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Research Article

Briquetting of Charcoal from Sesame Stalk

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Due to the easy availability of wood in Ethiopia, wood charcoal has been the main source fuel for cooking. This study has been started on sesame stalk biomass briquetting which can potentially solve the health problems and shortage of energy, which consequently can solve deforestation. The result of the data collection shows that, using 30% conversion efficiency of carbonizer, it was found that more than 150,000 tonnes of charcoal can be produced from the available sesame stalk in Humera, a place in north Ethiopia. The clay binders that are mixed with carbonized sesame stalk were found to have 69 liquid limits; thus, the optimum amount of clay that should be added as a binder is 15%, which results in better burning and heat holding capacity and better heating time. The developed briquetting machine has a capacity of producing 60 Kg/hr but the carbonization kiln can only carbonize 3.1 Kg in 2 : 40 hours; hence, it is a bottle neck for the briquette production. The hydrocarbon laboratory analysis showed that the calorific value of the charcoal produced with 15% clay content is 4647.75 Cal/gm and decreases as clay ratio increases and is found to be sufficient energy content for cooking.

1. Introduction

Eradicating poverty and hunger and providing energy are crucial for sustainable development goals. Without access to modern energy services, the poor in the developing countries are deprived of many potentials. So Ethiopia being one of the developing countries is currently in need of high energy in order to hold its fast growth [1].

Due to the easy availability of wood in Ethiopia, wood charcoal has been the main source fuel for cooking. But wood charcoal is risky to use due to its bad consequence on health and its disadvantage of pollution [2].

The quality of life has been improved by using energy resource for different daily activities of human beings; however, it has also created many problems. Global warming and harmful effects on the environment are the most serious ones affecting human health and causing pollution. Also it is now coming to be clear that the nonrenewable resources are gradually coming to an end; oil, natural gas, and coal are going to be depleted. Thus, energy problem is becoming very serious and the main objective is to assess a solution to fill the gap between demand and supply of energy sources [3]. Therefore, energy should be conserved and used wisely and alternative energy should be assessed.

Sesame stalk is plentifully available in the rural regions particularly in Humera, the largest farmland in north Ethiopia. It is not being used for any purpose; rather, they use wood for cooking and baking. More than 85% of the population in Ethiopia lives in rural area, and assuming that each family consists of five persons and uses annually about 3 tonnes of biomass as fuel, one comes to the figure that about 44.28 million tonnes of biomass is utilized annually only for domestic cooking in rural areas only. The urban populations of Ethiopia (up to 15%) are also using biomass for boiling and related items [1].

According to statistics published by the World Health Organization, air pollution created by the wood charcoal used for cooking in rural households kills about 500,000 women and children of India per year [4]. Considering the fact that almost 85% of Ethiopians live in rural areas, the rural women in Ethiopia are suffering the same and should be given an alternative source of energy. One way of tackling the pollution and health problems of the consumers of wood charcoal is producing briquette charcoal using sesame stalk by making simple extruder and effective carbonizer.

Briquetting of biomass products is a newly coming energy alternative to Ethiopia even if much more is done in other

Figure 1: Sesame stalk left at the farms (pictures taken on 21/02/13).

countries. The large amount of sesame coming from the largest farmland in Ethiopia, Humera, is not consumed by animals; it is simply left over the farmland as in Figure 1, and thus changing this sesame stalk to charcoal solves the energy shortage problem to a large extent [5].

With the objective of solving the problem of energy in the country by producing renewable energy from the sesame stalk and other additives, this research has developed scientific procedures and machines to change the sesame straw to a smokeless charcoal. It also determines the right proportion of binders to be used while producing briquettes from sesame. Finally smokeless charcoal of cylindrical shape with a better calorific value was produced by MSEs (medium and small scale enterprises) and distributed to the rural and urban households.

2. Briquetting of Biomass

2.1. Carbonization. Carbonization (or partial pyrolysis) drives off volatile compounds and moisture leaving fuel with a higher proportion of carbon remaining (char). This is the same process that creates charcoal from wood and is preferred particularly in urban environments for its superior burning characteristics and smokeless use. Carbonization which is a controlled process will bring char with less amount of harmful emission compared with burning raw biomass. Even if the need to carbonize wood depends on the application, most of the developing countries use traditional techniques of charcoal making having up to 10% conversion efficiency. However, some improved processes have been developed for small scale char production, with improved efficiencies of up to 30% [3].

2.2. Binding. Binding is the process of "sticking together" the compacted material. If subjected to sufficiently high temperature and pressure, biomass materials can bind without extra agents for binding. High temperature can melt a naturally occurring substance called lignin and under pressure this can act as glue [6]. If high temperatures cannot be achieved (as is the case with most locally made briquette machines), additional binding agents such as cassava flour, molasses, wheat flour, fine clay, and red soil need to be added to enhance or activate the binding process.

2.3. Drying. Drying is a critical process in briquette manufacturing and is often the limiting process for the producers in east Africa. Noncarbonized biomass requires the feedstock to be dried to a moisture content of around 13% before entering the carbonizer to increase the efficiency of carbonization. And after carbonization it needs drying in order to evaporate the water that was added to cool down the carbonizer. In addition, drying is needed to dry out the water in the briquettes (to less than 10% moisture content) since they are produced wet [7].

The developing countries in east Africa use sun drying due to the availability of high natural radiation from the sun. The briquettes are put over polypropylene, polyethylene, or related materials and laid under sunlight. Depending on the amount of radiation on the day, briquettes are completely dried within 3-4 days [3, 6].

2.4. Compaction/Briquetting. In all over the world a number of machines and techniques have been developed for briquetting charcoal on variable production scale. The local manufacturing sector in Uganda, for instance, has emerged in providing low-capital solutions to small scale briquetting technology while larger scale machineries are imported from India.

Among the many briquetting machines, Piston extruders, the relatively large machines, in which a weighty piston forces biomass material through a tapered die, are used to briquette charcoal. Another type of briquetting machine that uses a screw action to extrude a briquette through a die is screw extruders [7], on which biomass is fed into the machine from a hopper into the rotating screw. Powered by electric motor, the material is forced by the screw to pass through the die forming cylindrical briquette.

Roller presses [7] are also one of the commonly used charcoal briquetting machines that have two adjacently designed counterrotating rollers with indentations in the size and shape of the briquettes needed. Wet charcoal is fed to the hopper, which falls into the indentation and is compressed on turning the rollers. Then the briquettes withdraw from the machine as a single lump in pillow shape. The degree of compaction attained by a roller press is comparatively low compared to a piston or screw extruder and so it is suited more to briquetting of wet powders containing a binder to aid binding. Thus, production capacity of a roller press machine can reach 1.5 tonnes per hour which is very high. Roller presses are used by most of the largest east African producers of carbonized briquettes.

A considerable number of low-capital manual techniques have been developed both for carbonized and noncarbonized feed stocks. Many of these designs have been disseminated in the developing countries to encourage the production of briquettes among rural communities that would otherwise lack access to industrial technology.

3. Energy Characterization

3.1. Proximate Analysis of CNS and Its Char

Determination of Moisture Content. About 1 gram of finely powdered air-dried sample is weighed in and put in a crucible and is placed inside an electric hot air-oven at 105°C. The crucible is allowed to remain in oven for 1 hour and then taken out and weighed after cooling in designators. Thus, the amount of weight lost (ASTMD-3173 standard test method for moisture content) is the moisture content (on percentage basis) [3, 6, 7].

Determination of Volatile Matter. ASTMD-3275, standard test method for volatile matter, determines volatile matter by keeping dried sample of charcoal for six minutes in a closed crucible at 600°C and 900°C each, respectively. Then the loss in weight after the volatiles are evaporated is the total volatile matter available in the biomass and is reported on a percentage basis [7, 8].

Determination of Ash Content. The residual coal in the crucible is then heated without lid in a muffle furnace at 750°C for half an hour for ASTMD-3174. The crucible is then taken out, cooled first in air and then in desiccators, and weighed. Heating, cooling, and weighing are repeated, till a constant weight is obtained. The residue is reported as ash on percentage basis [9].

Determination of Fixed Carbon. The fixed carbon in percentage is calculated by difference [8]:

$$\text{Fixed carbon (\%)} = 100 - \text{\% of (moisture content + volatile matter + ash)}. \quad (1)$$

3.2. Procedure for Determination of Calorific Value of the Fuel by Using the Oxygen Bomb Calorimeter. A known mass of the given sample is taken in clean crucible. The crucible is then supported over the ring. A fine magnesium wire, touching the fuel sample, is then stretched across the electrodes. The bomb lid is tightly screwed and bomb is filled with oxygen 25 atmospheric pressure. The bomb is then lowered into copper calorimeter, containing a known mass of water. The stirrer is worked and initial temperature of the water is noted. The electrodes are then connected to 6-volt battery and circuit is completed. The sample burns and heat is liberated. Uniform stirring of water is continued and the maximum temperature attained is recorded. The experimental setup for determination of calorific value was established using bomb calorimeter. The calorific value of the CNS and its char is to be determined by using bomb calorimeter.

Table 1: Quantitative data of sesame stalk in Humera.

Names of places (weredas)	Hectares of sesame cultivated	Stalk (tonnage) (estimated yield 2 tonnes/hectare)
Kafta Humera	223,918	447,836
Welkait Tsegede	24,896	49,792
Tahtay Adiabo	19,433	38,866
Tsegede	17,497	34,994
Total	**285,744 hectares**	**571,488 tonnes of stalk**

Table 2: Chemical characteristics of sesame stalk.

Ash content	4.16%
Volatile matter	77.11%
Fixed carbon	14.54%
Moisture content	4.19%
Heating value	4152 Kcal/kg

Figure 2: Sesame stalk being chopped.

4. Materials and Methods

4.1. Sample and Data Collection. The main input material for this research is sesame stalk from Humera; therefore, field visits for data collection have been done first. The exact nature, location, suitability, and availability of the sesame stalk were dealt with. And then samples of sesame stalk and additives are collected. Table 1 shows the amount of sesame stalk produced around Humera.

4.2. Qualitative Data. Ash percentage is very low so that there will be less amount of ash left after burning and volatile matter is very high which makes the burning easier. The calorific value is reasonable for briquetting of charcoal from the sesame stalk. Table 2 shows the chemical characteristics of sesame stalk. The method of analysis is proximate analysis, adiabatic calorie meter, and eschka mixture.

4.3. Sample Preparations. The sesame stalk, husk, and the clay and the binder to be were first collected; then the sesame stalk was chopped manually to a size of 10 cm as in Figure 2, which is used for uniform heat distribution during the carbonization process.

4.4. Carbonization and Mixing. Carbonizer with low oxygen environment but able to withstand high temperature was

Table 3: Boiling test result.

Time taken till the first boil	Total length of burn	Amount of water boiled off	Amount of water boiled off per minute	% of ash remaining
20 min	1:32 hours	950 mL	10.3 gm/min	130 gm of 500 gm, that is, 26%

(a) (b)

Figure 3: (a) Crushing the carbonized sesame stalks. (b) Charcoal and clay mixing.

designed and prepared from sheet metal of 2 cm thickness. Then, after that, the chopped sesame stalk was carbonized. Three samples of the chopped and dried sesame stalk each of 11 Kgs were prepared for the carbonization. When these chopped sesame stalks were fully carbonized, clay with high plastic limit was added to these samples. The aim of the clay is to act as a binder and it was added in different amounts to the three samples. This binder was used to increase the bonding between the carbonized sesame stalks. It also increases the strength and heating time of the output charcoal. Mixing of the clay and carbonized sesame stalk was done manually after the carbonized sesame stalk was made powder using manually available crushing tools as shown in Figure 3; while mixing, the plastic clay was diluted with water up to its liquid limit which is 69.

4.5. Briquetting. Briquetting is one of several compaction technologies to form a product with better material property such as uniform shape and size, higher density, and low moisture content. The mixture of the clay, acting as the binder, and charcoal is then made into briquettes using an extruder machine. The extruder is a screw type press machine which is made from sheet metal welded on a solid steel shaft, designed to produce high density cylindrical briquette. In this case, the raw material is mixed well and at the same time it is transported to the end of the extruder. Finally, the briquettes were made dry under the sunlight for about 1-2 days. Figure 4 shows the briquettes while drying using sunlight.

Figure 4: The produced briquettes while drying.

5. Result and Discussion

5.1. Fuel Performance Tests

5.1.1. Friability Test. This test was conducted by putting 250 gm of briquette in a plastic bag and freely dropping the briquettes from a height of 2 meters for five times onto a concrete floor. The result showed that 213 gm (85.2%) of the briquettes was found unbroken and 37 gm (14.8%) of the briquettes was found as chips and powder. A research done on friability test in Kenyan biomass [8] showed that the % remaining unbroken from the drop test of the same height for sawdust and coffee husk with 15% clay as binder was found to be 48% and 44%, respectively, and another test done similarly on *Macadamia* nut shell also showed that 76% of it remained unbroken which is the maximum rank for friability test. Therefore, it is clearly seen that the sesame stalk briquette has got better quality in strength and durability. This can be a result of the availability of lignin that can better match with the available clay which also has good plasticity for binding.

5.1.2. Boiling Test. Boiling test was undertaken by combusting 500 gm of briquette in an Ethiopian metallic cookware called "fernelo" and 1 litter of water was used for boiling in an open metallic pot as shown in Figure 5.

Test results show that the sesame stalk has got almost similar properties when compared with the most common briquetting biomass which is sawdust [8].

As can be seen from Tables 3 and 4, the sesame stalk briquette is one of the potential briquettes with qualities comparable to sawdust and coffee husk and much better than the briquettes made from maize stover. The length of burn till

Table 4: Boiling test results: comparison with other biomass resources.

Type of briquette	Time taken till the first boil	Amount of water boiled off	Amount of water boiled off per minute	% of ash remaining
[1]Sesame stalk	20 min	950 mL	10.3 gm/min	26%
[2]Sawdust	25 min	—	17.3 gm/min	27%
[2]Maize stover	40 min	—	8.3 gm/min	34%
[2]Coffee husk	23 min		14 gm/min	20%

[1]Taken from Table 3, [2]Chardust Ltd., and Spectrum Technical Services, "The use of biomass wastes to fabricate charcoal substitutes in Kenya," Kenya, 2004 [8].

Table 5: Method of analysis: proximate analysis, adiabatic calorie meter, and eschka mixture.

Sample name	Clay content %	Moisture content %	Volatile matter %	Fixed carbon %	Ash %	Calorific value Cal/gm	Sulphur %
Sample 1	15	7.25	22.96	44.40	25.39	4647.75	0.21
Sample 2	20	6.35	20.63	32.90	40.12	3580.62	0.23
Sample 2	20	6.39	21.17	32.38	40.06	3578.67	0.20
Sample 3	25	7.57	22.90	29.63	39.90	3389.30	0.30

Figure 5: Boiling test equipment (from left to right: water holding basket, measuring cylinder, briquettes, digital weight meter, and cookware-fernelo).

it becomes ash is found to be 1:30 hours which is much better than mixed briquettes made from mixing charcoal dust, maize cob, saw dust, and paper as binder which took above 3 hrs on average [10]. This short burning time is an advantage in the cooking time which is an additional quality for briquettes found from sesame stalk. Comparing the percentage of ash content, sesame stalk briquette has 26% and lesser compared to those of briquettes made from sawdust and maize stover which are 27% and 34% (Table 4), respectively, and is much better than mixed briquettes made from mixing charcoal dust, maize cob, saw dust, and paper as binder that have a percentage of ash content of 34% and above [10].

The time taken till the first boil in Table 4 shows that the sesame stalk briquette has quick ignition time and comparable burning quality when compared with saw dust and coffee husk and has much better ignition time and boiling potential than maize stover.

5.1.3. Calorific Value. The hydrocarbon analysis in Table 5 shows that as the amount of clay binder increases from 15% to 25% the calorific value decreases from 4647 Cal/gm. to 3389 Cal/gm. and the ash content increases from 25% to 40%. The minimum possible clay content as a binder was also found to be 15%, for below this amount the charcoal produced was not able to bind itself and cannot be mechanically durable for transport and support cooking utensils. So the optimal calorific value of sesame stalk charcoal is 4647 Cal/gm. with lesser ash content. It is known that one of the determinants for the quality of biomass charcoal is the ash content after burning. The ash content is increasing as the amount of clay is increasing and is due to the ash content of clay which is about 90.1% [11]. The calorific value of briquette made from bagasse with the 1 : 1 : 40 ratios of clay, molasses, and bagasse proportion was found to be 4390 Cal/gm. and was highly recommended for cooking and house heating purposes [11] and sesame stalk briquette has got better calorific value of 4647 Cal/gm. which may be due to the amount of lignin and oily nature of sesame stalk. The moisture content of the briquette samples was less than 18% (% of water less than 18% of water is chemically bound with the materials and there is no free water); therefore, the moisture content value will not affect the chemical and physical property of briquettes [11]. The amount of volatile matter in sesame stalk briquette with 15% clay content, which is 23%, is best comparable with other briquettes made from bagasse, clay, and molasses with an average volatile matter percentage of 23 [11].

The percentage of fixed carbon in sesame stalk briquettes has decreased from 44.4% to 29.63% as the percentage of clay increases from 15% to 25%; this is due to the low carbon content of clay which is about 7% [11].

Hydrocarbon Laboratory Analysis of Sesame Charcoal. See Table 5.

6. Conclusion and Recommendations

This research reveals that there is a potential of producing more than 150,000 tonnes of charcoal each year in Humera from sesame stalk only. Sesame production is increasing from time to time in the northern part of Ethiopia since

it is becoming one of the cash crops with a major role in foreign currency generation. So, the production of sesame is highly expected to increase. The quality of the charcoal produced was found comparable with sawdust and coffee husk and other blended briquettes like bagasse, molasses, clay, and related biomass briquettes which are currently being used in east African countries with relatively better heating properties like higher calorific value, better burning performance, and improved waiting time upon heating.

The chemical characteristics of sesame show that there is very low percentage of ash and that there will be less amount of ash left after burning and volatile matter is very high which makes the burning process easier. The calorific value is also reasonable for briquetting of charcoal from the sesame stalk.

It was found out that clay was the compatible binding material with sesame stalk where 15% is the optimal possible clay content with an optimal calorific value of 4647.75 Cal/gm and minimum ash content. The main factors behind the quality of briquettes, ignition time, the percentage of volatile matter, the percentage of sulphur available in the briquette, the percentage of fixed carbon, and the percentage of moisture content of sesame stalk briquettes, when compared with other currently on-use biomass briquettes, showed that sesame stalk briquettes can better be used for cooking and heating purposes.

Humera, the area in which sesame is broadly cultivated, has natural gums that can replace clay for binding and can also be used as filler. Thus, further researches should be done to enhance the quality of the sesame stalk briquetting.

The briquetting machines and the carbonizer are locally made in the university workshops; thus, they can easily be made available in the local small and medium metal fabrication workshops in the region which will have a positive effect on technology transfer and innovation.

Briquetting of charcoal from sesame stalk can be one of the major goals of SMEs (small and microenterprises) that youngsters and women can do and bring change to their livelihood; hence, a great attention should be given by every stakeholder like SMEs, science and technology agency, ministry of energy, ministry of agriculture, and universities so that series of training courses should be given, researches should further be done, and there should also be followups so that this sector can bring a sustainable profit to the community.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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