BRIQUETTING OF BIOMASS AND URBAN WASTES USINGA HOUSEHOLD BRIQUETTE MOLDER

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ABSTRACT

This study was conducted to produce briquettes as alternative source of energy from abundant biomass and urban wastes using a locally fabricated household briquette molder which is composed of molders, handle and frame. The mixtures used were the following: Briquette 1: paper (100%); Briquette 2: carbonized rice husk or CRH (71%) + cornstarch (29%); Briquette 3: Sawdust (71%) + cornstarch (29%); Briquette 4: paper (50%) + CRH (50%); Briquette 5: paper (50%) + sawdust (50%); and Briquette 6: paper (50%) + CRH (25%) + sawdust (25%). Smaller sizes of balled homogeneous materials were placed into each of the molder of the machine. The materials were compacted by closing and pressing down the movable upper half portion of the molder then the briquettes produced were placed on trays for sundrying until ideal for fuel use. Briquettes 1 (Paper), 5 (Paper + Sawdust), and 6 (Paper + CRH + Sawdust) were found to be the most viable mixtures. This is based on practicality of production requirements and high production rate, better quality of fuel produced, fast operating performance in terms of boiling water and cooking rice and potential earnings that may be gained when adopted as an income generating project.

Keywords: Briquetting. Briquette molder, Briquette, Biomass utilization, waste to energy

INTRODUCTION

Philippine government agencies such as the Department of Energy (DOE), Department of Environment and Natural Resources (DENR), Department of Science and Technology (DOST) and other entities are currently promoting the development and widespread use of biomass resources through pilot testing, demonstration and commercial use of technologies such as biomass charcoal briquetting. The production and use of briquettes from abandoned resources like biomass and urban wastes are growing due to increase in fuel prices. Converting them, among others into briquettes, gives an opportunity to dispose of wastes and at the same time cleans the community of unwanted wastes, conserves the forest and reduces greenhouse gas (GHG) emissions and provides alternative/additional livelihood to the urban and rural poor communities (Banconguis, 2007).

The process of briquetting involves the compression of a material into a solid 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). In addition, if briquettes are produced at low cost and made conveniently accessible to consumers, it could serve as supplement to firewood and charcoal for domestic cooking and agro-industrial operations, thereby reducing the high demand for the latter two (Olorunnisola, 2007). Hence, these materials which were of low density prior to being converted into briquettes is compressed to form a product of higher bulk density, lower moisture content and uniform size and shape making these materials easier to package and store, cheaper to transport, more convenient to use, and better in combustible characteristics than those of the original waste material.

In many developing countries, large quantities of agricultural and forestry residues produced annually are mostly under-utilized. These residues are either left to decompose or just dumped at the back of the processing mills or along the roads. In worst cases, these wastes are burned inefficiently in loose form contributing more problems to the air quality of the environment. However, when these wastes are properly managed and utilized for cooking operations, they could become a renewable alternative source of energy. Previous studies have shown the potential of these residues when processed into upgraded fuel products such as briquettes. One of these locally available materials briquetted for fuel energy production is sawdust (Adekoya, 1989; Ajayi & Lawal, 1995; Olorunnisola, 1998).

Biomass is any organic matter that is available on a renewable or recurring basis, including agricultural crops and trees, wood and wood wastes and residues, plants (including aquatic plants), grasses, residues, fibers, and animal, municipal, and other waste materials (from http://www.epa.gov/sustainability/pdfs/Biomass%20Conversion.pdf). Almost any biomass can be briquetted either individually or in combination without using any binder (from http://www.lehrafuel.com/briquettes-manufacturing-process.html). In the Philippines, being an agricultural country, production of biomass wastes has not been a problem at all.

One third of the agricultural lands in the Philippines are cultivated for crop production (FAO, 2000). With the country's increasing population, the demand for rice is also increasing. During rice milling, the outer covering of paddy, known as rice husk, has to be removed before it can be processed further for human consumption. Rice husk accounts for 20 to 25% of the paddy's weight. According to data, the total rice husk potential of the country is estimated to be 3.14 million metric tons in 2005. The Province of Iloilo, which is the leader in terms of rice production in the Western Visayas region of the Philippines generates about 165,000 metric tons annually (from http://www.aseanenergy.org/download/eaef/105-2004%20Project%20%20Summary%20for%20web.pdf). Rice husk, however, has to be converted in carbonized form before this can be made as pure material or mixture in briquette production. This can be attained by subjecting the materials to carbonization or pyrolysis or the carbonized rice husk (CRH) can be obtained directly as a by-product when rice husk is used as fuel in direct combustion stoves or in gasifiers.

Another important source of biomass waste in the Philippines is sawdust which comes from logging and milling operations. The 2.06 million hectares established forest plantation in 2005 is projected to even increase in the next ten years. Wood production from new plantations is also estimated to increase thereby increasing the generation of an abandoned biomass waste in the form of sawdust. This waste material, however, is seldom used as fuel for cooking stoves because of its high moisture content, but it can be utilized as an added material for briquetting.

Based on the 20-day segregation test run conducted by Paul, et. al. (2007), the volume of wastes brought daily to the materials recovery facility (MRF) of Iloilo City located in Brgy. Calajunan varied from 3.85 to 13.48 tons. These wastes were first segregated mechanically. Then all materials of oversize fraction were further segregated manually by local waste pickers. Results of the study further revealed that 4554 kg of paper were collected or a daily production of 227 kg. These waste papers are presently sold by the waste pickers at Php1.50 per kilogram. Based on this test, which tackled only around 20 tons of the daily delivered 170 tons of domestic type waste at Calajunan, more than 2500 kg of waste paper per day could theoretically be recovered. This recovered waste paper could be an alternative and viable material in binding the biomass residues for binder-less and perhaps smokeless briquette production (Grigorion, 2003; Demirbas & Sahin, 1998).

The high generation of biomass wastes like rice husks and sawdust including high-energy material like waste paper found in the waste stream is a significant way of properly utilizing them as fuel by converting them into briquettes. This study evaluated the potential of converting these wastes into briquetted fuel by verifying the quality of briquettes produced using pure and combined mixture of biomass and waste papers after preliminary tests have been made on their mixing ratio.

Objectives of the Study

The objective of this study was to produce briquettes from abundant biomass and urban wastes using a hand-press briquette molder primarily designed for household or small-scale level of production as alternative source of energy. Specifically, this study aimed to determine the following:

1. Viable combination of pure biomass and urban wastes in briquette production;
2. Production requirements such as briquetting time and number of briquettes produced out of total materials used;
3. Quality of the briquettes produced based on their physical dimensions and appearance, bulk density, ash content, and heating value/calorific value;
4. Operating performance of briquettes when used for boiling water and cooking rice;
5. The significant difference among briquettes produced when analyzed according to production rate, boiling time and cooking time;
6. Economic analysis of briquette production; and,
7. The impact of briquetting biomass and urban wastes in terms of the potential daily production and earnings.

Significance of the Study

The conversion of biomass and urban wastes is an environmental way of recycling them into useful fuel briquettes to help reduce the dependence of the households on charcoal, a still commonly used fuel for cooking in the country. Less dependence in the use of charcoal would mean less cutting down of trees which has an impact on the depletion of forest resources. With the significant volume of waste paper collected at the Calajunan dumpsite, then the conversion of these wastes into briquettes may become a viable business enterprise and a source of income for Uswag Calajunan Livelihood Association (UCLA). The informal waste pickers of UCLA can become experts in recycling waste products like paper and other biomass wastes for profit, thereby providing the populace with a new and cheap alternative source of cooking energy. Other organizations and offices producing a lot of these wastes can also venture on the idea of producing and selling their own briquettes. The utilization of carbonized rice husks produced as by-products of rice husk stoves and gasifiers together with sawdust would find their value as an essential add-on mixture for briquette production, whereas, waste papers that cannot be sold as recyclable materials may still be utilized and molded properly as briquettes increasing their monetary value when sold as fuel for cooking.

Time and Place of the Study

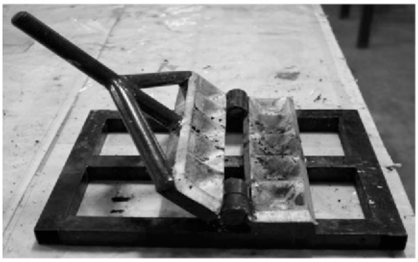
Purchase of materials and fabrication of the household briquette molder that was used for production of briquettes started in the first week of December 2010. The machine was fabricated by a local shop in Leganes, Iloilo. When the machine was done, production of briquettes and its evaluation followed at the Appropriate Technology Center, College of Agriculture, Resources, and Environmental Sciences (CARES), Central Philippine University, Iloilo City from January to the first week of February 2011.

METHODOLOGY

Technical Description of the Machine Used for Briquette Production

A simple briquette molder was developed to produce briquettes at the household level. The briquette molder was constructed using locally available materials. It was fabricated at a local welding shop making it easier for adoption should a local community decide on small-scale production of briquettes using any ideal material for briquetting. The machine, as presented in Figure 1, is composed of the briquette molders, a handle, and frame.

Briquette molders. Five symmetrical molders, connected on both sides by a hinge creating a movable top that could be raised, were used to contain



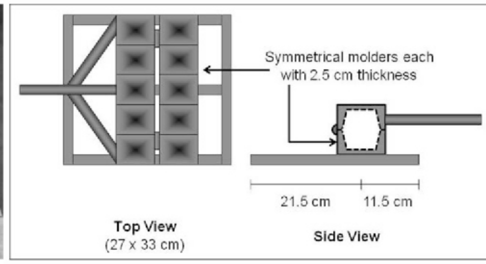


Figure 1. Household briquette molder used for briquette production, showing from left to right: the pictorial view of the machine and the schematic drawing showing its dimensions

the prepared mixture for compaction. Each molder was 5 cm long, 5 cm wide and 2.5 cm high. A cutting allowance was provided giving a total length and width of 27 cm and 6 cm, respectively. The molders were fabricated using a 1/8 in. thick flat bar and were welded together to attain the pillow-shaped briquettes.

Handle. This is the part of the machine that maneuvers the movement of the upper half of the molder. This is also responsible in creating the pressure needed in the compaction of the mixtures. A 3/4 in. (schedule 20) galvanized iron (GI) pipe with a length of 20.5 cm was welded at the center of the upper half of the molders and was braced with two similar pipes each having a length of 14 cm.

Frame. A 1/8 in. thick, 1 in. wide square bar was used as frame of the briquette molders. One side of the frame was used as support during compression of the prepared mixtures while the handle was being pushed downward to create more pressure.

The operation of the briquette molder works on the principle of compacting the prepared mixture through the two symmetrical molders fastened together by two hinges on one side and with a handle on the other side. The movable upper half of the molder is lifted so the mixture can be placed into the molders in the fixed bottom part. The mixtures are compacted by closing down the upper half molder. The pressure created on the mixtures depend on the control and power of the user of the machine and this can be created by pushing the handle down using one hand while the other hand holds the frame for stability.

Preparation of Materials

Three materials were prepared for this study namely, paper, carbonized rice husk (CRH), and sawdust. The papers used were wastes generated from the office of the Appropriate Technology Center of CPU CARES. These papers were a combination of mostly computer print outs and corrugated paper (cartons) that were soaked and pulped for 4 to 10 min. Pulping was done to disentangle the fibers using a locally developed pulping machine driven by a 1 Hp electric motor. Excess water from the pulped papers was squeezed using a plastic net bag.

The biomass wastes, on the other hand, were made available in sacks. The CRH and sawdust were smaller in size (0.1 to 0.6 mm). Cornstarch as the binding material was mixed when pure CRH and sawdust were used.

Cornstarch was weighed first using a 2 kg-compact scale then was carefully mixed with tap water in the container. The mixture was boiled to produce a gelatinous material. After cooling the binder, this was mixed with the materials (CRH and sawdust and its combination) by hand until a homogeneous state was attained. For mixtures that contained paper, cornstarch was not needed for tests because the papers already served as binding material.

Production and Evaluation of Briquettes

Six different types of briquettes were produced using biomass and urban wastes. Presented in Table 1 are the different mixing proportions of the tested materials. Briquette 1 was produced using 100% paper that was pulped prior to briquetting. Briquette 2, on the other hand, was made of 71% carbonized rice husk (CRH) with 29% cornstarch as binding material. Briquette 3 has also the same percentage of materials as Briquette 2 except that sawdust was used as biomass. Briquettes 4 and 5 were produced from a combination of 50% paper and 50% CRH, and 50% of paper and 50% sawdust, respectively. Briquette 6 was made of 25% sawdust, 50% paper and 25% CRH. Only Briquettes 2 and 3 utilized cornstarch as binding material. The rest of the briquettes had paper in the mixture that served as a binder at a higher percentage. In a study conducted by Demirbas and Sahin (1998), it was found out that waste paper maybe used as a partial binding material alone. With the mixing compositions used, briquettes mixed with paper were even more compact than the briquettes produced without paper.

Table 1. Mixing Compositions of Tested Mixtures

Briquette	Briquette Components							
	Paper (P)		CRH		Sawdust (SD)		Cornstarch	
	g	%	g	%	g	%	g	%
1	1,000	100	-	-	-	-	-	-
2	-	-	1,000	71	-	-	400	29
3	-	-	-	-	1,000	71	400	29
4	500	50	500	50	-	-	-	-
5	500	50	-	-	500	50	-	-
6	500	50	250	25	250	25	-	-

The dry weight of biomass and urban wastes and their combinations was fixed at 1000 g. A 20-kg Fuji spring-scale balance was used in measuring the weight of the materials. However, the total fresh weight of briquettes produced per type varied due to the added weight of water after the papers used underwent pulping. Once a homogeneous mixture was attained, smaller sizes of balled materials were placed into each of the molder of the machine. The materials were compacted by closing and pressing down the movable upper half of the molder. One hand of the operator holds the handle while the other hand to prevent the machine from tipping down. Excess water especially in mixtures with paper was also removed during compaction. After compaction, the movable top was lifted to take out the briquettes produced. The briquettes were then placed on trays and were sundried for more than 5 days. Once dried, the fuels were weighed again and the dimensions of the briquettes were measured using a vernier caliper. Figure 2 shows how briquetting of materials was performed.

Figure 2. Briquetting of wastes, showing from left to right: placement of balled mixtures in the molder, compaction of the materials, and the pillow-shaped briquettes produced.

The following parameters were analyzed for this study:

1. Production rate. This refers to the quantity of briquettes produced per unit time expressed in pieces per hour and in kilograms per hour.
2. Bulk density. This represents the ratio of the weight of briquettes produced per unit volume. This was determined by dividing the weight of one briquette with its volume.
3. Ash content. This is an approximate measure of the mineral content and other inorganic matter in biomass. This was measured by getting the ratio between the weight of ash produced and the initial weight of fuel used multiplied by 100.
4. Heating value/calorific value. This represents the amount of heat released during the combustion of a specified amount of fuel. This was determined using a bomb calorimeter found in the laboratory facility of Victorias Milling Company, Inc. in Victorias City, Negros Occidental.

The summary of the procedure in briquette production is presented in Figure 3. This involved four major steps, namely: preparation of materials used (pulped and squeezed waste paper, carbonized rice husk, and sawdust), mixing of the prepared materials by hand, compaction of the materials using the developed briquette molder, and sundrying of the briquettes to produce the finished products.

Performance Evaluation

Performance evaluation of briquettes was done in three test runs. Boiling of water and cooking of rice using the six different types of briquettes produced and with the use of charcoal as fuel were performed simultaneously using an ordinary charcoal stove found in the market. At the start of every boiling and cooking operation, the number of briquettes and charcoal was set to twelve (12) pieces. The fuel was gradually added to the stove until the required operation was performed. Two liters of water was used for the water boiling test while 750 g of rice with same amount of water was utilized for the cooking test. The total weight of fuel used and the total number of briquettes used as fuel were then noted including the total time of operation. An Oakton thermocouple thermometer was used in monitoring the temperature of the water during the water boiling test. After every boiling and cooking test, the weight of ash produced was measured.

All data presented in the results are averaged figures after the test was performed in three runs.

Statistical Analysis of Data

The average of all parameters analyzed was computed using the arithmetic mean. One-way analysis of variance (ANOVA) was used to determine whether the means of parameters of the performance of the molder based on the different briquettes produced analyzed were significantly different from each other. Significant differences between/among the means were determined using the Duncan's Multiple Range Test (DMRT) to further compute the numerical boundaries that allow for the classification of the difference between any two means as significant or non-significant. This was presented using the alphabet notation, *a* being the highest, followed by notations *b*, *c*, *d* , and *e,* the latest, being the lowest.

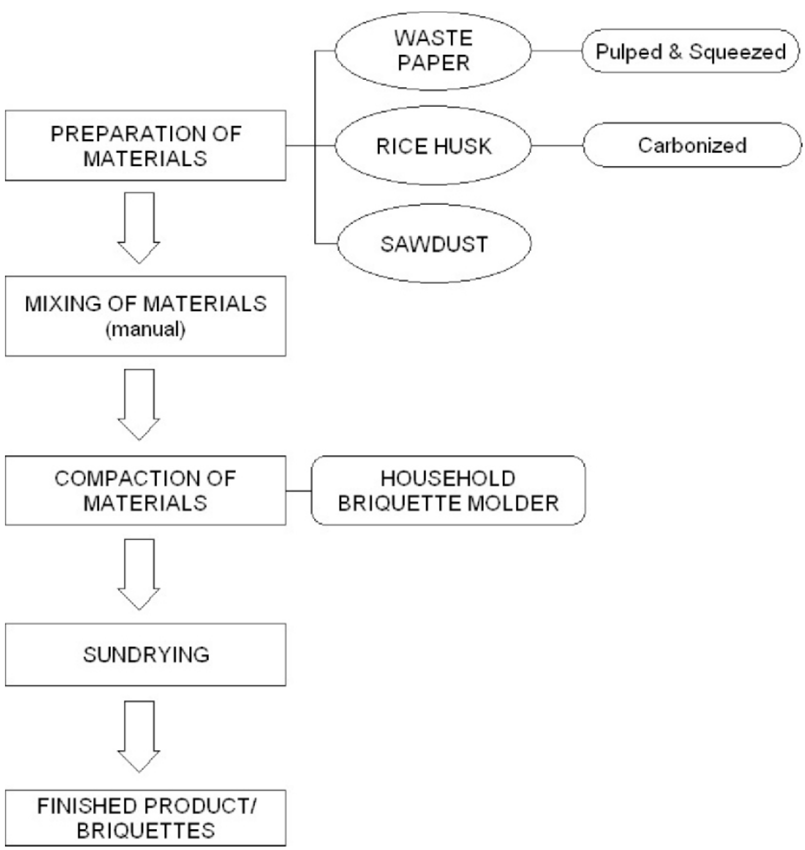


Figure 3. Summary of procedure for the production of briquettes.

RESULTS AND DISCUSSIONS

Production Requirements

Shown in Table 2 are the production requirements during the briquetting of wastes. All briquettes had the same total dry weight of 1,000 g except for Briquettes 2 and 3 which had 1,400 g because the 400 g weight of the binding material (cornstarch) was included in the mixture. Mixing time for all briquettes was at almost 4 min, except for paper, which did not require any mixing since the material utilized was just the same.

Table 2. Average Production Requirements During Briquetting of Wastes

Parameters Measured	Briq 1 (P)	Briq 2 (CRH)	Briq 3 (SD)	Briq 4 (P+CRH)	Briq 5 (P + SD)	Briq 6 (P+CRH+ SD)
Total dry wt. of mixture, g	1,000	1,400	1,400	1,000	1,000	1,000
Mixing time, min	-	4	3.3	3.6	4.1	3.8
Pulping time, min	8.6	-	-	4.2	6.3	5.5
Briquetting time, min	33	30.8	54	22	26.3	26.3
Briquettes produced out of dry materials, pcs	82	54	93	59	81	64
Fresh wt. per briquette, g	50.7	52.1	36.33	53	43	48.7
Dry wt. per briquette, g	12.8	26.2	11.3	18.5	12.1	15.8
Fresh wt. of all briquettes, g	4,427	2,790	3,358.3	3,091.6	3,420	3,088
Dry wt. of all briquettes, g	1,053.3	1,423.3	1,042	1,081.7	996.6	1,008.3
Drying time, days	9	7	6	5.7	5.7	5.6
Production rate, pcs/hr[1]	150 [b]	106 [c]	105 [c]	153 [b]	185 [a]	147 [b]
kg/hr[2]	1.92 [c]	2.78 [a]	1.18 [d]	2.97 [a]	2.28 [b]	2.31 [b]

[1] cv = 41.71%

[2] cv = 8.93%

[abcd] 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

For pure paper briquettes, it took 8.6 min to pulp the 1,000 g dry material, while it was around 4 to 6 min for Briquettes 4, 5 and 6 since all made use of the same amount (500 g) of paper. Results on briquetting time revealed that among the six briquettes, Briquette 3 made of pure sawdust was the most difficult to mold because it took 54 min for the prepared dry mixture to be molded into briquettes. The paper and CRH combination (Briquette 4) was the fastest at 22 min while for the rest, briquetting was completed after 26.3 to 33 minutes.

Numerically, more briquettes were produced for Briquette 3 at 93 pieces out of the dry materials used. This was followed by Briquettes 1 and 5 with 82 and 81 pieces, respectively. For production rate in terms of pieces per hour, results showed significant ($P<0.01$) difference with Briquette 5 (P+SD) having the highest at 185 pcs/hr followed by Briquettes 1, 4 and 6. The briquettes made from pure biomass (Briquettes 2 and 3) resulted in lesser number due to the difficulty in removing intact molded briquettes from the molder. Instead of producing five briquettes in one compaction, there were instances where only 2 or 3 intact briquettes were formed making the rate of production lower. As to the four other briquettes with paper acting as binding material, more were produced because the briquettes were compact, thus, these can be easily taken out from the molder. However, when the production rate was converted to weight per hour, Briquettes 2 and 4 produced the highest ($P<0.01$) due to the high content of silica in carbonized rice husk and also due to the heavier dry weight per briquette at 26.2 g and 18.5 g, respectively. This was followed by Briquettes 5 and 6 with 2.28 kg/hr and 2.31 kg/hr, respectively. Third was the pure paper with 1.92 kg/hr. The least was the pure sawdust with 1.18 kg/hr. The main reason why they had the least production in terms of weight per unit time was due to the lighter dry weight per briquette of the fuels compared to the other single-material briquettes produced.

Quality of Briquettes

Table 3 and Figure 4 present the quality of briquettes produced. The six types of briquettes were pillow-shaped and the colors of the briquettes varied depending on the main material used. Briquette 1 appeared to be white due to the quality of waste papers utilized which were mostly computer printouts. The fuels produced were hard and bulky with uneven surfaces. Briquette 2, which was made of pure CRH was black because of the carbonized materials. The resulting fuels were hard when pressed by hand and had an even surface with fine texture. The color of the pure sawdust briquettes (Briquette 3) is rust with crumbly rough texture. For Briquette 4, the fuels produced were porous with slightly bulky and dusty surface. White was the dominant color due to the pulped paper used with accents of black because of the CRH mixed. The combination of paper and sawdust (Briquette 5) produced slightly uneven and dusty surfaces. The briquettes were light brown with white spots and the fuels appeared to be porous. Briquette 6, which was a combination of paper, CRH and sawdust, were slightly bulky and porous with uneven surface. The briquettes were darker brown than Briquette 5 due to the presence of CRH, a black material, in the mixture.

The briquettes had approximate length and width of 5 cm and a height close to 4 cm. In terms of bulk density per briquette, the pure CRH briquettes (Briquette 2) had the highest at 0.3 g/cc primarily because of the addition of cornstarch as binding material which has a higher bulk density at 0.67 g/cc (from http://www.powderandbulk.com/resources/bulkdensity/material_bulk_density_chart_c.htm). This was followed by Briquettes 4 and 6 with 0.2 g/cc while briquettes which did not contain any CRH had a bulk density of 0.1 g/cc. Results revealed that all briquettes containing CRH (Briquettes 6, 2 and 4) produced numerically the highest ash content at 55.5%, 44.4% and 29.8%, respectively. This was expected since ash was already present in the material after undergoing pyrolysis. The high generation of ash in these types of briquettes could become a problem during cleaning of stoves and eventually during its disposal. Briquette 3 which contained only sawdust produced lower ash at 24.3% since most of the organic content of the materials used were completely combusted. Briquettes 1 and 5 had almost the same concentration of ash at 11.1% and 12.2%, respectively. The presence of paper in Briquette 5 decreased the ash by almost 50% when compared to Briquette 3 which was made of pure sawdust.

Table 3. Quality of Briquettes Produced

Parameters Measured	Briq 1 (P)	Briq 2 (CRH)	Briq 3 (SD)	Briq 4 (P+CRH)	Briq 5 (P + SD)	Briq 6 (P+CRH+SD)
Color	white	black	rust	black with white spots	light brown with white spots	dark brown with black and white spots
Length, cm (˜)	4.9	4.8	4.7	4.5	5.1	4.5
Width, cm (˜)	5.1	5.0	4.9	5.2	5.1	5.2
Height, cm (˜)	4.2	3.8	4.0	3.6	4.2	4.2
Bulk density, g/cc	0.1	0.3	0.1	0.2	0.1	0.2
Ash content, %	11.1	44.4	24.3	29.8	12.2	55.6
Heating value, Btu/lb	6,500	5,284	10,999	5,685	6,683	7,061

Figure 4. Types of briquettes produced using biomass and urban wastes, from left to right: paper, CRH, sawdust, paper and CRH, paper and sawdust, and paper, CRH and sawdust

A heating value of about 5,000 Btu/lb or greater is needed to sustain combustion (Lee, 2007). Results of laboratory analysis revealed that Briquette 3 (pure sawdust) gave the highest heating value at 10,999 Btu/lb with Briquette 2 or the pure CRH having the lowest at 5,284 Btu/lb. It can also be noted that briquettes with sawdust as add-on material also gave higher heating value. The heating value of the fuels produced implies a promising potential for the briquettes as substitute fuel. Charcoal has a heating value of 8,267 Btu/lb (from http://erdb.denr.gov.ph/publications/denr/denr_v10.pdf) whereas bituminous coal, a commonly used fuel in industries, has a heating value ranging from 10,500 to 15,500 Btu/lb (from http://www.ket.org/Trips/Coal?AGSMM/ agsmmtypes.html).

Operating Performance

The operating performance of the briquettes are presented in Table 4. The briquettes were tested based on their potential when used as fuel for boiling water and for cooking rice. The same type of concrete stove was used for this specific test. The data gathered were compared with that of charcoal, one of the most common fuels used by households in the rural areas of the Philippines. Initially, 12 pieces of briquettes and charcoal were placed on the stove at the start of every operation. This was the initial number of pieces used because the stove can only accommodate this much. The fuels were gradually added until the required operation was performed; thus, the data in the table show different number of briquettes both during the boiling of water and cooking of rice test. Results in Table 4 revealed that briquettes containing paper had the fastest start-up time of 1.2 to 1.8 min, whereas, the pure sawdust and charcoal can be started at 2.0 min. Start-up time for the pure CRH was 5.5 min. When the briquettes were being started-up, smoke was emitted but once the fuel was already glowing, smoke gradually dissipated. For Briquettes 2 and 4, however, significant amount of smoke was emitted during the entire operation.

Statistical analysis showed that among the six briquettes produced, Briquettes 1, 3 and 5 boiled 2000 g water the fastest ($P<0.01$) at 12.6 to 13 min followed closely by Briquette 6 at 15.6 min. Boiling time for these four briquettes was not significantly ($P>0.01$) different from each other but those of Briquettes 1.3 and 5 were significant faster than that of charcoal which boiled water at 19.3 min. The weights of briquettes used, which ranged from 265 g to 300 g, were also numerically comparable to that of charcoal which has a value of 245 g. The two briquettes with the least performance as to boiling time were Briquettes 4 and 2 which took more than 30 min to boil the water. For the cooking test, 750 g of rice was used because this amount represented the usual quantity cooked by a typical household having 4 to 5 members. Results revealed a significant ($P<0.01$) difference. Briquettes 1 and 5 had the fastest cooking time of 17 to 18 min. This was followed by Briquettes 3 and 6 at 23 min. Charcoal at 25.5 min was the third best followed by Briquettes 4 and 2 which had a cooking time of 33.3 and 46.7 min, respectively. The difference in the tested parameters can be explained by their differences in heating value. Due to the low heating value of Briquettes 2 and 4, more briquettes were used for boiling water and cooking rice and longer time was needed to perform the two operations. With these measured parameters, Briquettes 1, 5 and 6 are the recommended fuels because these fuels were able to boil water and cook rice in a shorter period using lesser amount. It was also observed that more blazes were produced in these types of briquettes which had little or no amount of CRH. Charcoal when used as fuel produced more glow than blaze.

Economic Analysis

The economic analysis in producing briquettes is shown in Table 5. The briquette molder costs Php6,000.00. Components of the fixed cost has a similar value of Php13.38, whereas, those of the variable cost differed because there were briquettes which made use of electricity for pulping of paper (Briquettes 1, 4, 5 and 6) while Briquettes 2 and 3, although no electricity was used, made use of cornstarch as binding material. Among the six briquettes, the pure paper (Briquette 1) incurred the highest total cost per day at Php194.84 followed by briquettes that made use of starch (Briquettes 2 and 3) at Php187.48. The briquettes which used a combination of paper, CRH and sawdust (Briquettes 4, 5 and 6) had a total cost per day of Php179.16 only. Dividing the total cost with an assumed 8-hour briquette production per day also gave the same trend for operating cost. Results further revealed that for every hour of operation, Briquette 1 obtained the highest cost at Php24.36 followed by Briquettes 2 and 3 (Php23.22/hr) and Briquettes 4, 5 and 6 with a value of Php22.40.

Potential Daily Production and Earnings

Table 6 presents the potential daily production and earnings of the different briquettes produced. Results on the briquette production for dry weight materials were achieved based on the production rate determined during the test and based on the assumption that when adopted as a project, production time would be managed in 8 hours. Results showed that when the

Table 4. Operating Performance of Briquettes as Fuel

[illegible]	[illegible] [illegible]	Briq 2 (CRH)	Briq 3 (SD)	Briq 4 (P+CRH)	Briq 5 (P + SD)	Briq 6 (P+CRH+SD)	Charcoal
A. Boiling Test							
Wt. of water used, g	2,000	2,000	2,000	2,000	2,000	2,000	2,000
No. of briquettes used, pcs	17	21	21	27	17	18	20
Wt. of briquettes used, g	298.3	546.7	370	470	265	268.3	245
Start-up time, min	1.2	5.5	2.0	1.8	1.4	1.4	2.0
Boiling time, min [1]	13.4 [a]	54.7 [d]	13.0 [a]	32.3 [c]	12.6 [a]	15.6 [ab]	19.3 [b]
Total operating time, min	31.9	60.1	23.0	60.3	22.7	25.0	44
B. Cooking Test							
Wt. of rice cooked, g	750	750	750	750	750	750	750
No. of briquettes used, pcs	15	23	20	21	18	21	16
Wt. of briquettes used, g	305.0	563.3	347.0	383.3	300.0	310	200
Cooking time, min [2]	17.3 [a]	46.7 [e]	23.0 [b]	33.3 [d]	18.4 [a]	22.7 [b]	25.5 [c]

[1] cv = 9.76%
[2] cv = 5.30%
[abcd] Any two means on the parameter measured followed by the same letter superscript are not significantly different at the 1% level of probability

fuels are sold at Php15/kg, a sales or revenue of Php28 to Php44 per kg may be earned for all briquettes except for Briquette 3 which can only earn Php17.40/kg. Due to the different operating cost of briquettes, the savings gained for every hour of operation also varied. Briquettes 2 and 4 could earn a savings of Php18 to Php21 while Briquettes 5 and 6 could generate Php11 to Php13. The pure paper briquette can have a savings of only Php4.44/hr while the pure sawdust incurred a negative value since the operating cost is higher compared to the revenue. The same trend is attained when the savings are computed on a daily basis for an assumed 8-hour operation. The data computed for the economic analysis is for one person only doing the job. Higher earnings are possible, therefore, if more members would work together as an organized association making this as part of their income generating project.

Table 5. Economic Analysis of Briquette Production

Parameters	Briq 1 (P)	Briq 2 (CRH)	Briq 3 (SD)	Briq 4 (P+CRH)	Briq 5 (P+SD)	Briq 6 (P+CRH+SD)
Investment Cost, Php	6,000.00	6,000.00	6,000.00	6,000.00	6,000.00	6,000.00
Fixed Cost, Php/day						
Depreciation[1]	7.40	7.40	7.40	7.40	7.40	7.40
Interest on Investment[2]	3.95	3.95	3.95	3.95	3.95	3.95
Repair & Maintenance[3]	1.64	1.64	1.64	1.64	1.64	1.64
Insurance[4]	0.49	0.49	0.49	0.49	0.49	0.49
Total	13.48	13.48	13.48	13.48	13.48	13.48
Variable Cost, Php/day						
Labor Cost	150.00	150.00	150.00	150.00	150.00	150.00
Cost of Electricity[5]	31.36	0.00	0.00	15.68	15.68	15.68
Starch[6]	0.00	24.00	24.00	0.00	0.00	0.00
Total	181.36	174.00	174.00	165.68	165.68	165.68
Total Cost, Php/day	194.84	187.48	187.48	179.16	179.16	179.16
Operating Time, hrs/day	8	8	8	8	8	8
Operating Cost, Php/hr	24.36	23.44	23.44	22.40	22.40	22.40

[1] Straight line method with 10% salvage value and life span of 2 years
[2] 24% of investment cost (IC)
[3] 10% of IC
[4] 3% of IC
[5] 1.12 kW/hr @ 2 hrs pulping operation/day for Briquette 1 and 1 hr for Briquettes 4, 5 and 6 @ Php14/kW-hr
[6] For whole day production

The conversion of the 4,554 kg of paper or a daily production of 227 kg collected based on the 20-day test done in Calajunan dumpsite in Iloilo City (Paul, et. al., 2007) into briquettes would create more income especially to the members of UCLA. When the collected waste papers are sold at a current rate of Php1.50 per kilogram, it would only give an approximate income of Php338. When the waste papers are converted into pure paper briquette, a gross income of as much as Php3,405 could be earned. More income may also be earned if paper is mixed as an add-on material to biomass wastes like CRH and sawdust.

Table 6. Potential Daily Production and Earnings in Briquetting of Wastes

Parameters Measured	Briq 1 (P)	Briq 2 (CRH)	Briq 3 (SD)	Briq 4 (P+CRH)	Briq 5 (P+SD)	Briq 6 (P+CRH+SD)
Production rate, kg/hr	1.92	2.78	1.18	2.97	2.28	2.31
Operating cost, Php/hr	24.36	23.44	23.44	22.40	22.40	22.40
Sales, Php/kg[1]	28.80	41.70	17.40	44.55	34.20	34.65
Savings, Php/hr[2]	4.44	18.26	(5.74)	21.11	11.80	13.94
Potential earnings, Php/day[3]	35.52	146.08	--	168.88	177.00	209.10

[1] Revenue for briquettes when sold at prevailing price of Php15/kg
[2] Sales less operating cost
[3] Savings multiplied with 8-hr production per day

Summary of Recommended Briquettes

Briquetting is one alternative method that may be utilized in achieving the utilization of biomass and urban wastes into a useful product. Among the different mixtures tried in producing briquettes for fuel use with the aid of a hand-press type molder, Briquettes 1, 5 and 6 are the most recommended mixtures because of their practicality, high rate of production and performance when used and compared to charcoal as fuel for boiling water and cooking rice. Produced fuels having high potential earnings per day like Briquettes 2 and 4 are not recommended because of their low performance as cooking fuels and also the difficulty in preparing and molding them. Presented in Table 7 are the three recommended mixtures of briquettes for easy identification including the outcomes of the corresponding parameters measured.

Table 7. Summary of Highly Recommended Briquettes

Parameters	Highly Recommended Briquettes		
	Briq 1 (P)	Briq 5 (P+SD)	Briq 6 (P+CRH+SD)
Production rate, pcs/hr	150 ^{b}	185 ^{a}	147 ^{b}
kg/hr	1.92 ^{c}	2.28 ^{b}	2.31 ^{b}
Heating value, Btu/lb	6,500	6,683	7,061
Boiling time, min	13.4 ^{a}	12.6 ^{a}	15.6 ^{ab}
Cooking time, min	17.3 ^{a}	18.4 ^{a}	22.7 ^{b}
Potential earnings, Php/day	35.52	177.00	209.10

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

CONCLUSIONS AND RECOMMENDATIONS

Converting wastes like waste papers, carbonized rice husks and sawdust using a simple technology such as the hand-press briquette molder has great prospects when utilized as fuel for household use and eventually as substitute fuel to charcoal.

The following are the conclusions derived from this study:

1. The most viable mixtures for the production of briquettes based on practicality and high rate of production, and performance when used and compared to charcoal as fuel in boiling water and cooking rice are Briquette 1 (100% Paper), Briquette 5 (50% Paper + 50% Sawdust), and Briquette 6 (50% Paper + 25% CRH + 25% Sawdust).
2. The six mixtures tested varied significantly in their production rate. In terms of production rate expressed in pcs/hr, Briquette 5 produced the most followed by either of Briquettes 1, 4, and 6. When expressed in kilogram per hour, Briquettes 2 and 4 obtained the highest followed by either Briquettes 5 or 6. Pure CRH (Briquette 2) and sawdust briquettes (Briquette 3) are difficult to form using the household briquette molder.
3. The briquettes produced using the briquette molder were pillow-shaped with dimensions of approximately 5 cm length x 5 cm width x 4 cm height. More ash is produced from mixtures with CRH. All the briquettes produced were analyzed to have a heating value of more than 5,000 Btu/lb, a value that is needed to sustain combustion. Briquette 3 (sawdust) had the highest heating value at 10,999 Btu/lb while Briquette 2 or the pure CRH had the lowest at 5,284 Btu/lb.
4. Briquettes 1, 3, 5 and 6 had the fastest boiling time while Briquettes 1 and 5 had the fastest cooking time.
5. Briquette 1 generated the highest operating cost followed by Briquettes 2 and 3. Briquettes 4, 5, and 6 obtained the lowest cost.
6. A potential net daily earnings ranging from Php35 to Php209 may be gained by one person in producing briquettes. The 227 kg daily waste paper collected at the dumpsite in Iloilo City could earn an income of Php338 when sold as paper only at the current rate of Php1.50/kg. But when converted as pure paper briquette it could earn a gross income of as much as Php3,405. More income may also be earned if paper is mixed as an add-on material to biomass wastes like CRH and sawdust. In addition, waste papers that cannot be sold as recyclable materials would have the potential to be utilized as briquettes increasing their monetary value when sold as cooking fuel.
7. Production of briquettes can be a viable business enterprise and source of income; members of an organization doing the job can become experts in recycling waste products like paper and other biomass wastes for profit,

thereby providing the populace with a new and cheap alternative source of cooking energy.

8. CRH produced as by-product of rice husk stoves and gasifiers together with sawdust would find their value as an essential add-on mixture for briquette production.

Based on the findings and conclusions of the study, the following are the recommendations for the improvement of this briquette molder:

1. The handle should be lengthened to improve hand compression during operation, thereby, improving the compactness of the briquettes.
2. A part should be added for bolting the frame to properly fasten the briquette molder for more compression during operation.
3. More molders should be added to increase the number of production.
4. Manual operation should be shifted to mechanical means for better compaction and faster operation.
5. Other binding materials should be used as substitute for cornstarch such as bentonite or other fruits with glutinous property.
6. Conduct further studies on optimizing production and operation parameters using Briquette 1 (100% Paper), Briquette 5 (50% Paper + 50% Sawdust), and Briquette 6 (50% Paper + 25% CRH + 25% Sawdust).

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