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DESIGN AND DEVELOPMENT OF A MODIFIED BIOMASS CHARCOAL PRODUCTION KILN

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Abstract

This research was focused on the design and development of a modified biomass charcoal production kiln. Society uses an ancient and rudimentary method of charcoal production that has received little investigation and analysis. The conventional charcoal production process has several drawbacks and disadvantages in terms of rate of carbonization, quality, yield, pollution, labor, and land costs. This study aimed to design and develop a charcoal production carbonization kiln that would alleviate the mentioned problems. The following results found the moisture content as (2,0.89) %, the volatile matter (8.84,3.02) %, the fixed carbon content (81.09,91.42)%, the heating value (29.982,32.762)MJ/kg, bulk density (342.53,434.5)kg/m^3, shatter resistance(88.8,91.12)%, water penetration resistance (26.34,17.99)%, ash content (8.06,4.660)%, efficiency(16,31)%, and production time per cycle(3,5) days for conventional earth mound kiln and improved carbonization kiln respectively. From the result, the maximum shatter resistance shows well in mechanical strength, and high-water penetration resistance shows that the charcoal has better water absorption and a good heating value. The higher density shows that the volume is reduced due to the escape of volatile components and high fixed carbon content. Finally, the modified carbonization kiln yield was improved by 48.38%.

Keywords: ***Biomass, Carbonization charcoal, Design, kiln, Molecular weight***

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I. Introduction

In developing countries, wood is the most common residential fuel. As most developing nations have an agriculture-based economy, biomass fuels continue to play a major role in both the residential and industrial sectors. A huge number of small, rural, and cottage businesses and commercial operations as well as the majority of rural and urban families, rely on biomass as their primary source of energy [2]. During the colonial period, farmers and landless laborers generated abundant charcoal for home consumption in developing nations in pit kilns (holes excavated in the ground) or mound kilns (piles of wood heaped on the ground and covered with dirt). Pit yields (weight of charcoal/weight of wood) range from less than 10 to 25 percent [1].

Various carbonization procedures have been used to produce charcoal for thousands of years across the world. Society employs an ancient and rudimentary method of charcoal production that has received little investigation and experimentation. We discovered during the field evaluation that the present charcoal manufacturing process is mound kilns (wood piles placed on the ground and covered with grass). However, these production systems are recognized to have several limits and drawbacks in terms of quality, yield, pollution, labor, and land costs. To address such issues, more efficient charcoal manufacturing methods must be developed[1].

When rubbed and handled, charcoal generated under poorly regulated carbonization conditions might be hard and brittle, or soft and crumbly. During kiln discharge and shipping, around 5 to 10% of such charcoal is typically reduced to fines and loss [3].

If wood is burned in the absence of oxygen, the chemical reaction is incomplete combustion with the creation of carbon monoxide[4],[5].

$$C + \frac{1}{2} O_2 \longrightarrow CO$$

The average charcoal production output from static kilns might reach 35%, whereas the lowest charcoal production yield from an earth mound kiln may reach 10%[6]. The goal of this project is to enhance the carbonization kiln that is used to carbonize carbonaceous materials to generate high-quality charcoal. [3].

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Fig. 1. Local charcoal making (earth mound kiln) and cover straw

II. Materials and Methods

A. Experimental Work

Various places were investigated to determine the disadvantages of conventional charcoal production. During the field evaluation, downsides were identified by seeing and interviewing the producers, as well as determining which type of carbonized kiln is best for producing high-quality charcoal depending on environmental circumstances and carbonized material shown in Fig. 2 and 6. Because bricks have a greater temperature resistance (7000 - 15000 ^{0}C), good corrosion resistance, availability, durability (6-10 years), and cheap cost, as well as ease of assembly, economy, fire resistance, rain resistance, and sun resistance. As a result, we use clay bricks as the primary building material for our small-scale carbonization kiln.

1) Conventional Charcoal Production: The conventional method was applied as shown in the Fig. 2

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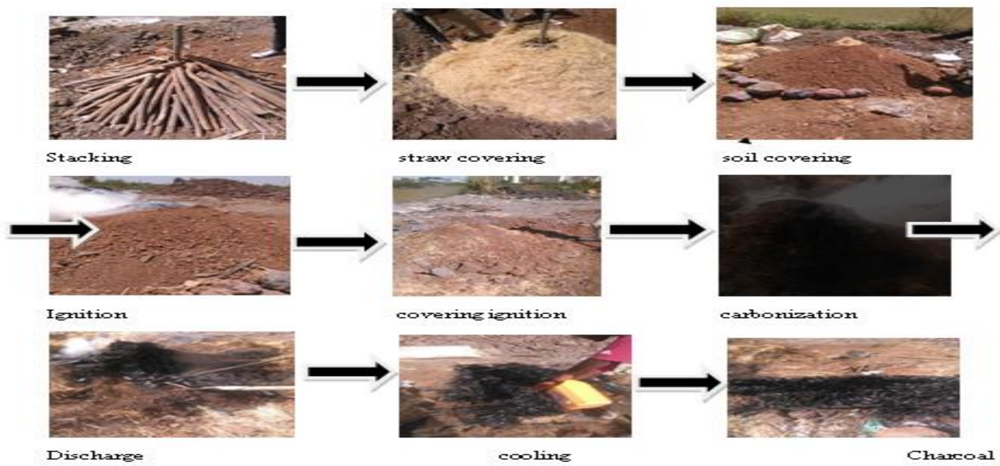

Fig. 2. Conventional earth mound kiln charcoal production experiment procedure

2) Improved Charcoal Production: The geometry was designed using solid work software (v18). The capacity of the kiln was 60kg and the geometry was designed based on this value. The construction of a carbonization kiln suited for local charcoal producers took into account several parameters, and it comprises the following elements. Wall thickness, smoke exit chimney, top cover (head), intake air vents, and anti–downdraft are all features of the carbonization chamber. The amount of air that enters the carbonization chamber determines how quickly biomass is carbonized. The air holes were placed around the outside of the carbonization kiln. It was controlled by placing air intake vents in strategic locations throughout the kiln. Because the carbonization process uses a finite amount of oxygen, we must restrict air entry by closing air input ports. The quantity of air supplied was managed by shutting and opening the air intake while keeping an eye on the smoke output. The amount of air was calculated to carbonize the wood based on the flow rate of air. Volume flow rate (Q) = A (area)* (v) velocity of air

$$Q = Axv \quad (1)$$

The area of inlet air needed for the kiln was determined by using anemometer velocity determination (Testo420i) averagely measured was 0.05m/s. The individual area for each two sides air inlet and the opening area is circular, A= πD2/ hole number.

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Table 1: Specification of Prototype Biomass Carbonization Kiln

	Component	Specification, cm	Material
1	Carbonization chamber	L=W=H=89cm	Clay brick
2	Wall thickness	12cm	Clay brick
3	Head of the kiln	R =44.5cm,L=89cm	Clay brick
4	Chimney	H=205cm,L=12cm,W=6cm	Clay brick
5	Inlet air vent	D=4.15cm	Clay brick
6	Loading and unloading door	H =88cm,W=40cm,	Metal sheet
7	Chimney cover	D =40cm,H=15.4cm	Metal sheet

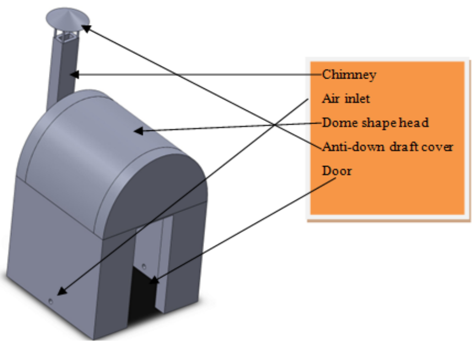

Fig. 3. (a) Model improved carbonization brick kiln. (b) Developed kiln


Fig. 4. (a) Wood charging. (b) Ignition

3) Performance evaluation: The performance of the kiln was performed using the following method tests the constructed kiln by producing charcoal.

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B. Mass Conversion Efficiency

$$Ek = \frac{MC}{MW} x100 \quad (2)$$

Where Ek = kiln efficiency, MC = mass of charcoal produced, and MW = mass of wood put into the kiln

B. Bulk density

$$\rho = \frac{m}{v} \quad (3)$$

Where,

ρ = Bulk density of charcoal, kg/m3

m = mass of charcoal, (kg)

v1=Volume of charcoal inserted, m3

C. Shatter Resistance and Weight Loss

The charcoal with known weight was dropped on the concrete floor from a height of one meter.

1) Weight loss (%):

$$Wl = \frac{w1-w2}{w1} x\ 100 \quad (4)$$

2) Shatter resistance, (%):

Sr= 100 – Weight loss (5)

Where: - w1 = Weight of charcoal before shattering (kg) and w2 is Weight of charcoal after shattering

D. Resistance to Water Penetration, %

Each charcoal sample was immersed in water for 30 seconds. The percentage of water gain was calculated as follows.

Water gain (%):

$$Wg = \frac{w2-w1}{w2} 100 \quad (6)$$

Where:-

w1 = Initial weight of charcoal (0.03kg) and w2 is the Final weight of charcoal

Heating Value (Hv)

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$$HV = 0.3535FC + 0.1559VM - 0.0078AC \quad (7)$$

Where:-FC is fixed carbon content, VM is volatile matter and AC is ash content [7]

E. Fixed Carbon

The FC was calculated by subtracting the sum of percentage volatile matter (PVM), (PMC), and Percentage ash content (PAC) from 100.

$$FC\,(\%) = 100 - \%\text{ of }(MC + VM + AC) \quad (8)$$

F. Volatile Matter

The dried sample left in the crucible was covered with a lid and placed in the furnace, maintained at 950ºC for 7 minutes. The crucible was cooled first in the air, put in aluminum foil, and weighed again. Loss in weight is reported as a volatile matter on a percentage basis.

$$(\%) = \frac{W2 - W3}{W2} 100 \quad (9)$$

Where, VM (%) = percentage volatile matter of charcoal, W2 = oven-dried sample weight of charcoal, and W3 =weight of the sample after furnace used.

G. Ash Content

The residual sample in the crucible was heated without a lid in the furnace at 750 ºC for five hours. The crucible was then taken out, cooled first in the air, then weighed in mass balance.

$$Ash\,(\%) = \frac{W2}{W1} 100 \quad (10)$$

Where, W1 = Initial weight of the oven-dried sample (g), W2 = weight of ash (g)

AC (%) = percentage ash content.

III. Results and Discussion

A. Comparison of Charcoal by Proximate Analysis

It was observed that the volatile matter of the charcoal produced in the earth mound kiln and improved carbonization kiln were 8.84% and 3.02% respectively. These show that the volatile matter of conventional earth mounds was higher than the improved carbonization kiln. Former literature [8] states that good charcoal has volatile matter below 30%. So, the results obtained agree with the literature. As the temperature increases the volatile matter decreases.

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It was observed that the average ash content of the conventional earth mound kiln and improved carbonization kiln was 8.06% and 4.66% respectively. The average ash content in the earth mound kiln was higher than the improved carbonization kiln. From the literature, the recommended good-quality charcoal contains an ash content of less than 5% [8]. Improved carbonization kiln has lower ash content than conventional earth mound kiln.

It is observed that the heating value of charcoal produced in the earth mound and improved carbonization kiln was 29.982 MJ/kg and 32.762 MJ/kg respectively. The heating value of the improved carbonization kiln obtained was higher than that obtained in a conventional earth mound kiln. The higher result obtained was due to the low moisture content and low ash value. Using equation (6) the above results were calculated and summarized in table 2.

Table 2: Average Proximate Analysis Value

No	Parameters	Earth mound	Improved kiln
1	Moisture content, %	2	0.89
2	Volatile matter, %	8.84	3.02
3	Ash content, %	8.06	4.66
4	Fixed carbon, %	81.09	91.42
5	Heating value MJ/Kg	29.982	32.762

B. Mass Conversion Efficiency

The percentage mass conversion efficiency shown in table 3 was used to compare the performance of an improved carbonization kiln with a conventional earth mound model charcoal-producing method. The findings demonstrated the mass conversion efficiency of two different charcoal manufacturing processes. The mass conversion efficiencies of the earth mound and the improved kiln were 31% and 16%, respectively. The production cycle per batch was 3 and 5 days for the earth mound and improved kiln respectively. The result from the earth mound kiln was 16% which agreed with the literature [1],[2]. This reduces the amount of charcoal product because, in the combustion process, the main output is heat [9]

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When compared to mound kiln charcoal, enhanced carbonization brick kiln charcoal had a higher shatter resistance (91.12 %), indicating its appropriateness for transportation. Water sprayed directly on charcoal reduces its mechanical strength, making it easily breakable. They have strong shock, impact, handling, and transportation resistance, as evidenced by their high shatter (91.12 %) and water penetration (17.99 %) as shown in table 4. The cause for the lower Shatter resistance in the earth mound kiln (88.8%) was attributed to the spraying of cold water on the hot surface making the charcoal become cracked and easily breakable.

Table 3: Charcoal Yields and Production Cycle

Kiln type	Mass of wood (kg)	Mass of charcoal (kg)	Conversion ratio,%	Production cycle per batch
Conventional	60	9.6	16	4 day
Improved	60	18.6	31	5day

Table 4: Comparison of Charcoal Based on Physical Properties

No	Properties	Earth mound kiln	Improved carbonization kiln
1	Shatter resistance, %	88.8	91.12
2	water penetration,%	26.34	17.99
3	Bulk density kg/m^3	384.6	434.5

IV. Conclusion

Carbonization is a thermochemical process that involves heating biomass at a high temperature with a small quantity of oxygen to produce solid fuel, such as charcoal. The kiln was equipped with air vents around the perimeter, a carbonized material intake and exit, an anti-downdraft system, and an exhaust chimney. In this research, experiments were conducted to compare the performance of the enhanced carbonization kiln to that of the earth mound kiln. With regards to creating a solid fuel, the improved carbonized kiln was constructed from burnt clay brick and has been found to have greater conversion efficiency, high heating value, low moisture content,

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environmental adaptability, reduced labor force, non-seasonal intermittent, and low cost. In general, the yield or conversion efficiency of a conventional earth mound kiln is enhanced by 48.38 % when employing an improved carbonization kiln. In this, the improved brick kiln needed 2 days for carbonization and 1 day for cooling. An enhanced carbonization kiln had a bulk density of 434.5 kg/m^3 while a conventional earth mound kiln had a bulk density of 384.6 kg/m^3. This indicates that the improved carbonization kiln performs nearly twice as well as the traditional earth mound kiln. As a result, we concluded that an enhanced carbonization kiln is a viable option for carbonizing biomass in both local charcoal-producing communities and at home.

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