

Cooking food with a solar PV-powered DC stove

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Abstract

An experimental setup to evaluate a new 12 V DC-powered electrical cooker is presented. The DC cooker is powered by a 450 W solar panel connected to a maximum power point tracking (MPPT) charge controller and a 12 V AGM 100 AH deep cycle battery. The cooking tests are performed when the DC cooker and the pot containing food are placed in a closed-insulating wonderbag cooker to reduce heat losses. Four different food cooking tests are carried out during different times of the day to evaluate the cooking performance of the system. The cooking tests are boiling rice at night, boiling eggs during midday, preparing chicken and turkey stew after midday, and frying chicken late in the afternoon. All foods are well cooked within 90 minutes, and the food that takes the longest time to cook is rice because the energy from the battery is solely used to cook the food. For all tests, the electrical cooking powers are comparable, implying that the system can be used at any time of the day which is better than existing solar cookers which operate optimally only under high solar radiation conditions. There is also no need to include an inverter since the cooker operates in DC mode.

Keywords: Cooking Food; DC Stove; Solar PV

1. Introduction

Solar cookers utilize the sun's energy to cook food and are vital in reducing greenhouse emissions generated by firewood used for cooking in developing countries. The four main types of solar cookers are concentrating solar cookers, box solar cookers, panel solar cookers, and indirect solar cookers. All these types of solar cookers have the disadvantage of not operating properly or very poorly in overcast or cloudy conditions. Concerted efforts to improve the performance of solar cookers for periods with little or no sunshine have been made by integrating them with thermal energy storage (TES) systems (Aramesh et al., 2019; Bhave & Thakare, 2018; Bhave & Kale, 2020; Coccia et al., 2020; Lecuona et al., 2013; Mawire et al., 2022; Omara et al., 2020; Rekha & Sukchai, 2018). However, there might be continuous days of bad weather which makes short-term TES null and void. The only option during continuous bad weather days is to resort to electrical cooking, liquified petroleum gas (LPG), paraffin, firewood, and other polluting fossil fuel-based cooking energy sources.

Instead of relying on these mentioned energy sources, solar photovoltaic (PV) panels can be used. Solar panels can operate during cloudy conditions although not optimally. PV panels can be used with an inverter and battery storage for operating small AC electrical cooking hot plates which increases the cost of the system due to the expensive inverter systems. A possible solution is to operate a DC stove together with a PV panel to reduce the cost. Some researchers have recently reported on an induction DC-powered cooker (Altouni et al., 2002) which requires specialized ferromagnetic cooking pots. Other researchers have investigated different versions of PV cookers with DC-to-DC converters, and storage generally with operating voltages above 12 V (Atmane et al., 2020; Lamkaddem et al., 2022). The 12 V option for a DC cooker removes the need for expensive DC-to-DC converters together with expensive inverters. According to our reviewed literature, a 12 V DC stove which can be powered by a 12 V battery charged with a solar panel has not been reported. In this article, the cooking performance of a new cheap 12 V DC cooking stove that is sold locally online in South Africa from Takealot (Takealot, 2023) is evaluated while being powered by a 450 W solar panel connected to a maximum power point tracking (MPPT) charge controller and a 12 V 100 AH battery. The DC stove and

cooking pot are tested in an insulated wonderbag slow cooker reported by Mawire et al., (2020) to reduce the impact of environmental conditions such as windspeed variability which increases heat losses. According to the knowledge of the authors, no study has ever been reported on a DC cooking stove integrated with a PV panel, charge controller, and battery storage together with an insulated slow cooker (wonderbag). The novel aspect of the study is that cooking is tested under different conditions, and this type of cooking setup will compete with current electrical cookers since cooking is possible any time of the day. Additionally, not only will the system cook food, but the system can also be a multi-purpose device providing energy for other DC appliances such as refrigerators and lights without the need for expensive inverter systems, The system can be used in remote locations without grid connectivity.

2. Experimental method

A photograph of the 12 V DC cooker with four terminals is shown in Fig. 1 (Takealot, 2023). The cooker has two coils indicated by the four terminals in Fig. 1. It implements DC heating at two powers of approximately 200 W and 300W. The heating powers are estimated from the measured resistances of the single coil and the two coils which are 0.8Ω and 0.6Ω , respectively. For 200 W, one coil consisting of two terminals (red and black) is connected to the 12 V battery/source. For the 300 W setting, the two red terminals are connected to the positive terminal of the battery/source, and the other two black terminals are connected to the negative terminal of the battery/source. The cooking surface of the DC stove is 16.7 cm in diameter, and its height is 5.5 cm. The total diameter of the cooker is 23 cm.



Fig. 1: A photograph of the 12 V DC cooker used in the experimental test (Takealot, 2023)

Fig. 2 shows a photographic view of the experimental setup. The sun charges the battery via the solar panel, and the charge controller regulates the amount of electrical energy supplied to the DC stove. A 100 AH battery was used to cook multiple meals. With a 100 AH battery, the theoretical energy supplied is 1200 WH which means that it is theoretically possible to cook for 6 H (1200 WH/200 W). The 12 V DC stove is placed in a wonderbag insulating cooker to reduce heat losses during the experimental trials which prevented most convection heat losses because of external windspeed variability. Power to the 12 DC stove is supplied from the charge controller.

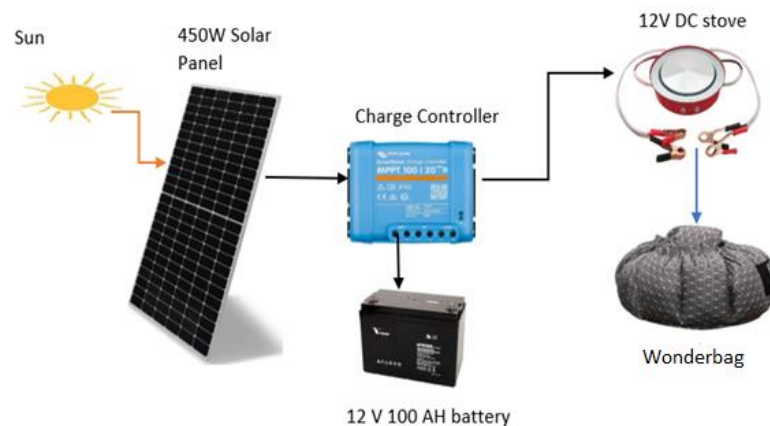


Fig.2: A photographic view of the experimental setup and connections.

Photographs of sections of the experimental setup are shown in Fig. 3. A 450 W solar panel is connected via the charger controller and battery shown in Fig. 3(a). The tilt angle of the panel was 30 ° which was chosen based on the balancing the panel to the supporting structure instead of the maximum PV output production. However, the tilt angle falls between 30-45 ° for maximum PV output production. The panel experienced a bit of shading, but it was used in the indirect mode to just charge the battery, so this tradeoff was acceptable since the battery was used to cook. A maximum power point tracking (MPPT) charge controller controls the charging of the battery providing maximum power to the DC stove. The maximum operating current of the charge controller is 20 A. Only one coil was used in the cooking tests since the controller could not provide adequate current to run both coils. The output of the charge controller ensured that maximum power was transferred to the DC cooker. Each experimental cooking test was run for a maximum period of 90 minutes. Two multimeters measured the DC voltage and current every five minutes manually to estimate the electrical heating power. Two other multimeters recorded the cooking and ambient temperatures which were manually recorded every five minutes. An RS solar power meter was used to measure the global horizontal irradiance (GHI) every five minutes manually. Ideally, the irradiance on the plane of the array should be measured but only estimated values were used for the GHI since the DC cooker operated in the indirect mode, and only an estimate was required. The experiments were carried out in a closed wonderbag shown in Fig. 3(c) where the DC cooker, the cooking pot, and the food were placed to reduce heat losses. The electrical heating power to the DC stove can be estimated by multiplying the measured current through and voltage across the stove together, and it can be expressed as:

$$P_E = VI, \tag{1}$$

where P_E is the electrical heating power, V is the measured DC voltage and I is the measured current.



Fig. 3: Photographs of the experimental setup showing (a) the PV panel connected to the DC cooker in a wonderbag, (b) the 12 V AGM battery and the MPPT controller, and (c) a closed wonderbag with the DC cooker and the cooking pot with food.

Fig. 4 shows a photograph of the silver stainless steel cooking pot used as a cooking utensil enclosed in the wonderbag. It has an outer diameter of 21cm and a height of 10 cm, making its capacity 3.5 litres



Fig.4: A photograph of the silver stainless steel cooking pot used in the experiments.

The total cost of the system is around R6,000 (USD 314) (Mawire et al., 2024). The PV system seems expensive, but for South African conditions it is reasonably priced considering that the system can be used as a multipurpose system with the capability of cooking, heating, cooling, and lighting applications. Only the cooking application is presented in this paper. Also, quality components and a large charging panel were used to make the price more expensive. The real price could be 50 % lower (USD 157) if a smaller solar panel and cheaper components were used (Mawire et al., 2024). The larger panel enables the charging of the battery faster, and it provides more versatility in terms of operating more DC devices.

3. Results and discussion

Fig. 5 shows experimental results for the cooking tests. The cooking tests were performed from 20-23 March 2023. The first test was boiling 203 g of rice with 500 ml of water at night on 20 March 2023. This was followed by boiling 285 g of eggs in 300 ml of water around midday on 21 March 2023. The third test was after lunchtime (14:25-15:55 hrs) on 21 March 2023, and this involved preparing chicken (280 g) and turkey (233g) stew using 200 ml of water. The last test performed on 23 March 2023 involved frying 425 g of chicken in 134 g of sunflower oil late in the afternoon.

Midday and after-lunch cooking have the highest solar radiation for cooking and charging the battery, thus their electrical cooking powers are slightly higher than the other tests. It is important to note that the cooking tests are terminated when the food has been cooked, thus the electrical cooking powers for all three tests dropped to zero after the food is cooked well. The only cooking test to last for 90 minutes is boiling of rice at night which shows the lowest cooking power since the stored energy from the battery is solely used to cook rice. The cooking powers for all four tests are comparable and fall within 165-210 W implying that food can be cooked efficiently at any time of the day, unlike traditional solar cookers which require high solar radiation conditions. Boiling of eggs is shorter than the other cooking processes since the mass of water used is less. Frying of chicken shows the highest temperatures achieved since sunflower oil with a lower thermal mass is used to fry chicken instead of water. The temperature drop in the frying of chicken at 35 mins is due to the opening of the wonderbag to examine whether the chicken is well-fried. The other drops for frying of chicken and cooking the chicken and turkey stew are due to switching off the power and allowing the food to simmer and cook slowly in the wonderbag to save power. It must also be stated that, unlike traditional cooking, the possibility of burning food regularly is drastically reduced due to the lower cooking power involved. Also, unlike traditional solar cookers, trapped/stored heat inside the wonderbag can be used to extend the cooking period without power thus saving power for cooking purposes.

The overall average thermal efficiencies of the PV cooker ranged between 4-16 % and the water heating efficiencies between 38-57 %. More details of the efficiencies have been reported in our related work (Mawire et al., 2024).

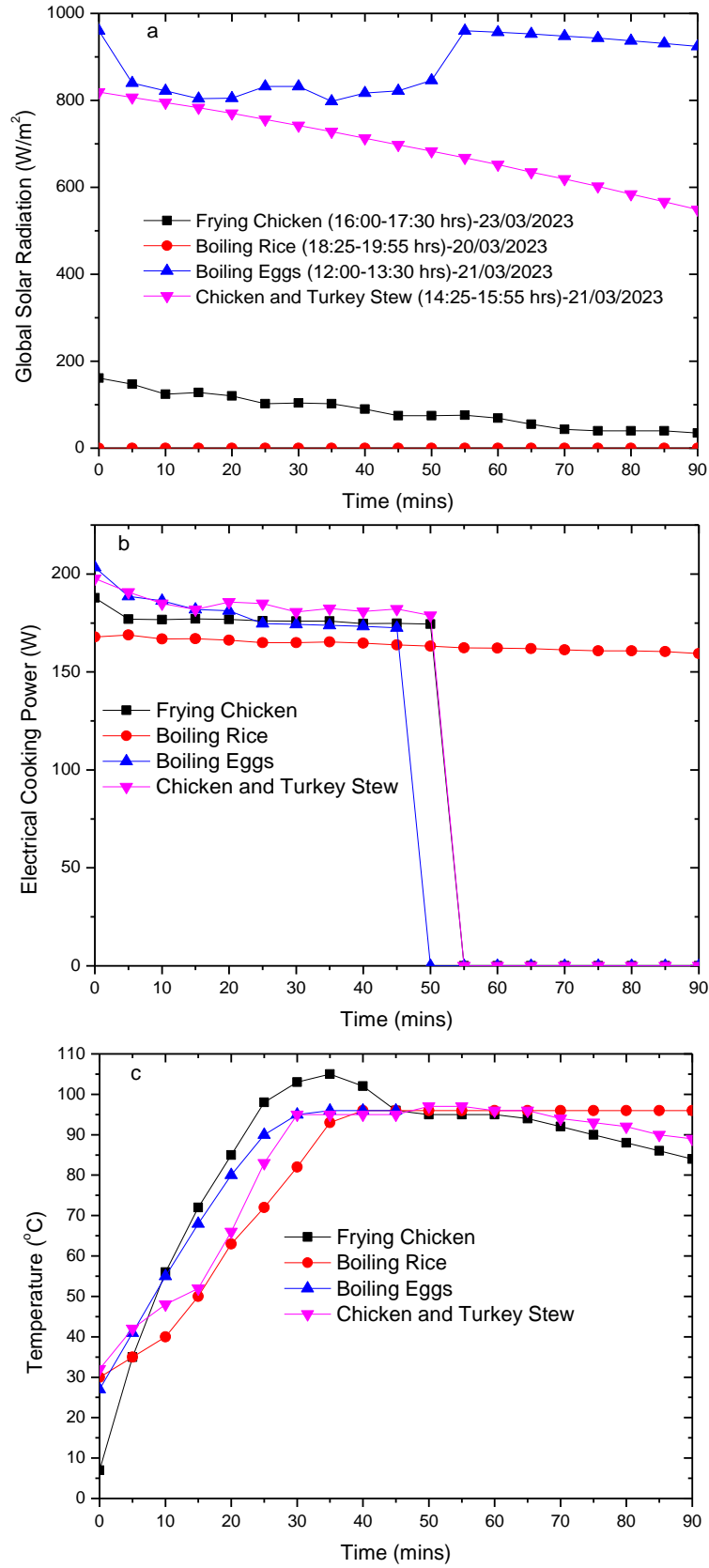


Fig. 5: Experimental cooking results for the four cooking tests showing: (a) the global solar radiation, (b) the electrical cooking power, and (c) the temperature profiles of the cooked food.

Fig.6 shows crispy and well-cooked chicken and chips (fries) using the solar PV-powered DC stove.



Fig. 6: Chicken and chips (fries) cooked using the solar PV-powered DC stove.

4. Conclusion

A new 12 V DC cooking stove powered by a PV panel integrated with battery storage and an MPPT charge controller was experimentally evaluated for cooking different foods under four different conditions. All the cooking tests showed that the cooker can cook food well in 90 minutes or less. For all cooking tests, the electrical cooking powers were comparable, implying that the system can be used at any time of the day which is better than existing solar cookers which operate optimally only under high solar radiation conditions. The cooker also does not require an expensive inverter since it operates in the DC mode. Future work will involve comparing the reported cooker with a parabolic dish cooker which shows the highest cooking temperatures and the fastest cooking speeds under different weather conditions.

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