

An Improved Solar Cooker for Application in Developing Countries. -Technical performance & cost considerations

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ABSTRACT: Over 1/3rd of the world population relies on fuel wood and biomass for their daily cooking needs with daily fuel wood requirement per person estimated at 1.3 kg. The use of solar energy would help in reducing the daily recurring burning of fuel wood, which would reduce deforestation, environmental and other ecological degradations. This paper presents test results and cost assessment of a new improved solar cooker designed for application in the developing countries. The newly developed cooker has been evaluated according to the two standard Figures of Merits (F_1) and (F_2), through; temperature stagnation and water boiling tests respectively. Sample cooking tests have been conducted using simulated solar radiation and the results have shown that the cooking requirements could be achieved. Comparative performance tests of painted and unpainted cooking pots had been undertaken and the results show that painted cooking pot achieves about 20% more heat compared to the unpainted cooking pot. The economic and environmental assessment of the system has also been performed. Using the cooker once a day could bring an annual savings of up to 1,281.2 Mtons and 114.2 Mtons of fuel wood and CO₂ respectively.

Key words: Box solar cooker, fuel wood for cooking, Economic and Environmental benefits of solar cooker

1. INTRODUCTION

Since the Industrial Revolution in 1750, human activities have substantially added to the amount of heat-trapping greenhouse gases in the atmosphere. The burning of fossil fuels and biomass (living matter such as vegetation) has also resulted in emissions of aerosols that absorb and

emit heat, and reflect light. The addition of greenhouse gases and aerosols are changing the composition of the atmosphere which in turn would influence the earth temperature, precipitation, storms and sea level [1]

Approximately over 2.4 billion people over one-third of all humanity and two-thirds of the developing world cook over biomass fuel wood, charcoal, dung and crop residues [2].

Over 70% of the forty of the world's poorest country's fuel come from dwindling supplies of fuel wood. In most towns and cities of these countries fuel comes from charcoal inefficiently produced from fuel wood. Fuel wood and agricultural residues are the major energy sources for cooking in the developing countries, this account up to 90%. For example in Tanzania with 32 million people, over 90% of the country's energy comes from wood/charcoal [3].

According to the FAO projects, in the year 2000 [4] as many as 3 Billion people will have insufficient access to fuel wood to meet their basic cooking energy needs. In Haiti for example, even tree stumps and roots (the last remaining vegetation holding down the soil) are dug up to make charcoal. Every trace of a tree is removed to convert it to increasingly expensive charcoal, promulgating the ultimate 'scorched earth' policy.

In some coastal areas, mangroves are cut below water line to feed the charcoal kilns, weakening the trees and eventually killing the trees. Without mangroves, estuaries can fall into rapid decline, spreading ecological devastation [5].

Study show that two of three developing countries are in the midst of a fuel wood shortage [6]. This paper presents new passive solar cooker designed, constructed and tested for sustainable cooking applications especially in the developing world.

2. THE SOLAR COOKING SYSTEM

A simple box type solar cooker has been developed from reused and recycles materials; the cooker comprises four components as follows:

1. Wooden box casing provided by 12mm plywood followed by 50mm

thickness glass fibre insulation to reduce heat losses and also to accommodate the rest of the system components,

2. Metallic tray collector made of copper plate coated with mat black paint to absorb solar radiation.
 3. Double glass lid cover which allow the radiation to pass and also reduces heat loss.
 4. Reflecting booster this enable more solar radiation with the help of a mirror or other reflecting materials.
- The developed solar cooker is presented in Figure 1.



Figure 1: Developed passive solar cooking system

The developed solar cooker has an upper aperture area of 0.2 m^2 and its overall external sizes are $(0.5\text{m} \times 0.6\text{m} \times 0.3\text{m})$ able to accommodate different cooking pots suitable for cooking meals for up to 5 people of typical rural area habitants. The use of solar energy would help in reducing the daily recurring burning of fuel wood, which would reduce deforestation, environmental and other ecological degradations. A schematic diagram of the solar cooking system is shown in Figure 2.

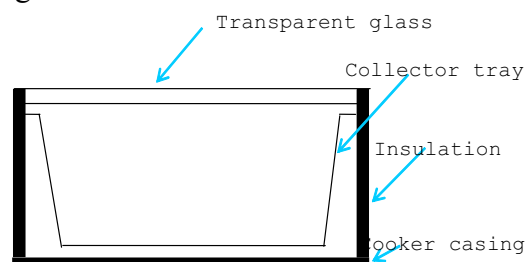


Figure 2: schematic diagram of the developed solar cooker.

3. TEST METHODOLOGY

Indoor test of the developed solar cooker was conducted using simulated solar radiation. The measured parameters included, ambient, plate, top glazing, and bottom glazing temperatures. The system is first tested to satisfy the two standard Figure of Merits (F_1) and (F_2) temperature stagnation and water boiling tests respectively [7; 8]. Sample cooking tests were then carried out using long grain rice as the cooking material.

3.1 Stagnation and Water Boiling Tests

The first test was the temperature stagnation test; this is known as F_1 performance evaluation which is used to evaluate the performance of the newly developed rectangular solar cooking system, in line with the box type solar cookers test criterion.

Mullick et al [7] defined the First Figure of Merit (F_1) for Box type solar cookers evaluation as; the ratio of optical efficiency ($F'_{\eta o}$) to overall heat loss coefficient (F'_{UL}). This is given as;

$$F_1 = \frac{F'_{\eta o}}{F'_{UL}} = \frac{T_p - T_a}{H} \quad (1)$$

Where;

T_p Collector plate temperature °C

T_a Ambient temperature and °C

H Solar radiation (W/m^2)

For example, under a solar radiation of $600W/m^2$ and a T_p and T_a of $105^\circ C$ and $22^\circ C$ respectively, the first Figure of Merit F_1 of the solar

cooker is evaluated from equation (1) as;

$$F_1 = \frac{T_p - T_a}{H} = \frac{105 - 22}{600} = 0.14 \quad (2)$$

Air stagnation evaluation performance test coupled with the above equation, provides a general guide for evaluating solar cookers in which a minimum acceptable value of F_1 is 0.12, for high thermal effectiveness of the system [8].

The second Figure of Merit (F_2) is another way of evaluating box type solar cooker through water boiling test. F_2 is related to F_1 as shown in the following Equations [9].

$$F_2 = F'_{\eta o} C_R = \frac{F_1 (MC)_w}{A_t} \ln \left[\frac{1 - \frac{1}{F_1} \left(\frac{T_{w1} - T_a}{H} \right)}{1 - \frac{1}{F_1} \left(\frac{T_{w2} - T_a}{H} \right)} \right] \quad (3)$$

Where;

C_R = Heat capacity ratio

T_{w1} = Water temperature 1

T_{w2} = Water temperature 2

A = Aperture area of the cooker

t = Time interval raising T_{w1} - T_{w2}

And the $F'_{\eta o}$ is given as follows;

$$F'_{\eta o} = \frac{F_1 (MC)_w}{C_R A_t} \ln \left[\frac{1 - \frac{1}{F_1} \left(\frac{T_{w1} - T_a}{H} \right)}{1 - \frac{1}{F_1} \left(\frac{T_{w2} - T_a}{H} \right)} \right] \quad (4)$$

In the F_2 water boiling test, one litre of water was used in a cooking pot to evaluate the cooker performance. Using a radiation level of $600W/m^2$ the following temperatures were recorded, $110^\circ C$ and $86^\circ C$ for collector plate and inside air temperatures respectively for a period of 2 hours 45 minutes.

3.2 Cooking performance tests

Two sets of cooking tests were carried out using eggs and parboil long grain rice. The cooking test was performed indoor using simulated solar radiation. The test was inn until the food was cooked. A maximum temperature of 80°C was recorded in the pot for the eggs cooking test. The results of the test are presented in Figure 3 which shows the temperature variations at various points of the cooker.

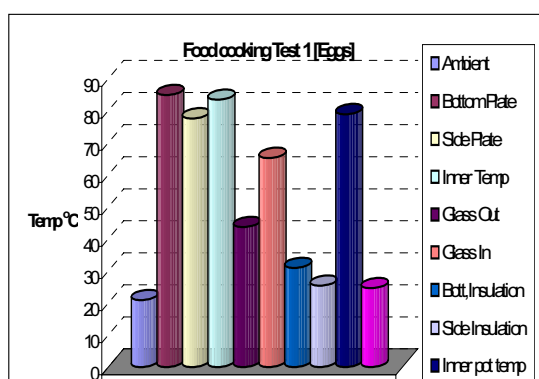


Figure 3: Solar cooking evaluative test

In the case of rice cooking, 300 grams of American parboiled long grain rice adequate for a meal of 4-5 adults was cooked under 3 hours period under and 600W/m² solar radiation level.

Figure 4 shows the temperature variation at different positions of the solar cooker.

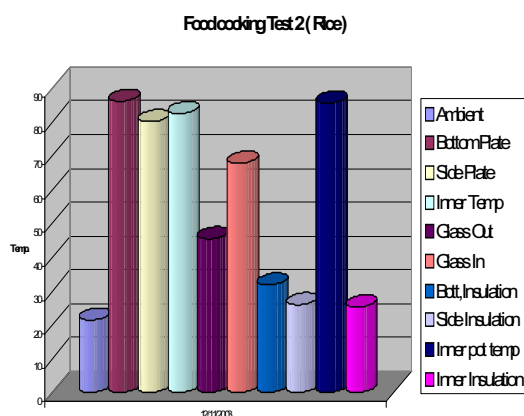


Figure 4. Rice cooking test

3.3 painted & unpainted cooking pots - Comparative test

There is an argument on which material is best suits for the solar cookers collectors, some people uses aluminium foils while others prefers mat black paints. Water boiling test was conducted employing painted and unpainted pots. In these tests one litre of water was used to evaluate the performances of the two cooking pots. The results obtained show a temperature of 83°C and 101°C for the unpainted and painted cooking pot respectively.

The comparative test has shown an improved performance of the painted pot over the unpainted pot. This justifies the theory of using black body on both the collector tray surfaces and the cooking pot, though still aluminium foils are still used instead of the mat black paint.

4.0 ENVIRONMENTAL ASSESSMENT AND COST ESTIMATES.

In the developing world, systematic mass usage of the abandoned sunshine as an alternative renewable energy source for cooking could provide numerous environmental and economic benefits. These can be summarised as follows:

- 1) Reduce dependence on expensive finite fossil fuels.
- 2) Preserve forests and soil erosions results in better crop yields to farmers.
- 3) Saves time and money.

4.1 Environmental assessment

The rate at which the environment is being exposed to global warming, ozone layer depletion and dessert encroachment as the result of human interference cutting down trees

for energy needs for cooking is alarming in the developing world. Averagely over 80% of energy consumption for cooking/water heating in the developing world relied on fuel wood and charcoal on a daily basis. Apart from the CO₂ released to the environment, the use of fuel wood is causing desertification and other ecological degradation which drastically affects the land fatality.

4.2 Fuel wood savings

The estimated average daily fuel wood requirement per person in the developing world is 1.3 kg. The amount of wood burned on daily basis, apart from the associated health hazard (passive smoking) also emits huge CO₂ to the environment.

According [4] about 3 Billion people are in need of fuel wood in the world. If solar cookers are introduced to 50% of these people in desperate need of fuel wood would bring a dramatic economic and environmental savings. The daily monthly and annual fuel wood consumptions are shown in Table 1. Single cooking with solar can adequately cook for 5 people at a time. Solar cooking would bring tremendous benefits in the developing world economically, environmentally and otherwise. Using a single solar cooker 3 times a day would bring saving of 2.4 tons of fuel wood annually.

Period	Fuel wood / person (tons)	Family of 5. (tons)	2.7 Billion people (Megatons)
<i>Daily</i>	0.0013	0.0065	35.1
<i>Monthly</i>	0.04	0.2	105.3
<i>Annually</i>	0.5	2.4	1281.2

Table 1: Estimated daily, monthly and annual developing world fuel wood consumption.

4.3 CO₂ savings

CO₂ is one of the green house gases responsible of causing global warming, which results in sea-rise, desertification, rainfall shortages, and danger of infrared radiation from the ultraviolet rays etc. The recent catastrophes of; Katrina, Tsunami and Bangladesh storm are living witnesses before us. For burning one kilogram of fuel wood 0.27 kg of CO₂ is released to the environment. Therefore the CO₂ released for burning 1,281.2 Megatons of fuel wood is 345.91 Mtons, as presented in Table 2 below.

Period	CO ₂ (kg) / Person	Family of 5 (kg)	2.7 Billion People (Megatons)
<i>Daily</i>	0.351	1.755	0.9477 B
<i>Monthly</i>	10.53	52.65	28.43 B
<i>Annual</i>	128.1	640.58	345.91 B

Table 2: CO₂ released to the environment from fuel wood burning.

When a solar cooker is used at least once a day the CO₂ savings would be about (33%). The CO₂ savings would amount to 345.91 x 0.33 = 114.2 Megatons. Using a single solar cooker once a day, 0.64 tons of CO₂ would be saved annually per a family of 5 persons.

4.4 Economics analysis

Solar systems are capital intensive. The cost of purchasing and installing a solar cooking system is high in comparison to the conventional system it replaces. But the conventional system is energy intensive, that is, the annual energy costs are higher than those of an equivalent solar system. Purchasers of solar systems expect the resulting fuel

savings eventually to pay for the system and save on the cost of future energy needs.

Solar energy is a primary source of energy for our planet. Its increased utilisation would result in all-round benefit both in maintaining sustainability of the environment and economic gain. Further to its environmental benefits, using the solar cooker would save a lot of time and money since the energy source is free and it is easy to operate. The introduction of solar cookers as an alternative renewable energy source would go a long way in energy savings and conserving our forests decreasing deforestation.

4.5 System costs estimates

In the developing world - Nigeria for example - a family of five in (which is the design capacity of the developed solar cooker) requires a fuel wood costing about £0.25 daily.

The estimated daily recurring expenses on fuel wood are presented in Table 3.

Period	Amount/ family (£)	Fuel wood /person (kg)
Daily	0.25	1.3
Weekly	1.75	9.1
Monthly	7.50	39
Annually	91.50	474.5

Table 3: system cost analysis

The rectangular box type solar cooker was constructed out of recyclable available materials, and its conservative estimated cost is varied between £20 and £30 only. The system is mostly constructed from available materials, therefore mass production and vigorous orientation about its

economic, environmental and social benefits would further reduce the cost of the viable renewable efficient solar cooker.

4.6 Payback period

Ignoring the negligible inflation and interest rates, the payback period of the cooker, would be dependent on usage once twice or three times a day.

Solar cooking systems were introduced and monitored in refugee camps in Somalia and some other parts of East Africa. The average uses of these cookers were 25% and 75% for single meal and double meal cooking respectively and over 40% reduction of fuel consumption was recorded [7].

When the solar cooker is used to prepare three meals daily, the payback period is only four month and using the solar cooker for two meals per day, the solar cooker's payback period would be 6 month. While if the system is used once a day its payback period would be one-year (see Table 4). The expected life time of the solar cooking system is 10 years.

Cooking	System unit cost (£)	Monthl y savings (£)	Payback period (Month)
3 meals /day	30.00	7.50	4
2 meals / day	30.00	5.00	6
1 meal / day	30.00	2.50	12

Table 4: system payback period

Therefore by using solar cooker, the energy saving per person on an annual basis could drastically reduce

cooking fuel consumptions down to 60%.

5. CONCLUSIONS

Judging by the results presented in this paper, the developed solar cooker has passed the F_1 and F_2 standards of merits performances tests. Both Stagnation temperatures, Water boiling and cooking performance tests were conducted using simulated radiation of 600 W/m^2 , a bottom plate temperature of 105°C was recorded from the box solar cooker. The system was able to cook rice at 85°C temperature.

Different types of food, breads, cakes and vegetables could be prepared with the cooker. Water pasteurisation can be easily conducted with no bill. The cooker could bring a dual benefit reducing burning of fuel wood, reducing CO_2 emissions saving the ecosystems and brings saving up to 30% for the first year and 95% for the subsequent years.

Using these alternative sources could also open new job opportunities to the people improves life condition of people and finally brings security and reliability of other energy supplies. Other benefits of the solar cooking system include;

- 1) Prevents lung and eye diseases caused by smoky fires.
- 2) Free children from the burdens of fuel wood gathering so they can attend schools.
- 3) Improving health by allowing nutritional, longer-cooking foods, such as maize and beans, to be cooked by people who can't afford to normally cook them due to fuel expense.
- 4) Reduce water-borne diseases through solar water pasteurisation.

- 5) Cooks healthy food with little attention and no risk of burning the food and other fire hazards.
- 6) No soot accumulation on pots and no burns from fire (notably of the children).

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