

Determination of Temperature Variation of a Box-Type Solar Cooker

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ABSTRACT

A solar cooker is a device that cooks food using only solar radiation and can save conventional fuel to a significant amount. It is a simple, safe, and most convenient way to cook food without consuming fuels or heating up the kitchen. It, however, only supplements cooking fuel and cannot replace it in total. Solar energy is abundantly available worldwide and it is possible to cook a noon meal for 4 to 5 in a normal box-type solar cooker on clear sunny days. Concentrating solar cookers can cook for larger numbers than box-type solar cookers. In a simple solar cooker one can bake and boil, and in cooker for domestic use it is possible to cook food for 4 to 5 persons. Bigger sized solar concentrated cookers are also available for cooking food for up to 15 persons at a time. The experiment was performed to obtain cooking temperatures of a box-type solar cooker. The experiment showed a maximum plate temperature of 98°C and a minimum temperature of 35°C. Water temperature of the box-type solar cooker was also measured and a maximum water temperature of 61°C was recorded.

(Keywords: conventional fuel, solar cooker, radiation, renewable energy and food)

INTRODUCTION

A solar cooker is a device which uses infrared radiation from sunlight to cook food. The first documented effort of using solar energy to prepare food was by the French–Swiss Physicist Horace de Saussure [1]. He reported cooking fruit in 1767 using a sealed window box with five panes of glass stacked one atop another [2]. Multiple panes of glass reduced heat loss through the window and made the box more efficient at retaining heat. In 1830, Sir John Herschel used a similar device to cook food while aboard a ship on

his way to South Africa [3]. In August 1866, Augustin Mouchot came up with the idea of using mirrors to focus sunlight in an effort to make solar ovens more efficient. His design was the first description of a parabolic trough solar oven [4]. The first octagonal oven, a device that uses multiple reflective mirrors to focus sunlight onto a fixed point, was developed by W. Adams in 1876. [3].

In the 1960s and 70s, the concept of developing renewable energy technologies became more and more popular all over the world due to increased public awareness of the need to protect our dwindling natural resources [5]. Since that time, solar cooking technology has been the focus of considerable interest in both developed and developing nations because of the ability of solar ovens to prevent deforestation, reduce local dependency on fossil fuels, and reduce a community's carbon emissions [6]. The first modern book about solar ovens published in the USA was written by Heather Gurley in 1983 and entitled *Solar Cooking Naturally* [7]. In 2000, an international standard for solar ovens was finally described. Nowadays, solar ovens are widely used in developing nations due to their convenience, cleanliness, and low production costs [1]. There are four main types of solar oven designs: box cookers, paraboloidal reflectors, parabolic troughs, and spherical reflectors.

Types of Solar Cookers

A survey of solar cookers worldwide shows that a wide variety of cookers have been designed. However, the available designs of solar cookers fall into four main categories namely, the solar box cookers, popularly known as solar ovens, panel cookers, collector cookers, and concentrating or reflector cookers [8]. The feature

common to each design is the shiny reflective surface that directs the sun's rays onto the cooking area and dark inner walls of the cooking area and cooking vessel. Each type of solar cooker has its own advantages when compared on their cooking ability, ease of construction, and safety of use.

The solar box cooker or solar oven is the most common type of solar cooker made for personal use. It consists largely of a box made of insulating material with one face of the box fitted with a transparent medium, such as glass or plastic. The panel cooker is quite similar in operation to the solar box cooker. The same principles are employed but instead of an insulated box only, the panel cooker typically relies on large (often multi-faceted) reflective panels, which focus the sunlight on a cooking vessel [8]. The collector cooker is made up of two parts that often share a single casing: a collector for gathering heat and a cooking part for exploiting the yield. A typical collector cooker would consist of a flat plate solar collector, side and head mirrors, and the cooker part. The user is not affected by radiation and heat as the cooking part is separate and protected from radiation. Oil is used as the heat transfer medium in order to allow higher temperatures to be reached. The concentrating solar cooker or reflector cooker utilizes the principles of concentrating optics. It concentrates direct solar radiation on the bottom of the cooking pot, heating the pot in a fashion similar to a traditional electric or gas-powered stove. The most commonly used shape is that of a parabola hence, the name parabolic cooker. Using mirrors and/or lenses, this cooker can achieve extremely high temperatures.

Box Cookers

The simplest type of solar oven is a box cooker. As the name implies, box cookers are highly insulated cube shaped structures with a single window that allows sunlight to pass into the interior of the cooker [9]. They are usually made of locally sourced materials such as wood, cardboard, mud bricks, or stone and have a reflective surface made of polished aluminum or foil on the inside. The cooking vessel is generally a black pot capable of absorbing heat and infrared radiation. The cooking vessel is either placed directly on the floor of the oven or suspended slightly above the cooker floor on a shelf ("How to: Make a Cardboard Box Oven," 2008). One of the limitations of a box cooker is that they can only

heat a limited amount of food in several hours. However, simple box cookers can reach temperatures of 130 – 150°C well above the minimum temperature of 65°C necessary to kill most pathogenic bacteria [9]. That is to say, most box-type solar ovens are small and designed to heat only small amounts of food therefore, the current commercial designs are not 100% appropriate in terms of the project for The United States Army which is to heat large quantities of human waste to temperatures that will kill all pathogenic bacteria within several hours.

MATERIALS AND METHOD.

The materials used in the conducting the experiment were: weighing balance, water, digital thermometer and mercury in glass thermometer. The materials used in the construction of the box solar cookers included: wood, cardboard box, metal sheets, iron rod, angle iron, sawdust, nails, glass sheet, glue and aluminium foils.

Principle of Operation of Solar Cooker

A solar cooker is a container or a device that traps solar energy and helps in heating and cooking food. It mainly works on three principles i.e. concentration, absorption and retention. A solar cooker has a mirror that helps in letting the sun's UV rays in and converts it into infrared light rays. The infrared radiation has the power to make the protein fat and water molecules present inside the food to shake vigorously which heats up the food. The sun's heat actually does not help in heating the food, but it is the rays derived from the sun which converts into heat energy and cooks the food. A lid is used to cover the food kept inside a pot so that the heat energy does not escape. An effective solar cooker thus helps in capturing heat and cooks the food.

Method

Experiments were conducted on the constructed solar cookers outdoors during November 17, 2017 and November 25, 2017 to check the temperature increase in the Box solar cooker. Also, atmospheric and water temperatures in the solar cooker were measured. The test run from 10:05 am to 6:05 pm on the first day while the test started from 10:15 am to 5:15 pm on the other test day. The digital and mercury in glass

thermometer were used to measure the cooking fluid, the absorber plate and the ambient temperature. Weighing balance was used to measure the mass of water. Ambient temperature, absorber plate temperature, and maximum water temperature was measured and recorded.

Thermal Performances of Solar Cookers

A simple procedure used by El-Sebaai and Ibrahim (2005) was adopted to evaluate the thermal performance of the solar cookers [10]. The performance testing procedure consisted of the following:

- a. Water boiling tests.
- b. Temperature. The measured variables were: ambient temperature, the temperature of the water in cooking pots, the initial water temperature and the absorber plate temperature.

Overall Thermal Efficiency

Overall thermal efficiency was calculated by following equation (El-Sebaai and Ibrahim, 2005)

$$\eta_u = \frac{M_f C_f \Delta T_f}{I_{av} A_c \Delta t} [11]$$

Where:

η_u = overall thermal efficiency (%)

M_f = mass of cooking fluid (kg)

C_f = specific heat of cooking fluid (j/kg.K)

ΔT_f = difference between the maximum and ambient air temperature.

I_{av} = average solar intensity (W/m²) during the time interval.

A_c = is the aperture area (m²) of the cooker.

Δt = time required to to achieve the maximum temperature of the cooking fluid(s).

Cooking Power

The cooking power of the different solar cookers was calculated using equation given by Kundapur and Sudhir (2009) as follows: [12]

$$P = \frac{T_{w2} - T_{w1}}{t} C_{pw} m_w [11]$$

Where:

P = cooking power (w).

T_{w2} = final water temperature (°C).

T_{w1} = initial water temperature (°C).

t= time(s).

m_w = mass of water (kg).

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

RESULT AND DISCUSSION

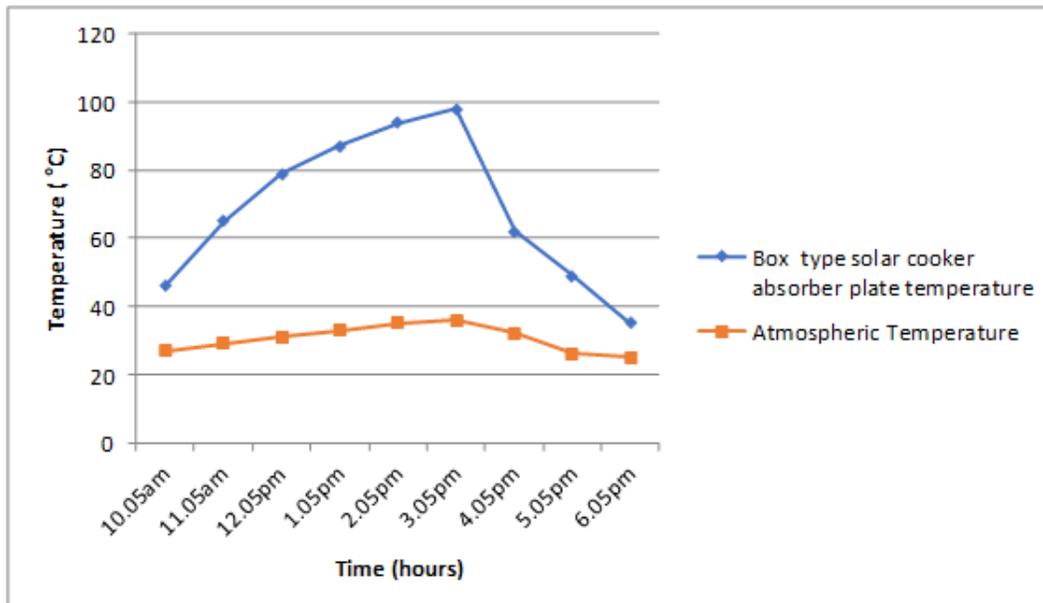


Figure 1: Box-Type Solar Plate Temperature versus Atmospheric Temperature.

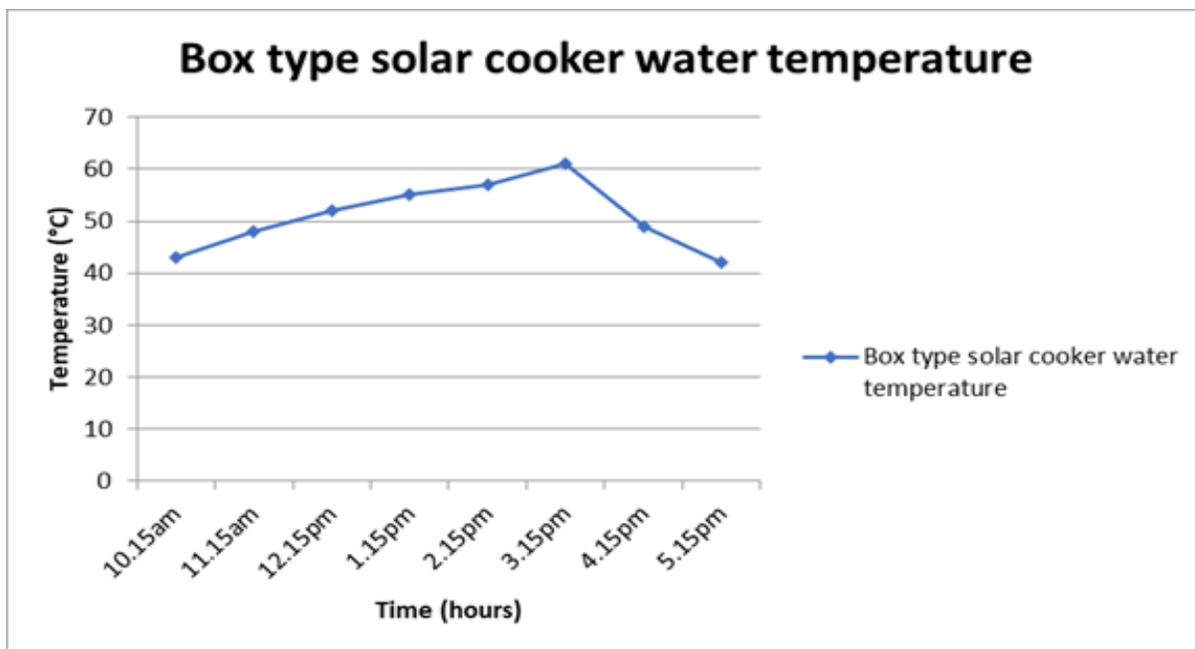


Figure 2: Box-Type Solar Cooker Water Temperature.

The experiment was conducted on November 17, 2017 at Nsukka where the longitude and latitude are (Latitude 6.8°N and Longitude 7.29°N) [48]. The experiments run from 10:05 am to 6:05 pm for solar plate temperature of box-type solar cooker. The second experiment which was determination of box-type solar cooker water temperature run from 10:15 am to 5:15 pm on November 25, 2017.

The temperature of the solar plate increased gradually from 46°C to 98°C, then dropped gradually to 35°C at 6.05 pm. The maximum box-type solar plate temperature obtained was 98°C at 3.05 pm. The experiment conducted by Elamin and Abdalla (2015) show that parabolic solar cooker attained maximum temperature of water (86.5°C) then box-type cooker (52.35°C) and finally the panel cooker (43.5°C).

The atmospheric temperature varied from 25°C to 36°C. It increased gradually from 27°C at 10:05pm on 17th November, 2017 to a maximum value of 36°C at 3:05pm the same day. The gradual decrease was observed from 4:05pm to 6:05pm. Elamin and Abdalla (2015) observed maximum atmospheric temperature of approximately 39°C which is slightly higher than the one obtained from this work.

The water temperature of box-type solar cooker varied from 43°C at 10:15am to a maximum value of 61°C at 3:15pm. This then gradually decreased from 49°C at 4:15pm to a minimum value of 42°C at 5:15pm. Kimambo (2007) obtained a maximum water temperature of 65°C for wooden box solar cooker and 59°C for Sunstove box solar cooker. Also in the same work, Kimambo (2007) measured maximum water temperature of 90°C for glass mirror reflector and 65°C for polished reflector.

CONCLUSION

Cooking is an activity that must be carried out almost on a daily-basis for the sustenance of life. An enormous amount of energy is thus expended regularly on cooking. Cooking may be classified into four main categories based on the required range of temperature viz. Baking (85-90°C), Boiling (100 to 130°C). Frying (200 to 250°C), and Roasting (over 300°C). It was observed that on a bright sunny day, a box-type solar cooker will give a temperature of above 98°C from the plate. The maximum atmospheric temperature recorded during the experiment was 36°C.

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