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Research Note

Conversion of Degradable Municipal Solid Waste into Fuel Briquette: Case of Jimma City Municipal Solid Waste

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ABSTRACT

The study was done to explore the production of charcoal briquettes that could meet the need for energy in the community of Jimma city. The primary objective of this work is to produce charcoal from the most promising wastes. Under these objectives the main activities which performed were sorting waste, characterization of wastes that can easily degradable, designing carbonizer equipment, manual press molding machine, and characterizing charcoal briquettes. Degradable municipal waste was collected from Jimma city. The charcoal production process includes a collection of degradable municipal waste, drying, carbonization, crushing and sieving, binder preparation, binder – charcoal mixing, briquette charcoal (compaction and drying), and packing. The test result of degradable municipal solid waste for its density, % of moisture, % of volatile matter, % of ash, % of fixed carbon, and caloric value of was determined as 157.3kg/m^3, 18.15%, 66.95%, 4.07%, 10.83%, and 18.5MJ/kg, respectively. In the same way the test result for charcoal briquette for its density, porosity weight index, shatter resistance ,moisture content, volatile matter, ash content, fixed carbon content, and caloric value was obtained as 50.06kg/m^3, 29.05%, 92.3 %, 9.87%, 29.4%, 3.21%, 57.52% and 27.0MJ/kg, respectively. These results show in the range compared with others reported in literature. Therefore, there is the possibility to convert Jimma City degradable solid wastes into charcoal briquette using starch as a binder. We can increase the quality of charcoal briquette rather than polluting the environment.

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INTRODUCTION

Background

Biodegradable materials can serve as an alternative renewable and carbon-neutral raw material for the production of energy. There is a scarcity of energy and there is the need to source alternative forms of energy, which is different from conventional types. According to information found from the municipality of Jimma town, 54,30 and 16% of the waste generated from the town are biodegradable, disposable, and recyclable, respectively. According to literature, the food wastes constitute of 32.1% of the total household wastes by weight [1–3].

Total generation rate of solid waste which is expressed as the amount of waste (kg) generated by one person per day will be the total waste collected in nine days divided by the total number of people and it will be 0.14kg/ca/day. It is known that the total population of the town is about 159,009. Taking this figure into account, the daily, weekly, monthly, and yearly solid waste generation rate of Jimma town is estimated to be 22.26, 155.82, 667.8, and 8,124.90 tons, respectively [2]. Solid waste management is one of the major problems in different countries like Ethiopia. Solid wastes from households, agro-industries, and different companies dumped in open lands or accumulated in open-dumping sites are one of the main challenges in Ethiopian cities. The majority of the wastes generated are not appropriately collected and dumped. Studies conducted in Ethiopian cities (such as Addis Ababa, Jimma, Bahir Dar, Awassa, Mekelle, Adama,, and Diredawa) indicated that inadequate solid waste management has resulted in the accumulation of solid waste on open lands, in waterways and drains [4].

Statement of the problem

Jimma city is one of the largest, oldest, and commercial centers of the Ethiopian country which is situated in southwestern Ethiopia. An increase in the number of population is observed in the town. There is no standard waste controlling system for the city at present. Solid waste is simply dumped at environmentally sensitive locations, and polluting the environment. Hence, the need for the design and

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implementation of a sustainable and environmentally friendly waste treatment mechanism becomes apparent. The major physical characteristics measured in waste are (a) density, (b) size distribution of components, and (c) moisture content. Other characteristics that may be used in making the decision about solid waste management are (1) color, (2) voids, (3) shape of components, (d) optical property (e) magnetic properties, and (f) electric properties. Proximate analysis of waste aims to determine % of moisture, % of volatile matter, % of ash, and % of fixed carbon. Ultimate analysis of waste aims to analyze the percent of carbon, hydrogen, oxygen, sulfur, and ash.

From the research conducted, the contents of carbon and nitrogen in food waste are 53 and 0.68%, respectively. These values vary somewhat from the ultimate values which are 48 and 2.6% for carbon and nitrogen, respectively [5].

Objective

General objective

The general objective of this research article is to convert Jimma town degradable solid waste streams into valuable products for better environmental management.

Specific objectives

This research was performed under specific objectives of::

- To sort and characterize Jimma town biodegradable municipal solid waste,
- To convert Jimma town biodegradable municipal solid waste to charcoal briquette,
- To characterize charcoal briquette and to know the best binder for charcoal briquettes production and to design carbonizing and molding equipment.

LITERATURE REVIEW

Solid waste and its management

Solid waste management is one of the major challenges in many developing countries like Ethiopia. Solid wastes from households, agro-industries, and food industries dumped in open lands or accumulated in open-dumping sites is one of the major problems in Ethiopian cities. The majority of the wastes generated are not appropriately collected and dumped. Studies made in Ethiopian cities (such as Addis Ababa, Jimma, Bahir Dar, Awassa, Mekelle, Adama, and Diredawa) indicated that inadequate solid waste management has resulted in the accumulation of solid waste on open lands, in waterways and drains [4]. Like most towns in the country settlement expansion and an increase in the population are observed in the Jimma town. Despite its age-old urban history, the town, waste disposal practice is still inappropriate and inadequate from environmental and public health protection points of view. There is no proper waste management system for the town at present. Waste is simply dumped at environmentally sensitive locations, and posing pollution impacts and public health threats.

Physical, chemical and biological characteristics of municipal solid waste

The major physical characteristics measured in waste are (a) density, (b) size distribution of components, and (c) moisture content. Other characteristics that may be used in making a decision about solid waste management are: (a) color, (b) voids, (c) shape of components, (d) optical property,(e) magnetic properties, and (f) electric properties. Important chemical properties measured for solid waste are: (a) moisture (water content can change chemical and physical properties), (b) volatile matter, (c) ash, (d) fixed carbon, (e) fusing point of ash, (f) calorific value, (g) percent of carbon, hydrogen, oxygen, sulfur, and ash. Proximate analysis of waste aims to determine moisture, volatile matter, ash, and fixed carbon. Ultimate analysis of waste aims to analyze the percent of carbon, hydrogen, oxygen, sulfur, and ash. From the research conducted, the contents of carbon and nitrogen in food waste are 53 and 0.68%, respectively. These values vary somewhat from the ultimate values which are 48 and 2.6% for carbon and nitrogen, respectively [5].

MATERIAL AND METHOD

Materials

- Carbonizer for carbonizing charcoal
- Grinder for grinding
- Dryer (sunlight) for drying of charcoal briquette
- Mixer for mixing binder and carbonized charcoal
- Sieve for the screening of ground charcoal
- Manual press molding machine
- Oven for characterization of BMSW and charcoal briquette
- Oxygen bomb calorimeter for characterization of charcoal briquette
- Binder (starch) for binder preparation
- Water for binder preparation and mixing
- Biodegradable municipal solid waste as raw material

The procedure of charcoal briquette making

The schematic flow diagram is presented in Figure 1.

Collection and sorting of biodegradable municipal waste

The municipal waste will essentially include a variety of individual household waste, wood, sawdust, plastic, bottle, unsold of charcoal recovered from the points of sale and etc., Those waste were sorted to remove plastic, metal, glass bottle and textiles and any other non-degradable municipal waste. The collection of solid waste is presented in the Figure 2.

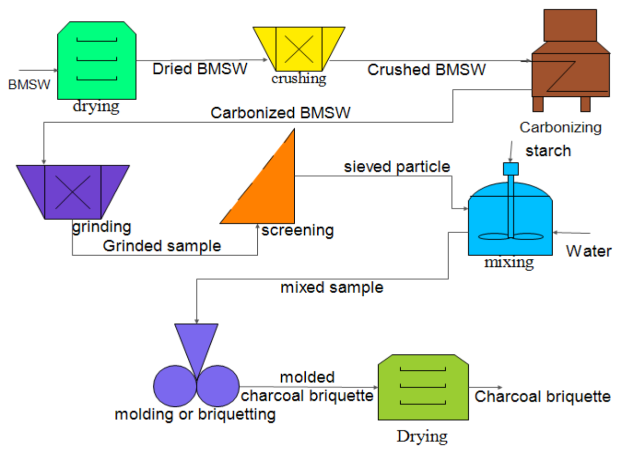

Figure 1. Flowsheet for charcoal briquette production

Figure 2. Collecting solid waste

Characterization of degradable solid waste

Proximate analysis

Proximate analysis is the analysis of wastes to determine density, % of moisture content, % of ash content, and % of volatile matter.

Density: The density of the degradable solid waste sample was determined by weighing an empty cylindrical container of known volume and then carefully filled with the BMSW sample.

$$\rho_{BMSW} = \frac{M_{BMSW}}{V_{con}} \quad (1)$$

where ρ_{BMSW} is density of BMSW (g/cm^3), M_{BMSW} is mass of BMSW (g) and V_{con} is the volume of the container (cm^3).

Percentage moisture content: It is determined by weighing a portion of a sample and oven drying it at 105℃ for three hours.

$$MC\ (\%) = \frac{B}{A} \times 100 \quad (2)$$

where MC is moisture content, A is the mass of the sample before drying, g and B is the change in weight of the sample before and after drying in the oven.

Percentage volatile matter: The composition of volatile matter of degradable solid waste was performed by allowing the sample in furnace till the same weight was obtained. Then it was being placed in a furnace at a temperature of 550℃ for 10 minutes and weighing after to obtain the difference in weight. The percentage of volatile matters were computed by using the following equation:

$$VM\ (\%) = \left(\frac{W_3 - W_2}{W_2}\right) \times 100 \quad (3)$$

where, VM (%) = percentage volatile matter of BMSW, W_2 = furnace dried sample weight of BMSW, g and W_3 = change in weight of furnace dried BMSW before and after transfer tofurnace.

Percentage ash content: A sample of the degradable solid waste was allowed in an oven till the same weight was detected. The oven-dried sample was then placed into the furnace at a temperature of 900℃ and left for about 30 minutes.

$$AC\ (\%) = \left(\frac{W_2}{W_1}\right) * 100 \quad (4)$$

where, W_1 = initial weight of the oven-dried sample (g), W_2 = weight of ash (g) and AC (%) = percentage ash content.

Percentage of fixed carbon: The fixed carbon of a fuel is the percentage content of carbon present for combustion. The percentage of content fixed carbon of briquettes was calculated according to literature [6] by subtracting the sum of PVM and PAC from 100. The same process was repeated until the completion of the samples by using the following equation.

$$PFC = 100 - (PMC + PVM + PAC) \quad (5)$$

where, PFC (%) = fixed carbon percentage, PMC = percentage of moisture content, PVM = percentage of volatile matter, and PAC = percentage of ash content.

Caloric value: The calorific value presents the energy content of the fuel. According to literature [7] it is the characteristics of biomass fuel that relays upon its chemical constitutes and percent of moisture content. The most advantageous fuel characteristics are its calorific or heat value.

$$Hc = (WT - e_1 - e_2 e_3)/m \quad (6)$$

where, Hc= Gross heat of combustion, T= Observed temperature rise, W= Energy equivalent of the calorimeter being used, e_1= Heat produced by burning the nitrogen portion of the air trapped in the bomb to form nitric acid, e_2 = Heat produced by the formation of sulfuric acid from the reaction of sulfur dioxide, water, and oxygen, e_3 = Heat produced by the heating wire and cotton thread and m= mass of the sample. But in our laboratory bomb calorie meter is not available, so we use PMC, PVC, and PAC correlation to calculate the caloric heating value by this equation [8].

$$GCV\left(\frac{MJ}{Kg}\right) = 37.777 - 0.647M - 0.387A - 0.089VM \quad (7)$$

$$R^2 = 0.97$$

where GCV=gross caloric value, M =moisture content, A=ash content, VM=volatile mater content, and R =coefficient of determination.

Drying

Sorted waste contains many ingredients like food waste, chatt leaf and stalk, and other biodegradable waste which contain a high amount of moisture; then it dry by sunlight to reduce the moisture content until it dried as shown in Figure 3.

Crushing

The sun-dried biodegradable municipal solid waste was crushed manually. The crushed biodegradable was then added to carbonizer for further processing.

Carbonization and design of carbonizer

The degradable municipal waste was carbonized by using the common drum method. Design the furnace as carbonizer that is easy and simple cylindrical design constructed to provide a means of creating very low oxygen environment, an exterior large drum or metal cylinder was constructed using a drum of about 20 cm in length and 10cm diameter or width with an

Figure 3. Sample drying

opening at the entrance for loading the feedstock and have a hole in the lower side.

First, construct the largest carbon steel cylinder with a diameter of 18 cm and a height of 20cm that have five holes or above five at the bottom and used as the cover for the entrance opening of the drum during firing. The second-largest cylinder with a diameter of 18cm and a height of 20 cm which is open at the bottom and opens at the top within the size of the third small cylinder and put in the largest one. Then the third smallest with a diameter of 10cm and a height of 12cm which is open at the bottom and has seven or above seven holes at the top and put in or place in the second-largest cylinder.

A fire port at the lower entrance of the drum and light through the wicks. At the begging of the carbonization process, the lid will be allowed open for approximately 10 minutes for the volatile gases to escape out. The lid was then tithed thereafter; properly sealed to prevent oxygen from entering. The degradable solid waste was left to carbonize for three hours and above. The Carbonizer for carbonization of sample is showin in Figure 4.

Grinding

The dried raw materials were ground to smaller particles and screened using a sieve. The sieved pulverized charcoal was weighed and prepared for grinding as shown in Figure 5.

Binder preparation

To meet the proposed target the starch was used as a binding material. The binder materials were used for strengthening the charcoal briquettes. The binder was prepared by dissolving 150g of starch in 100 ml of cold water to form a paste and after 500 ml of water was put to boil. The obtained paste was gradually allowed to mix with the boiling water and gently stirred till the smooth homogeneous starch solution was observed.

Briquetting charcoal (Compaction)

The starch bonded carbonized materials were pressed in a manual cylinder mold for the production of briquette fuel.

Figure 4. Carbonizer for carbonization of sample

Figure 5. Sieving

Design of mold machine (Manual briquetting)

Initially, we selected the size (diameter = 4.5cm) of the charcoal briquette as a constant factor, and based on this we started to design a manual press charcoal briquette machine.

In order to obtain a charcoal briquette of diameter 4.5 cm, we designed a three cylindrical shape with a similar diameter. A cover of a similar diameter was done at the lower entrance on the same line which is guided on guideways. A large cylinder of size (i,e D=30cm, and H=36cm) is designed on three small cylinders to hold them externally at the bottom and holds raw material internally. The press unit of height 87cm is designed internally in large cylindered metal which has three metal plates attached in the same direction to the circled metal plate.

Drying and packing

The molded briquettes were placed on clean aluminum trays and dry in the sun for 2 days as shown in Figure 6. The produced briquettes were collected and dried under the sunlight, and after packed in a plastic bag.

Combustion characteristics of the charcoal briquette

The properties like density, porosity index, shatter resistance, percentage volatile matter, percentage ash content, percentage fixed carbon, and gross calorific value of the degradable solid waste briquettes were investigated.

Density: According to literature [9], it is defined as the mass of packing of the molecules of the substance divided by its volume. The weights of briquettes were determined in the laboratory using a digital balance. Volumes of briquettes were determined by a simple calculation based on the direct measurement of height and diameter of the briquettes since briquettes were cylindrical in shape. The volume was evaluated using.

$$\rho_{\mathrm{br}} = \frac{\mathrm{M}_{br}}{\mathrm{V}_{\mathrm{br}}} \quad (8)$$

where, M_{br} = weight of charcoal briquettes in g, V_{br} = briquettes volume, cm^3, and ρ_{br} = density of charcoal briquette, g/cm^3.

Porosity index: The porosity of briquettes was determined based on the amount of water each sample absorbs. A pre-weighed briquette was immersed in water for 30 seconds. Then the briquettes were taken out of the water and reweighed to obtain the wet weight of briquette. The weight of water in briquette was determined by subtracting the dry weight of the briquette from the wet weight of the briquette. The porosity index was obtained by dividing the mass of water absorbed into the mass of the briquette immersed in water [10]. Similarly, another batch was introduced and the same process was repeated until the completion of the samples. Then the porosity index is calculated by using Equation (9).

Figure 6. Molded charcoal briquette

$$PI\ (\%) = \left(\frac{W_w - W_s}{W_s}\right) \times 100 \quad (9)$$

where, PI = porosity index, W_s = dry weight of the sample briquette (g) and W_w = wet weight of the sample briquette after immersed in water (g).

Shatter resistance: According to literature [11] each briquette sample was allowed for the test to drop from a height of 2m onto concrete five times. The durability (%) can be calculated as the ratio of the final mass of the briquette retained after five drops to the initial mass of the briquette. The fraction of the briquette that retained shattered was used as an index for briquette durability.

$$WL\ (\%) = \left(\frac{W_1 - W_2}{W_2}\right) \times 100 \quad (10)$$

$$SR\ (\%) = 100 - WL \quad (11)$$

where WL (%) = percentage weight loss, W_1 = mass of briquette before shattering (g), W_2 = mass of briquette after shattering (g) and SR (%) = percentage shatter resistance.

Percentage of moisture content: According to literature [12] the moisture content of the briquette can be determined by weighing a portion of a sample and oven drying it at 105℃ for three hours. The change in weight was used to detect the briquette's moisture content using an equation similar to Equation (2).

Percentage volatile matter: According to literature [11], Volatile matter refers to the part of a biomass matter that is released as volatile gases. The high volatile matter content of a biomass material indicates that during combustion; most of it was volatile and burn as gas in the cookstove. The percentage volatile matter of the briquettes was determined in accordance with; a portion of a briquette will be kept in an oven until a constant weight of the sample is obtained. The oven-dried sample was kept in the muffle furnace at a temperature of 550℃ for 10 minutes. After which the volatile matter in it was have allowed to escape, the crucible allowed to cool down in a desiccator and weighed to obtain the mass of volatile parts of the sample i.e the change in mass of the sample before and after kept to the furnace (See Equation (3)).

Ash content: All chemical breakdown of a biomass fuel produce a solid residue, which in cases can be called ash. The ash can cause problems for the thermo-chemical conversion process, and particularly for combustion because some chemical compounds in the ashcan react to form slag. The amount of ash is an important data when biomass is used as fuel in boilers because at high temperatures can melt and cause fouling of equipment. The residual ash is undesirable, so the lower level is the best fuel quality. Ash is expected to have values for commercial fuels from 0.6 to 9.8%, energy crops from 1 to 9.6%, cereals from 1.8 to 4.8%, and industrial waste from 0.4 to 22.6%. General values may appear in a range from levels below 5–20% [13, 14]. A portion of a sample was placed in an oven until it is free of moisture. The oven-dried briquette was then placed in a pre-weighed crucible. This was being transferred into the furnace at a temperature of 800℃ and left for about 30 minutes. During this time the sample was turned to white ash. Then, the crucible was be put to desiccators and then cooled. After cooling the crucible was reweighed to obtain the mass of ash. The same process was repeated until the completion of the samples. The ash content was calculated by dividing the weight of ash to that of the weight of the dry sample and will be determined using an equation similar to Equation (4).

Percentage of fixed carbon: Carbon content refers to the percentage of carbon present in a particular sample. Essentially, the fixed carbon of a fuel is the percentage of carbon available for combustion. This is not equal to the total amount of carbon in the fuel (the ultimate carbon) because there is also a significant amount that was released as hydrocarbons in the volatiles. Fixed carbon gives an indication of the proportion of char that remains after the devolatilization phase. The percentage fixed carbon of briquettes was calculated by subtracting the sum of PMC, PVM, and PAC from 100 (See Equation (5)). The same process was repeated until the completion of the samples.

Caloric value: The caloric value is measured by an oxygen bomb caloric meter. However due to non availability of equipment we use literature to calculate the gross caloric value by using PMC, PVC, and PAC that already calculated before. But in our laboratory bomb calorie meter is not available, so we use PMC, PVC, and PAC correlation to calculate the caloric heating value by an equation similar to Equation (7) [15].

RESULTS AND DISCUSSION

The characterization of the degradable solid waste and charcoal briquette production from degradable municipal waste were studied. Density, the content of moisture in percent, percentage of volatile matter, the content of ash, and content of fixed carbon and caloric heat value of biodegradable municipal solid wastes were determined. The physical and combustion properties of the charcoal briquettes examined in this work were limited to density, porosity index, shatter resistance, percentage moisture content, percentage volatile matter, percentage ash content, and fixed carbon percentage and calorific heat value.

Proximate analysis

Density

Density was determined by using Equation (1), where M = 0.8kg and V = $(\pi D^2/4)\times h$ (h = 20cm and D = 18cm, then V = 0.05086m^3); therefore, ρ_{Bmsw} =157.3kg/m^3.

This implies the biodegradable municipal solid waste has low energy density; therefore, it is difficult to store for a long time. Then it is better to increase its density by drying, carbonizing, and molding biodegradable municipal solid waste while using directly for charcoal purposes.

Moisture content

The moisture content of BMSW was determined by weighing 31.4 g of the sample and drying it in the oven at 105℃ until three hours or until the mass of a sample was constant (5.7g). It is determined using Equation (3), where B = 5.7g and A=31.4g, then: MC (%) = $\frac{5.7}{31.4} \times 100\%$=18.15%.

That means biodegradable municipal solid waste has high moisture content and it implies very difficult to prepare charcoal briquettes simply from BMSW. Therefore, further drying before carbonization is needed to lower the moisture content of this biodegradable municipal solid waste for charcoal briquette production.

Volatile matter

The content of volatile matter was computed using Equation (3), where $W_2 = 31.4$g and $W_3 = 10.38$g and finally VM (%) $= \left(\frac{31.4-10.38}{31.4}\right) \times 100$=66.95%.

And the average value of 66.95% was recorded at 550℃ for 10min. This highest value of volatile matter enhances the biodegradable municipal solid waste to be easily ignited. As compared with the volatile matter of charcoal briquettes it is too high. This is because of easily disintegration or unbounded biodegradable municipal solid waste. However, the structure of charcoal briquette is strongly bonded with binder starch.

Ash content

The content of ash was calculated as the weight of ash divided by that of the weight of the dry sample, it is determined using Equation (4). Where W_2 = 2.13g and W_1=52.3g, then AC (%) $= \left(\frac{2.13}{52.3}\right) \times 100$=4.07% was recorded at 900°C. This is lower than ash content of charcoal briquette and this variation is because of starch blinded to charcoal briquette. In the fresh biodegradable municipal solid waste particle are not bonded to each other and this allows the adequate flow of oxygen in the internal part of in internal part of this waste. However, in the charcoal briquettes, particles are bonded to each other because of starch added which makes high ash content.

Fixed carbon content

Using Equation (5) we calculated Fixed carbon content = $100 - (18.15 + 66.95 + 4.07) = 10.83\%$.

According (AYSE O and serdar Y. 2016) the average fixed carbon content of biomass is fallen in the range of 11.78%-24.16%. The total fixed carbon content obtained in our work is 10.83%. This result may not fit the literature value range because our raw material contains high moisture content materials like food waste (fruits peel and spoiled vegetables) and other wet materials.

The caloric value of biodegradable municipal solid waste

Using Equation (7) the heating caloric value of BMSW is calculated.

$GCV = 37.777 - 0.647 \times 18.15 - 0.387 \times 4.07 - 0.089 \times 66.95 = 18.5kJ/kg$

Summary of characterization of degradable solid waste is given in Table 1.

TABLE 1. Properties of degradable solid waste

Properties	Numerical value
Density	157.3kg/m^3
Moisture content	18.15%
Volatile matter	66.95%
Ash content	4.07%
Fixed carbon	10.83
Caloric value	18.5kJ/kg

Combustion characteristics of the charcoal briquette

The density of charcoal briquettes

The density of charcoal briquette was obtained by using Equation (8).

$\rho_{br} = \frac{0.155kg}{2.0665\times10^{-4}} = 750.06kg/m^3$

This value implies that the charcoal briquettes obtained from degradable solid waste in our work have a high density as the compared density of wood charcoal, density of charcoal briquette produced from cane bagasse and that produced from sawdust.

According to literature [16] the density of charcoal briquette bonded with starch give a density of 546kg/m^3. The diameter of the mold or cylinder has an effect on the density of charcoal briquettes.

Porosity index (weight, %)

Porosity is a measure of the void spaces in a material and is a fraction of the volume of voids over the total volume; it generally lies between 0-1. The porosity index is the weight of water absorbed divided by dry weight of sample briquette when immersed into water. A briquette with a higher porosity index has lower water resistance capacity. Hence, briquettes having a low porosity index are desirable to storage and water resistance.

The porosity index was calculated by using Equation (9), where W_w = 95.5g and W_s = 74g:

PI (%) $= \left(\frac{95.5-74}{74}\right) \times 100 = 29.05\%$

The above value of the porosity index obtained was existing between 0 and 1 that has low water resistance. Therefore if charcoal briquettes have a higher porosity index, it will absorb more water and will be disintegrated easily.

Shatter resistance (weight, %)

The Shatter resistance was calculated by using Equation (10) and (11), where W_1 = 45.9g and W_2 = 42.4 g:

WL (%) $= \left(\frac{45.9-42.4}{42.4}\right) \times 100 = 7.623\%$

Therefore SR (%) $= 100 - 7.623 = 92.377\%$

The above values of shatter resistance obtained show high shatter resistance. That means the reaction force of denser charcoal briquettes has higher shatter resistance than that of less dense charcoal briquettes when they are allowed to fall from 2m height from top to the ground. This leads to denser charcoal briquettes are more chance to lose part of it. Higher shatter resistance implies a lower weight loss and resistance to handling stress. Therefore charcoal briquette produced in our work has good durability.

Moisture content

The moisture content of charcoal briquette was obtained by using an equation similar to Equation (2).

MC (%) $= \frac{B}{A} \times 100$ where B = 5.4g and A = 54.7g

MC (%) $= \frac{5.4g}{54.7g} \times 100 = 9.87\%$

The above value of content moisture obtained in our work was fall in the percentage of 5-10% according to literature [7].

Volatile matter

The volatile matter of charcoal briquettes is calculated by using Equation (3) as follows.

W_2 = 93.24 g and W_3=65.82

$$VM\ (\%) = \frac{93.24-65.82}{93.24} \times 100 = 29.4\%$$

The above values of volatile matter obtained in our works are in the range of 20-30% according to literature [7] a charcoal briquette with low volatile content tends to incomplete combustion which leads to an insignificant amount of smoke and release of toxic gas.

Content ash

The ash content was obtained by using an equation similar to Equation (4). Where for sample 1 W_2 = 3.15 and W_1 = 98.23, Then:

$$AC = \left(\frac{3.15}{98.23}\right) \times 100 = 3.21\%$$

The above value of ash contents of charcoal briquettes obtained in our work is in the range of as compared to or as recommended in literatures [13, 17] ash content for good quality charcoal briquettes are fall in the range of 3-4%.

As the ash is an impurity that will not burn, fuels with low ash content are better suited for thermal utilization than fuels with high ash content. According to literature [18] higher ash content in fuel usually leads to higher dust emission.

Fixed carbon percentage

The value of fixed carbon for charcoal briquettes was obtained using Equation (5):

$$PFC = 100 - (9.87 + 29.4 + 3.21) = 57.52\%$$

This value of fixed carbon content is very low as compared with literature [16] that is from 70-75%. A lower fixed carbon, a better result during combustion, and a lesser probability of CO_2 generation. Charcoal Briquettes having high volatile matter have lower fixed carbon, which low fixed carbon tends to be harder, heavier, stronger, and easier to ignite than briquettes containing high fixed carbon [18, 19].

Caloric value

By using Equation (7) we calculated the value of charcoal briquette: GCV (MJ/kg) = 27.05MJ/Kg.

The above caloric value of charcoal briquette produced from biodegradable municipal waste is higher than that of the caloric value of wood charcoal 8.27 MJ/kg and higher than charcoal briquette produced from bagasse which has a caloric value of 23.4 MJ/kg according to literature [7]. The higher calorific value of caloric value reflects the high quality of charcoal briquettes. Summary of characterization of charcoal briquettes obtained from two experiments are given in the following Table 2.

TABLE 2. summary of property for charcoal briquette

Properties	Value obtained
Density	750.06 kg/m^3
Porosity index weight	29.05%
Shatter resistance	92.377%
Moisture content	9.87%
Volatile matter	29.4%
Ash content	3.21%
Fixed carbon percentage	57.52%
Caloric value	27.53 MJ/kg

Factors affecting the charcoal briquette

The factor that affects charcoal briquette includes particle size, the diameter of the mold, binder, or starch content. The binder or starches content affects the quality of charcoal briquettes by their amount. In our work, we used 25% of starch content to produce charcoal briquette. According to literature [13] the charcoal briquettes that good quality was obtained at starch content from 25-30%. Below that content of starch the charcoal briquette shatters easily like during transportation.

The particle size of our raw material is 4 mm. By this particle size, we get the charcoal briquette with the moisture content of 9.87%, a density of 750.06 kg/m^3, a volatile matter of 29.4%, an ash content of 3.21%, fixed carbon percentage of 57.52% and caloric value of 27.5 MJ/kg. Therefore according to literature [13] the charcoal briquettes those good qualities were obtained at a particle size of less than 4 mm. The two different diameters of the cylinder may show variation property of charcoal briquette. This shows the relationship between the property of charcoal and the diameter of the mold. A small diameter of mold cylinder low porosity index weight or less number of pores was obtained and has low shatter resistance. But at a large diameter of the mold or cylinder has high porosity index weight and high shatter resistance. The good charcoal is obtained for starch and sawdust used as a binder.

Strength and weakness of the product

Strength

The charcoal briquette obtained from solid waste has better heating value as compared to charcoal from wood and charcoal briquette produced from molasses. Some of the characterization properties of charcoal briquette tested in this work was fall in the range. Therefore, it is recommended to convert solid wastes into charcoal briquette rather than polluting the environment.

Weakness

Due to the present atmospheric condition of Jimma city the product was loose some quality as compared with standard value since it requires sufficient sun to dry charcoal briquette**.** Fixed carbon content affected by the carbonization process performed in our work that was made manually is allowing the little amount of oxygen since the carbonizer has a hole at the bottom and at the top.

CONCLUSIONS

This work shows the characteristics of degradable solid waste and the produced charcoal briquette for its proximate analysis. The test result for density, % of moisture, % of volatile matter, % of ash, % of fixed carbon and caloric value of degradable municipal solid waste was determined as 157.3 kg/m^3, 18.15%, 66.95%, 4.07%, 10.83% and 18.5MJ/kg, respectively. In the same way the test result of charcoal briquette for its density, porosity weight index, shatter resistance ,moisturecontent,volatile matter, ash content, fixed carbon content and caloric values were obtained as 50.06kg/m^3, 29.05%, 92.3%, 9.87%, 29.4%, 3.21%, 57.52% and 27.0MJ/kg, respectively. These test results are in the range comparing with other works of literature. Therefore there is the possibility to convert Jimma City degradable solid waste into charcoal briquette using starch as a binder. As illustrated from the above the charcoal briquette produced had high density, moisture content that is typical, has high volatile content, has typical ash content, and low content for fixed carbon as relative to other charcoal briquette obtained from the different feedstock. The application of charcoal briquette for alternative energy sources is to be encouraged to reduce deforestation. Besides using solid waste as wood charcoal can reduce waste accumulation to the environment. This work is aimed to help in the controlling of the solid waste and could be used as a tool for handling a decision towards waste generated daily in various activities of people in Jimma city.

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Persian Abstract

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چکیده

این مطالعه به منظور بررسی تولید زغال بریکت زغال که می‌تواند نیاز انرژی در جامعه شهر جیما را برآورده کند، انجام شد. هدف اصلی این کار تولید زغال بریکت از زباله‌های جامد شهری است. بر اساس این اهداف، فعالیت‌های اصلی انجام شده عبارتند از طبقه‌بندی زباله، توصیف ضایعات که به راحتی قابل تجزیه هستند، طراحی تجهیزات کربنایزر، دستگاه قالب‌گیری مطبوعاتی دستی، و توصیف قالب‌های زغال سنگ. زباله‌های قابل تجزیه شهری از شهر جیما جمع‌آوری شد. فرایند تولید زغال بریکت شامل: جمع‌آوری زباله‌های قابل تجزیه شهری، خشک کردن، کربن‌زدایی، خرد کردن و غربال کردن، تهیه چسب، مخلوط کردن چسب - زغال، تولید زغال بریکت قالبی (متراکم و خشک کردن)، و بسته‌بندی است. آزمایشاتی برای تعیین خواص پسماندهای جامد قابل تجزیه شهری، از جمله: چگالی، درصد رطوبت، درصد ماده فرار، درصد خاکستر، درصد کربن ثابت و مقدار کالری انجام شد که نتایج آن به ترتیب ۱۵۷/۳ کیلوگرم بر متر مکعب، ۱۸/۱۵ درصد ، ۶۶/۹۵ درصد، ۴/۰۷ درصد، ۱۰/۸۳ درصد و ۱۸/۵ MJ/kg به دست آمد. از طریق روشی مشابه نتیجه آزمایش زغال بریکت از نظر چگالی، شاخص وزن تخلخل، مقاومت در برابر خرد شدن، رطوبت، ماده فرار، محتوای خاکستر، میزان کربن ثابت و مقدار کالری به ترتیب ۵۰/۰۶ کیلوگرم بر متر مکعب، ۲۹/۰۵ درصد، ۹۲/۳ درصد، ۹/۸۷ درصد، ۲۹/۴ درصد، ۳/۲۱ درصد، ۵۷/۵۲ درصد و ۲۷/۰ MJ/kg به دست آمد. این نتایج در مقایسه با سایر نتایج گزارش شده در مقالات، در محدوده قابل قبولی قرار دارد. بنابراین، امکان تبدیل ضایعات جامد قابل تجزیه شهر جیما به زغال بریکت، با استفاده از چسب به عنوان اتصال‌دهنده، وجود دارد. در نتیجه می‌توان به جای آلاینده کردن محیط، کیفیت زغال بریکت را افزایش داد.