TECHNICAL AND ECONOMIC EVALUATION OF THE JACK-DRIVEN BRIQUETTING MACHINE

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ABSTRACT

This study was conducted to evaluate the technical and economic performance of the designed briquetting machine that utilizes a hydraulic-type bottle-jack for better compression in producing briquettes. The machine can compact 16 cylindrical (with a hole at the center) briquettes in one pressing or about 200 to 240 pcs/hr. The jack creates the needed pressure by thrusting the molders up to fully compact the materials. With the aid of one spring on both sides, which jointly holds together the molder and jack flooring supports, the piston of the jack when loosened is pulled back to its normal position allowing a semi-automatic type of operation. The briquettes produced by the machine functioned well as fuel when subjected to cooking and boiling tests indicating its potential as alternative source of energy. This was also highlighted by a higher percentage (81%) of willingness by waste reclaimer-respondents to buy them as fuel for various cooking and heat applications. The production cost per hour for briquettes ranged from about Php32 to Php34 or Php0.13 to Php0.16 per briquette. Leveling-up of operation may even increase production giving annual potential earnings of about Php29,000.00 to Php69,000.00. The quality of the three briquettes produced slightly varied and some of the parameters analyzed like bulk density, heating value, moisture, N and S closely met or have met the requirements of DIN 51731.

***Keywords**: briquetting machine, technology, briquette production, briquettes, biomass, energy conservation*

INTRODUCTION

Background and Rationale

Briquetting involves the compression of a material into a solid fuel product of any convenient shape that can be utilized as fuel just like the use of wood or charcoal. The conversion of combustible materials found in the waste stream was found to be a better way of turning waste into wealth (Adegoke, 2002). It 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. 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 (from http://www.cd3wd.com/cd3wd_40/vita/ briquette/en/briquette.htm; Demirbas & Sahin, 1998; Immergut, 1975). 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; from http://www. paceproject.net/ UserFiles/File/Urban% 20Living/make% 20briquettes.pdf). Many parameters are also considered on the determination of the quality of briquettes produced which include production rate and economic analysis and thermophysical 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).

Some briquetting technologies developed include wooden compound levers, hydraulic pistons, car jack presses, and solar or pedal powered versions (Stanley, 2003; Chaney, Clifford & Wilson, 2008). Pressing is achieved through a simple lever mechanism and this design does not require special parts as opposed to screw presses and hydraulic jack presses (Stanley, 2003). Another one uses a hydraulic bottle-jack positioned at the bottom in order to compress the materials to be briquetted in an upward manner (Beaverton Rotary Foundation, 2013).

At the national level, researchers of the Forestry Products Research and Development Institute (FPRDI), based in UP Los Baños, Laguna, fabricated a modified manual briquetting machine that produces 10 pieces of cylindrical briquettes with center hole in one pressing. The charcoal briquettes were produced from coconut shell charcoal fines with cassava starch as binding material. In St. Paul University in Dumaguete City, Negros Oriental their briquetting machine employs a hydraulic bottle-jack positioned at the bottom. It was observed, however, that the water dripping from molders during the compression also went to the hydraulic press. The machine can produce 20 cylindrical briquettes (with no hole) in one pressing. Another visit to the fabrication site of RU Foundry and Machine Shop Corporation in Bacolod City also revealed another low-density charcoal maker. The machine likewise uses a car jack press principle in which compression is done by revolving the screw press in a downward manner. It can produce twelve cylindrical briquettes in one pressing.

Central Philippine University (CPU) also developed different briquetting technologies in the past years (Belonio, 2000; Paclibar, 2002). The technologies gave more emphasis on the use of purely biomass wastes (carbonized rice husk) including the use of binding materials such as cornstarch and animal manure. But with the increasing generation of urban wastes such as paper (Paul et al., 2007), a more flourishing fuel for heat energy may be provided in the market. Hence, paper was considered as an add-on material for briquette production. It led to the development of hand-pressed briquette molders (Paul, Lange & Romallosa, 2009; Romallosa & Hornada, 2011) through CPU's Approtech Center for the value-adding test to produce alternative fuels and raw materials (AFR) for industrial purposes and for household energy supply.

The output of the study led to the fabrication of minimal number of units for use by the members of the Uswag Calajunan Livelihood Association, Inc. (UCLA), which is located in Brgy. Calajunan, Mandurriao, Iloilo City. The units were then field tested and utilized by the members in their briquette production (Romallosa, *et al*., 2011).

The limitations from the commercial briquetting technologies developed were considered in the criteria for designing an improved version of a briquetting machine. These include among others the portability of the machine, location of the jack, shape of the fuel including the number of pieces that can be produced in one pressing.

This study was conducted to evaluate the technical and economic performance of the briquetting machine. It also covered the verification of the operating performance of the machine through actual field production test by identified members of UCLA, physico-chemical quality of briquettes produced, fuel potential, product acceptance, and economic analysis of briquette production.

METHODOLOGY

Technical Description of the Jack-Driven Briquetting

Machine

The hydraulic-type bottle-jack press briquetting machine as shown in Figure 1 consists of four major parts: briquette molders, cover, hydraulic jack and frame.

Briquette molders. The new machine was constructed with sixteen cylindrical holes. Each molder was constructed using a schedule 20 galvanized iron (GI) pipe having an inside diameter 57 mm (2-1/4 in.) and a height of 10 cm (4 in.). It was welded in the middle with a 10 mm diameter plain round bar to create the hole needed for the briquettes. Each hole was also drilled with twelve 5 mm (1/4 in.) diameter holes distributed evenly along the circumference of the pipe. A 4 mm (1/8 in.) thick metal plate was inserted at the bottom and this is supported by 4 pieces of 8 mm diameter round bar welded to connect this sliding metal plate to another plate where the hydraulic jack pushes it up during compression. The said sliding plate is responsible for holding the materials for compression.

Cover. The cover of the machine held the materials when the hydraulic jack was compressing it up. It was made of a 13 mm (½ in.) thick metal plate. It was welded with three hinges to allow easy opening of the cover. During operation, it was locked by two bolts welded on the opposite side of the hinges.

Hydraulic jack. A 10-ton capacity bottle-type hydraulic jack was utilized for this machine. It was placed under the metal plate that supported the legs of the briquette molder. The jack was supported by a 13 mm (½ in.) thick metal plate braced by I-bars to withstand the forces created during compression. The metal plate was welded on the four legs of the machine that served as support.

Frame. The frame served as the legs and support of the machine. It was constructed from a 48 mm x 48 mm (1-1/2 in. x 1-1/2 in.) angle bar. The machine was 650 mm high. The cover measured 300 mm x 300 mm while the protruding leg measured 410 mm x 410 mm. It approximately weighed 65 kg.

Figure 1. The final design of the hydraulic-jack driven briquetting machine.

Principle of Operation

The machine produced briquettes through the compressive force delivered by the hydraulic jack. The materials (paper, sawdust and carbonized rice husk) were first prepared separately, after which, they were placed into each of the cylindrical molders until totally filled. The molders were then closed and locked by the bolts then the hydraulic jack was pumped. While the materials were being molded, excess water would come out of the holes of the molders. The metal plate that served as the molder support protected the jack from water drips during operation. The different legs that supported the molders were also responsible in distributing the load from the jack since these legs were also welded on the same metal plate pumped up by the jack. Once the materials had been compressed, the cover was oscillated to open position. Pumping of the jack was continued until the briquettes were pushed out of the molders. After this, the jack was released forcing the two springs to automatically pull down the molder support back to the jack's normal position. This mode of operation had eliminated any activity that would require the user to lift anything making it very easy to operate. The user would only require human power in pumping the hydraulic jack. The use of the machine is presented in Figure 2.

Figure 2. Briquetting of wastes showing "from left to right" the placement of mixtures in the molder, compaction of the materials, and removal of briquettes produced from the molders.

Briquette Production and Evaluation

Laboratory test. Three different types of briquettes utilizing biomass and urban wastes were produced for this study using the 4x4 briquetting machine. The briquettes were made of the following mixing proportions: Briquette 1: paper (100%); Briquette 2: paper (50%) + sawdust (50%); and Briquette 3: paper (50%) + CRH (25%) + sawdust

(25%). The dry weight of biomass and urban wastes and their combinations were all fixed to 3000 g. The weighed materials were mixed manually in pure form or with add on materials in a container based on the recommended mixing ratio until homogenized. Then they were placed in the briquetting machine for compaction and the fuels produced were sundried after until 20 to 30% moisture was attained making them ideal for the boiling water and cooking rice tests.

Performance evaluation of briquettes was done in four test runs. Boiling of 2000g or 2 li of water using the three different types of briquettes produced and charcoal as fuels were performed simultaneously using a concrete stove. During this test, the initial weight of fuel used, number of pieces of briquettes or charcoal used as fuel and the total length of operation was recorded and monitored. After boiling test, the weight of ash produced was also measured. The same procedure was followed for the cooking test using 750g of rice.

Dried briquettes were sent to Bauhaus-Universität Weimar in Weimar, Germany for other 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 (Stanislav, *et al*., 2010).

Actual field production test. Verification of the performance of the machine was done through an actual field production test for 15 days (Figure 3). UCLA members who had been trained on briquette production through participation in previous studies or attendance in trainings conducted were commissioned for this test. Field production test was performed to determine the average volume of briquettes they could produce under simulated work conditions wherein each participant was compensated based on the actual number of briquettes produced. The same mixture of materials as in the laboratory test was utilized for this field test.

Figure 3. The actual field production test in UCLA Center (left) and the briquettes produced hanged for drying (right).

The actual field production test was performed in UCLA Center located just 100 m across Iloilo City's controlled disposal facility in Brgy. Calajunan, Mandurriao. The Center has an approximate floor area of 144 m^2 and was made from 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. On the other hand, two additional persons were assigned for the pulping of waste papers. This set-up wherein a certain team is assigned to pulping and another assigned is only to briquetting indicates a specialized type of work. This manner is common in work places to attain higher production.

Production of briquettes was done in modes that represent 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 three 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 on a realistic average production rate per person. The first mode represented an output-oriented worker who can increase his income if he can produce more. The second mode represented a worker, who was willing to earn that much, but if he wanted to increase his fixed income, then he can produce more so that he can have a bonus. The third mode represented a worker who does not really mind the volume he can produce as long as he is paid a fixed amount of money. The estimation of the fixed rate at 150 pieces per day was based on the average briquettes produced during previous briquetting tests conducted.

Product acceptance by users through survey. A survey was conducted to determine the acceptance of the UCLA members and other waste reclaimers found in the vicinity of Calajunan Disposal Facility on the use of the newly developed briquetting machine including their views on the utilization of briquettes as substitute fuel for cooking. UCLA has about 250 members living near the vicinity of the dumpsite; however, there are also non-UCLA members recovering wastes in the site. From this number, the sample size was determined using an online program (from http://www.raosoft.com/samplesize. html) at 0.95 reliability. The formula yielded a sample size of 152, however, 160 respondents were included in the survey. These respondents were identified using the incidental sampling technique (Altares, *et al*., 2003). In this method, the interviewer simply asked the waste reclaimers who were present in Calajunan Disposal Facility during the time of survey (Figure 4). The respondents were asked about their personal background, waste management/waste picking background, housing condition, kitchen/cooking devices, and their acceptability/use of briquettes.

Figure 4. Conduct of survey on product acceptance of the technology developed.

Instrumentation

The following instruments and equipment were used in the conduct of the study: 20-kg Fuji spring-scale balance, 1-kg compact scale, 50-kg pocket spring-balance, 22 and 25 cm diameter cooking pots, 56-cm big pail, 60-cm wash basin, thermocouple thermometer, moisture meter, steel tape, Vernier caliper, timer, pulping machine and concrete charcoal stoves.

RESULTS AND DISCUSSION

Operating Performance of the Machine

Shown in Table 1 are the results of the operating performance of the machine when subjected for testing in the laboratory. These are the same parameters analyzed as those from the previous study (Romallosa & Hornada, 2011) such as the weight of waste paper and biomass materials used. Longer pulping time was needed for Briquette 1 since this type of fuel utilized pure paper; hence, more time was also needed to disintegrate the structures of paper. Briquettes that utilize less paper needs less electrical energy consumption since the pulping machine used requires a 1-Hp motor to operate it. However, more time would also be needed if more materials were mixed as fuel. It was observed that when pure paper was used, the materials really penetrated through the surface of the molders creating more friction especially when they were being compressed. However, when paper was mixed with additional materials like sawdust and CRH, the operation became less strenuous especially on the use of the machine.

Data in Table 1 revealed a no significant difference at the 5% level of probability when the machine was evaluated in terms of production rate expressed as number of briquettes produced in an hour. The production rate range from 205 to 239 pcs/hr. Regardless of the mixtures used, the machine could produce almost the same number of briquettes. With the improved device, more briquettes can really be produced when numerically compared to that of the hand press briquetting technology previously developed (Romallosa & Hornada, 2011). The higher number of briquettes produced was due to the increased number of molders, i.e., from 5 to 16 molders in one pressing. The addition of a hydraulic jack made the operation easy in terms of physical effort needed and less complication in maneuvering it. Human power is only needed in the manipulation of the lever of the jack during the operation.

Briquette 3 statistically obtained the highest ($P<0.01$) production rate at 4.56 kg/hr followed by

Briquettes 2 and 1 with values of 3.98 and 3.30 kg/hr, respectively. Briquette 3 were heavier due to the use of three different materials (paper, sawdust and CRH) that made it heterogeneous. Mixing of these materials prior to molding them has reduced the presence of voids. It can be noted also that for Briquette 3 and even for Briquette 2, the amount of water during mixing has reduced because the add-on materials absorbed them. These moistened the mixtures only. Once these materials were compressed, less moisture was removed, therefore, the briquettes produced were thicker and heavier. In the case of the pure paper briquettes, the production rate in terms of weight per hour was less because the pulped papers placed in the molders contained higher water content, so during compression, most of the water together with some pulped papers were forced out through the tiny holes found at the periphery of the molders. After compaction, the paper briquettes produced were less dense; hence, the weight was also less (16 g).

Table 1. Operating Performance of the Machine in Terms of Technical Requirements and Output in Producing Briquettes.

Parameters Measured	Briquette 1 (P)	Briquette 2 (P + SD)	Briquette 3 (P + SD + CRH)
Total dry wt. mixture, kg	3	3	3
Dry wt. of paper (P), kg	3	1.5	1.5
Dry wt. of sawdust (SD), kg	-	1.5	0.75
Dry wt. of carbonized rice husk (CRH), g	-	-	0.75
Pulping time, min	8.61	4.96	2.46
Mixing time, min	-	1.79	2.14
Briquetting time, min	43.47	37.08	36.65
Total operating time, min	52.07	43.83	41.25
Briquettes produced, pcs	189	150	164
Dry wt. per briquette, g	16	21	20
Dry wt. of briquettes produced, g	2.86	2.91	3.13
Production rate, pcs/hr[1]	217 [ns]	205	239
kg/hr[2]	3.30 [c]	3.98 [b]	4.56 [a]

[1] cv = 8.00%

[2] cv = 5.54%

[ns] Not significant

[abc] Any two means on the parameter measured (in a row) followed by the same letter superscript are not significantly different at the 1% level of probability

Field Production Briquetting Test

Results of the 15-day actual field production test revealed a slightly different production rate. No statistical analysis was 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 2, the amount of dry mixtures used varied from 796 kg to 1,152 kg maximum dry weight mixture. The analyzed production rate in terms of pcs/hr confirmed the non-significant results during the laboratory testing. This means that the highest production rate for Briquette 3 (as revealed in Table 1) might only be coincidental such as the capability of the person to be familiar right away with the operation. When the data was analyzed numerically, it was still Briquette 3 which had the highest production rate, followed by Briquette 2 (137 pcs/hr) and Briquette 1 (105 pcs/hr). When analyzed in terms of weight of briquettes produced per hour, the data also substantiated the results at the laboratory level.

The actual field testing likewise made possible the observation of the durability of the machine. The parts that gave in due to the wear and tear of 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.

Table 2. Operating Performance of the Machine through Actual 15-day Field Production Test* by Identified Members of UCLA.

Parameters Measured	Briquette 1 (P)	Briquette 2 (P + SD)	Briquette 3 (P + SD + CRH)
Total dry wt. of 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
Ave. daily operating time, hr	6	6	6
Total briquettes produced in 5 days, pcs	50,410	65,759	71,753
Average daily briquettes produced per person, pcs/day	630	822	897
Total dry wt. of briquettes produced in 5 days, kg	807.00	921.00	861.00
Average daily dry wt. of briquettes produced per person, kg/day	10.09	11.51	10.76
Average production rate per 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

Quality of Briquettes Produced

In general, results of the study presented in Figure 9 and Table 3 revealed that properties of fuel briquettes depend mainly on the type of material they are made from and on the type of the 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, 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 had been developed and adopted under local conditions in order to utilize the abandoned biomass wastes in the country (Baconguis, 2007). The three different biomass materials were utilized using the improved machine since these were the mixtures that were recommended during the previous study (Romallosa & Hornada, 2011).

As presented in Figure 9, the three types of briquettes were different in color. They are cylindrical in shape with a hole in the center. 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 have a diameter within the 5-cm range and a thickness that varied 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 value 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 recorded to be highest for Briquette 1 at 0.49 g/cc (486.60 kg/m^3) followed by Briquette 3 (0.46 g/cc; 461.90 kg/m^3) and Briquette 2 (0.39 g/cc; 389.31 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 briquettes (Olorunnisola, 2007) compared to those from the two other mixtures. The use of the jack-driven machine has also improved the bulk density by about 0.32 g/cc or by 246% when compared to those made using the previous machine developed (Romallosa & Hornada, 2011). 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).

Figure 9. Types of briquettes produced using biomass and urban wastes, from left to right: paper, paper and sawdust and paper, sawdust and CRH.

Table 3. Quality of Briquettes Produced.

Parameters Measured	Briquette 1 (P)	Briquette 2 (P + SD)	Briquette 3 (P + SD + CRH)
Physical Characteristics			
Color	White with spots of black prints	Light brown with white spots	Black with white and light brown spots
Shape	Cylindrical with hole	Cylindrical with hole	Cylindrical with hole
Diameter, cm	5.37	5.53	5.48
Height, cm	1.54	2.34	1.96
Inner holed diameter, cm	1.20	1.21	1.21
Weight per briquette, g	16	21	20
Volume per briquette, cc	33.15	53.30	43.97
Bulked Density, g/cc	0.49	0.39	0.46
kg/m^3	486.60	389.31	461.90
Heating value, Btu/lb	6,439	7,153	5,872
Proximate analysis			
Ash yield, % dm	21.0	14.6	31.0
Moisture, %	5.6	7.1	5.8
Ultimate analysis			
Hydrogen, % dm	5.1	5.9	4.8
Nitrogen, % dm	<0.1	<0.1	<0.1
Sulfur, % dm	0.035	0.036	0.028

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) for it 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 7,153 Btu/lb. The pure paper briquettes obtained a heating value of 6,439 Btu/lb while that of paper mixed with sawdust and CRH was 5,872 Btu/lb. All three mixtures recommended had a heating value that can sustain combustion (Yaws, 1999; Lee, 2007) 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 agree 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 standards (DIN 51731) for compressed natural wood briquettes at 7,248 Btu/lb, results revealed that Briquette 2 had the closest numerical value (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.

The proximate analysis of the briquettes included the ash yield, and moisture while the ultimate analysis 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 a 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 decreasing the moisture content by almost 4% when compared to briquettes pressed manually (Romallosa & Hornada, 2011). The moisture recorded also met the DIN 51731 standards that require fuels to have moisture of less than 12%.

The content of H in the three briquettes produced ranged from 4.8 to 5.9% with Briquette 2 having the highest. (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 correspond to higher heating value among the three mixtures. For the N content, which influences the emission of nitrogen oxides (NO_x) and corrosion (Voicea, *et al*., 2013), all three briquettes obtained 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 (SO_x) 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 standards set under DIN 51731 standards of <0.3% and <0.0.08%, respectively. This implies that the briquettes produced, when used as fuel for heating operations, would emit less NO_x and SO_x which are pollutants in the atmosphere.

Alternative Fuel Potential of Briquettes

All tests presented in Table 4 were done using the same size of the usual charcoal stove used by a household and the results were compared with that of charcoal. The number of pieces of fuel used for each test was based on the number of fuel the stove can contain. Twelve pieces of briquettes were used for each type in each test while that of charcoal made use of 24 pieces of fuel since these were smaller than the briquettes. With this number of fuel, boiling of water was fastest ($P<0.01$) in Briquettes 1 and 2 at almost 13 min for both. The data obtained using cylindrical briquettes with a hole also yielded similar results with that of the hand-pressed briquettes (Romallosa & Hornada, 2011). The ranking as to which briquette boils water the fastest was similar with that of the previous study showing once again that the briquettes performed better than charcoal.

When the fuels were tested for cooking 750 g of rice, the paper briquettes exhibited significantly ($P<0.01$) the fastest cooking time at 19.88 min over the other two types of briquettes at about 23 min. Again, charcoal resulted in the longest cooking time (25.43 min).

Personal Profile of Respondents Users

One hundred sixty (160) respondents who were mostly (89.4%) residing in Brgy. Calajunan, Mandurriao were interviewed to determine the briquette acceptance. Results shown in Table 6 revealed that 69% were members of UCLA while the others who were present in the disposal facility during the time of interview were non-members or those waste reclaimers who did not signify voluntary participation in the association. Their average age is 37.52 years and most of the respondents are women (59.4%). In terms of their highest educational attainment, almost the same percentage (27 and 25%) were elementary and high school undergraduates; although there were waste reclaimers with college degree also (6.9%). Most of the waste reclaimers found at the facility are married (74%) with more than 50% having 3 or more children.

Table 4. Operating Performance of Briquettes as Fuel.

Parameters Measured	Briquette 1 (P)	Briquette 2 (P + SD)	Briquette 3 (P + SD + CRH)	Charcoal
Boiling Test				
Wt. of water used, g	2,000	2,000	2,000	2,000
No. of fuels used, pcs	12	12	12	24
Wt. of fuels used, g	257	250	295	244
Start-up time, min	1.07	1.16	1.52	1.87
Boiling time, min [1]	12.59 [a]	12.46 [a]	16.02 [b]	19.38 [c]
Total operating time, min	52.07	43.83	41.25	55.00
Cooking Test				
Wt. of rice cooked, g	750	750	750	750
No. of fuels used, pcs	12	12	14	17
Wt. of fuels used, g	252	249	340	204
Cooking time, min [2]	19.88 [a]	23.01 [b]	22.63 [b]	25.43 [c]

[1] cv = 4.60%

[2] cv = 5.69%

[abc] Any two means on the parameter measured followed by the same letter superscript are not significantly different at the 1% level of probability

Table 5. Distribution of Respondents according to Their Personal Profile (n=160).

	Frequency	Percent
Age		
23 years old and below	30	18.8
24 – 46 years old	89	55.6
47 years old and below	41	25.6
Total	**160**	**100.0**
Mean Age = 37.52 years old		
Residence		
Brgy. Calajunan, Mandurriao, Iloilo City	143	89.4
Brgy. So-oc, Arevalo, Iloilo City	10	6.2
Brgy. Pakiad, Oton, Iloilo	4	2.5
Gender		
Female	95	59.4
Male	65	40.6
Total	**160**	**100.0**
Highest Educational Attainment		
Elementary undergraduate	44	27.5
Elementary graduate	24	15.0
High School undergraduate	40	25.0
High School graduate	29	18.1
College undergraduate	12	7.5
College graduate	11	6.9
Total	**160**	**100.0**
Civil Status		
Married	118	73.8
Single	24	15.0
Live-in	15	9.4
Number of Children		
3 and below	90	56.2
4 to 6 children	37	23.1
7 and above	29	18.1
No answer	4	2.5
Total	**160**	**100.0**
Mean Number of Children = 3.71		
Classification of Respondents *(n=160)*		
UCLA Member	111	69.4
Non-UCLA Member	49	30.6
Total	**160**	**100.0**

Fuel Related Parameters

When the respondents were asked about their cooking facility and related information, results in Table 6 show that charcoal stove followed by the wood stove were the two commonly used cooking devices as claimed by 72.5% and 58.7% of the waste reclaimers, respectively. With these devices, wood and charcoal were also the main fuels utilized while others can afford to use LPG. Six respondents indicated that they were using briquettes and rice husk as fuel for cooking. These fuels were mostly sourced from the dumpsite (76.2%) while others were buying it (52.5%) or getting it from nearby places (14.4%). The results further show that a great majority (88.1%) of the respondents were already familiar with the use of briquettes as cooking fuel. Their familiarity may be attributed to the posted list of activities and many actual field tests that had been conducted and performed at the UCLA Center, which is just approximately 100 m away from the Calajunan Disposal Facility. These activities may have encouraged some (17%) of the waste workers to produce their own briquettes.

When each of the respondents were later provided with 3 kg of briquettes produced by selected participants during the 15-day actual field test held in UCLA Center, more than 83% indicated that they were using them for cooking rice and food and for boiling water. Others (31%) claimed that they were using them for cooking food for their animals.

In terms of acceptability of the technology, 93.1% of the respondents signified its usefulness as substitute fuel for cooking. Should these fuels be introduced in the market later on, 81.2% are willing to buy them as cooking fuel in their respective households. The outcome of this survey is a positive indicator of the potential of briquettes as substitute fuel for various cooking and heat applications.

Table 6. Distribution of Respondents according to Different Parameters (n=160).

Parameter	Frequency	Percent
Type of Cooking Device *(Multiple Response - MR)*		
Charcoal stove	116	72.5
Wood stove	94	58.7
Stone	14	8.75
LPG stove	13	8.1
Steel bars	9	5.6
Type of Fuel Used *(MR)*		
Wood	139	86.8
Charcoal	110	68.7
LPG	13	8.1
Briquettes	4	2.5
Rice husk	2	1.2
Source of Fuel *(MR)*		
Dumpsite	122	76.2
Bought	84	52.5
Nearby places	23	14.4
Familiarity with Briquettes as Cooking Fuel *(n=160)*		
Familiar	141	88.1
Not familiar	19	11.9
Production of Own Briquettes *(n=160)*		
Yes	27	16.8
No	133	83.1
Ways of Utilizing Briquettes Provided *(MR)*		
For cooking rice	149	93.1
For cooking food	144	90.0
For boiling water	134	83.7
For cooking food of animals	50	31.2
Usefulness of Briquettes as Substitute Fuel *(n=160)*		
Yes	149	93.1
No	11	6.9
Willingness to Buy Briquettes if Sold in the Market *(n=160)*		
Yes	130	81.2
No	4	2.5
Not sure	26	16.2

Economic Analysis

The cost analysis in producing briquettes is presented in Table 7. The improved briquette molder entailed additional cost as compared to the hand-press molder. The total cost of investment was Php37,000.00 while the fixed cost gave the same value for the three types of briquettes. The production of pure paper briquettes, however, entailed a higher variable cost of Php229.12 per day when compared to the other two briquettes which needed only Php214.56 per day. This was mainly due to the higher cost of electricity needed for pulping operations. Considering all the costs incurred at an assumed 8-hour operation per day, the cost of producing any of the three recommended briquettes ranged from about Php32.00 to Php34.00 per every hour of operation or Php0.13 to Php0.16 for every briquette produced. The design and development of this machine can be an answer to the limited commercial production of biomass briquettes in the country that would help convert combustible materials found in the waste stream into wealth (Primer on Biomass Briquette Production, 2010; Adegoke, 2002).

Table 7. Cost Analysis in Briquette Production.

Parameters Measured	Briquette 1 (P)	Briquette 2 (P + SD)	Briquette 3 (P + SD + CRH)
Investment Cost, Php	37,000.00	37,000.00	37,000.00
Fixed Cost, Php/day			
Depreciation [1]	30.41	30.41	30.41
Interest on Investment [2]	8.11	8.11	8.11
Repair & Maintenance [3]	3.38	3.38	3.38
Insurance [4]	1.01	1.01	1.01
Total	**42.91**	**42.91**	**42.91**
Variable Cost, Php/day			
Labor Cost [5]	200.00	200.00	200.00
Cost of Electricity [6]	29.12	14.56	14.56
Total	**229.12**	**214.56**	**214.56**
Total Cost, Php/day	272.03	257.47	257.47
Operating Time, hrs/day	8	8	8
Operating Cost, Php/hr	34.00	32.18	32.18
Php/pc [7]	0.16	0.16	0.13

[1] Straight line method with 10% salvage value and life span of 3 years

[2] 24% of investment cost (IC)

[3] 10% of IC

[4] 3% of IC

[5] The average daily earnings by waste picking is Php123.80 (Ikuse, *et al.*, 2014)

[6]1.12 kW/hr @ 2 hrs pulping operation/day for Briquette 1 and 1 hr for Briquettes 2 and 3 @ Php13.00/kW-hr

[7]Operating cost divided by production rate in pcs/hr from Table 1

Potential Daily Production and Earnings

Data in Table 8 shows the computation for the potential earnings in the production of briquettes based on the production rate presented in Table 1 and operating cost in Table 7 with all data converted on a daily basis. When the briquettes are sold after mark-up at Php15.00/kg multiplied by the production rate for each briquette, the sales or revenue that may be generated would range from Php396.00 to Php548.00 per day. Subtracting the earned revenue with the cost of operation would give the producer potential daily earnings of Php124.00 to Php290.00, a value quite significantly higher when compared to the majority of waste reclaimer's surveyed daily income of Php124 (Ikuse, *et al.,* 2014). When computed on an annual basis, one person may earn Php29,000.00 to Php69,000.00 just by producing briquettes. Higher earnings may be realized if more members of an organization would work together for their income-generating project.

Table 8. Potential Daily Production and Earnings in Briquetting of Wastes.

Parameters Measured	Briquette 1 (P)	Briquette 2 (P + SD)	Briquette 3 (P + SD + CRH)
Production Rate [1], kg/day	26.40	31.84	36.48
Operating Cost [2], Php/day	272.00	257.44	257.44
Sales [3], Php/day	396.00	477.60	547.20
Potential Earnings:			
Php/day [4]	124.00	220.16	289.76
Php/yr[5]	29,760.00	52,838.40	69,542.40

[1]Obtained from Table 1 multiplied by 8-hr production per day

[2] Obtained from Table 7 multiplied by 8-hr operation per day

[3] Revenue for briquettes when sold at a mark-up price of Php15.00/kg (@ Php0.25 per briquette after mark-up)

[4]Sales less operating cost

[5] Potential earnings in Php/day multiplied by 20 days production per month for 12 months

CONCLUSIONS AND RECOMMENDATIONS

It can be concluded, in general, that the designed jack-driven briquetting machine has technically improved in terms of operating performance and production of briquettes based on the laboratory and actual field production tests conducted. Specifically, the bulk density of the briquettes was improved to a value comparable to other briquettes produced made from agricultural, forest origin biomass and waste paper that use a horizontal crank-and-piston briquetting press and Shimadzu hydraulic press.

The physico-chemical quality of the produced briquettes implies optimism as to their potential when utilized as fuels for heating operations due to their heating value that can sustain combustion. Its utilization for briquette production has also presented economic viability as an income-generating project.

Based on the findings and conclusions of the study, the following are recommended:

In spite of Briquette 3's high potential earnings, it is recommended that paper (Briquette 1) or a combination of paper and sawdust (Briquette 2) be utilized for briquette production using the designed jack-driven briquetting machine due to their better physico-chemical properties like bulk density, heating value, proximate and ultimate analyses.

Connection of the lever of the hydraulic-type bottle-jack to an electric motor for mechanized operation leading to higher production rate. Improvement of the hinge of the cover so that it would be able to withstand the pressure received during compression. Allow better catchment for water drips for cleaner operation by improving the height of the guide on the perimeter on the plate and by adjusting the inclination of the plate so that the water would easily flow into the spout provided. Attachment of rollers or wheels for easy mobility of the machine.

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