COMPARATIVE PERFORMANCE ANALYSIS OF A SOLAR BOX COOKER AND IMPROVED CHARCOAL STOVES IN MOZAMBIQUE

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Summary

With exception of South Africa, where only 16% of the population depends on traditional biomass energy, almost 80% of the population in the sub-Saharan Africa depends on biomass resources for cooking and heating. The burning of traditional biomass in the so-called three stones stove puts pressure on biomass resources because of its inefficiency. Besides, fumes and soot are related to respiratory diseases that are the common cause for deaths among women and children in Africa. The shortage of fire wood makes women and girls to walk in search of fuel for cooking. Solar cooking is one of the possible solutions for this poignant problem. Yet another partial solution is the use of improved biomass stoves. This paper presents a comparative analysis of the performance of solar box cooker and improved charcoal stove in Mozambique, in its technical and economic aspects.

key-words: charcoal stoves, solar box cooker, solar energy.

1. Introduction

Most of the energy used in rural areas of Sub-Saharan African countries is to provide heat for cooking and boiling bathing water. Traditional biomass in the form of firewood is the most widely used energy source for providing the above services in households. The burning process of firewood using the three stones stoves is inefficient and puts pressure on biomass resources causing deforestation in densely populated areas. On the other hand, Africa has the world’s best solar resources. Several countries in the region have exploited solar energy for water heating, crop drying and telecommunications, among other uses. Solar energy can contribute to the supply of heat energy in households of African countries (Ogunlade et al., 2007; Hancock, Klingshirn & Seidel, 2007; Kristjansdottir, 2004; Kimambo, 2007).

The Government of Mozambique, the private sector and academic institutions have been working together to promote solar cooking. Eduardo Mondlane University carries out projects on capacity building, resource mapping, and technology development in this field.

The ProBEC (Programme for Basic Energy and Conservation), GIZ and the Mozambican government introduced improved charcoal cooking stoves in the cities of Maputo and Matola in 2007 (Chidamba, 2010). The following were the objectives of the research:

- To evaluate and compare the thermal performance factors of the stoves
- To carry out the cost analysis

1.1 Description of the Stoves

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1.1.1 Charcoal Stoves

Traditional Stove

The traditional stove (figure 1.1-A) has a rectangular shape made of scrap metal with 0.39 m of height and the combustion chamber sized 0.04 m^2. The primary air intake area dimension is 0.015 m^2. The thickness of the metal around the combustion chamber is 0.003 m. The contact area between the charcoal and air is spread along the bottom of the combustion chamber with an area of 0.01 m of width and 0.20 m length. The weight of the Traditional charcoal stove has 5.93 kg.

EMU Stove

EMU stove (figure 1.1- B) has a metal holder with a ceramic liner insulation of 0.025 m thick. The diameter and the depth of the combustion chamber is respectively, 0.25 m and 0.07 m, the ash droplets have 0.015 of diameter. The primary air intake dimensions are: 0.06 m of inner depth, 0.1 m of diameter, 0.06 m of height of the ceramic layer and 0.11 m of height. The weight of EMU stove is 4.5 kg. The metallic holder is usually painted in red.

POCA Stove

POCA is a ceramic, charcoal-burning stove (figure 1.1- C) that is made in a semi-industrial process involving an electric kiln. The stove body has a 0.235 m combustion chamber which has a height of 0.7 m and as it goes down it forms a shoulder and a base that is 0.275 m in diameter. Three grate supports are formed inside the shoulder area and spaced 120 degrees apart. The grate is conical shaped with 0.21 m in diameter and 0.7 m of depth. The grate has an array of 0.0135 m hole with primary air inlets and ash drop holes. At the base of the stove, there are two 0.085 m of length and 0.035 m of width air inlets. The stove rests on a plate and this plate serves as an ash catcher. So far, POCA is being produced only as a one plate stove (Chidamba, 2010).

Figure 1.1: A-Traditional stove, B-EMU stove and C-Poca stove

1.1.2 Solar box cooker Description

The solar cooker used for experiment is the box type (T16) with three reflectors insulated by a 5.10^{-4} m high glass anodized aluminum foil. Table 1.1 gives the solar cooker dimensions.

Table 1.1: Solar cooker dimensions

Parameter	Dimension
Outer dimension of cooker	(72x48x28) x10^{-3} m^3
Inner height	(20-24) x 10^{-2} m
Area of glass plate	0.29 m^2
Area of outer reflectors	0.7 m^2
ickness of the glass plate	(3-4) x 10^{-3} m
Thickness of the walls	3 x 10^{-2} m
Weight	12 kg
Area of absorber plate	0.16 m^2

Figure 1.2: Solar box cooker

1.2 Research Scope

This study analyzes two different cooking technologies, namely: improved charcoal stove and solar box cooker (SBC). A traditional charcoal stove has been also tested as to establish a baseline. The tests performed are: WBT (Water Boiling Tests) and Controlled Cooking Test (CCT). The variables analyzed are: cooking power, thermal efficiency, time to boil water, cost of fuel, life cycle cost, life cycle savings and payback period**.** This study excluded analysis of the charcoal stoves fumes emissions. Future work will consider this analysis and therefore will give the complete study on charcoal stoves. The comparison in this study involved a box cooker with reflectors, so research with other types of solar cookers is suggested.

2. METHODOLOGY

Laboratory tests comprising the Water Boiling Test and Controlled Cooking Test were performed. Experiments carried out included:

- Determination of the local boiling point
- Determination of the Moisture Content and the Heating Value of the Charcoal
- Water Boiling Test
- Controlled Cooking Tests

2.1 Determination of the local boiling point

The local boiling point is the point at which the temperature no longer rises, no matter how much heat is applied. The local boiling water was determined by boiling 2.5 litres of water in a pot. Using the same thermometer that was used for testing, the boiling temperature was measured when the thermocouple was positioned in the centre, roughly 0,05 m above the bottom of the pot. When temperature increase was no longer observed, with the temperature oscillating several tenths of a degree above and below the boiling point, the maximum and the minimum temperature was recorded during a five minute period at full boiling. The maximum and the minimum temperatures were then averaged (local boiling temperature) (Bailis *et al*., 2007).

2.2 Determination of the Moisture Content and the Heating Value of the Charcoal

To determine the moisture content of the charcoal, charcoal samples were randomly obtained and crushed, weighed and placed in an oven for two hours at 110°C (Bailis *et al*., 2007). The charcoal tested was produced from chanati trees (scientific name: *Colophospermum mopan*) in Massingir, Gaza Province. The samples were weighted after two hours and the new dry mass was recorded. The moisture content was then calculated using the following equation:

$$MC_{wet}(\%) = \frac{(\text{Mass of fuel})_{wet} - (\text{Mass of fuel})_{dry}}{(\text{Mass of fuel})_{wet}} * 100 \qquad \text{(eq.1)}$$

The calorific value of the charcoal was taken from the data calculation sheet used to record all measurements developed by the Shell Foundation HEH Project because their calorimeter bomber was not available to perform the test. The high heating value of charcoal from *Colophospermum mopan* is in order of 29.400, 00 kJ/Kg [Aprovecho Research Centre].

2.3 Water Boiling Tests (WBT)

Water Boiling Tests were performed according to WBT developed in 1980's by Volunteers in Technical Assistant (VITA) which were updated in 2003 by Shell Foundation, University of California-Berkeley, and Aprovecho Research Centre. The tests conducted were as follows:

- In the first phase, the cold-start high-power test,
- In the second phase, the hot-start high-power Test
- In the third phase, low power test-simmering

The WBT outputs of the test are: time to boil burning rate, specific fuel consumption, firepower, turn-down ratio (ratio of the stove's high power output to its low power) and the thermal efficiency.

2.4 Controlled Cooking Test (CCT)

Controlled Cooking Test was conducted following the CCT test procedure prepared by Bailis *et al* (2007). The significant outputs of the CCT test are: reduction of specific fuel consumption and reduction in time spent while cooking. These parameters were used to perform the cost analysis.

2.5 Testing the Solar Box Cooker

The WBT for the solar box cooker followed the American Society of Agricultural Engineers standard (American Society of Agricultural Engineers [ASAE], 2003). The test consisted heating up 2.5 litres of fresh water inside the pot. The thermocouple was inserted in the pot to monitor the water temperature variations while it was being heated up inside the solar cooker. Over 30 minute intervals, the sun was tracked manually. The primary parameters generated by the experience are: water temperature inside the pot, wind speed, air temperature and global radiation. The above parameters were recorded over 10 minute intervals with exception of the global solar radiation which was recorded every minute. The single figure of merit of ASAE standard which is the cooking power that was then computed using equation 2. Then the cooking power P is normalized to a figure of 700W/m^2 using equation 3.

$$P = \frac{(T_2 - T_1)m_w C_w}{600} \qquad \text{(eq. 2)}$$

$$P_s = P\frac{700}{I_s} \qquad \text{(eq. 3)}$$

The standardized cooking power Ps was plotted against the temperature difference T_d, for each time interval. A liner regression of the plotted points was used to find the relationship between cooking power and the temperature difference. A total of 39 observations were made during three different days.

The single performance figure is cooking power which corresponds to a temperature difference of 50 °C, (i.e. T_{water}-$T_{ambient}$) computed using the linear regression.

Thermal efficiency of the solar cooker

The thermal efficiency of the solar box cooker was calculated using the basic equation describing an energy balance on the thermal mass within the cooking vessel (Shaw, 2007). Therefore:

$$m_w C_w \Delta T = \eta_0 IAt \qquad \text{(eq. 4)}$$

Isolating the efficiency η, the following equation is obtained:

$$\eta_0 = \frac{m_w C_w \Delta T}{IAt} \qquad \text{(eq. 5)}$$

Since $P = \frac{m_w C_w \Delta T}{t}$ then

$$\eta_0 = \frac{P_s}{IA} \qquad \text{(eq. 6)}$$

2.6 Cost Analysis

Family Interviews

An interview was conducted to give subsidy to the research and to obtain input data for the cost analysis. A total of 30 families using charcoal exclusively, of Maputo suburbs - Polana Caniço, were interviewed. These families are characterized by low income (i.e., less than the minimum salary in Mozambique which is approximately USD100), can't afford cooking by gas or electricity and their main activity is small businesses. The important parameters analyzed are:

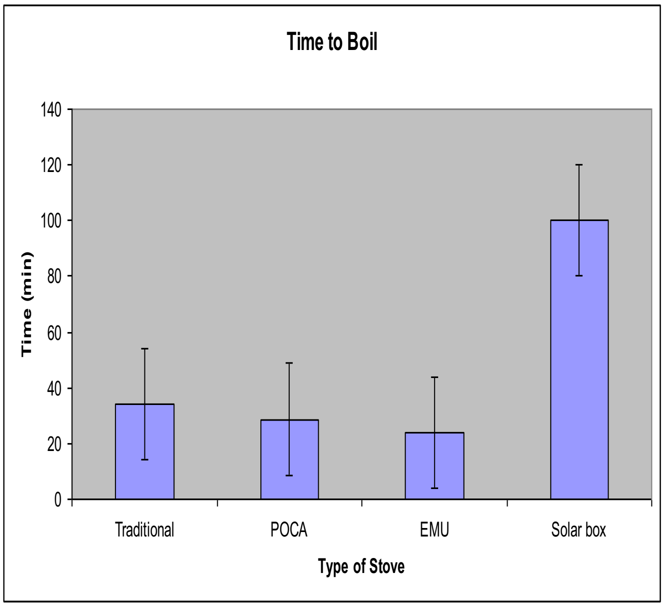
- Number of family members
- Number of meals prepared per day and the time of each meal
- Location of meal preparation
- Type of charcoal stove used
- Cost of the fuel (charcoal)

Cost analysis involves several parameters (Habermehl, 1999). In this study, the cost analysis of charcoal stoves and the solar box cooker involved the insight of the cost acquisition, the running cost, the life cycle saving and the payback period. Since solar box cooking and charcoal cooking is complementary, the combination of both cooking technologies was also analyzed.

3. RESULTS

The local boiling point calculated and used throughout the test is 98.7±0.16^{o}C. The moisture content of charcoal computed using equation 1 is 5.0±5.4x10^{-4} %.

3.1 The Water Boiling Test Results



Fiure 3.1: Time to boil

According to the figure 4.2, the time to boil 2.5litres of water is less in charcoal stoves (traditional: 34±1 min, POCA: 28.7±2.5 min, EMU: 24±9.2 min) than solar box cooker (113±15 min). This is explained by the difference of the source of energy (i.e., charcoal and direct solar energy), and the energy density of charcoal (heating value) is higher than the solar energy density. The duration of performing a certain task have impact on which technologies is preferable. In this case, charcoal stoves perform better that solar box cooker.

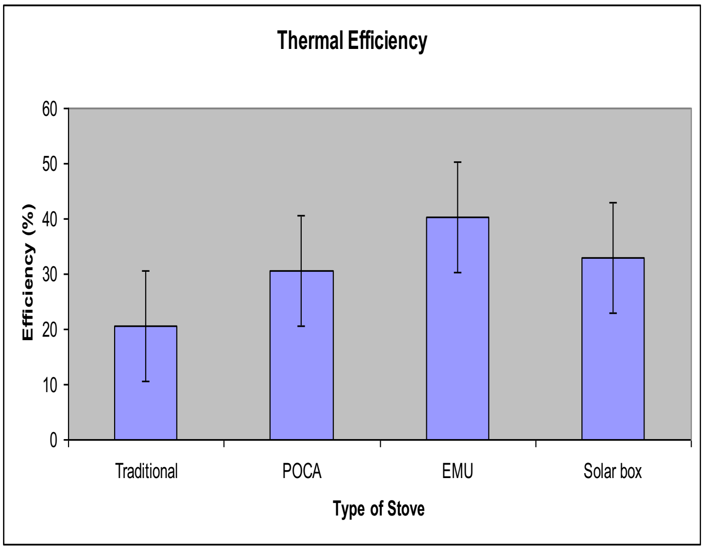


Figure 3.2: Thermal efficiency

The thermal efficiency of EMU stove is greater (40.3±13%) than solar box cooker (32.8%). The solar box cooker efficiency is higher than POCA stove (30.7±10%) and traditional stove (20.7±7.9%), see Figure 3.2. The combination of the factors that pay important role in the efficiency (insulation, combustion chamber) make EMU stove convert better the chemical energy into useful energy compared to traditional and POCA stove. In the other hand, solar box cooker transforms better the incoming radiation into useful energy with grace of good insulation if compared to traditional and POCA stove.

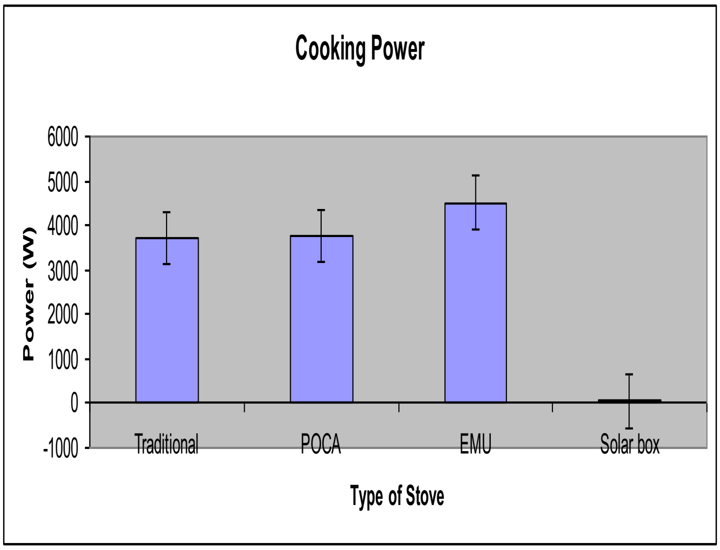


Figure 3.3: Cooking Power

According to figure 3.3, EMU stove has higher cooking power (4512.5±17 W) compared to POCA (3764.7±6 W), Traditional (3716±9 W) and solar box cooker (61.5 W). The solar box's ability to perform a cooking task is very poor when compared to charcoal stoves. Hence, the conversion process of charcoal into heat energy is faster than the conversion of solar radiation into to heat; and density of energy of charcoal is higher than the solar radiation density.

3.2 Design Aspects

Solar box cooker has good insulation but the cooking vessel is not sufficient to cook food for a characteristic African family (with over five members) at a go. The reflective surfaces are not well fixed to the box resulting in displacement from stove when the wind blows. With an average weight of 12 kg, the solar box cooker is heavy for a cook to carry to the cooking place. Improved charcoal stoves showed mass reduction during the tests, i.e., the weigh of stove before the test (ex.: hot start) is higher than the weigh of the same stove after the test, therefore they need reinforcement of the binding material especially EMU stove that showed breaking lines. EMU stove has thicker ceramic layer than POCA stove contributing for less heat losses. The primary inlet air of POCA is very limited and the air mixing holes (ash dropping holes) are few and the charcoal bottom holder is weak (it broke down duration the tests). Solar cooker needs uplifting stands or a table to put it up while improved charcoal stoves need to increase the stands to avoid, in both cases, bending too much when cooking.

3.3 Other Variables

The following table presents other qualitative and quantitative variables to take into account when comparing both technologies.

Table 3.1: Other variables

Other variables	Solar Box Cooker	Charcoal Stove		
		Tradi tional	POCA	EMU
Fuel demand	No	yes	yes	yes
Emission	No	yes	yes	yes

Life span	> 5 years	> 5 years	…..	….
Ease of use	need training	ease	ease	ease
Weather Dependence	Yes	No	No	No
Cook all Food	No	yes	yes	yes
Cost (USD)	130	5	8	10

From table 3.1 and from the discussion of figures 3.1, 3.2 and 3.3, it is notable that families need to switch from the use of traditional stove to either ceramic stoves or solar box cooker. Solar box cooker takes advantage of POCA and EMU because it needs no fuel to operate it, there are no operation emission associated. Improved charcoal stoves show relative advantage compared to solar box cooker since they are cheaper, they are no weather dependence and families need no additional training if they shifted from traditional stove. The weaknesses of solar box cooker are following: the purchase price is high, it depends on weather conditions and the cookers need training to use it. Improved charcoal stoves decline if CO_2 and fuel emissions and fuel demand is analyzed.

3.4 Interview Results

Table 3.2 Interview results

No	Parameter	Result
1	Number of members	6±1
2	Number of meals per day	2
3	Period of cooking	1 morning and1 afternoon
4	Type of Fuel	Charcoal
5	Place where they prepare the meal	Outside
6	Type of stove	Traditional = 100 %
7	Cost of fuel (USD/month)	40,3±0.01

The family size is six members per family. Each family cooks twice per day, once in the morning and the other in the evening. Fifty percent of the families cook outside the main house. All families use metal stove (traditional) spending USD26.7 per month.

3.5 Cost Analysis

The cost analysis involved life cycle cost (LCC), life cycle savings (LCS), annual savings (AS) and the payback period (PP).

Life cycle savings of POCA and EMU correspond to 9% (i.e., USD 181.4) and 30% (i.e., USD 592.3) respectively as compared to traditional charcoal stove. But, the combined cooking solar box and EMU stove demonstrated much better life cycle savings than the charcoal cooking only which are between 40 and 58%.

The combination of solar box cooker and EMU stove showed precious payback period of cooking over charcoal cooking only which is less than 3 years in all cases.

If a family shifts from traditional to POCA stove, the payback period is 6 months and 10 days and if EMU stove is used instead of traditional charcoal stove for meal preparation the payback period is 2 months and 12 days.

4. CONCLUSION AND RECOMMENTATION

4.1 Conclusion

Water boiling tests were performed with success. Charcoal stoves demonstrated less time in boiling 2.5litres of water (traditional: 34±1min, POCA: 28.7±2.5min, EMU: 24±9.2min) than solar box cooker (113±15min). The thermal efficiency of EMU stove is greater (40.3±13%) than solar box cooker (32.8%). The solar box cooker efficiency is better than POCA (30.7±10%) and traditional stove (20.7±7.9%). In terms of the power of the stoves, the EMU stove demonstrated superior cooking power (4512.5±17W) compared to POCA (3764.7±6W), traditional (3716±9W) and solar box cooker (61.5W).

During CCT tests, improved charcoal stoves showed reduction in fuel consumption per Kg of food cooked as compared to traditional charcoal stove. It was also noted the reduction in time needed to cook a meal.

The life cycle cost and the life cycle savings of the combined solar box cooker and improved charcoal stove is better than either improved charcoal stoves only or traditional charcoal stoves.

The payback period of the combined solar box cooker and EMU stove is precious and it is less than 3 years and cooking could save between 40 to 58% of fuel cost every year throughout its life cycle. Improved charcoal stoves showed short payback period which is less than 3 months when they replace traditional charcoal stove.

4.2 Recommendation

Based on these research findings, cooking with improved charcoal stove only or combined with solar box should be massively promoted countrywide. The implementation of solar cooking projects should be piloted at communities that face scarcity of fuel wood and are in need of alternative cooking technologies.

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