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Design of a Corncob Baking Oven for Rural Households Application in Tanzania

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Abstract: **The main purpose of this study was to develop and fabricate a corncob baking oven for domestic household application in rural areas. The study was done as a case study in Mbeya region. Through engineering design approach, a corncob baking oven was designed and fabricated. This oven was later tested to evaluate its performance in-terms of temperature variation in the combustion and baking chambers of the oven. Prior to this test material characterization for corncobs in terms of proximate analysis was done, through this analysis basic information such as moisture content, volatile matter, fixed carbon ,ash content for corncob were measured (Table 6). On top of these characteristics, calorific value for corncob was also measured, where high heating value was found to be 16.52 MJ/kg and low heating value was found to be 15.85 MJ/kg. After this, three tests were done, where 450 g, 412 g, and 423 g of corncobs were charged at different time into oven combustion chamber. Temperature variations in combustion and baking chambers were recorded at an interval of 2 minutes; the average values for temperature variation are presented in Fig. 3 which shows how temperature changes were varying in both oven chambers. The highest temperature attained was 612^{o}C and 235^{o}C for combustion and baking chambers respectively and from 5th minute since combustion was started to 50th minute, temperature in the baking chamber was experienced to vary between 235^{o}C and 150^{o}C which is a reasonable zone temperature for baking process.**

Keywords: **Baking oven, Corncobs, Bread, Energy, Agricultural wastes.**

1. INTRODUCTION

1.1 Background:

Tanzania is among of the sub-Saharan African countries whose more than 90% of their primary energy comes from biomass (Lema, 2007). Currently bread is among the diet food for many people in developing countries Tanzania inclusive, and it is prepared by using baking ovens powered by either wood or electricity. During baking, the heating process is done by a combination of three forms of heat; by infra-red energy that is radiated from oven walls, by circulating hot air; and by conduction through the baking pan or tray. That means the efficiency of the baking process depends on the optimal use of three different parts of the device: the walls, the tray, and the ventilation system. In Tanzania bread is baked in large electric fired ovens and wood fired ovens, meaning that the investment cost for this kind of ovens is high and can only be afforded by very few people who specifically intend to produce bread at large scale for commercial purposes.

Because of high investment cost for ovens, it has contributed much to price variation for breads and its related products prepared through baking ovens. Likewise it has made bread and its related products such as cake be perceived as type of food for high and medium class income people, leaving the low income people particularly in rural un-served with the food they admire to eat. These challenges and the dependence on wood as source of energy which in turns contributes to deforestation provided the motive to develop and design a baking oven which can use agricultural wastes (corncobs in particular) as source of energy. Targeting users at household level, this technology will bridge the gap posed by oven products because people at all levels of income will be capable of preparing breads and its related products at their choice.

1.2 Agricultural Wastes in Tanzania:

Tanzania has a characteristic growing economy which depends on agriculture activities. Annually from agriculture alone, Tanzania generates more than15 million tones of crop residues (Mhaiki and Mwenzengule, 2008). Most of these wastes are dumped and very little are used as source of energy in very traditional ways. Corncobs are maize crop residues obtained after corn grains have been shelled from the core of the corn. Because maize crop is cultivated in almost every part of Tanzania, corncobs is a promising feedstock to offer possibility of renewable energy production to most families. Maize is considered to be the most important crop in Tanzania covering 45% of the total arable land of the country. Maize production has reportedly increased from 2 million tons in 2000 to over 4 million tons in 2011, with yield of about 1.5 tons per hectare (MAFAP, 2013).

According to Graham, R.L., *et al.*, 2007, the stover to grain ratio of 1:1 is accepted, and on average an equal amount of corn grains and stover are produced. On the other hand, corncobs make up 15-20% of corn stover (Daron Z., 2008). Based on this approach for over 4 million tons of maize grains produced in the country, an estimate amount of 525,000 – 700,000 tons/annum of corncobs are generated in Tanzania. This is a potential feedstock which is available in almost every rural area in Tanzania, and currently just dumped as other crop residues or rarely used as source of energy in very few occasions. Trying to use this potential and renewable source of energy, this study designed, fabricated, and tested a corncob oven that apart from utilizing this source of energy also brings the service of making and supplying breads and its related products to household level of all levels of income.

2. MATERIAL AND METHOD

To achieve the objective of this study, the following methods were adopted;

2.1 Data Collection:

Data and information (data sheet, catalogue with different parameter specifications) were collected through literature reviewing and experiments.

2.2 Material Characterization:

Material characterization for corncobs was done to determine the proximate analysis of corncobs. Proximate analysis was used to determine the moisture content, volatile matter, fixed carbon, and ash content of corncobs. It was done by using an oven, muffle furnace, and weighing balance. The formulae in Table 1 were also used.

TABLE 1: FORMULAE TO CALCULATE PROXIMATE ANALYSIS (source: Raphael, I. *et al*., 2013)

Parameter on Test	Formulae (On Wet Basis)	Formulae (On Dry Basis)
Moisture Content	$\frac{(Initial\ Mass - Dry\ Mass) * 100}{Initial\ Mass}$	$\frac{(Initial\ Mass - Dry\ Mass) * 100}{Dry\ Mass}$
Volatile Matter	$\frac{(Dry\ Weight - Weight\ of\ Char) * 100}{Initial\ Weight}$	$\frac{(Dry\ Weight - Weight\ of\ Char) * 100}{Dry\ Weight}$
Ash Content	$\frac{Weight\ of\ Ash * 100}{Initial\ Weight}$	$\frac{Weight\ of\ Ash * 100}{Dry\ Weight}$
Fixed Carbon	Fixed Carbon = 100% - [%Moisture - %Volatile +%Ash]	Fixed Carbon = 100% - [%Volatile + %Ash]

2.3 Baking Oven Development:

Three different working principles were developed, and out of these, one alternative was selected as the best by using a convergence matrix method. This alternative was further developed through design analysis to estimate different oven parameters.

2.4 Manufacturing of Baking Oven:

Tools and procedures like cutting and joining, cutting and grinding discs, hacksaw, welding machine, and an oxidize flame were used in fabricating the corn cob baking oven.

2.5 Performance Test for the Baking Oven:

The fabricated prototype baking oven was tested to evaluate its performance. Temperature variation in the combustion and baking chambers were measured by using a thermocouple (type K) connected to a temperature control.

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3. RESULT AND DISCUSSION

After doing the design analysis, selecting the suitable materials for the baking oven, calculating oven parameters, an engineering drawing (Fig.1) for the proposed corncob baking oven was prepared.

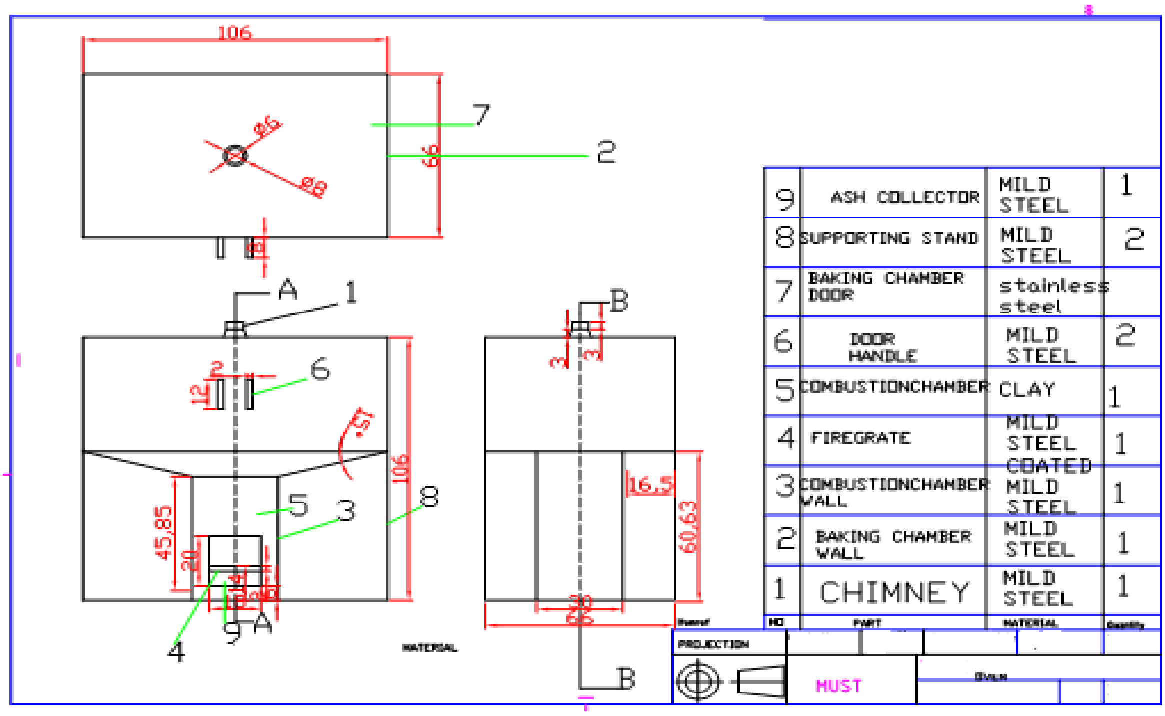

Fig.1: Engineering Drawing of a Proposed Corncob Baking Oven

3.1 Determining Baking Oven Design Parameters:

To calculate the baking oven design parameters, material properties such as high resistant to corrosion, low thermal conductivity, ability to withstand thermal stress, and high thermal diffusity, were considered. Materials like ceramic tile, composite material of ashes, clay, mild steel, and stainless steel were used in the fabrication of this oven, Table 2 and Table 3 summarizes material characteristics for baking oven combustion and baking chambers.

TABLE 2: MATERIAL SPECIFICATION FOR COMBUSTION CHAMBER

Material to be Used	**Thermal Conductivity**	**Thickness**
Ceramic Tile	0.01 w/mk	20 mm
Composite Material of Ashes and Clay	0.18 w/k	5 mm
Mild Steel	41 w/mk	1.5 mm

TABLE 3: MATERIAL SPECIFICATION FOR BAKING CHAMBER

Material	**Thermal Conductivity**	**Thickness**
Stainless Steel	15 w/mk	3 mm
Ashes	0.06 w/mk	10 mm
Mild Steel	41 w/mk	2 mm

Based on the material specifications, quantity of bread to be baked, calorific value of corncobs, and other assumptions, design calculations were done to identify the baking oven design parameters. Some of the parameters used in the calculation are outlined in Table 4.

TABLE 4: PARAMETERS USED IN DESIGN CALCULATION

Name of parameter	Value
Specific Heat Capacity of Water	4200 J/kg^{o}C
Specific Heat Capacity of Flour	1800 J/kg^{o}C
Weight of Dough Containing 45% Water and 55% Flour	16 kg
Latent Heat of Water	2500 J/kg
Average Room Temperature	15^{o}C
Water Evaporating Temperature	100^{o}C
Oven Efficiency	35%
Baking Time	18 minutes
High Heating Value of Corncob	16.52 MJ/kg
Lower Heating Value of Corncob	15.85 MJ/kg

Based on the parameters given in Table 4, oven parameters presented in Table 5 were calculated, and Fig.2 presents the prototype of the fabricated corncob oven.

TABLE 5: CALCULATED OVEN PARAMETERS

Name of Parameter	Value
Dimension of combustion chamber;	
Length	30 cm
Width	30 cm
Height	50 cm
Dimension of baking chamber;	
Length	100 cm
Width	60 cm
Height	40 cm
42 holes for inlet air, each with diameter of	6 mm
Diameter of chimney	100 mm
Amount of fuel	678.1 g

Fig.2: Fabricated Corncob Oven

3.2 Performance Test of the Baking Oven:

Before performing the performance test, proximate analysis to characterize corncobs were done. Result for this analysis is shown in Table 6.

TABLE 6: PROXIMATE ANALYSIS RESULT

Parameter	Percentage (%) on dry basis
Moisture content	20 - 30
Volatile matter	80.72
Fixed carbon	15.64
Ashes	1.85
HHV	16.52 MJ/kg
LHV	15.85 MJ/kg

After the proximate analysis, tests to measure temperature variations in the combustion and baking chambers were done. The oven was placed in a controlled room, and three experiments were done. Corncobs of 450 g, 412 g, and 423 g were charged into the combustion chamber to conduct the respective experiments. Few millilitres of kerosene were sprinkled onto corncobs for each experiment to initiate combustion, the temperature variation for combustion and baking chambers were recorded at an interval of two minutes for a period of fifty minutes. Fig. 3 presents the average temperature variation in the combustion and baking chambers for the three experiments.

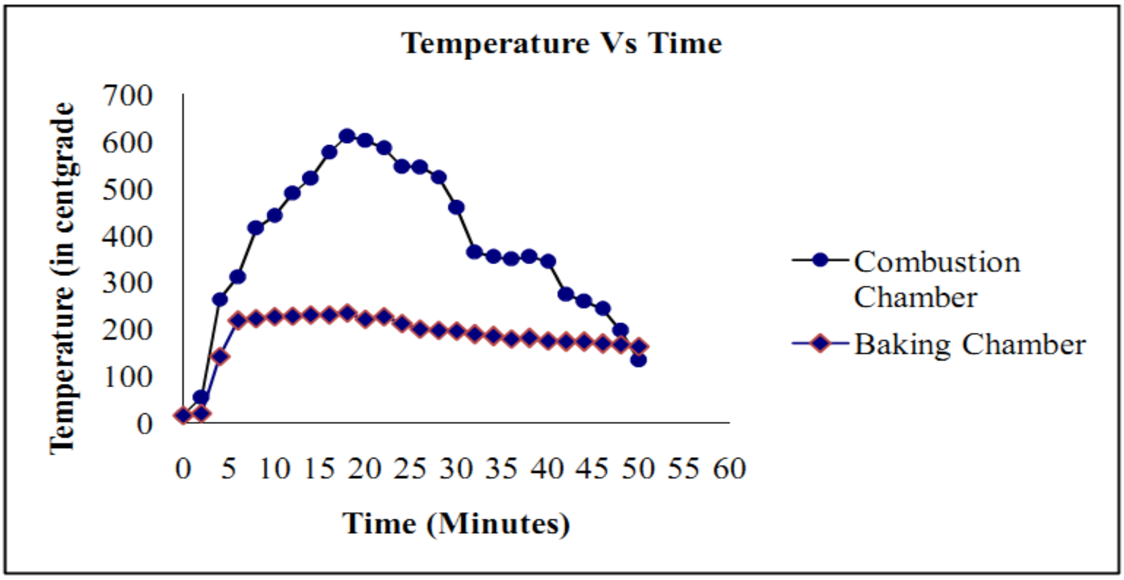

Fig. 3: Temperature Variation in Combustion and Baking Chambers

The highest temperature attained in the combustion chamber was 612°C, and baking chamber highest temperature attained was 235°C. From the 5th minutes of combustion to 50th minute, baking chamber temperature varied between 235°C and 150°C, this is a reasonable temperature for baking process, and since it was lasting for more 30 minutes, the designed corncob baking oven can fit its intended purpose. The temperature variation in the chambers was facilitated by fuel reduction in the combustion chamber as it is burnt down (consumed). However with this promising result, a lot of smoke was observed emitted by the oven, this probably could be associated with high moisture content of corncobs (20 – 30%), this makes the corncob oven un-fit to be used in a poorly ventilated environment. To minimize smoke emission, the corncobs should be dried on the sun for at least three days to minimize moisture content in the corncobs.

Apart from the described analysis, the designed oven can play a big role in reducing the processing cost of bread and its related products. This is because if an average of 678 g of corncobs is capable of generating 11,202.285 kJ and bake 16 kg of dough (bread), and considering rural areas in Tanzania, where this type of energy source is available in plenty and for free, it can significantly reduce bread processing energy cost and hence the bread price. Comparing to electric oven which are normally available in town, 11,202.285 kJ is equivalent to 3.11 kWh, and according to TANESCO (2013), this amount of energy can be sold at Tsh. 1,328.7 (Tsh. 427.23 per 1 kWh). Therefore adopting this technology can play big role in reducing energy cost for baking bread and its related products, reducing their prices, make breads available in rural areas, and above all maximize the economic value of agricultural wastes.

4. CONCLUSION

The designed and fabricated corncob baking oven showed promising results, and as it has been described in the results analysis, the adoption of this technology will facilitate at large in minimizing energy cost and hence bread processing cost. Apart from maximizing the economic value of agricultural wastes (corncobs in particular), rural residents in Tanzania will benefit a lot to this technology because they will prepare all king of foods (bread inclusive) which require this technology.

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