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# Briquette production from sugar cane bagasse and its potential as clean source of energy

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**Large quantities of bagasse are regularly accumulated on open spaces around sugar factory thereby endangering fragile ecosystem. The sugar cane bagasse carbonization process can be put into effect as an environmentally friendly, energy self-providing continuous flow technology. Therefore, the objective of this study was to use bagasse for the production of high caloric value briquette to safeguard the environment from pollution. Bagasse sample was collected from Wonje sugar factory and carbonized in an oxygen deficient environment at Ethiopian Rural Energy Development and Dissemination Center Laboratory, Addis Ababa. The carbonized materials were mixed with clay and molasses as a binder in different ratio to make a briquette using briquette extruder machine. Caloric value of the briquettes produced from bagasse using clay and molasses as a binder in different ratio ranged between 3,529-4,064 and 3,964-4,442 cal/g, respectively. The highest caloric value using clay as a binder was in the ratio 20:80 and the lowest caloric value using molasses as a binder was in the ration 25:75. Further analysis showed that through conversion of bagasse from Wonji sugar factory into briquette, annually the factory could generate $3.1\times10^{-10}$ cal of energy and substitutes 13.01 $m^3$ of firewood or save 0.13 to 0.16 ha of tropical forests from deforestation and have the potential to sequestrate 17.90 to 22.03 tons of carbon annually. Further, the study concluded that briquettes produced from bagasse could be used as a quality source of energy and bagasse waste management option around sugar industry.**

**Key words:** Energy, briquette, carbon sequestration, caloric value.

## INTRODUCTION

Sugar development sector is one of enormous projects which enables industry take a leading role in the nation's economy. Ethiopia has huge human as well as natural resources which enable the nation to broaden this export oriented manufacturing industry sector and its productivity. The nation has suitable climate, wide and proved irrigable agricultural land (more than 500 thousand hectares) as well as abundant resource of water to use through canal

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schemes. The government in its effort to ensure equitable share of the nation's resource among its peoples, has started broadening the sugar development sector.

The industrial strategic development plan of Ethiopia gives great emphasis to improve export-led products to join the international market in large-scale such as sugar factory. Sugar sector plays a unlimited role in the socio-economy of Ethiopia since it produces sugar for household and industrial consumptions, provides great job opportunity for the nationals, serves as source of energy and co-products are used for miscellaneous purposes. However, the liquid, gaseous and solid effluents produced from sugar industry have adverse impact on ecosystem and environment due to their high BOD load and toxicity. Bagasse is a main byproduct of sugar industry which finds a useful utilization in the same industry as an energy source. Sugarcane consists of 25 to 30% bagasse whereas sugar recovered by the industry is about 10% (Maung et al., 2015). Bagasse has high calorific value and hence it is usually used as a fuel in boilers in the sugar mills to generate steam and electricity. Each ton of sugarcane generates approximately 26% of bagasse (at a moisture content of 50%) and 0.62% of residual ash (Maung et al., 2015). However, currently, not all bagasse produced is used in the factories for the generation of heat and power. It is difficult to handle, transport and where storage facilities are lacking, and hence the surplus is dumped in compounds around the factory posing serious environmental problems, including fire hazards.

Huge amount of bagasse are produced annually by the sugar factories in Ethiopia constituting about 4.6% of the total bagasse production (Thinda et al., 2012). Disposal of bagasse has become a serious problem and large quantities of bagasse are regularly accumulated on open spaces around sugar factory thereby endangering fragile ecosystem. To reduce pollution hazards, industry should implement environment management system to advance economic and environmental performance of sugar processing unit.

In the search for new alternative sources of ecologically friendly energy, the utilization of Bagasse for the production of briquettes has become a good alternative. A briquette is biochar in a particular shape, made by using pressing techniques and adhesives (Fikri and Sartika, 2018). Bagasse carbonization process is environmentally friendly, energy self-providing continuous flow technology. Thus, the objective of the research was to use bagasse for the production of energy (high caloric value briquette) and ultimately safeguard the environment from pollution.

## MATERIALS AND METHODS

Wonji-Shoa Sugar Factory is found in Oromiya Regional State at 108 km South of Addis Ababa near Adama city in Woniji town which was established by a Dutch holding HVA Company, 1954 (Figure 1).

In this study, apparatus such as carbonization machine, bagasse, plastic bags, oven, analytical balance, bomb calorimeter, briquetting extruder machine, mixer, cook stoves, molasses, and clay were used to produce briquette.

### Sample collection and preparation

Bagasse sample was collected from Wonje Sugar Factory by using different plastic bags and transported to Ethiopia Biotechnology Institute laboratory before characterization of the sample.

Then, the collected samples of bagasse were chopped into suitable size, and then dried in oven dryer at a temperature of 500°C for 24 h. All physical and chemical analyses of the sample were done at Ethiopian Rural Energy Development and Dissemination Center Laboratory. Figure 2.

### Procedure of briquette production

The bagasse sample was allowed to dry in oven for 24 h before carbonization to remove the moisture and facilitate the carbonization process. The bagasse sample was carbonized separately in an oxygen scarce environment using metal barrel-kiln carbonization machine. The process of carbonization was carried out in oxygen limited condition in barrel kiln with long chimney; which was used to control the proper air for carbonization process. Then, the carbonized material was removed immediately from the metal barrel-kiln carbonization machine and cooled using water. The cooled charcoal was dried in a naturally ventilated room at temperature of 25 to 30°C for two days. After being cooled and dried, the carbonized bagasse was ground using a milling machine (hammer mill) and sieved with a mesh size of 3 mm to obtain particles in the size range from 1 to 3 mm Figure 3.

The prepared carbonized materials/charcoal powder was mixed with a binder to produce a briquette. Clay and molasses were used as a binder in different ratio for making briquette during the experiment. Based on the experiment design the binder was manually mixed in different concentration with the prepared carbonized materials/charcoal. Then the mixture was converted into briquettes by using a briquette extruder machine. Finally, the briquettes were placed on a suitable material for drying under the sun.

### Proximate analysis of produced briquettes

All proximate analysis of the produced briquette was carried out in the Ethiopian Rural Energy Development and Dissemination Center Laboratory, Ethiopia, Addis Ababa.

#### *Moisture content*

The percentage of moisture content of the raw biomass (PMC) was determined using standard method of American Society for Testing Materials (ASTM D 4442-07) on the basis of dry biomass which was found by weighing samples of obtained briquette (W1) and oven drying it at 105°C and intermediate weight of sample was recorded in every 60 min until the constant weight was obtained (W2). Then, the difference in weight (W1 - W2) was calculated to determine the sample's percentage moisture content using the following equation:

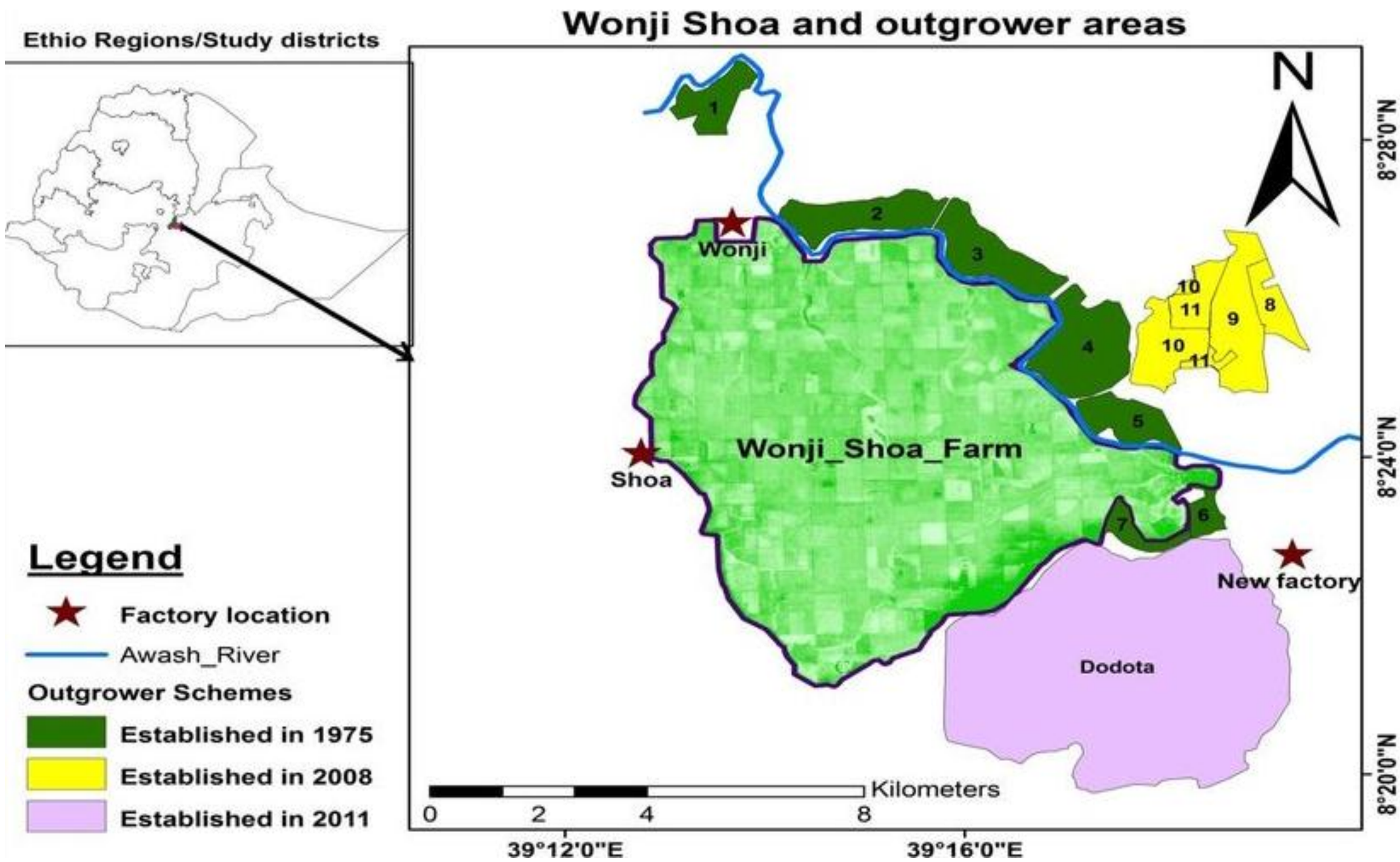


**Figure 1.** Map of Wonje sugar factory area.

$$PMC = (W1 - W2/ W1) \times 100 \quad (1)$$

where W1 = Initial weight of sample before drying, W2 = Final weight of sample after drying and PMC = percentage moisture content.

### *Volatile matter*

The percentage of volatile matter (PVM) content was determined using the standard method CEN/TS 15148. Two grams of sample was pulverized and oven dried at 105°C until its weight was constant. Then, the sample was heated at 550°C for 10 min and weighed after cooling in desiccators. The PVM was calculated using the following equation:

$$PVM = (W1 - W2/ W1) \times 100 \quad (2)$$

where PVM = Percentage of Volatile Matter, W1 = Initial weight of sample, and W2 = Final weight of the sample after cooling.

### *Ash content*

The percentage of ash content (PAC) was determined using CEN/TS14775 standard method. The percentage of ash content (PAC) was also determined by heating 2 g of the pulverized sample in the furnace at a temperature of 550°C for 4 h and weighed after cooling in a desiccator to obtain the weight of ash. The PAC was determined using the following equation:

$$PAC = (W2/ W1) \times 100 \quad (3)$$

where W1 = Initial weight of dry sample, W2 = Final weight of ash obtained after cooling sample and PAC = percentage of ash content.

### Fixed carbon

The percentage of fixed carbon (PFC) was calculated by subtracting the sum of percentage volatile matter (PVM) and percentage ash content (PAC) and percentage moisture content from 100% as shown in the following equation:

$$\text{Fixed Carbon} = 100\% - (PAC + PMC + PVM) \quad (4)$$

### *Gross calorific value*

To determine the gross calorific value of produced briquette, Bomb Calorimeter at Ethiopian Rural Energy Development and Dissemination Center Laboratory was used. The briquette specimens were analyzed by an adiabatic oxygen bomb Calorimeter Parr 6200 calorimeter of Parr M39889 and Parr M39805 oxygen bomb, which were used as per instruction manual according to ASTM D-5865-95.

**Figure 2.** Bagasse sample preparation.

**Figure 3.** Metal barrel-kiln carbonization machine.

**Table 1.** Caloric value of the raw samples (boiler bottom ash, boiler fly ash and raw bagasse).

| Raw material | Trial one (cal/g) | Trial two (cal/g) | Trial three (cal/g) |
|---|---|---|---|
| Boiler bottom ash | ± 676.5 | ± 651.64 | ± 663.6 |
| Boiler fly ash | ± 800 | ± 750 | ± 775.8 |
| Raw bagasse | ± 3561.2 | ± 3813.83 | ± 3746.59 |

***Emission test, burning time and combustion efficiency***

The emission of the produced briquette was analyzed using dust detector (TISCH Air Environment) equipment) and CO analyzers (Gas Alert Micro 5).

**Data collection and analysis**

Data were collected before carbonization process to determine the caloric value of the sample and on carbonization process and the laboratory analysis of briquettes. The results were recorded, processed and analyzed using Microsoft excels. Descriptive statistics and chart graph were used to compare means and standard deviation (SD) of the result of analysis. All the analysis assays were done in triplicate (n=3).

## RESULTS AND DISCUSSION

### Physical and chemical analysis

#### *Caloric value of raw material*

The study analyzes the caloric value of boiler bottom ash, boiler fly ash and raw bagasse to be used for the production of briquettes; hence characterization raw material of briquette for their proximate and physical properties is very important (Oladeji, 2010). The result of the caloric value of the raw samples (Boiler Bottom Ash, Boiler fly ash and raw bagasse) is shown in Table 1.

The calorific value defines the total heat energy which occurs in a material. From the table, raw bagasse has the highest calorific value of 3,813.83 cal/g, which may be due to the high carbon content of bagasse. Boiler bottom ash and boiler fly ash had the lower caloric value of 651 and 750 cal/g, respectively and which is very less with the calorific values of cotton stalk 1,670.9 cal/g, bamboo leaves 1,572.5 cal/g and prosopis 1,773.9.47 cal/g (Bharat, 2012). This may be due to the fact that it has low carbon content because it was burned to start the boiler for the electrification purpose. Due to high content of caloric value, raw bagasse was selected for the production of briquette.

#### *Conversion efficiency and caloric value of carbonized bagasse*

The conversion efficiency of the bagasse into carbonized material is 38.36% (from 100 kg of raw bagasse net average carbonized bagasse amounted to 38.36 kg) which was relatively good when compared with Weldemedhin et al. (2014), 31.02±0.84% for that of coffee pulp and 32.61±1.60% for coffee husk. Annually, Wonje Sugar Factory generates 15,000 tons (15, 000,000 kg) of excess bagasse (Personal communication with the Wonji Sugar Factory officials and calculated result from compiled annual report of the factory). Based on this fact, if the factory carbonized all the excess bagasse, annually the factory produced 5,754 tons (5,754,000 kg) of carbonized bagasse.

Calorific value is the most significant combustion property for determining the suitability of briquette as fuel. Calorific value gives an indication on the quantity required to generate a specific amount of energy. The average caloric value of the carbonized bagasse was 5,535.5 cal/g, which is high value to produce energy or briquette. As a result, if 5,754 tons (5,754,000 kg) of carbonized bagasse without any binder, the factory could possibly produce 31,851,276,000 calorific value of total energy annually. Therefore, Wonje Sugar Factory could generate $3.1 \times 10^{-10}$ cal of energy annually from excess carbonized bagasse.

One kilogram of fuel wood gives 13.8 MJ of energy, which is equal to 3,296.82 cal/g of energy and 1 $m^3$ of fuel wood equals to 750 kg (FAO, 2020). Therefore, through production of briquettes, the factory could possibly substitute energy obtained from 13.01 $m^3$ of firewood. Tropical high forest could give 80 to 100 $m^3$ of firewood per hectare (FAO, 2020). Based on this conversion, Wonje Sugar Factory could save 0.13 to 0.16 ha of tropical forest from deforestation annually. Correspondingly, the aboveground carbon sequestration of tropical rain forest is 137.73 tons of carbon per hectare (Terakunpisut et al., 2007). Accordingly, the factory could save forests which have the potential to sequestrate 17.90 to 22.03 tons of carbon annually.

### Production of briquette

The quality of briquettes is dependent on the raw materials and the briquetting process. The desired qualities for briquettes as fuel include good combustion, stability and durability in storage and in handling (including transportation), and safety to the environment

**Figure 4.** Produced briquettes.

when combusted (ElHaggar, 2007). In this study, the carbonized bagasse briquettes were produced using clay and molasses as a binding to compare the caloric value of each briquette in different ratio Figure 4.

All briquettes made from this study except a mixture of carbonized bagasse with 30% of clay as a binder, all have a greater calorific value of briquettes produced from elephant grass which was 3817.6 cal/g (Onuegbu et al., 2012). The Caloric Value of Carbonize Bagasse using clay as a binder with different ration is as shown in Figure 5.

The highest caloric value was in the ratio 20: 80 (20% of the sample was clay and the rest 80% was carbonized bagasse). The lowest value was in the ration 30:70 which is 3,529 cal/g. The caloric value of briquettes produced in the ratio 22:78 and 25:75 is 3920 and 3865 cal/g, respectively. The result shows that when the amount of clay increases the caloric value will decrease; this is due to the nature of binding material clay.

The average of the calorific mean values of the briquettes produced from carbonized bagasse in the ratio of 20: 80 (20% of the sample was clay and the rest 80% was carbonized bagasse) is 4.064 cal/g. If, 5,754 tons (5,754,000 kg) of carbonized bagasse was mixed with the specified proportion of the binder Wonji Sugar Factory could possibly produce 6,904.8 tons (6,904,800 kg) of briquettes annually, which would have a calorific value of 28,061,107,200 as total energy. Therefore, Wonje Sugar Factory could generate $2.8 \times 10^{-10}$ cal of energy annually from excess carbonized bagasse in the ratio of 20:80 (20 percent of the sample was clay and the rest 80% was carbonized bagasse).

One kilogram of fuel wood gives 13.8 MJ of energy, which is equal to 3,296.82 cal/g of energy and 1 $m^3$ of fuel wood equals to 750 kg (FAO, 2020). Therefore, through production of briquettes, the factory could possibly substitute energy obtained from 11.34 $m^3$ of firewood from excess carbonized bagasse in the ratio of 20: 80 (20% of the sample was clay and the rest 80% was carbonized bagasse). Tropical high forest could give

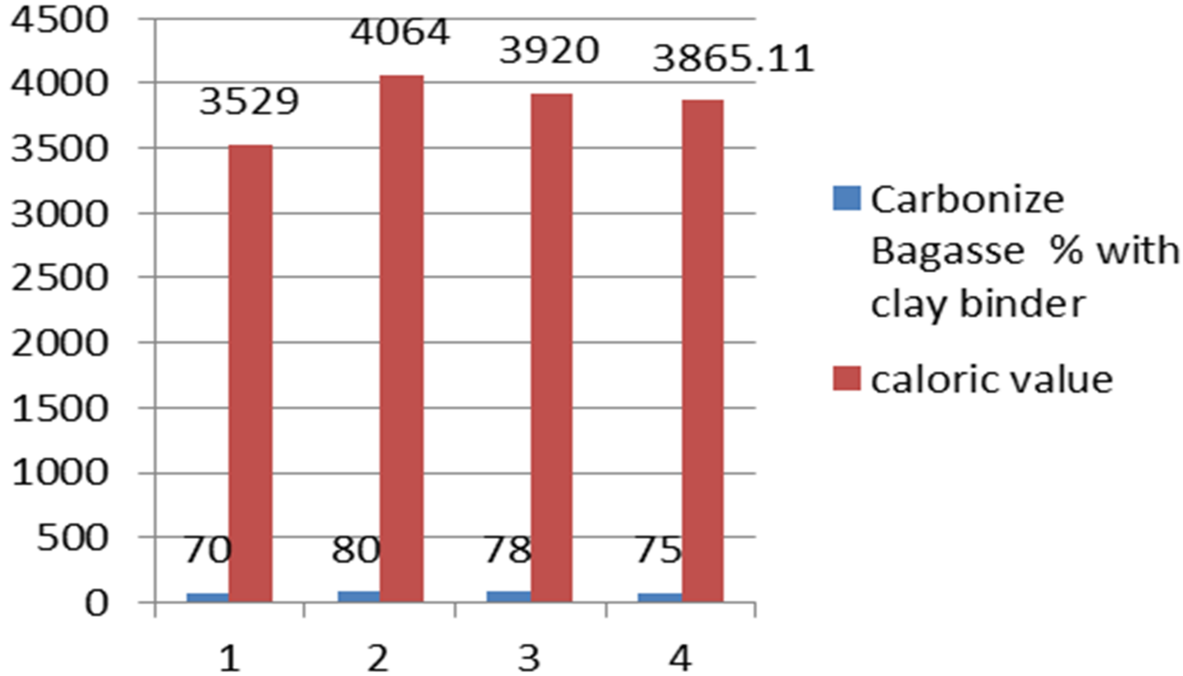


**Figure 5.** Caloric value of carbonize bagasse briquette using clay as a binder.

80 to 100 $m^3$ of firewood per hectare (FAO, 2020). Based on this conversion, Wonje Sugar Factory could save 0.12 to 0.14 ha of tropical forest from deforestation annually from excess carbonized bagasse in the ratio of 20:80 (20% of the sample was clay and the rest 80% was carbonized bagasse) . Correspondingly, the aboveground carbon sequestration of tropical rain forest is 137.73 tons of carbon per hectare (Terakunpisut et al., 2007). Accordingly, the factory could save forests which have the potential to sequestrate 16.52 to 19.28 tons of carbon annually. The Caloric Value of Carbonize Bagasse using molasses as a Binder with different ration is as shown in Figure 6.

The Caloric Value of Carbonize Bagasse using molasses as a binder with different ration analysis in graph 2 shows that when the amount of molasses as binder increases from 10 to 25% the calorific value decreases from 4442 to 3964 Cal/g.

Maximum caloric value was recorded in the ratio 10: 90 (10% of the sample was mollasse and the rest 90% was carbonized bagasse). The lowest value was in the ration 25:75 which is 3,964 cal/g. The caloric value of briquettes produced in the ratio 14: 86 and 18:82 was 4,080 and 4,004 cal/g, respectively. The result shows that when the amount of molasses increases the caloric value decreases.

The average of the calorific mean values of the briquettes produced from carbonized bagasse in the ratio of 10:90 (10% of the sample was mollasse and the rest 90% was carbonized bagasse) is 4.442 cal/g. If, 5,754 tons (5,754,000 kg) of carbonized bagasse was mixed with the specified proportion of the binder, Wonji Sugar Factory could possibly produce 6,329.4 tons (6,329,400 kg) of briquettes annually, which would have a calorific value of 28,115,194,800 as total energy. Therefore, Wonje Sugar Factory could generate 2.8 × $10^{-10}$ Cal of energy annually from excess carbonized bagasse in the ratio of 10: 90 (10% of the sample was mollasse and the rest 90% was carbonized bagasse).

One kilogram of fuel wood gives 13.8 MJ of energy, which is equal to 3,296.82 cal/g of energy and 1 $m^3$ of fuel wood equals to 750 kg (FAO, 2020). Therefore, through production of briquettes, the factory could possibly substitute energy obtained from 11.37 $m^3$ of firewood from excess carbonized bagasse in the ratio of 10:90 (10% of the sample was mollasse and the rest 90% was carbonized bagasse). Tropical high forest could give 80 to 100 $m^3$ of firewood per hectare (FAO, 2020). Based on this conversion, Wonje Sugar Factory could save 0.11 to 0.15 ha of tropical forest from deforestation annually from excess carbonized bagasse in the ratio of 10: 0 (10% of the sample was mollasse and the rest 90% was carbonized bagasse). Correspondingly, the aboveground carbon sequestration of tropical rain forest is 137.73 tons of carbon per hectare (Terakunpisut et al., 2007). Accordingly, the factory could save forests which have the potential to sequestrate 15.6 to 20.65 tons of carbon annually.

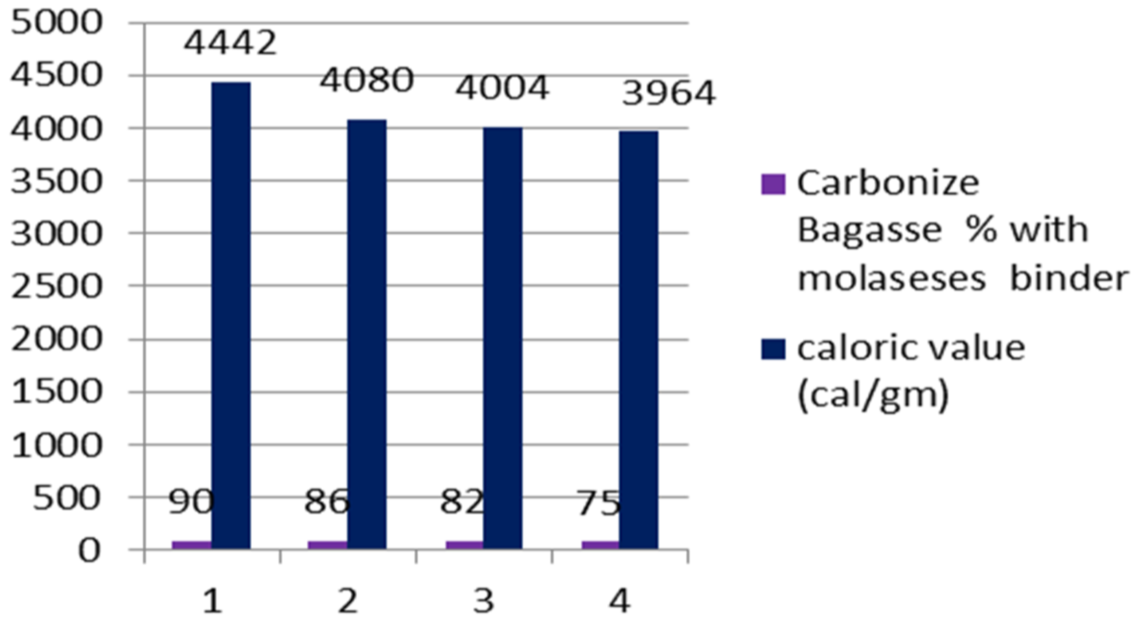


**Figure 6.** Caloric value of carbonize bagasse briquette using molasses as a binder.

**Table 2.** Proximate value of produced briquette using clay as a binder at 20:80 ratio and molasses as a binder at 10:90 ratio.

| Sample type | Moisture content (%) | Volatile matter (%) | Ash content (%) | Fixed carbon (%) | Gross heat (caloric value, cal/g) |
|---|---|---|---|---|---|
| Bagasse briquette (clay as a binder 20:80) | 6 | 27 | 4 | 40 | 4064 |
| Bagasse briquette (molasses as a binder 10:90) | 5 | 25 | 3 | 42 | 4080 |

***Proximate value of the optimal briquette produced***

Table 2 shows the proximate analysis of the produced briquette using clay as a binder at 20:80 ratio and molasses as a binder at 10:90 ratio.

The moisture content of bagasse briquette clay as a binder in the ratio 20:80 and bagasse briquette molasses as a binder in the ratio 10:90 is 6 and 5%, respectively, which were less than the rice husk and corncob briquette 12.67 and 13.47%, respectively (Oladeji, 2010). High moisture levels cause lower thermal efficiency and burning rate so that it is preferred that the bio-briquette has a lower moisture level (Onukak et al., 2017).

The high volatile matter would make the fuel smoky with a lot of pollutants during combustion. The higher volatile matter can be reduced significantly by carbonization (Ibeto, 2016). The volatile matter of bagasse briquette (Clay as a binder 20:80) and bagasse briquette (molasses as a binder 10:90) obtained from this study is 27 and 25%, respectively and less than the briquettes produced from rice husk which was 67.98 (Oladeji, 2010).

Ash is the non-combustible inorganic residue remains after complete combustion. The main component present in ash is a non-combustible mineral known as silica, which is left behind after the combustion process has ended (Glushankova et al., 2018). Presence of ash decreases the heating value (Onukak et al., 2017) so that the quality briquettes have low ash contents (Carnaje et al., 2018). The tolerance level for the ash content in a fuel is below 4% (Oyelaran et al., 2017). The ash content of bagasse briquette (Clay as a binder 20:80) and bagasse briquette (molasses as a binder 10:90) obtained from this study is 4 and 3%, respectively.

Briquette produced from bagasse clay as a binder in the ratio 20:80 and molasses as a binder in the ratio 10:90 were greater than the fixed carbon content of the charcoal briquette produced from sawdust briquette which was a fixed carbon content of 20.7% (Akowuah et al., 2012). Fixed carbon is the major quality measuring parameter that determines the energy behaviors in the production of densified biomass briquettes. The fixed carbon of bagasse briquette clay as a binder in the ratio 20:80 and bagasse briquette molasses as a binder 10:90

**Table 3.** Combustion test and smoldering characteristics.

| Type of briquette | Measured smoldering characteristics | | | |
|---|---|---|---|---|
| | **Weight of briquette (g)** | **Time taken to light the charcoal (min)** | **Burning rate (g/min)** | **Duration end of burning (min)** |
| CBC (70:30) | 150 | 6 | 0.32 | 175 |
| CBM (90:10) | 170 | 4 | 0.61 | 168 |

Ratio obtained from this study is 40 and 42%, respectively.

Calorific value or heating value regulates the energy content of a fuel. It is also the property of biomass fuel that can be influenced by its moisture content and chemical composition. In addition to this, it is the most important fuel property (Aina et al., 2009). The gross heat (caloric value) of briquette produced from bagasse clay as a binder in 20:80 ratio is less than the briquette produced from molasses as a binder 10:90 ratio this might be because of the binding material property. A high calorific value will make combustion more efficient thereby reducing the amount of bio-briquettes used (Shekhar, 2011).

### *Combustion test*

The combustion test of charcoal briquettes with different binder mix ratio was comparatively tested. It was measured against commercial. The test was conducted using the medium size. During the test the following parameters was evaluated: ease of lightning, smoldering characteristics of briquette, smokiness and odor, spark generation. Table 3 shows the combustion test and smoldering characteristics of briquette produced from bagasse clay as a binder in the ratio 20:80 and molasses as a binder in the ratio 10:90.

The result for combustion test, flame and heat efficiency test of the produced briquette from bagasse clay as a binder 20:80 ratio and briquette produced from molasses as a binder 10:90 ratio confirmed that there was no smoke except at a startup. No spark formation, no soot production, no smell or odor.

Once the briquette fired it and is not possible to quit the fire for any moment since its used long period of time for cooking about 3 to 4 h and these proper cooking times must be known to manage the proper energy consumption. Durability is one of the advantage of briquette from other fuel charcoal; furthermore predicting the practical cooking time is the important aspect in energy efficient way utilization and for a better way utilization and efficient application or usage of the produced. The duration of the produced briquette from bagasse clay as a binder 20:80 ratio and briquette produced from molasses as a binder 10:90 ratio is 115 and 112 min, respectively, it can be used for cooking, which took too long a time for cooking, especially in Ethiopian traditional food like shero and others.

## Conclusion

The findings showed that bagasse was a good source to produce briquette and have high potential as a source of environmentally friendly energy, which reduces pollution around sugar factory and can be used as a good environment management system (EMS) to the sugar industry. Utilization of bagasse for the production of briquette to produce clean energy can reduce indoor air pollution and respirator infectious disease that occurred due to the release of smoke during cooking. Using bagasse for the production of briquette can also save forests from deforestation and can be used as a climate change mitigation option. Moreover, producing briquette from bagasse can generate additional income and create job opportunity for the local community and micro enterprise.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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