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Performance and efficiency evaluation a of double reflector indoor solar cooker

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Abstract
The performance and efficiency of an indoor solar cooker has been evaluated. The tests were conducted at the premises of the Sokoto Energy Research Center Usmanu Danfodiyo University Sokoto, Nigeria (latitude $13.07°N$, longtitude $5.23°E$ and altitude 351m above sea level). The cooking results shows that the cooker is 88.5 % efficient. Other parameters evaluated include the efficiency, first and second figures of merit.

Keywords: multiple fuels, collector, inlet, outlet, Steam

1. Introduction

Cooking with energy from the sun has been known for ages, in the world, wood remains the main source of fuel in rural households [1]. According to [2] more than one billion people rely entirely on wood as a source of cooking fuel. Many poverty-stricken families worldwide spend 25% or more of their income on cooking fuel [3]. Millions of people use wood in combination with Liquefied Petroleum Gas (LPG). Again, In the opinion of [2], LPG has been penetrating the rural market as a complementary source of fuel rather than a substitute fuel. Households in rural areas follow a *'multiple fuel'* strategy for cooking which means a combination of technologies (i.e. wood and LPG) while performing their daily task.

Currently more than two billion people in the world cannot access energy services that are based on efficient use of gaseous and liquid fuels, or electricity. Without this access, they rely on the burning of solid fuels to generate energy for essential daily activities such as cooking. According to the World Health Organization (2008) the reliance on solid fuels for cooking purposes causes constant damage not only to the environment, but also to the economy and the health of the members of rural families [4].

An odd antecedent of the current solar cooking movement is the story of what Buti and Perlin call "the burning mirror". Greeks, Romans, and Chinese all explored the use of curved mirrors, which they found could concentrate the sun's rays in manner that would cause nearly any object to explode in flames [5].

A more direct route to solar cooking came from extensive efforts to harness the sun for horticulture. Travel and trade on a global basis had seen the transport of tropical plants and fruits to northern countries, creating a desire for these products, which could not be raised in northern climates. The principle of the greenhouse, the so-called "solar heat trap", was further utilized in what is thought of as the very first attempt to use solar energy to cook. In the early 1900s, a number of buildings designed to take advantage of solar energy were constructed, using heat trap principles, but were soon forgotten, then revived in the 30s when several largely solar heated office buildings were constructed [6]. Two organizations, the then Pillsbury Corporation and a non-governmental organization called Meals for Millions, jointly sponsored demonstrations of cooking and later taught villagers how to build ovens with local materials [7]. In 1988, Pillsbury, in cooperation with Foster Parents (now Save the Children) sponsored a similar project in Guatemala. These projects were among the early nation-to nation projects, starting a long stream of such projects around the world that continues to flow today. Since that time, numerous other organizations have been formed to sponsor projects and promote solar cooking activities. This thumbnail sketch is only a small part of the history, much unknown even to solar cooking supporters, of the many men and women who have caught a glimpse of the potential of the sun to cook food and have attempted over the centuries to spread that knowledge to others who can benefit.

In Nigeria, some institutions and research centers have been conducting a number of researches and development activities in different types of solar cookers. Among them is the Sokoto Energy Research Center, Usmanu Danfodiyo University Sokoto Nigeria, where from 1983 to date a number of solar cookers have been developed [8]. These include solar hot box, solar concrete hot box, all sides reflecting booster solar cooker, 2 sides reflecting booster box type solar cooker. Others are Fresnel reflector type, oil storage type, global solar cooker and a mirror dish concentrating type of cooker.

Solar energy can therefore make a major contribution to the energy needs for cooking food especially for remote and rural areas where solar radiation is available at a large scale and there is lack of other sources of energy available. Even when other sources of energy are available, environmental and economic benefits dictate the implementation of new alternative energy techniques. Solar cookers are primarily used to cook and pasteurize water [9]. Additional uses are continuously being developed.

This paper is therefore aimed at determining and evaluating the performance and efficiency of an indoor solar cooker, at different temperatures.

2. Materials and methods

The widely accepted test procedure for testing thermal performance of solar cookers is the American Society for Agricultural Engineers (ASAE) standards. The solar indoor cooker is designed and constructed using locally available materials i.e. plane glass, plane mirror, galvanized iron sheet, cotton wool, wood, iron pipes with diameter, black paint, copper pipes with diameter and plywood.

The cooker has two segments which comprised of the cooker and the collector. The cooker was connected to the collector with the aid of inlet and outlet pipes made of corrugated iron pipes which are connected to a set of copper pipes of the collector which were painted black. The aim of painted copper pipes is to receive solar radiation with the help of glass and plane mirror reflector placed at the bottom of the cooker. The cooker is pivoted with a cover of a single reflector in a wooden frame fixed using hinges to the cooker. The back of the glass was protected with plywood, a stand made of iron was provided. Inside the cooker was galvanized iron sheet coated black, the two pipes that connected the cooker and collector serve as medium in which the water will be circulating. The plane mirror focuses direct solar radiation to the bottom of the cooker. Both the cooker and stand were expose to solar radiation. The top of the cooker was covered with double glass and the collector was covered with single glass pane and coated black. The cooker was shielded with a galvanized iron sheet and has a surface of about 80cm×40cm length and thickness of 0.03cm. In order to reduce heat losses from the absorber plate, the space between the plate and two glass panes that covered the cooker, a cotton wool or a foam is used to fill-up the space and serve as insulator material. The cooking pot used is made of Aluminium painted black with a diameter of 20 cm and 12 cm height, when cooker is not in use the hinged wooden framed glass is used as a cover for the cooker.

Important general consideration is the selection of material for the construction of indoor solar cooker include local availability, ability to withstand environment, operating condition and non-toxic effect.

Other Instruments used during the test includes; pyranometer, anemometer copper constantan wire, wet and dry bulb thermometer, thermocouple digital temperature indicator, steel bar Aluminium pot and clock. Plate 2.1 shows the double reflector indoor solar cooker used in this study.

Plate 2.1: Double reflector indoor solar Cooker.

In this double reflector solar cooker, the solar collector heats a small header tank containing water until it is hotter than the energy store. Steam is then transferred down (or along) a small diameter tube to the energy store where it condenses in a pressurized water storage medium. The energy storage unit consists of a high temperature pressurized water vessel mounted separately from the collector. Working fluid is returned to the solar collector header tank at the end of the day by a reverse pressure difference developed when the solar collector header tank temperature drops below the storage tank temperature. Heat is transferred from the store to the cooking surface by a heat pipe system controlled by the standard rotary control on the front of the stove. A steam heated cooking surface was developed in the form of a drop-in replacement for a conventional electric hot plate so that solar heated cooking surfaces could be easily integrated with existing bench top cooking appliances.

The food used for the tests is a piece of yam of about 40g boiled in 500 ml of water. The cooker was made to stand for a period of the experiment the reflector was adjusted so as to always receive direct sunlight for optimum performance.

The two figures of merit are given by Equations (1) and (2) in accordance with American Society of Agricultural Engineers Standard (ASAE) S580;

$$F_1 = \frac{T_p - T_a}{H} \quad (1)$$

and

$$F_2 = \frac{F_1 (m_w c_{p,w})}{At} ln \left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{wi} - T_a}{H}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{wf} - T_a}{H}\right)} \right] \quad (2)$$

The efficiency (n) of a solar cooker can be computed using Equation (3)

$$n = n_0 - a_1 \frac{T_c - T_a}{E_e} - a_2 \frac{(T_c - T_a)^2}{E_e} \quad (3)$$

$n_0 =$ efficiency of the collector at zero temperature difference between absorber temperature and ambient temperature.

$$n_0 = \alpha \tau F \quad (4)$$

3. Results and Discussion

Figure 3.1 displays the relationship between the time, temperature and wind speed at stagnation. It is clearly seen that the highest temperature of 62.4^{0}C was obtained at around 1:00pm. The highest wind speed of 4.35 m/s was recorded at around early hours of the day.

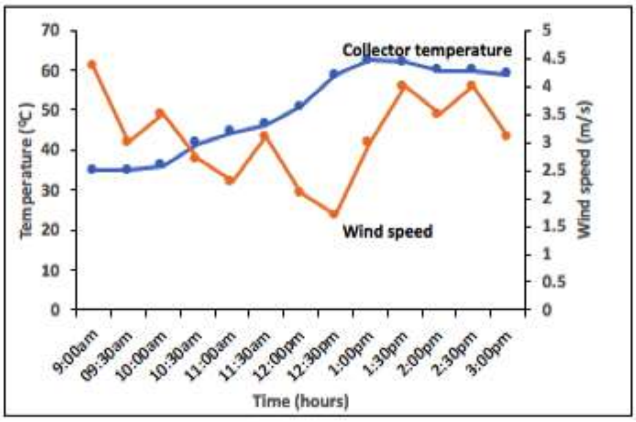

Fig 3.1: Time against Temperature and wind speed (stagnation)

The plot of time against temperature and wind speed (cooking) is also displayed as Figure 3.2. The highest water temperature during cooking recorded was 67^{0}C at around 3.00 pm. The corresponding wind speed observed for this period was 4.75 m/s.

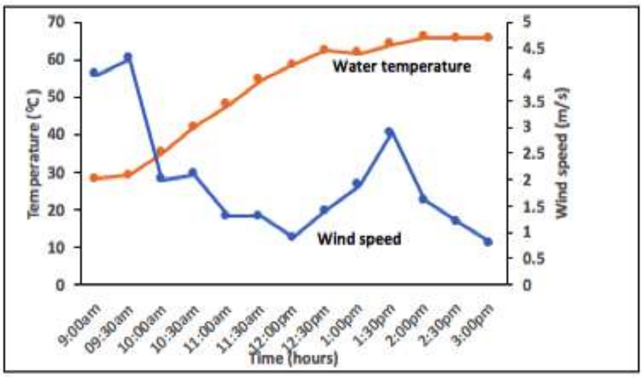

Fig 3.2: Time against Temperature and wind speed (cooking test)

Table 3.1 displays the calculated figures of merit and the efficiency of the solar cooker.

Table 3.1: Figures of merit and efficiency

F_1 (no load)	F_2 (load)	% Efficiency (n)
0.08	0.61	88.5%

Conclusion

A double reflector indoor solar cooker was successfully tested and is found to be 88.5 % efficient. Stagnation and cooking experiments were conducted in which a piece of yam of approximately 40 grams was cooked in about 30 minutes.

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