Design and Assessment of a solar collector system for low-cost, pollution-free cooking and grilling applications

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Abstract

Recently, using solar energy for several purposes has become very important to preserve the environment, reduce pollution, and reduce consumption. Examples of these applications are cooking, barbecuing, desalination, and generating electrical power. Solar oomph is extremely important in providing the energy used in cooking. In the current work, a solar collector consisting of six flexible reflective panels was designed and assembled for solar cooking and grilling operations in the city of Jazan, southwestern Saudi Arabia. Pots of different sizes have been prepared for cooking operations, as well as a grid for grilling operations. They are installed at the center of the collection of reflected rays from the solar center, in addition to a movable stand and a manual system for directing the direction of the falling sunlight. The current solar energy system provides an estimated power of about 2,300 watts from 9 a.m. to 5 p.m. It took 16 minutes to cook 2700 grams of vegetables with the current system and less than two minutes to boil 2 liters of water. Grilling a whole chicken weighing 800 grams, cut in half, takes about ten minutes. Cooking was also done inside the kitchen using a solar energy source by transferring heat from the solar concentrator's absorber to a 35-diameter pipe filled with vegetable oil as a heat transfer fluid. The absorber temperature reached 321 degrees Celsius, while the internal cooking stove registered 129 degrees.

Keywords:

Parabola, Solar collector, Solar energy, Solar cooking, Solar grilling.

Highlights:

- Solar cooking and grilling eliminate the consumption of gas or coal, creates a cleaner and less polluted environment, and lowers air temperatures.
- Recent experimental studies on cooking and grilling technology using concentrated solar energy collectors were learned.
- The solar system collector structure, tracking method, receiving system, heat transfer and storage are classified.
- The solar cooking and grilling system has maximum efficiency and lowest costs.
- This sheet provides information on how to use the cooker in the most effective way.
- This work contributes to popularizing the optimal use of the cooker.
- The work was developed for cooking inside the kitchen.

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1. Introduction

With the advancement in using solar energy for multiple purposes instead of coal and oil, this research presented the design, construction and testing of an equivalent solar collector scheme for the purpose of cooking, reducing pollution and reducing cost. Solar energy is an important and practical solution for preserving the environment, reducing pollution, and promoting economic, social, and industrial growth [1-3]. Aramesh et al. [4] have made some modifications to the solar cooker. Several solar cooker designs and technological solutions have been implemented [5-28]. Concentrated solar cookers can cook food quickly and contribute significantly to achieving the development goals [10, 11]. The thermal performance of a solar box that uses high temperatures, loads and fluids is improved [3, 17, 26, 29-33].

Austin et al. [13], Kenneth and Subhash [25], Mahendra et al. [31], Mehmet et al. [34], Muhammad et al. [35], Ndiaga and Ali [36], Noureddine et al. [37] explored the idea of solar collectors and their use for cooking and drying and in water desalination systems. Ashmore et al. [7], Das et al. [18], Haftom et al. [23], Battocchio, et al. [14] mentioned the idea of solar collectors for heating water and liquids without implementing them practically for cooking purposes. Mayank and Subhra [33], modified solar water heaters, Ramy et al. [38], used solar dryers, Azmi et al. [13], Pimpan et al. [39] used condensate water heating without using it for cooking, grilling or heating water.

Fatma et al. [22] categorizes solar cookers into four types: concentrators (parabolic trough, cylindrical, spherical, and Fresnel), box stoves, solar ovens, and cookers. The results of Ndiaga and Ali [36] and Noureddine et al [37] show that the best diameter/height ratio is 2. Increasing the amount of liquid from 0 to 18 kg h-1 improves the storage temperature by 65 °C and increases the insulation thickness from 0.01 to 0.08 m. Ramy [38] claims that a parabolic dish/trough cooker with a guiding system reduces radiation loss because the small absorption area. Other advantages include higher food cooking temperatures and shorter heating times (Pimpan et al. [39]).

2. Research Methodology

Six parabolic solar panels, covered with reflective aluminum material are assembled as one unit and mounted on a movable base and vertical stand. This system is designed to hold cookware or grilling using solar (renewable thermal) energy. Both were conducted to assess system's energy was evaluated for direct and indirect cooking. It also looked at how solar center absorber is stored and transferred to the internal cooking systems.

3. Experimental Test Apparatus

The existing scheme (Fig. 1) was created and produced in Jazan, southwestern Saudi Arabia. The system consists of six flexible reflective panels to reflect sunlight back to the focus (pan or grill) and a movable support. The concentrator has a total area of 3.26 square meters (192 cm in length and 167 cm in width). Manufactured from high quality carbon steel, it is coated with a 0.7mm layer of highly reflective, non-corrosive aluminum alloy and formed into a parabolic shape. The concentrator length is 167 cm off the ground, and the cooking pot is placed 80 cm from the reflector. This design, at the intensity of solar radiation in the Jazan region, gives an average power output of 2300 watts from 9 a.m. to 5 p.m. With this system, it takes 16 minutes to cook 2.7 kg of vegetables and less than 2 minutes to boil 2 L of H_2O. Ten minutes is enough to grill a whole flattened chicken weighing 800 grams. As it does not cause fires or pollution, it is recommended that it be installed in public parks to discourage charcoal barbecues and gas cooking. When food is cooked internally, a black aluminum pot is installed in the center to absorb and store as much of the sun's heat as possible. It is filled with salt water and equipped with a copper coil containing oil (heat exchanger-1) to transfer the absorbed heat to the internal cooking pot (heat exchanger-2) installed on the stove. Jazan city is located between the latitude (11′ 09.38″ 17° N and 18′ 00.20″ 17° N.) and longitude (01′ 47.34 ″43° E and 09′ 56.64″ 43° E).

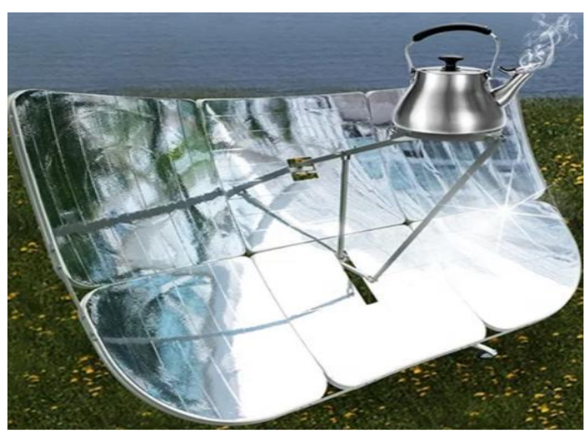

Fig. 1. Solar concentrating system

Temperature readings were taken at the solar ray's collection center (Fig.2). Average temperatures ranging from 315 degrees Celsius to 325 degrees Celsius were observed from 9:30 a.m. until 4 in the afternoon on most days. Solar energy measurements in the city of Jazan (Fig. 3) show the variation in intensity for June 2024 over five days from the 7th to the 12th.

Figs. 2 and 3 show the temperatures and intensity of sunlight recorded from nine in the morning until four in the afternoon, when the solar energy capacity is estimated at 1200 watts. A picture (Fig.4) shows the areas surrounding the absorbent or food slurry and temperature distribution using modified RIT. A record of temperatures ranging from 313oC to 373oC (Fig. 4), compared to the maximum one that recorded by a classical thermometer of 325oC (Fig.2) due to inaccuracy of measuring instrument. Figure 5 shows cooking meat, rice, etc. in a closed container, in which it takes about three minutes for water to turn into steam.

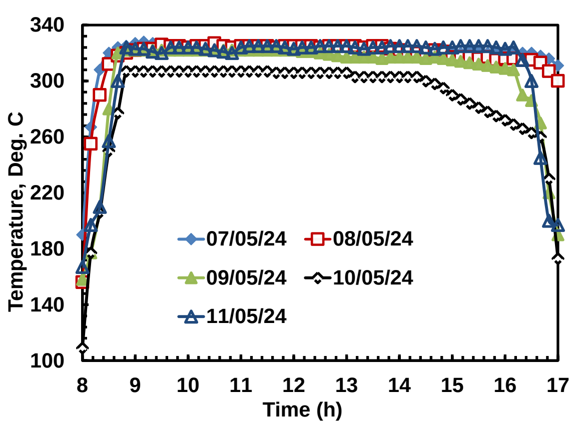

Fig. 2. Daily temperatures recorded in the absorber over five days

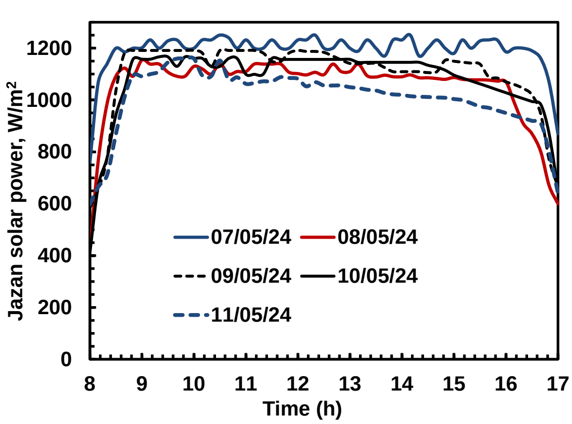

Fig. 3. Solar intensity variation in Jazan city over time in May 2024

Fig. 4. Temperature contour under cooking pot

Fig. 5. Solar concentrator

The cooking experiment took place at 10:30 a.m., was finished at around 9:50 a.m., making the total cooking time with this system about 20 minutes. Cooking vegetables in an open pot (Fig.6) took about 12 minutes to complete. Fig. 7 shows pictures of solar barbecue operations. Grilling 400 grams of chicken meat takes about twelve minutes, and is completed at eleven in the morning. This method is example of using raw coal to avoid polluting the environment and to ensure safety by eliminating the need to start fires to obtain coal.

Fig. 6. Solar-cooking vegetables in an open pot

Fig. 7. Solar grilling processes

4. Bringing thermal inside kitchen

The aim of this work is to design, build and test a parabolic cooking system using unconventional energy to save gas, reduce pollution and decrease air temperature. When the water of the solar collector absorber boils, its heat is transferred to the oil inside the copper tube surrounding the inner cooking pot through a small pump, bringing the temperature of the cooking pot to above 100oC. Trails have current indoor cooker is capable of cooking 2.0 kg of vegetables in 40 to 50 minutes during peak sunlight hours. Laboratory tests show that the system works reasonably well during cooking operations. Three types of heat transfer fluids were tested from the absorber to kitchen room, and Figure 8 demonstrates that soybeans are the best for cooking. The internal cooking temperature was plotted (Fig. 9) over five consecutive days, from June 1, 2024, to June 6, from 8 a.m. to 5 p.m., which shows some variations due to weather changes. The energy required for cooking is the sum of the heat required to bring one liter of water to the boil, the heat required to convert 99.96oC water to 100oC steam, and the heat required to cook one kilogram of vegetables at 100oC for about twenty minutes.

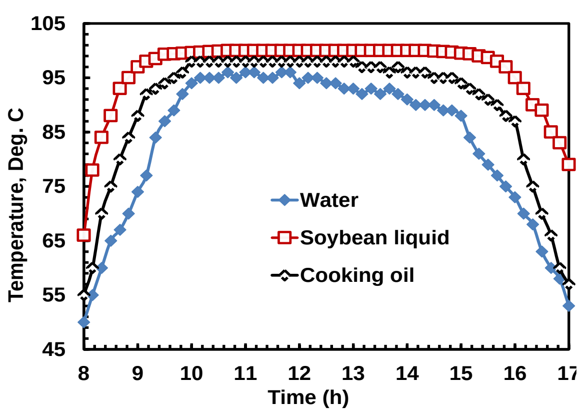

Fig. 8. Working fluid type

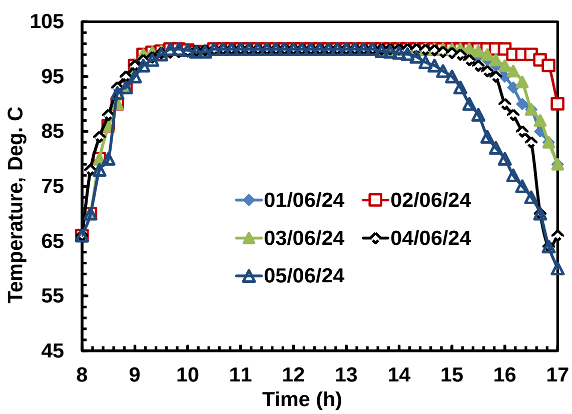

Fig. 9. Cooking pot temperatures (soybean liquid)

5. Effect of vessel design on cooker performance

Pot dimensions studied (Ahmad et al. [1]) by varying the diameters and height. The results showed that the longer the pot and the greater its clearance, the more concentrated will be on a smaller area and at a longer height, and the greater the radiation it will receive on both sides. In the present work, it is conducted, black aluminum alloy pan placed in the center of the collector to absorb and store maximum solar heat is filled with salt water and equipped with a copper coil containing heat transfer oil (heat exchanger-1) and another vessel (heat exchanger-2), installed on a rack to kitchen purposes. The wider vessel appears an advantage in total radiation absorbed, mainly due to more radiation impinging on the covering pots.

6. Theoretical analysis to improve food leveler performance

The current work developed analyses (Rongrong et al. [40], Swati [41], and Tegenaw et al. [42]) to simulate the solar collector absorber and heat transfer fluid (vegetable oil) to the internal cooking pot to achieve the highest food processing efficiency. Figure 10 shows a way to use solar energy in food preparation operations inside kitchen rooms. Swati [41] stated that the parabola shape for reflecting and its area is:

$$s_b = 8.38f^2\{[1+(d/4f)^2]^{0.5}\} \quad (1)$$

Where d is diameter which is:

$$R_b = 1.066[(d-y)^{0.5}-d] \quad (2)$$

The collector depth is:

$$h_b = h + y^2/h \quad (3)$$

The parabola arc length is:

$$b_b = 2R_b(\pi/180) \quad (4)$$

The concentration is defined as:

$$C = A_{abs}/A_b \quad (5)$$

The reflection ray slant is:

$$\beta = sin^{-1}(y/\mathrm{R}) \quad (6)$$

The thermal equivalent solar collector efficiency is:

$$\eta_{th} = I_o - U_a \frac{A_{abs} C_w (T_w - T_o)}{I_b A_b} \quad (7)$$

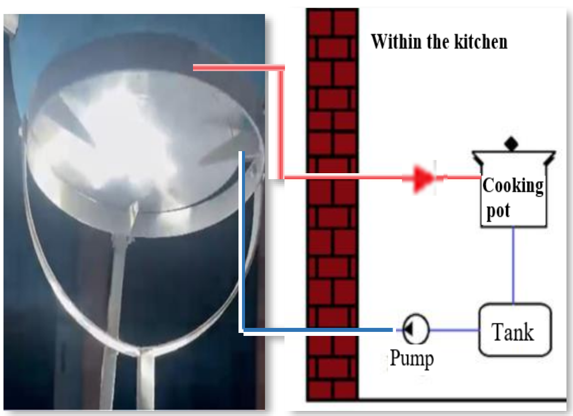

Fig. 10. Solar indoor cooking

The parabolic:

$$\eta_{ovl-c} = \frac{m_w C_w (T_w - T_o)}{0.5 \int I_b \, A_b \cos(43.3 - a)} \quad (8)$$

Where mw water mass, Tw and To water and atmospheric temperature, Ib is the area efficiency, Ab is the radiation and a is the solar declination. Internal thermal transfer efficiency:

$$\eta_{ith} = \frac{A_b f_b e^c [(T_w - T_o)_b - (T_w - T_o)_{ind}]/I_o}{A_{ind}(1 - e^c)} \quad (9)$$

Previous equations, Manikumar et al. [31] and Tegenaw et al. [42], Wanjun et al. [43], and Xabier et al. [44] show that radiation force lifts reflective absorber. Beam is not focused properly on the pot, which reduces the heat gain coefficient and thus reduces cooking efficiency. Nevertheless, Figure 11 shows how using Equations 6-9 helps to maintain efficiency without loss. The figure depicts the parabolic collector's overall efficiency. System efficiency without beam divergence is greater than its efficiency with beam divergence. The system efficiency is higher at a concentration area ratio of 26 than at a low area ratio for the parabolic trough and pot. That is the concentration coefficient factors influencing absorber temperature rise.

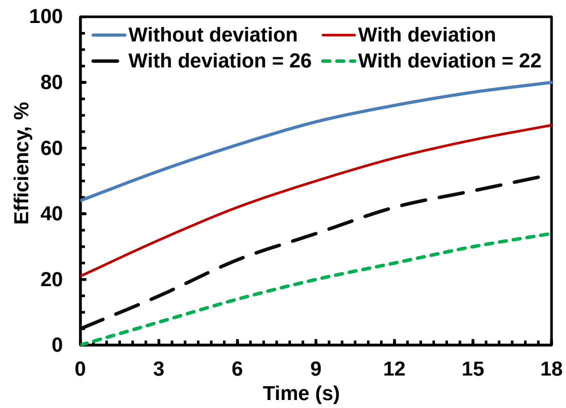

Fig. 11. Overall collector efficiency

7. Conclusion

Because cooking and grilling operations are vital daily activities, consuming coal and gas contributes to environmental pollution, high air temperatures, and transportation problems. In this research, a solar collector system was designed, assembled and implemented for cooking purposes and barbecue operations. The effect of different designs and configurations of cooking and grilling appliances on performance and overall costs was studied. The practical results showed the necessity of generalizing this system to cooking operations on rooftops, in public places, and inside homes to achieve cooking and barbecue operations faster than traditional methods and to reduce dependence on fossil fuels. Furthermore, it takes less time to cook or grill food than using traditional gas or coal power, resulting in less pollution and lower costs. 325°C was obtained at the concentrated collector absorber and over 100°C at the pot. The use of this system reduces gas or coal consumption, creates a cleaner and less polluted environment, reduces air temperatures, provides the most effective information on cooking processes and contributes to the optimal use of the cooker.

Highlights

- This research confirms the possibility of its use in rural and urban areas, including rooftops and public parks.
- The possibility of cooking at temperatures well above 100 degrees Celsius.

- This study confirms that the issue is not just about saving cooking fuel, but also about creating a non-polluting environment.
- This work will inform future improvements in cooker design.

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