 5212 | 149863 | 6180 | 150646 | 5021 | | |
| July | 178645 | 5763 | 154860 | 4995 | 148735 | 4797 | | |
| August | 164773 | 5315 | 199967 | 6451 | | | | |
| September | 160620 | 5181 | 152751 | 5091 | | | | |
| October | 142980 | 4612 | | | | | | |
| November | 144905 | 4674 | 164456 | 5481 | | | | |
| December | 112817 | 3639 | 145217 | 4840 | 158142 | 5101 | | |
| total | 1940002 | 63348 | | | | | | |
| Average | 161666.83 | 5279 | 162914.3636 | 5506.545 | 168165.5 | 5511.5 | | |

**Table 2.** Solar Concentrator Parts.

| Solar Concentrator Type: | Linear Fresnel Reflector |
|---|---|
| Reflector Area: | 3m² |
| Number of Mirrors: | 68 pcs |
| Size of Mirrors: | 5 in. width × 24 in. length |

The effect of cloud cover certainly affects the amount of concentrated solar irradiance, limiting the amount of temperature available for heating.

*B. Full load experiment*

Under a full load condition of 10 kilograms, the researcher conducted three trials each for the manually operated solar cashew nut roaster and the motorized cashew nut roaster. The cooking time recorded for each of these trials is shown in Fig. 4 below. It is observed that the manually operated cashew nut roaster had a slow temperature rise than the motorized solar cashew nut roaster, which then constitutes its slower cooking time.

**Table 3.** Cloud Cover Categorization.

| Sky Condition | Description |
|---|---|
| Clear (C) | no clouds to 1/10 cover |
| Scattered (S) | 1/10 to 5/10 cover |
| Broken (B) | 5/10 to 9/10 cover |
| Overcast (O) | 100% cloud cover (gloomy day) |

The average cooking time of the manually operated cashew nut roaster is 93 minutes (1 hour and 33 minutes), while the average cooking time of the motorized solar cashew nut roaster is 63 minutes (1 hour and 3 minutes).

Fig. 1. Linear Fresnel Reflector Set-up.

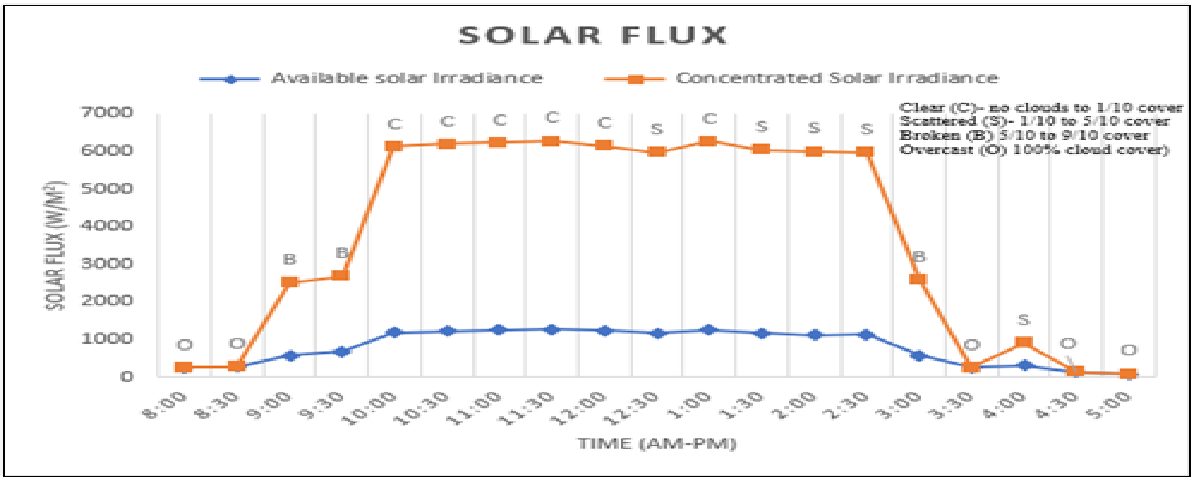


**Fig. 2.** Solar flux recorded on February 2, 2021.

A 30-minute difference in cooking time is a significant improvement in the aspect of improving the performance of the existing cashew roaster and equates to an additional 2 to 3 batches of cashew kernels to be roasted in a day.

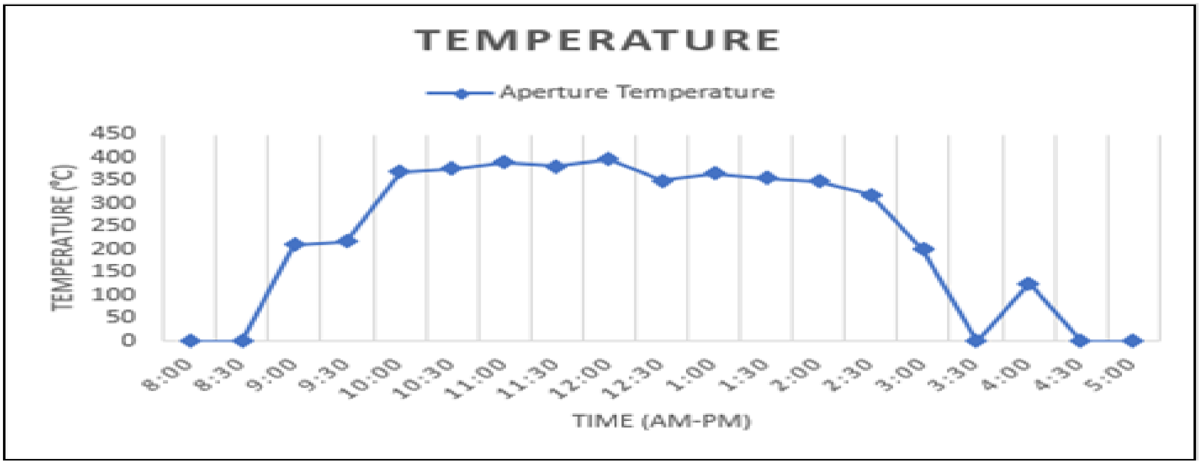


**Fig. 3.** Equivalent Temperature for the concentrated solar irradiance on February 2, 2021.

*C. Moisture content Analysis*

The initial moisture content of pre-dried cashew kernels ranges from 5-8%. The experimental investigation results in an average moisture reduction of 3.9% per hour by the STP's roaster.

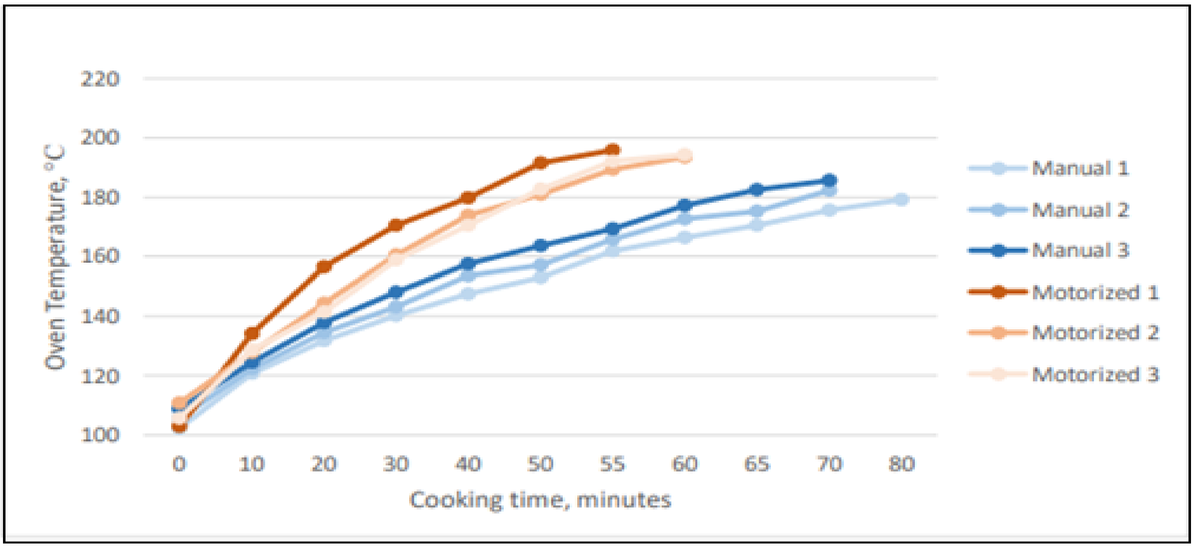


**Fig. 4.** Cooking time vs Temperature for Manual Operated and the STP.

## Conclusion

The assessment of the STP system thermal and productivity test results produce a solar flux of up to four times the available solar irradiance equal to 396.6°C intended for heating. Furthermore, the oven chamber can hold a maximum temperature of 296°C. Roasting time was reduced by 30 minutes for a full load of 10 kg with an average moisture reduction of 0.06% per minute. Increased roasted cashew kernels production helps to increases profit for the farmers. Thus, the field data generated from this study as to the concentrated solar irradiance will help identify the ideal conditions for solar technology and improve solar cooking in the region.

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