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Development of Local Technology for a Small-Scale Biochar Production Processes from Agricultural Wastes

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Abstract

A charcoal fired reactor for small-scale production of biochar was successfully designed, fabricated and tested. The method of biochar production offered by this equipment was evaluated by comparing its output with a single barrel method of production. The results obtained during the test indicated that the efficiency of the equipment based on its output per kg of Cocoa pod husk was 79.9%. It has the capacity to produce 18.3 kg of Biochar from Cocoa Husk per day using 1bag of local Charcoal. Cocoa pod Husk can be effectively used as raw material for Biochar production. The Specific Heat Capacity of Cocoa pod Husk was obtained as 3.8 kJ/kg K using the Choi and Okos model. The equipment can be afforded by small scale farmers at production cost of N24, 600.00.This machine can be easily used and maintained without any formal training. The reactor is therefore appropriate for use by subsistent farmers, and households for producing biochar on a small scale

Keywords: crust, tropical, cultivated, fallow, simulated, rainfall, aggregate

INTRODUCTION

All crops have varieties and physical properties, which are essential inputs into the design of their processing equipments or machine. A cocoa pod is approximately 20 cm long and 10 cm wide. A section through the pod shows a rough leathery rind about 3 cm thick, filled with sweet (although not edible), slimy and pinkish pulp, enclosing from 30 to 50 large, soft, pink or purple almond-like seeds or beans. The physical structure of a longitudinally and transversely sectioned cocoa pod is shown in Figs. 1 and 2 (Fabunmi 2004).

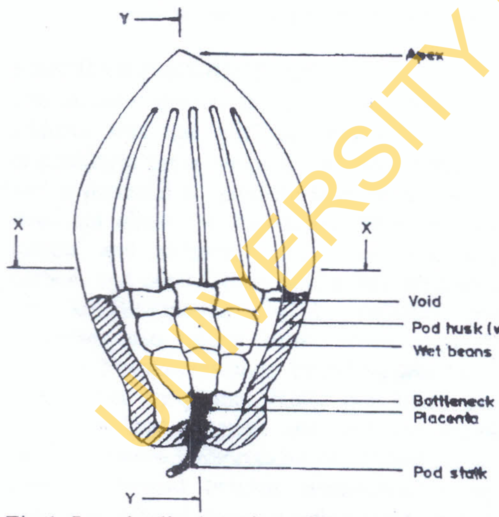

Fig 1. Longitudinal section of a cocoa pod showing the physical features (section y-y)
Source: (Fabunmi, 2004).

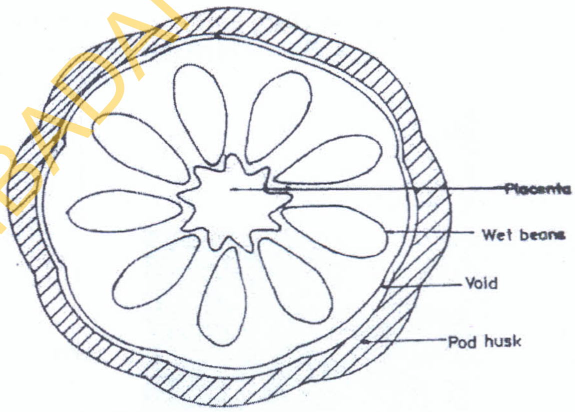

Fig 2. Transverse section of a cocoa pod showing the physical features (section x-x)
Source: (Fabunmi, 2004).

Cocoa tree has fruits usually considered drupes but referred to as pods, indehiscent, variable in size and shape, 10–32 cm long, spherical to cylindrical, pointed or blunt, smooth or warty, with or without 5 or 10 furrows; pods white, green or red, ripening to green, yellow, red or purple; seeds 20–60 per pod, arranged in 5 rows, variable in size, 2–4 cm long, 1.2–2 cm broad, ovoid or elliptic; cotyledons white to deep purple, convoluted, large. Seeds/kg 625–1125. Roots mostly a mass of surface-feeding roots, with taproot penetrating to 2 m in friable soil, less deeply when compacted (Reed, 1976).

According to Adeyi (2010), the proximate compositions of five agricultural wastes were determined and latter subjected to low temperature conversion process in the presence of nitrogen atmosphere. These agricultural wastes are *Cocos nucifera* husk, *Theobroma cacao* pod, *Kola nitida* pods *and Plantago major* peels (ripe and unripe peels). All the samples investigated have different intrinsic proximate compositions which affect the yields of their respective chars. Out of the sample investigated, *Cocos nucifera* husk recorded the lowest bulk density (0.0746g/cm3), and ash content (3.95%), cellulose contents (0.52%) and has the lowest char yields. On the other hand, *Theobroma cacao* pods recorded the highest cellulose content (41.92%), ash contents (12.67%), and crude fiber content (33.60%) and has appreciably high char yields. The lignin contents of samples fell in the range of (6.06%-33.60%).The percentages of chars obtained after conversion at 420^0C for each of the precursors were relatively lower to those obtained at 360^0C.

The husk had high proportions of total ash (> 9%), crude fibre (> 20%), cell-wall contents (hemicelluloses, 11%; cellulose, 35%; lignin, 15%; pectin, 6%) and mineral elements (K, 3.18%; Ca, 0.32%; P, 0.15%). (Sobamiwa and Longe 1993)

OBJECTIVES

The objectives of this work were as stated below:

(a) To design and fabricate a reactor for small scale production of biochar (from cocoa pod husk), using locally sourced materials.
(b) To generate the working drawings of the equipment obtained in (a).
(c) To test and evaluate the equipment efficiency.
(d) To characterize the equipment obtained in (a)

BIOCHAR PRODUCTION

The ancient method for producing biochar as a soil additive was the "pit" or "trench" method, which created terra preta, or dark soil. While this method is still a potential to produce biochar in rural areas, it does not allow the harvest of either the bio-oil or syngas, and releases a large amount of CO_2, black carbon, and other GHGs (and potentially, toxins) into the air. (Wikipedia, 2010). Biochar production processes can utilize most urban, agricultural or forestry biomass residues, including wood chips, corn stover, rice or peanut hulls, tree bark, paper mill sludge, animal manure, and recycled organics, for instance. (www.terrapreta.bioenergylists.org 2010)

Modern method biochar production is sought in pyrolysis. This is done on either small or large scale. Small-scale biochar production technologies are replacing the old fashioned way of making biochar. This small-scale production allows subsistence farmers to produce small quantities of biochar usable for their farms or garden. **Pyrolysis** is a form of incineration that chemically decomposes organic materials by heat in the absence of oxygen. Pyrolysis typically occurs under pressure and at operating temperatures above 430 °C (800 °F). (Wikipedia 2010)

The yield of products from pyrolysis varies heavily with temperature. The lower the temperature, the more char is created per unit biomass. High temperature pyrolysis is also known as gasification, and produces primarily syngas from the biomass. The two main methods of pyrolysis are "fast" pyrolysis and "slow" pyrolysis. Fast pyrolysis yields 60% bio-oil, 20% biochar, and 20% syngas, and can be done in seconds, whereas slow pyrolysis can be optimized to produce substantially more char (~50%), but takes on the order of hours to complete. For typical inputs, the energy required to run a "fast" pyrolyzer is approximately 15% of the energy that it outputs. Modern pyrolysis plants can be run entirely off of the syngas created by the pyrolysis process and thus output 3–9 times the amount of energy required to run. Alternatively, microwave technology has recently been used to efficiently convert organic matter to biochar on an industrial scale, producing ~50% char. Fig 3 describes pyrolysis process flow diagram.

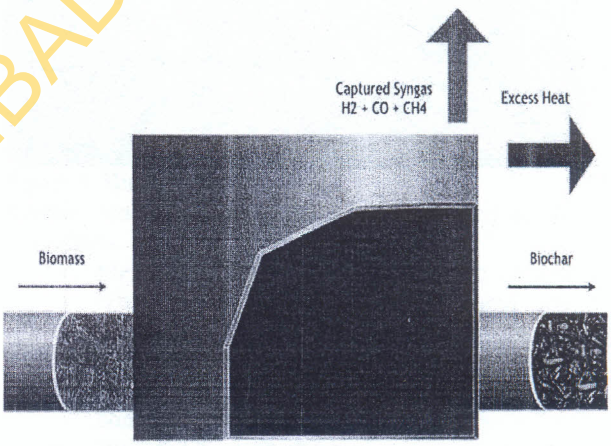

Figure 3: Simplified pyrolysis process flow diagram
Source: www.biochar.info.com

There are two methods to turn wood into charcoal known as the direct and indirect process. The **indirect** method involves baking the wood in some air tight vessel. This produces the highest yields of charcoal but requires a more elaborate set up. The direct method burns the wood in some container where the amount of oxygen is controlled.

www.biochar.info (2009) described a carbon zero experimental biochar kiln. It is a simple closed retort kiln built with insulated firebrick. Its enclosure is designed for a 200 liter steel barrel as a retort. The barrel is filled with split wood or other biomass feedstock, covered, and heated from below with a separate wood fire until it reaches pyrolysis temperatures (above 320 °C).

Another good method used to produce biochar in small quantity for use by the small-scale farmers is using two-barrel charcoal retort. The arrangement consists of two metal barrels, the larger about 20 cm (8 in) wider and 10 cm (4 in) higher than the smaller vessel. In the larger one , air intake is allowed some centimeters (about 25 mm) from the bottom that allow an ample amount of air intake. The smaller one has no hole on it. The biomass was stocked into the smaller barrel as tight as possible, with the whole inverted into the larger barrel. The space between the barrels was then filled with wood and ignited. The process took one hour, while the produced charcoal was left to cool for one hour. The biochar was then ready.

Theoretical Analysis

1. Fourier's law states that the rate of heat conduction through a plane layer is proportional to the temperature difference across the layer and the heat transfer area, but is inversely proportional to the thickness of the layer.

   Fourier's law:

   $$\dot{q} = -kA\frac{\Delta T}{\Delta x} \quad (1)$$

2. $$\dot{Q} = mh_c \quad (2)$$

   $m = mass\ (kg)$

   $h_c = HHV\ (kJ/kg)$

3. $$Q = mC_p\Delta T \quad (3)$$

   $m = mass\ (kg)$

   C_p = specific heat capacity $(kJ/kg°C)$

   ΔT = change in temperature (°C)

4. $$\dot{Q} = \frac{\Delta T}{R_T} \quad (4)$$

   ΔT = change in temperature (°C)

   R_T = Total thermal resistance (W/K)

   $\dot{Q}$ – Rate of Heat transfer (W)

EXPERIMENTAL PROCEDURE

The cocoa pod husk used for the biochar production was collected from Moniinu village cocoa farm in Ikoyi Osun State. Single Barrel fired by wood was used to produce biochar from the husk and the result was compared with biochar produced using a reactor fired by charcoal. Dry cocoa husk was fed into the barrel and sealed. The set up was then fired for some 75 minutes. After this time the biochar obtained was quenched with water and was then sundried. Figures 4 - 5 show the setup.

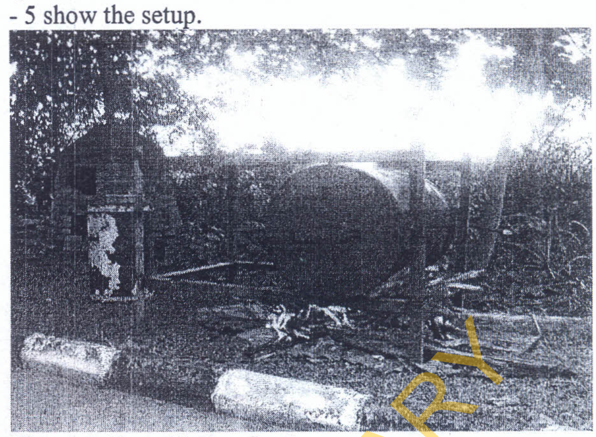

Figure 4: Barrel being fired

Figure 5: Biochar Ready

Biochar production using the reactor took the below procedures:

i. Measured quantity of material to be charred (Dry Cocoa Pod husk) was prepared into batches (B, C, and D - 1kg each), to be fed into the cylinder compartment of the reactor.
ii. Batch B was fed into the cylinder compartment of the reactor.
iii. Prepared burning charcoal is then fed into the space around the cylinder, the watch was then started to monitor time of the operation.
iv. After 10 minutes of firing, a sample was collected via the bottom lid.
v. The first sample was collected after another 10 minutes and quenched with water.
vi. The mass was recorded
vii. The mass of un-charred materials was also taken
viii. The procedure was repeated for other batches.

Figure 6 shows the reactor while being used for biochar production.

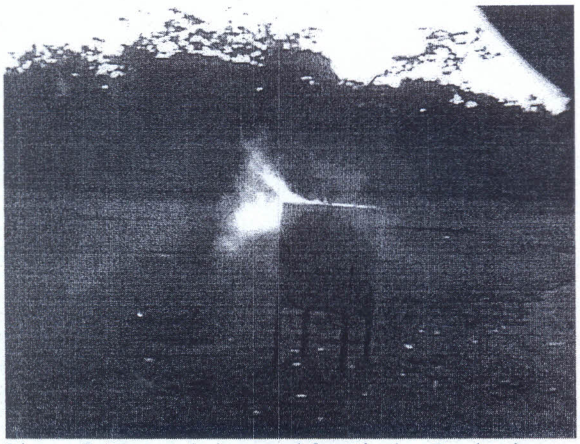

Figure 6: Reactor being used for Biochar Production

The reactor used for the production has two compartments. It is designed to char biomass. It consists of the following parts majorly:

i. Insulated Outer Box with a cover
ii. Cylinder with a cover
iii. The lower lid

It has the capacity to produce 18.3kg of biochar per day with average of 1 bag of local charcoal as fuel taking 5kg of cocoa husk per batch. The performance of the reactor is based on the mass biochar produced per kg of cocoa husk.

$$\%\ \text{mass of biochar} = \frac{\textit{mass of biochar obtained}}{\textit{mass of cocoa husk}} \times \frac{100}{1}$$

RESULTS AND DISCUSSION

Table 1: Single Barrel Production Result

S/N	Mass of Cocoa Husk (M_1) kg	Mass Biochar before Milling (M_2)kg	Mass of Biochar after Milling (M_3) kg	Mass of Foreign Matter $(\Delta M = M_1 - M_2)kg)$	Un-Charred Mass $M_0(kg)$
1.	7.0	3.418	3.365	3.484	0.098

Table 2: The Reactor Production Results

S/N	Batch	Time Taken (Min)	Mass of Cocoa Husk (M_1) kg	Mass of Biochar before Milling (M_2) kg	Mass of Biochar after Milling (M_3) kg	Mass of Foreign Matter $(\Delta M = M_1 - M_3)Kg$	Un-Charred Mass $M_0(Kg)$
1.	B	25	1.0	0.757	0.714	0.238	0.005
2.	C	20	1.0	0.852	0.808	0.111	0.037
3.	D	20	1.0	0.789	0.744	0.243	0.038

From the results shown in tables 1 - 2 above, it was obtained that the single barrel wood-fired production had 48.82% of Biochar of 7 kg husk. The average performance of the equipment is 79.9%. Table 3 shows comparative speed and capacity of production.

Table 3: Comparative Speed & Capacity of Production

Group	Drum Diameter (cm)	Feed Volume (litres)	Cycle Time (hours)
F Gunther Holon (Sweden)*	30	40	~3.0
ENC J Briggs	40	150	0.5
Odesola & Owoseni	42	90 (5kg dry Cocoa Husk)	1.75
GBD P Wright	52	>200	24.0
Lakeland Coppice	213	5446 (2 t dry wood)	72.0

CONCLUSIONS

After testing the reactor using dry Cocoa pod husk and comparing its production with existing methods the conclusions were reached:

- The efficiency of the equipment based on its output per kg of Cocoa pod husk is 79.9%
- It will produce 18.3kg of Biochar from Cocoa Husk per day using 1bag of local Charcoal.
- Cocoa pod Husk can be effectively used as raw material for Biochar Production
- Available data shows that the reactor can compete well with existing technology for biochar production.

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