Quality Analyses of Biomass Briquettes Produced using a Jack-Driven Briquetting Machine

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Abstract

The study relates to a compact briquetting machine developed in the Philippines that can compress and produce cylindrical briquettes having a hole at the center using biomass and urban wastes with the aid of a hydraulic jack and is semi-automatically returned to start position using a pulling device. The machine can compact 16 cylindrical briquettes in one pressing or about 200 to 240 pcs/hr. The quality of the three types of briquettes produced using waste paper, sawdust and carbonized rice husk, slightly varied. Parameters analyzed like bulk density, heating value, moisture, N and S closely met or has met the requirements of DIN 51731.

Key Words: biomass, briquette production, briquettes, briquetting machine, briquette analysis, alternative fuel

1. *Introduction*

The Philippines being an agricultural country generates a lot of biomass waste with promising potentials when properly utilized as renewable source of energy for cooking. These abandoned biomass waste resources include, among others, rice husk, rice straw, sugarcane bagasse, coconut wastes, forestry residues and urban waste (Baconguis,2007). According to the United Nations, when these agricultural biomass wastes are converted to energy, they can substantially replace fossil fuel, reduce emissions of greenhouse gases (GHG) while closing the carbon cycle loop and provide renewable energy to people in developing countries such as the Philippines. As raw materials, biomass wastes are considered attractive potentials for large-scale industries and community-level enterprises. At small scale level, biomass is recognized as a source of renewable energy with capabilities of meeting both heat and electricity demand most effectively in the form of combined heat and power, contributing towards international commitments to minimize environmental damage (Laryea-Goldsmith et al, 2011).

The process of briquetting involves the compression of materials into a solid fuel product of any convenient shape that can be utilized as fuel just like the use of wood or charcoal. This conversion of combustible materials found in the waste stream was considered to be a better way of turning waste into wealth (Adegoke, 2002). Briquetting is one of several compaction technologies in the general category of densification in which the material is compressed to form a product of higher bulk density, lower moisture content, and of uniform size, shape, and material properties. There are two ways by which compaction can be accomplished; either with or without the use of a binder. One must have something to make the materials stick together during compression like the use of paper, which has excellent adhesive properties; otherwise, it will just crumble into pieces (Demirbas & Sahin, 1998; Immergut, 1975). In a community-based energy briquette production project at an informal settlement in Nairobi, Kenya, paper served as binder in producing doughnut-shaped briquettes from materials like discarded coffee hulls, rice husks, charcoal particles, sawdust and wood chips (Njenga et al, 2009).

In producing briquettes, a hole at the center of the fuel is believed by many to improve the combustion characteristics of the briquette because it encourages rapid drying, easy ignition and highly efficient burning due to the draft and insulated combustion chamber that the hole creates (Chaney, Clifford & Wilson, 2008). Many parameters are also considered in the determination of the quality of briquettes produced from different agricultural and forest origin biomass.

Some of these include production rate and economic analysis and thermo physical properties and chemical composition of the materials used for briquette production (Stolarski et al, 2013; Singh &Kashap, 1985; Chin & Siddiqui, 2000; Vassilev et al, 2010; Voicea et al, 2013).

Due to the abundance of biomass and other materials appropriate for briquetting, different technologies (internationally and locally) had been developed and introduced to many stakeholders. Some of these include the wooden compound levers, hydraulic pistons, car jack presses, and solar or pedal powered versions (Stanley, 2003). Enhancing a briquetting technology that would utilize the abundant biomass wastes found in the locality, however, need to consider the limitations of the existing technologies. Some of these limitations are the size and bulkiness of the machine and location of the jack at the bottom making it prone to water drips. On the average, most of the machines developed can only produce about two to ten pieces of briquettes in one pressing; whereas, if the number of molders is increased, production may also be improved. With an enhanced briquetting technology, it aimed on the production of high quality briquettes as a solid fuel by utilizing abandoned biomass and urban wastes found in the vicinity. The quality of the three types of briquettes produced was further evaluated in terms of physical parameters, bulk density, heating value, and proximate and ultimate analyses of the fuels.

2. Materials and Methods

2.1 Study Area

The Philippines is an archipelago of 7,107 plus islands located in Southeast Asia. It has a land area of 300,000 km^2 with a total population of 92 million based on the 2010 Philippine Census of Population and Housing. The country is divided into three island groups, namely, Luzon, Visayas and Mindanao with 18 administrative subdivisions known as regions. Iloilo City, the capital of the Province of Iloilo belongs to the Western Visayas region. According to the same census, the city having a population of 424,619is composed of six districts including Mandurriao which has 180 urban barangays. One of which is Brgy. Calajunan where the city’s controlled disposal facility is located and where the field test of the machine was conducted. Other preliminary testings were conducted at the Appropriate Technology Center inside the campus of Central Philippine University (CPU) located in Jaro, Iloilo City. The conduct of the study took place from July 2013 to June 2014.

2.2 Technologies Utilized

Briquette molders and pulping machine were the two major equipment utilized in the simulated biomass briquette production test. A single unit of briquette molder can produce in one pressing 16 pieces of cylindrical briquettes with a hole at the center. Figure 1 presents the enhanced jack-driven briquetting machine utilized for the study which is comprised of four major parts, namely, the briquette molders, cover, hydraulic jack and frame. The biomass materials were first prepared separately, mixed, then placed into each of the cylindrical molders until totally filled. The molder’s cover was then closed and locked by the bolts then compressed by the 10-ton capacity bottle-type hydraulic jack. Once the materials were compressed, the cover was opened and the jack was thrusted again until the materials were pushed out of the molders.

A pulping machine driven by a 1-Hp capacitor-start single-phase electric motor was utilized to disentangle and homogenize the waste papers. The machine was designed to have this size in terms of electric energy consumption so that it would not create heavy electrical load during operation. The device operates like a blender where the shredded papers or manually stripped papers are loaded inside the cylinder of the machine.

2.3 Mixture Preparation

Iloilo City, being an urbanized metropolis generates a lot of waste paper. The abundance of these materials generated during the 20-day segregation test (Paul et al, 2007; Paul et al, 2009) initiated further exploration of waste paper as a potential alternative source of fuel.

The cellulose in paper contains proteinaceous materials that have excellent adhesive property making it useful as partial binding material (Njenga et al, 2009; Demirbas & Sahin, 1998)To maximize the potential of waste paper, the addition of commonly produced biomass wastes in the form of sawdust and carbonized rice husk (CRH)were considered as key ingredients in the formulation of mixtures for briquette production. In summary, three materials shown in Figure 2 were recommended for the simulated briquette production test; namely, paper, sawdust and CRH. They were produced using the following mixing proportions: Briquette 1: paper (100%); Briquette 2: paper (50%) + sawdust (50%); and Briquette 3: paper (50%) + sawdust (25%) + CRH (25%).During production, waste papers were recovered from the disposal facility and from particular colleges of CPU, whereas, the biomass wastes were obtained from the dumpsite and nearby rice mills and furniture shops within Iloilo City. Addition of biomass materials to waste papers can expand the maximization of the waste papers since literatures have already indicated that the heating values of sawdust and rice husk can sustain combustion (Lee, 2007).

2.4 Briquette Production and Evaluation

Three different types of briquettes utilizing biomass and urban wastes were produced for this study using the 4x4 briquetting machine. Performance of the machine was done through actual field production test for 15 days (Figure 3) in order to determine the average volume of briquettes the participants could produce under simulated work conditions. Each participant was compensated based on the actual number of briquettes produced.

This was performed at the center of Uswag Calajunan Livelihood Association (UCLA), a registered association of waste reclaimers. It is located just 100 m across Iloilo City's disposal facility. The Center has an approximate floor area of 144 m^2 and is made of light construction materials such as plywood for its flooring and nipa shingles for its roofing. Eight units of the jack-driven briquetting machine were utilized for this test. Two persons working as a team operated each machine while two additional persons were assigned for the pulping of waste papers. This set-up wherein a certain team is assigned to pulping and another for briquetting indicates a specialized type of work. This manner is common in work places to attain higher production. Operation started at around past 7 in the morning until around 5 in the afternoon. The start and end of production have all been at the participant's pacing. They were observed as to how they organized and put their respective responsibilities in order. The arrangement of equipment and other necessary instruments used during production have also been arranged in a manner that would be safe for them and at a location that would not disrupt their work activities. Production started from the preparation of materials followed by pulping of paper. With time, they became familiar as to the volume of materials they would prepare; just enough for the whole day production.

Production of briquettes was done in modes that represented different possible types of productivity. These included a team/worker who produced briquettes based on the following rates:

- Paid for every 4 pieces of briquettes produced per day
- Paid on a fixed rate by producing 150 pieces per day with bonus for every 4 additional briquettes formed
- Paid on a fixed rate with no required number of briquettes produced

These different rates were representative of three different possible productivities for workers, hence, the total production divided by the number of days and number of participants would illustrate the average production rate per person. The estimation of the fixed rate at 150 pieces per day was based on the average briquettes produced during previous briquetting tests conducted (Romallosa, 2014).

All briquettes produced were sundried until 20 to 30% moisture was attained. Dried samples were then sent to Bauhaus-Universität Weimar (BUW) in Weimar, Germany for further physico-chemical tests. The identification and characterization of chemical and phase composition of a given solid fuel was the initial and most important step during the investigation and application of such fuel (Vassilev et al, 2010).

3. Results and Discussion

3.1 Technical Performance of the Briquetting Machine

Results of the 15-day actual field production test revealed slightly different production rate. No statistical analyses were made since the amount of materials used was only summed up after the 5-day test for each briquette type. Moreover, the purpose of the field test was to observe and record the performance of the workers in terms of briquette outputs rather than the amount of materials used. As shown in Table 1, the amount of dry mixtures used varied from 796 kg to 1,152 kg maximum dry weight mixture. Briquette 2 obtained the highest production rate (1.92 kg/hr) followed by Briquettes 3 and 1 at 1.79 kg/hr and 1.68 kg/hr, respectively. As observed during the performance evaluation, less pure paper briquettes were produced due to the friction created by pure paper materials on the surface of the molders. Unlike when mixed with either sawdust or CRH, the operation as observed, was simpler for them. The materials were easier to handle on the molders when the mixtures were heterogeneous because of less moisture since the add-on materials had gradually absorbed the moisture of pulped papers. The higher production rate in terms of weight of briquettes produced was due to the compactness of the mixtures when placed into the individual molders.

The actual field testing also made possible the observation of the durability of the machine. The parts that gave in due to the wear and tear on the use of the machine were the welded hinge of the cover and the springs that pull together the molder support and jack flooring when the hydraulic jack was loosened.

3.2 Quality of Briquettes Produced

In general, the results of the study presented in Figure 4 and Table 2 revealed that properties of fuel briquettes depended mainly on the type of material they are made from and on the type of briquetting machine used to produce them. These are supported by the findings of Stolarski et al (2013). The machine produced briquettes that are cylindrical in shape and with a hole at the center which is similar with other briquettes previously developed and produced from other places (Njenga et al, 2009; Chaney, Clifford & Wilson, 2008; Stanley, 2003; Beaverton Rotary Foundation, 2013). This designed machine can be added to the energy conversion technologies that was developed and adopted under local conditions in order to utilize the abandoned biomass wastes in the country (Baconguis, 2007).

As presented in Figure 4, the three types of briquettes were all cylindrical in shape with a hole at the center but were different in color. The briquettes on the first column appeared mostly white because the waste papers were the only components of this fuel. On the other hand, the briquettes found at the center had light brown color with traces of white spots. This was due to the presence of 50% waste paper and 50% sawdust. For the third column, the presence of CRH in the mixture made black the dominant color of the fuels with specks of white and light brown materials.

The briquettes had a diameter within the 5-cm range and a thickness that varies from 1.54 to 2.34 cm while the inner hole was about 1.20 cm. Briquettes with more mixtures (Briquettes 2 and 3) were heavier than the pure paper. The values for the weight and volume per briquette were necessary data for the computation of the bulk density of the fuels. With a hydraulic jack, the bulk density of the briquettes was highest for Briquette 1 at 0.49 g/cm^3(485.41 kg/m^3) followed by Briquette 3 (0.46 g/cm^3; 459.01 kg/m^3) and Briquette 2 (0.39 g/cm^3; 390.06 kg/m^3). The higher density observed in the 100% waste paper briquettes may be due to its homogenous nature, which may have enabled the material to form a stronger bond, resulting in a denser and more stable briquette (Olorunnisola, 2007) compared to those from the two other mixtures. The bulk densities of the briquettes produced were also numerically similar with the results of the studies of Stolarski et al (2013) and Demirbas and Sahin (1998) which produced briquettes made from agricultural, forest origin biomass and waste paper using a horizontal crank-and-piston briquetting press (bulk density ranged from 469 to 542 kg/m^3) and Shimadzu hydraulic press (bulk density reported to be 0.32 g/cc or 320 kg/m^3). It can be noted that the density of the briquettes improved with increasing pressure leading to enhanced quality of briquettes (Singh & Kashap, 1985; Chin & Siddiqui, 2000).

This parameter is important in briquetting because the higher the density of the fuels, the higher is its energy/volume ratio. Briquettes with high-density are also favored due to its enhanced features needed for transport, storage and handling (Bhattacharya et al, 1990).

Heating value is a major quality index for fuels (Demirbas & Sahin, 1998). Fuels such as briquettes need a heating value of about 11.66 MJ/kg (5,000 Btu/lb) to be able to sustain combustion (Yaws, 1999; Lee, 2007). The waste paper mixed with sawdust briquettes produced using the jack-driven machine had a heating value of 16.68 MJ/kg (7,153 Btu/lb). The pure paper briquettes obtained a heating value of 15.01 MJ/kg (6,439 Btu/lb) while those of paper mixed with sawdust and CRH were 13.69 MJ/kg (5,872 Btu/lb). All three mixtures recommended had a heating value that can sustain combustion making them an ideal and feasible fuel for cooking and other heat-related applications. The calorific power or heating value of the material is influenced by the species and the moisture content (Voicea et al, 2013). The results of this study, however, do not support the claim that a lower moisture may lead to higher heating value. The heating value was rather influenced more by the materials used especially sawdust since it has a higher heating value compared to pure paper and CRH. When the heating value of the briquettes were compared to that of the German or Deutsches Institutfür Normung (DIN) standards 51731 for compressed natural wood briquettes at 16.90 MJ/kg (7,248 Btu/lb), results revealed that Briquette 2 had the closest numerical valueat 16.68 MJ/kg (7,153 (Btu/lb). This indicates that this low-cost technology can also create fuel briquettes that can closely meet the standards set for products that are mostly manufactured by companies using high technologies.

Proximate analyses of the briquettes included the ash yield, and moisture while that of the ultimate analyses covered the organic forming elements in biomass (Vassilev et al, 2010), namely: hydrogen (H), nitrogen (N) and sulfur (S). Ash yield is the inorganic oxides that remain after complete combustion of materials (Speight, 2008). Results show that the third briquette had the highest ash content at 31.0% followed by Briquette 1 at 21.0%. Briquette 2, which is a mixture of paper and sawdust, contained the lowest amount of ash at 14.6%. It can be noted that agricultural biomass like rice husk (such as found in Briquette 3) yields higher ash, thus, contains much more ash-forming elements than most of forestry biomass like sawdust (Stolarski et al, 2013; Vassilev et al, 2010). This parameter is an important characteristic influencing the burning technology, emission of solid particle, and the handling and use of ash (Voicea et al, 2013). The ash content of Briquette 2 (paper and sawdust) is numerically comparable with that of bituminous coal at 15.7% (Vassilev et al, 2010).

The moisture of the briquettes produced ranged from 5.6 to 7.1% of its dry matter (dm) weight. The use of a hydraulic jack in the compression of the briquettes and the presence of many holes on the side of the molders (Stanley, 2003) were instrumental in squeezing out excess water. The moisture recorded also met the DIN 51731 standards that require fuels to have moisture of less than 12%.In addition, the briquettes produced had numerically lower moisture than most other fuel materials like mixed waste paper, coal, biocoal briquette and sawdust briquettes, its moisture from 7.42 to 8.8% (Onuegbu et al, 2011; Stolarski et al, 2013; Vassilev et al, 2010).

The content of H in the three briquettes produced ranged from 4.8 to 5.9% with Briquette 2 having the highest value. Voicea et al (2013) mentioned that H is an important characteristic that influences the calorific power and the value should be high; hence, the higher H value in Briquette 2 also corresponded to higher heating value among the three mixtures. For the N content, which influences the emission of nitrogen oxides (NOx) and corrosion (Voicea et al, 2013), all three briquettes had the same value of less than 0.1% of its dry matter weight. The value obtained for S, which influences the emission of sulfur oxides (SOx) and corrosion were at almost the same value ranging from 0.028 to 0.036% of the dry matter weight. The briquettes produced contained lower N and S when compared to other biomass briquette fuels such as mixed paper, refuse-derived fuel and bituminous coal (Stolarski et al, 2013; Vassilev, 2010; Demirbas & Sahin, 1998). The results for N and S also conform with the DIN 51731 standards of <0.3% and <0.08%, respectively. This implies that the briquettes produced, when used as fuel for heating operations, would emit less NOx and SOx which are pollutants in the atmosphere. The jack-driven briquetting technology made briquettes of higher bulk density and lower moisture content. It also molded materials having uniform size, shape and properties.

The briquette molder with good compressive ability proved that paper can be used as a reliable binding material for briquette production (Demirbas & Sahin, 1998; Immergut, 1975).The case of producing briquettes by utilizing biomass wastes can also be likened to the implementation of a community-based energy briquette production in an informal settlement in Nairobi, Kenya. In this project, briquette production made use of paper as binder with other mixtures coming from discarded materials like coffee hulls, rice husks, charcoal particles, sawdust and wood chips. The briquettes are cylindrical having a hole with size and shape like a doughnut (Njenga et al, 2009).

4. Conclusions

The technology utilized for briquetting is relatively easy to install and operate due to its simple yet sturdy, low-cost design. The provided equipment during the simulated test was able to withstand the wear and tear of operation showing suggestive results in terms of production rate, bulk density, heating value of briquettes including the proximate and ultimate analyses of the fuels produced. Quality briquettes could be created from biomass, making these material flows a renewable source of cost-effective fuels.

The physico-chemical quality of the produced briquettes implied optimism as to their potential when utilized as fuels for heating operations due to its heating value that can sustain combustion, likewise, implying that the fuels produced using a simple jack-driven briquetting machine, would emit less NOx and SOx which are pollutants in the atmosphere.

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Conflicts of Interest

The author declares no conflict of interest.

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Figures

Figure 1: The hydraulicjack-driven briquetting machine utilized in the biomass briquette production test.

Figure 2: The materials used in briquette production, namely, from left to right: waste paper, sawdust and carbonized rice husk.

Figure 3: The field production test at UCLA Center and the briquettes produced hanged for drying.

Figure 4: Types of briquettes produced using biomass wastes, from left to right: a) paper,b) paper + sawdust, and c) paper + sawdust + CRH.

Tables

Table 1: Operating Performance of the Machine during the Field Production Test*.

Parameters Measured	Briquette 1 (P)	Briquette 2 (P + SD)	Briquette 3 (P + SD + CRH)
Total dry wt. mixture, kg	796	1,152	924
Total dry wt. of paper (P), kg	796	576	462
Total dry wt. of sawdust (SD), kg	-	576	231
Total dry wt. of carbonized rice husk (CRH), kg	-	-	231
Average daily operating time, hr	6	6	6
Average daily briquettes produced per person, pcs/day	630	822	897
Average daily dry wt. of briquettes produced per person, kg/day	10.09	11.51	10.76
Average production rate person, pcs/hr	105	137	149
kg/hr	1.68	1.92	1.79

*15-day field production test at 5-days each for every briquette type

Table 2: Quality of Biomass Briquettes Produced.

Parameters Measured	Briquette 1(P)	Briquette 2(P + SD)	Briquette 3(P + SD + CRH)
Diameter, cm (≈)	5.37	5.53	5.48
Thickness, cm (≈)	1.54	2.34	1.96
Weight per Briquette, g	16	21	20
Volume per Briquette, cm^3	33.15	53.30	43.97
Bulk Density, g/cm^3	0.49	0.39	0.46
kg/m^3 [a]	485.41	390.06	459.01
Heating Value, MJ/kg [b]	15.01	16.68	13.69
Proximate Analyses			
Ash Yield, % dm	21.0	14.6	31.0
Moisture, %	5.6	7.1	5.8
Ultimate Analyses			
Hydrogen, % dm	5.1	5.9	4.8
Nitrogen, % dm	<0.1	<0.1	<0.1
Sulfur, % dm	0.035	0.036	0.028

[a] Mean of bulk density = 444.83 kg/m^3
[b] Mean of heating value = 15.13 MJ/kg