DOI: https://doi.org/10.59122/134CFC7



# Design and Construction of a High-Efficiency Biomass Charcoal Kiln in Ethiopia

Sisay Wondmagegn Molla<sup>1\*</sup>, Mequannent Esubalew<sup>2</sup>, Ambachew Balemual<sup>3</sup>, Sahlu Mhriet Gela<sup>1</sup>

Tadelle Nigusu Mekeonnen<sup>1</sup>, Wassie Adane Eshetu<sup>1</sup>, Mekash Tesfaw Gezahgn<sup>1</sup>

<sup>1</sup>School of Chemical and Mechanical Engineering, Woldia University, Woldia, Ethiopia

<sup>2</sup>Department of Chemical Engineering, University of Gondar, Gondar, Ethiopia

<sup>3</sup>Faculty of Chemical and Food Engineering, Bahir Dar, Ethiopia

\*Corresponding Author's Email: siswondmagegn23@gmail.com

## **Abstract**

This study aimed at the design and construction of a high-efficiency biomass charcoal kiln in Ethiopia. Traditionally, local communities in Ethiopia use a premival and inefficient technique of charcoal making to which very little scientific study has been directed. This conventional charcoal making process hasnumerous downsides with regard to rate of carbonization, quality, yield, pollution, labor, and land costs. The current research, therefore, aimed at the design and construction of a high-efficiency biomass charcoal kiln that reduces the above listed problems. Charcoa produced by both the traditional erth mound kiln and the newly designed and constructed improved carbonization kild were compared for their properties. The results showed 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<sup>3</sup>, 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. Based on these results, the improved carbonization kiln's carcoal displaed higest shatter resistance of 91.12% faring well in mechanical strength, and it has high-water penetration resistance meaning it has improved water absorption and a decent heating value. The increased density means the volume is decreased due to the leakage of volatile contents and more fixed carbon content. Lastly, the modified carbonization kiln's production was enhanced by 48.38%.

Keywords: Biomass, Carbonization, Construction, Charcoal, Design, Kiln, Molecular Weight

## I. Introduction

In developing countries, wood is the most common residential fuel. As most developing nations have an agriculture-based economy, biomass fuels remain the main supplies of energy for both homes and

Received: 21 March 2022; Revised: 28 February 2023; Accepted: 12 March 2023; Published: 30 April 2023.



industries. Loads of small businesses, workshops, and family homes—especially in rural areas—depend almost entirely on biomass (like wood or crop waste) for their daily energy needs [2]. During the colonial period, farmers and landless laborers generated abundant charcoal for home consumption in third world nations in pit kilns (pits excavated in the ground) or mound kilns (heaps of wood piled on the ground and enclosed with dirt). Pit produces (weight of charcoal/weight of wood) range from below 10 to 25 percent [1].

Various carbonization procedures have been used to produce charcoal for thousands of years across the world. As depicted in Fig. 1, society employs an age-old underdeveloped technique of charcoal making that very little studies tried to investigate and improve via 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 with regard to quality, produce, 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].

$$C + \frac{1}{2} O2 \longrightarrow CO$$

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].



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

ISSN (E): 2959-3921

(P): 2959-393X (Provisional)

DOI: https://doi.org/10.59122/134CFC7



## 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. Because bricks have a greater temperature resistance (7000 - 15000 °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

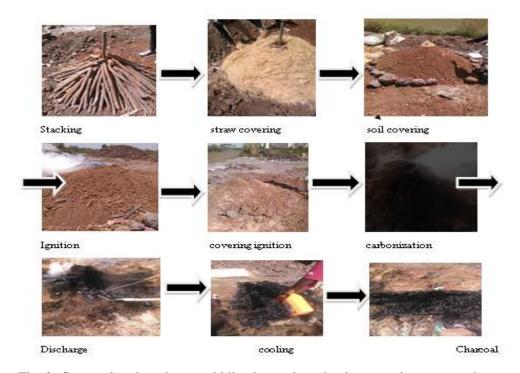


Fig. 2: Conventional earth mound kiln charcoal production experiment procedure

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 antidowndraft 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

(P): 2959-393X (Provisional)
DOI: https://doi.org/10.59122/134CFC7



the carbonization kiln and depicted in Fig.3. 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. As depicted in Table I, 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

$$Q = Axv \tag{1}$$

As depicted in Fig. 4, 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,  $A = \pi D2$ / hole number.

Table I: 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 |

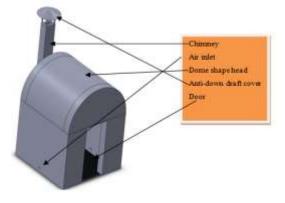




Fig. 3: (a) Model improved carbonization brick kiln. (b) Developed kiln

(P): 2959-393X (Provisional)
DOI: https://doi.org/10.59122/134CFC7





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.

## B. Mass Conversion Efficiency

$$Ek = \frac{MC}{MW} x 100 \tag{2}$$

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

B. Bulk density

$$\rho = \frac{m}{v} \tag{3}$$

Where,

 $\rho$  = Bulk density of charcoal, kg/m<sup>3</sup>

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 (%):

$$Wl = \frac{w_1 - w_2}{w_1} x \ 100 \tag{4}$$

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.

Received: 21 March 2022; Revised: 28 February 2023; Accepted: 12 March 2023; Published: 30 April 2023.

ISSN (E): 2959-3921

(P): 2959-393X (Provisional)

DOI: https://doi.org/10.59122/134CFC7



Water gain (%):

$$Wg = \frac{w^2 - w^1}{w^2} 100 \tag{6}$$

Where:-

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

Heating Value (Hv)

$$HV = 0.3535FC + 0.1559VM - 0.0078AC$$
 (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.

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

## F. Volatile Matter

After the sample was dried, it was left in the crucible, covered with a lid, and moved into the furnace, maintained at 950°C for 7 minutes. The crucible was first cooled in the air, put in aluminum foil, and weighed again. Loss in weight is stated as a volatile matter on a percentage basis.

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

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 remaining sample in the crucible was reheated without a lid in the furnace at 750 °C for five hours. Then the crucible was removed, cooled first in the air, then weighed in mass balance.

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

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

(P): 2959-393X (Provisional)
DOI: https://doi.org/10.59122/134CFC7



charcoal has volatile matter below 30%. So, the results obtained agree with the literature. As the temperature increases the volatile matter decreases.

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 II.

Table II: 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 III 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 traditional one was 31% while that of the improved kiln was 16%. 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].

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

4

DOI: <u>https://doi.org/10.59122/134CFC7</u>

transportation resistance, as evidenced by their high shatter (91.12 %) and water penetration (17.99 %) as shown in Table IV. 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 III: Charcoal Yields and Production Cycle

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

Table IV: 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 <sup>3</sup> | 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, 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/m³ while a conventional earth mound kiln had a bulk density of 384.6 kg/m³. 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.

DOI: https://doi.org/10.59122/134CFC7



# References

- 1. Hassan Gomaa and Mohmed Fathi, "Simple charcoal kiln," Int. J. Acad. Res., pp. 1–74, 2000.
- 2. D. M. Kammen and J. L. Debra, "Review of technologies for the production and use of charcoal". *Renewable Appropr. Energy Lab. Report.*, March 1, 2005.
- A. W. Toole, P. H. Lane, C. Arbogast, Jr., W. R. Smith, R. Peter, E. G. Locke, E. Beglinger, and E. C. O. Erickson, "Charcoal production, marketing, and use", *Forest Products Lab.*, Report no. 2213, July 1961.
- 4. W. M. Lewandowski, E. Radziemska, M. Rims, and P. Ostrowski, "Modern methods of thermochemical biomass conversion into gas, liquid, and solid fuels," *Ecol. Chem. Eng. S*, vol. 18, no. 1, pp. 39–47, 2011.
- 5. J. A. Libra, K. S. Ro, C. Kammann, A. Funke, N. D. Berge, Y. Neubauer, M. Titirici, C. Fühner, O. Bens, J. Kern & K. Emmerich, "Hydrothermal carbonization of biomass residuals: A comparative review of the chemistry, processes, and applications of wet and dry pyrolysis," *Biofuels*, vol. 2, no. 1, pp. 89–124, January 2011.
- 6. A. Ogundele, O. Oladapo, and A. Aweto, "Effects of charcoal production on soil in kiln sites in Ibarapa area, South-Western Nigeria," *Ethiop. J. Environ. Stud. Manag.*, vol. 5, no. 3, pp. 296–304, 2012. doi: 10.4314/ejesm.v5i3.12.
- 7. R. A. P. Lomeda-De Mesa, A. N. Soriano, A. R. D. Marquez, and A. P. Adornado, "Study on the proximate and ultimate analyses and calorific value of coal blending between torrefied biomass from coconut (Cocos nucifera) husk and Semirara coal," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 471, no. 1, 2020.
- 8. FAO, "Forest product conversion factors for the Unece Region," *Geneva Timber For. Discuss. Pap.*, vol. ECE/TIM/DP, p. 38, 2010, [Online]. Available at: http://timber.unece.org/fileadmin/DAM/publications/DP-49.pdf.
- 9. A. M. Shakorfow, "Biomass . Incineration, Pyrolysis, Combustion and Gasification," *Int. J. Scie. & Res.*, vol. 5, no. 7, pp. 13–25, July 2016.