The Design Development of Solar Box Cooker on Wheels as an Alternative for Philippine Rural Households

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ABSTRACT

Solar Box Cookers are a good alternative in mitigating fossil fuels and biomass use, especially for tropical developing nations such as the Philippines, but their wide acceptance is limited by their high dependence on sufficient sunlight for better performance. This research aims to develop a thermal-efficient, portable Solar Box Cooker with Sand Sensible Heat Storage materials, Coconut Coir (*Cocos nucifera*) agricultural waste insulators, and locally sourced building materials. The designed and constructed cooker was evaluated using three thermal performance tests: the Stagnation Temperature test from the Bureau of Indian Standards (BIS), the Cooking Power test from the American Societal of Agricultural Engineer (ASAE) Standards, and a rice cooking test. Data obtained from the three-day trials of each test were used to determine the first figure of merit (F_1), the single measure of performance ($P_s(50)$), and its ability to cook 300 g of NFA rice with 500 mL of water, respectively. It was found that the cooker achieved an F_1 of 0.06 Km²/w, a $P_s(50)$ of 6.651 W, and cooked rice for one-third of the tests. Obtained experimental findings showed that the device is marked as a Grade-B solar cooker. Results indicated that the solar box cooker is capable of pasteurizing water and cooking rice.

INTRODUCTION

The world's energy consumption increases due to high industry and household demands such as cooking, which greatly consumes fossil fuels and biomass. Solar energy, a renewable and abundant energy source in tropical nations, is utilized by solar box cookers (SBCs). The use and potential of SBCs, however, are not generally accepted due to their reliance on persistent solar radiation. Insulators aid in the accumulation of sufficient temperatures and the reduction of heat loss. Coconut coir (*Cocos nucifera*) insulator was found to perform well as it had a remarkable stagnation temperature of 159°C and thermal efficiency of 37.00% (Aremu & Akinoso, 2013). Sensible heat storage (SHS) materials store energy in the form of specific heat, which facilitates prolonging heating processes (Abate, 2014; Bauer et al., 2018). An SBC with sand SHS material was identified as more efficient in storing energy than water, as it had an efficiency of 4.145%. (Francis et al., 2016). The Philippines produces a considerable number of agricultural wastes, including coconut coir (*Cocos nucifera*), and uses sand for multiple construction purposes. Thus, this research aims to design and construct an SBC with Vibro sand SHS material, coconut coir (*Cocos nucifera*) insulator, and readily available materials in the Philippines; as well as to evaluate the cooker's thermal performance through the Stagnation Temperature, Cooking Power, and rice cooking tests.

METHODOLOGY

1 — DESIGN AND CONSTRUCTION

- The design structure was made upon reviewing the availability, efficiency, and cost of the materials and recommendations from previous researchers.
- The finalized design was constructed through the aid of a woodworks company.

2 — PERFORMANCE TESTING → **3 — PERFORMANCE EVALUATION**

- **STAGNATION TEMPERATURE** — Bureau of Indian Standards (BIS); *First Figure of Merit (F_1)* → *Grade A SBC: $F_1 \geq 0.12$; Grade B SBC: $F_1 < 0.12$*
- **COOKING POWER** — American Society of Agricultural Engineers (ASAE) Standards; *Cooking Power Regression* → $P_s(50)$: a unit for comparison of different solar cookers; Coefficient of Determination $R^2 > 0.75$
- **RICE COOKING** — (300 g of NFA rice with 500 mL of water); *Cooking Time* → 120 - 180 minutes; Rikoto and Garba, (2013); Aremu et al. (2019)

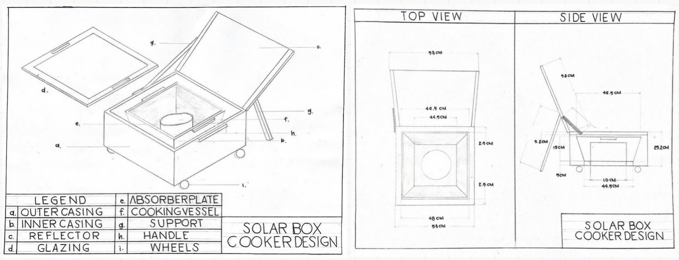

Figure 1. Schematic Diagram of the Solar Box Cooker

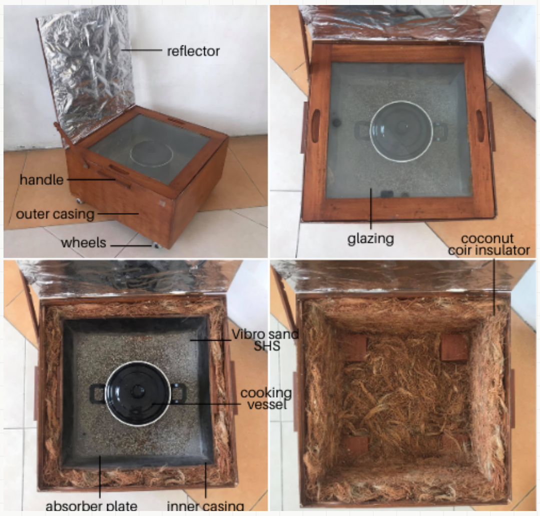

Figure 2. Constructed Solar Box Cooker

RESULTS & DISCUSSION

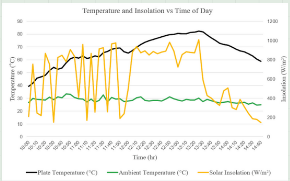

Figure 3. Temperature Variation Curve During Stagnation Temperature Test Day 1 (15/01/2021)

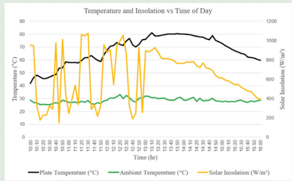

Figure 4. Temperature Variation Curve During Stagnation Temperature Test Day 2 (16/01/2021)

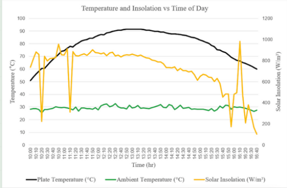

Figure 5. Temperature Variation Curve During Stagnation Temperature Test Day 3 (17/01/2021)

Table 1. Summary of Data from Days 1 to 3 of the Stagnation Temperature Test (15/01/2021 to 17/01/2021)

	Day 1	Day 2	Day 3
Highest Plate Temperature (°C)	82.3	80.3	91.5
Mean Ambient Temperature (°C)	29.3	28.5	29.2
Mean Solar Insolation (W/m²)	716	644	824
Mean Wind Speed (m/s)	1.1	1.0	1.0
F_1 (Km²/w)	0.05	0.07	0.07

The mean F_1 obtained by the SBC was 0.06 Km²/w, which is 50% of the BIS (2000) standard value of 0.12 Km²/w. This marks the device as a Grade B solar cooker. Intermittent cloud coverage transpired during the first and second trials, while relatively good radiation persisted during the third day. The SBC reached a plate temperature above 90°C and sustained a temperature above 75°C for 265 minutes. The data were insufficient in determining the optimal stagnation plate temperature due to variations in ambient temperatures throughout the trials.

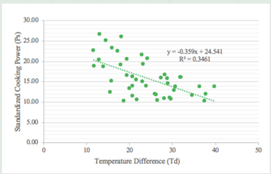

Figure 6. Overall Cooking Power Performance

Table 2. Summary of Data from Days 1 to 3 of the Cooking Power Test (02/03/2021, 03/03/2021, 05/03/2021)

		Day 1	Day 2	Day 3
Cooking Regression Equations	Intercepts (W)	26.78	13.93	31.21
	Slope (W/° C)	-0.53	-0.013	-0.52
Coefficient of Determination (R^2)		0.57	0.0005	0.74
Mean Ambient Temperature (°C)		34.5	30.3	30.2
Mean Solar Insolation (W/m²)		770	573	813
Mean Wind Speed (m/s)		0.9	1.5	1.5

The single measure of performance $P_s(50)$ was determined as 6.651 W using the regression equation $P_s = 24.541 - 0.359\ T_d$, which is lower compared to previous studies. The coefficient of determination was 0.35, meaning only 35% of standardized cooking power can be predicted by the temperature difference which does not satisfy the ASAE (2013) standard value. This is due to sudden cloud formations and fluctuating insolation at certain intervals during the first and second trials.

Figure 7. From Left to Right: Resulting Rice Load of Rice Cooking Test Days 1 to 3 (17/03/2021 to 19/03/2021)

Table 3. Summary of Data from Days 1 to 3 of the Rice Cooking Test (17/03/2021 to 19/03/2021)

	Day 1	Day 2	Day 3
Highest Pot Temperature (°C)	71.1	78.5	83.3
Mean Ambient Temperature (°C)	30.1	31.4	31.6
Mean Solar Insolation (W/m²)	467	730	723
Mean Wind Speed (m/s)	0.3	1.0	0.7
End of Recording	14:00	14:30	16:00

For the first, second, and third trials, the rice was uncooked, partially cooked, and cooked for 420 minutes, respectively. The cooking time was slower compared to previous studies. Frequent opening of the glazing and pot to check the rice could have contributed to the obtained time. Moreover, the second and third days had favorable weather conditions, while the first day had the least sunlight availability.

CONCLUSIONS & RECOMMENDATIONS

The results indicated the developed solar box cooker's underperformance when subjected to inconsistent weather conditions. However, it was still able to show its competence in sustaining heat inside the cooking chamber. The cooker's performance under unremitting solar radiation showed its ability to pasteurize water and cook rice. Future research should create designs that optimize available materials and solar radiation in the country and consolidate other standardized tests with more trials. A comparative analysis of varying cooker configurations in different sites should also be done to determine the most suitable design for a specific region in the Philippines.

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