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Fabrication and Performance Evaluation of Improved Corn Cob Residual Carbonizer to Produce Bio-Charr for Energy

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Abstract—Agricultural residue has great potential to offer domestic energy demand for rural community. Utilizing the residue as it is, does not fit to environmentally friend and not suitable to sustainable development scheme. Nevertheless, burning corn cob residue without change their nature to recover desirable heat considered as inefficient and insufficient. Because combustion of corn cob residual yields low heating value and density. Moreover, poor consumption of the residue subjective to respiratory infection disease. Therefore, converting the residue into useful energy resource is very imperative. To enhance the utilization, upgrading of the residue is most important. As a result, corn cob residue was carbonized, applying an improved carbonizer with very limited supply of air. On drum body, certain shacks were provided to follow up enhancement of carbonization process which by turn decrease carbonizing time. After corncob carbonization was completed, carbonized corncob was extracted from reactor over prepared floor to reduce temperature. Meanwhile products were carefully removed to minimize losses and screened to separate products. Hence charred and uncharred products were identified and organized as well as mass of broken & unbroken charred were separated and measured. Thus, mass of charred and uncharred was to be 109.3 and 15.7 kg respectively whereas mass of broken and unbroken became 4.6 & 104.7 kg respectively. Volume based conversion rate of improved carbonizer became 86.36 % whereas 56 % for the former carbonizer. Time acquired per batch for improved carbonize became 90 to 110 minutes whereas 3 to 4 hours depending on season & environment.

Keywords—Corncob residue, Improved, carbonizer, Charred, Hole

I. INTRODUCTION

Fire wood and wood charcoal are main biomass energy resource for cooking in developing countries. In developing country, cooking usually accomplished on open fires where excessive heat gets lost without doing anything. Thus, an inefficient cooking process certainly leads to extreme deforestation in developing rural regions as well as considerably increases carbon-dioxide emissions and complicity of climate change. Due to significant smoke inhalation during fuel consumption, people those living in these developing regions also suffer from respiratory infections and disease [1].

Development endeavor of many countries can be expressed in term of energy consumption. Household energy consumption can be affected with type of fuel, family status and environmental conditions [2]. Type of fuel used and energy consumption pattern can be influenced with growth rate of urban populations that mostly happened by high migration flows from rural areas to urban. This subsequently led to major changes or shift particularly in utilizing the domestic energy scheme. Wood fuel is main energy resource in rural areas of African for this reason energy consumption of the areas is still low [3]. Cooking with fire wood became subjective to respiratory infection disease when openly used without employing technology. In some African countries, urban women were interviewed on consumption of wood as fuel. They found it was difficult to burn, dangerous for children, smoky and mess. For this reason, they did not want to use wood as fuel [4].

In Ethiopia, most domestic energy requirement is fulfilled with wood and other products associated with residue that rush into complete devastation of the forest resources. The way of processing biomass fuel as source of energy is very traditional and insufficient system where it cannot hit target of energy demand [5]. Thus, to meet domestic energy demand, per each year numerous amounts of forest gets destroyed for fuel purpose. However huge volume of agricultural residues that has big potential for energy are available.

Corn cob residue in rare case is used as animal fodder and source of fuel for rural families [6]. However, majority of agrarian community in these areas usually paid lesser attention for postharvest by-products such as cob [7]. Consequently, farmers residing in maize belt also engaged in the act of forest destruction in an attempt to find additional financial income by supplying the urban market with fire wood and charcoal [5].

However, burning agricultural by-product without changing their physical nature to recover heat is considered as inefficient and poor consumption because of the low heating value and pollution problem [5], [8] & [9. Most of agricultural residues have low density materials and low high heating values [10],[11]. Apart from these, their combustion cannot effectively be controlled and easily be maintained for proposed purpose or determination as fuel [12]. Therefore, converting the waste materials into useful resource is a matter of persistent issue. To enhances an effective and efficient utilization of agricultural residue, promoting corncob to a high-quality energy resource is so important. Once corn cob residue was carbonized well, it serves as rich char which has high energy density and tough products.

II. RELATED WORK

On carbonization technology, several works had been done so far. However, many of them are connected with industrial drive where energy resource is associated with electricity and not compatible with my research work. Since biomass firing as heat is going to be used for the process, review of the literatures was mainly concerned with heat generated from incomplete combustion of biomass. Carbonizer is key tool that helps by converting waste material in to valuable products for production of best fuel energy [13]. Carbonization process requires dry waste materials, heat resource and little amount of oxygen [14]. The waste materials can be any of a variety of agricultural residual including corncobs, bagasse, millet stalks, groundnut shells, palm leaves or bamboo. In general, the reactor is cylindrical in shape and may be different on sizes depending on the feed stock used. According to Akintaro, 2017 [15] size of locally made carbonization kiln for corncob residue become 1500 mm in height and 1000 mm in diameter. The reactor is typically operated at a temperature range of 450 – 510°C with little amount of oxygen to remove water and other volatile constituents from organic materials [16], [17].

Time of carbonization of organic waste depends on nature and volume of material used as well as working condition of the environments for the case of biomass firing as resource of heat. In most case, carbonizing period range from 45 to 100 minutes depending on size and feature of material employed [5],[18]. Size or thickness of layer of material used for carbonization also matters charring time and conversion rate of efficiency. According to D-Lab, 2020 [14] having layer thickness of 25cm per batch feeding feed stock yields good conversion rate and effective carbonization processes. Adding of extra water on surface of carbonization reduced the latent heat generated during carbonization and minimize favor for complete combustion that result to ash.

In the past, Bako Agricultural Engineering Research Center had developed corncob carbonizing technology for charring of agricultural by-product. As a matter of fact, raw corn cob could be converted to charred matter by employing carbonizing technology. At this point the raw cob was made to be burnt in very limited supply of atmospheric air and charring time. So far significant effort has been made inducing the farmer to utilize corn cob carbonization technology so as to redirecting ones focus of attention to this issue and encouraging the utilization of charred corn cob as a substitute to wood and wood charcoal. This could play great deal in minimizing tendency of continual destruction of forest resource and climatic irregularities.

However, the effort made could not able to hit the target due to various drawback of the technology. The size of corn cob carbonizing drum was very small and at once, it accommodated only 150 kg of raw corn cob. One batch charring time took 3 up to 4 hours depending on the season and environmental condition. Thickness of corn cob residue layers was about 25cm which caused to incur additional more time to carbonize any given organic matters. This implies that charring time for one batch carbonization was too long and moreover, volumetric conversion efficiency that based on volume of corncob charcoal became 56% which still requires great attention. Therefore, this activity was initiated to solve all these problems by optimizing the size of carbonizing technology and applying holes on the drum part that enhanced effectiveness of carbonization activity and which returned reduce charring time.

III. MATERIAL AND METHOD

MATERIAL

Based on the design specification, materials that are necessary for manufacturing of an improved corncob carbonizer was identified & selected. Accordingly, different size of sheet metals, water pipe for handling purpose, M16 bolt and nut, deformed bar and five varieties of corn cob residues namely (BH-661, BH-541, Local, Shone and Limmu), Carpet, Thermometer, Bomb Calorific and Stop Watch are among materials used for carbonization process. In whole raw corn cob residue that was applied for carbonization were obtained from local fields of farmers and investors in free of charge. These agricultural residues were mainly chosen for they are produced in large quantity in local areas and frequently, they were presented in widespread for local consumption and contributing for environmental pollution.

METHODOLOGY

Manufacturing of Carbonizer

Manufacturing of an improved corn cob residual carbonizer was proceeded based on prepared design specification. Improvement of the part was performed and continued as follow. Consequently, 1.5 mm thickness sheet metal was rolled to create 1100 mm diameter of drum body. Twelve holes were provided on the drum body in order to facilitate carbonization of raw corn cob and fellow up of carbonization processes. Each hole was 16mm in diameter and pitted on circumference of the drum part. From sheet metal, exhaust chimney and coal tar box were prepared separately and then integrated to make one part. Carbonizer is cylindrical designed reactor that was fabricated to deliver effective carbonization with low oxygen environment. It was made from materials stated above through drum height of 1200 mm and 1100 mm diameter. On top of the drum part, opening venturi was provided for loading of corn cobs feedstock. An appropriate metal plate was constructed and was used as cover for the top opening of the drum during firing of feedstocks.

Eventually, all parts of unit were assembled to give complete corncob carbonization equipment and prepared for experimental testing. The size of the former corn cob carbonizing drum was very small and it accommodated only about 150 kg of raw corn cob per batch whereas the improved corn cob can hold about 400 to 500 kg raw corn cob per carbonizing activity.

Biomass Preparation
From the field of private investor and known farmers, required raw corn cobs which customarily considered as wastes were collected. The collected feedstock was set over the sun so as to diminish the moisture content of cobs and sorted out to ensure effective carbonization process. Based on their distinct sizes, corn cobs residues were categorized to provide more surface or contact area for the carbonization activity.

Corn Cob Characterization
Graduated plastic cylinders was used to determine or estimate the basic density of corn cob. It was perfectly calibrated and engaged to measure the parameters. The cylinder was packed with prepared samples and well compressed. Thus, the density was calculated employing mass of material per volume.

Bomb calorimeter was used as per methodology described by ABNT [18]. Based on this, the higher heating value of corn cob residue was determined. This method helped to estimate maximum amount of energy potentially recoverable from a given biomass source such as the corn cob. Characterizing of the raw corncob high heating value is important when it is used in production of charcoal for energy purposes.

Carbonization
Once corncob carbonizer was set into working condition, batch by batch fuel material has been fed to reactor. Thickness of layer corn cob residue for former carbonizer was 250 mm. It was additional factor that influenced carbonization time to be longer. Decreasing the thickness of layers was one of the parameters that get improved. Therefore, thickness of layer of improved carbonizer became 200 mm. Alternative 5cm thick feedstock was prepared and ignited outside of carbonizer to create fire embers.

After fuel materials reached graduated height in the drum, fire ember or glows were dispersed consistently over raw fuel in order to facilitate carbonization activity per batch until the drum was get filled. At the commence of the carbonization process, combined part of exhaust chimney and lid was left open for the volatile matters to discharge and collection of tar in middle cyclone. Enhancement of carbonization had been checked up throughout activity with the changing of the color of the smoke from dark to white.

Carbonization process became speed up or faster than usually due to application of the holes on the drum body. Eventually, the drum was closed after application of the last batch & change of the color of smoke has been checked up via upper lid. After the upper lid was closed, to prevent air from entering proper sealing was performed. The corn cob residue was left to carbonize for 90 to 120 minutes. When the smoke releasing ceased or after it becomes colorless, top most lid that was integrated with chimney locked down and water get jacketed.

Later of these entire process, carbonized corncob was extracted from reactor over prepared floor to further reduce temperature so as to safely collect charred products. The products were carefully removed from carbonizing device to diminish damage occurred while the operation. From the collected products, charred and uncharred corn cob were identified, sorted out and recorded for to calculate and determine effectiveness and efficiency of the reactor. Weight of broken and unbroken charred corn cobs were measured to measure or estimate the quality and quantity of the charred products. In doing so data were collected, processed and analyzed carefully to mark out or predict the performance of corn cob carbonizer.

Charred Characterization
Bulk density was measured immediately after ejection from the reactor. It was calculated from the averaged mass, diameter and height of corn cob charcoal. Calorific value was determined from standard method using Bomb calorimeter. Energy density was calculated by multiplying density through high heating value. Thus, calorific value and energy density of each corn cob variety were determined employing above mention instrument and methods.

IV. RESULTS AND DISCUSSION

Corn Cob Characterization
Basic Density: -The basic density of evaluated raw corn cob ranged from 191.67 to 230.50 kg.m^{-3} for all varieties. Shone and BH-541 obtained the highest average basic density of 220.42 and 230.50 kg.m^{-3} respectively, however the density of Shone and BH-541 did not differ from the density of BH-661 which was 210.39 kg.m^{-3}. Local variety had the lowest raw corncob basic density of 191.67 kg.m^{-3}; nevertheless, density of Limmu variety quite similar to density of Local variety.

The values of basic density specified above are similar to literature stated below. On the other hand, corn cobs residues presented as individual pieces little be similar in shapes and sizes. The basic density of whole raw corn cobs would range from 160 to 210 kg.m^{-3} [19],[20]. Hence, the basic density value we discovered agreed with this author. However according to Oladeji, J.T., 2010 [21] studied basis density of white and yellow raw corn cob varieties, basic density of raw corncob of white and yellow varieties became 95.33 to 98.00 kg.m^{3} respectively which far below that were stated in above literature and our work.

For selection of the variety for charr production, basic density is considered as one of the key factors. Corn cob residue with the highest specific gravity should be preferred, because the use of denser cob results in higher production of charr than other corn cob variety. According to our study BH-543 has highest specific gravity due to it is denser and more tough in feature than the remaining residues. According to McKendry,2002 [22] the density has impact on fuel storage requirements, the sizing of the materials handling system, and on how the material is likely to behave during subsequent thermochemical processing as a fuel or feedstock.

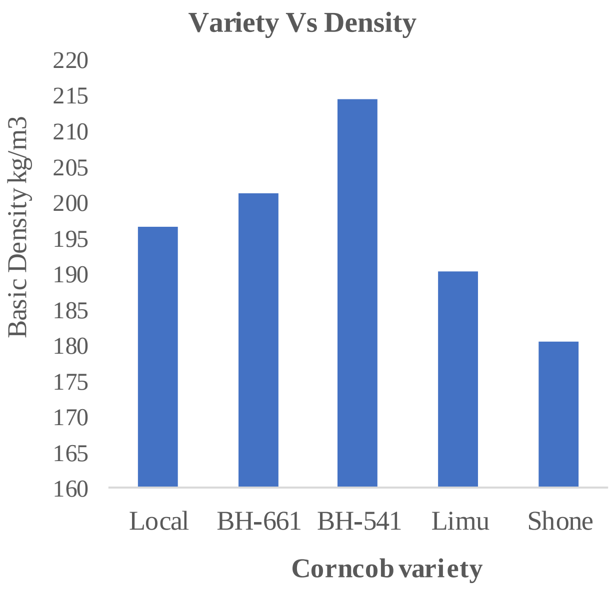

Figure 1. Mean Values of Raw Corn Cob Density

High Heating Value

The average high heating value of studied raw corncob was 16.29 MJ.kg^{-1} with mean values ranging between 15.89 and 16.69 MJ. kg^{-1}. The high heating value of raw corn cob residues showed little variation according to these authors [9],[23]. Because of the slight variation among the values found in many studies, high heating value is not determining factor for selection of corn cob as best fuel. However, with other authors, higher heating value of dry based corncob residue ranges from 18.3 to 18.8 MJ/kg [24],[25]. This is because; most of these residues are low density materials [9]. Apart from that, their combustion cannot be effectively controlled [11].

Calorific value of any substance can be expressed with extent of energy content available or amount of heat released during combustion in air. The calorific value is usually measured in terms of the energy content per unit mass [23]. In other way, high heating value of a material can be stated as total energy content released when the fuel gets combusted in air. Hence, high heating value of a given biomass characterizes the maximum amount of energy possibly extracted during utilization. Lignin and other extractives content available in corncob residue influenced the high heating value of the cob. This imposed ash content of the substance. However, this relationship was not considered in this work.

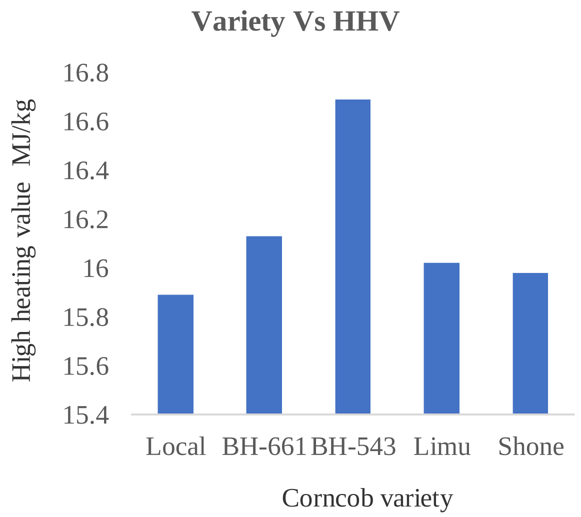

Figure 2. Mean Values of Raw Corn Cob HHV

Energy Density

Figure 3 below indicates energy density of corn cob residue. Energy densities of both raw and charred corn cob were expressed with Giga Joule. Charred corn cob of BH-541 records highest energy density than other. The high heating value of charred corncob is higher than raw corn cob. This is because during carbonization, bonds in the raw corn cob were easily be broken down. However, the compounds that have heat strong bonds remain preserved. From experimental test result, it can be concluded that high heating value of charred corncob showed an average increase of 58.08%, when it is related with high heating value of raw corn cob.

This is the main reason for the increase in energetic density of charred corn cob as compared to raw corn cob, because this is a multiplication between density and high heating value. Thus, as portion of the corncob is degraded during carbonization as well as charred density is less than the corn cob, but charred high heating value is significantly greater, resulting in a higher energetic density of briquette.

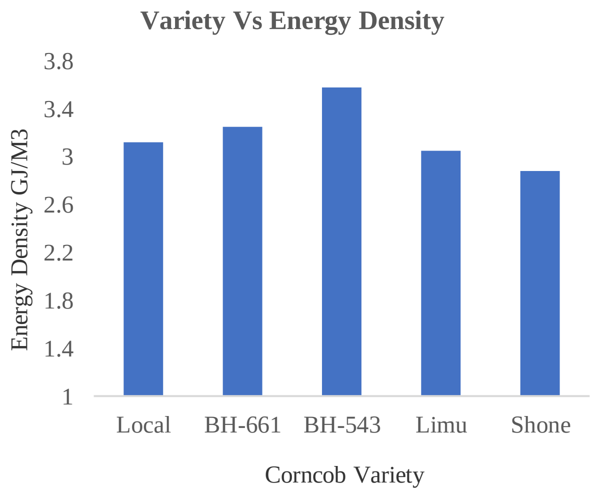

Figure 3. Mean Energetic Density of Raw Corn Cob in GJ.M^{-3}

Carbonization of Corncob

After corncob carbonization was executed, carbonized corncob was removed over prepared carpet to further cool and safely collect charred from processed. The product was carefully withdrawn from reactor to further reduce damage and screening get performed so as to separate charred and uncharred cob easily. From this, charred corncob and uncharred products were identified, sorted out and recorded. Mass of broken & unbroken charred corn cobs were separated and measured to estimate quality and quantity of the charred products. Therefore, mass of charred and uncharred corn cobs was measured to be 109.3 kg and 15.7 kg respectively. Mass of broken and unbroken charred corn cobs became 4.6kg & 104.7 kg respectively. Volume based conversion rate of modified carbonization technology became 86.36 % & whereas 56 % for the former carbonizer. One batch charring time acquired 90 to 110 minutes for improved carbonize whereas 3 to 4 hours depending on season & environment for former.

Corncob and corn stover are among agricultural residue that become most hopeful resources as cooking fuels. They are usually available in surplus or substantial quantities as waste. However, the utilization of these agricultural residues as it for fuel purpose is quite challenging due to their low bulk density, low heat release and the excessive amounts of smoke they generate [26].

Above entirely stated physical characteristics make corncob residue difficult to holder, stock, transport and utilize biomass residues in their raw form. Thermal value of corncob residue can be improved with application of carbonization processes [12],[27]. This involves the densification of loose biomass residue to produce fuel characterized with improved calorific value compared to the biomass in its original state [28].

The study insisted or encouraged farmers to utilize carbonized corncob as alternative material for energy resource. Its charred cob production is so attractive and engage many human powers for job creation. This will increase the sources of energy for domestic and industrial use in developing economy.

V. CONCLUSION AND FUTURE SCOPE

An improved corn cob carbonizer allowed to carbonize raw corn cob with good mass and volume-based conversion efficiency of any given varieties. Therefore, applying this specific corn cob carbonizer assisted to redirect one focus on attention and encouraged operation of corn cob charcoal as substitute to fire wood and wood charcoal, where corn cob was abundantly available. In general, carbonizing corn cob minimized or managed coal tar and smoky that are connected with health hazards associated with respiratory infection and increase energy density of corn cob. Hence, volume-based conversion rate of an improved carbonizer becomes 86.36 % and one batch charring time was lowered below two hours due to application of hole that enhanced carbonization and decrement of thickness of corn cob layer below 25cm. These whole parameters played great role to achieve effective and efficient carbonization processes. Thus, popularizing this technology to immediate user will rescue our economy and environment as much. Moreover, it minimizes forest resource continual destruction as fire fuel and plays great deal in climate mitigation program.

Among varieties, BH-543 variety shows highest basic density, high heating value and energy density. In addition, the variety has better production in yield than other when compared with similar production land. Biomass physical feature and size of raw corn cob of BH-543 medium in size and its strength is higher than BH-661 as well as the remaining variety.

It can be recommended that corncob carbonization technology considered as means for production of charr that supposed to be substituent for wood charcoal. Carbonizer minimizes loss of energy occurred due to inefficient of way of processing and insufficient system to satisfy energy demand particularly for rural communities. To enhances an effective and efficient utilization of agricultural residue, promoting corncob to a high-quality energy resource is so important. Once corn cob residue was carbonized well, it serves as rich char which has high energy density and tough products. Furthermore, encourage farmers residing in maize belt areas as source of additional financial income by supplying the urban market with charcoal of corncob.

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