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Development of a low-cost briquetting system utilizing agri-waste materials as a renewable energy fuel

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ABSTRACT

Briquetting is the most known and widely spread technology of materials compacting. It converts low-bulk-density materials into high-density fuel briquettes. This study investigated the viability of different agricultural wastes and animal manure as major raw materials in the briquetting process using solar power to maximize its full potential as a sustainable energy resource. It consisted of the design and development of a briquetting system, establishment of the operating conditions, performance testing, and product evaluation. Based on a series of tests conducted, a mixing speed of 600 rpm for 3 min, compressive force of 400 N, with briquetting speed of 1800 rpm in 9 s can produce twenty briquettes of 50 mm in diameter and 50 mm in length. Briquettes produced have a calorific value of 4256.12 J/kg, ash content of 2.26 %, moisture content of 19.81 %, and compressive strength of 7.6 MPa. Energy efficiency of 164.46 % indicated that the output energy equivalent is higher than the energy utilized in the production of briquettes, thus showing that the briquetting system developed is viable in the production of briquettes from agri-wastes and animal manure.

Keywords: *agri-wastes, briquetting, energy efficiency, solid fuel*

1. Introduction

Conventional uses of renewable energies are widespread in developed and developing countries reflecting the major threats of climate change due to pollution, exhaustion of fossil fuels, and the environmental, social and political risks of fossil fuels. The Philippine government through the Department of Energy (DOE) invested in clean energy, particularly renewable energy. There are different renewable energy laws, policies, mechanisms and rules that have been formulated and approved for implementation in order to attain the objective of creating a future of less carbon.

In particular, Republic Act 9367 or the Biofuels Act of 2006 provides fiscal incentives and mandates the use of biofuel-blended gasoline and diesel [1]. More so, Republic Act No. 9513 known as the Renewable Energy Act of 2008 accelerates the exploration, development and utilization of renewable energy resources, achieving energy self-reliance, adopting clean energy to mitigate climate change, and promoting socio-economic development in the rural areas [2]. According to DOE, renewable energy has long been a major contributor to the country's primary energy supply mix. The country's total primary energy supply mix for 2011 has reached 39.40 million tons of oil equivalent (MTOE), 60 % of which was harnessed from indigenous sources. On June 14, 2011, the National Renewable Energy Program (NREP) was launched. NREP institutionalizes a comprehensive approach to address challenges and gaps in the application of renewable energy technologies in a sustainable way, and outlines action plans to increase investors in renewable energy development. These include geothermal, hydropower, biomass, wind, solar and ocean energies. NREP seeks to increase the RE-based capacity of the country to an estimated 15,304 MW by 2030 [3].

Renewable resources are important in modern society due to their positive effects on agriculture, the environment and the economy. A significant advantage of renewable resources lies in their contribution to the conservation of finite fossil resources. It is also important to note that renewable resources have an important role to play in reducing CO_2 emissions since only as much CO_2 is released in their combustion or bioconversion as is absorbed during growth. Thus, no additional greenhouse effect is produced. Increasing the share of renewable energy in the energy balance enhances sustainability. It also helps to improve the security of energy supply by reducing the community's growing dependence on imported energy sources.

The Philippine Energy Plan (2009-2030) emphasizes three broad policy thrusts based on the concept of enabling better energy choices for a better quality of life. These major aspects would have an important impact within the next 20 years on the country's energy future. This includes the assurance of energy security, pursuance of effective implementation of energy sector reforms, and implementation of social mobilization and cross-sector monitoring mechanisms. It is along this premise that the country must intensify the development and utilization of renewable and environment-friendly alternative energy resources and technologies [4].

Biomass is a valuable alternative energy resource which is abundantly available in the Philippines. It is carbon-based and is composed of a mixture of organic molecules containing

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hydrogen, usually including atoms of oxygen, often nitrogen and also small quantities of other atoms, including alkali, alkaline earth and heavy metals. It takes carbon out of the atmosphere while it is growing, and returns it as it is burned. If it is managed on a sustainable basis, biomass is harvested as part of a constantly replenished crop [5].

Energy from waste such as biomass is a proven renewable energy source using various energy conversion technologies, which include direct combustion, pyrolysis, and gasification [6]. Direct combustion technology is used for burning waste which cannot be recycled by any other method. The combustion process produces high pressure steam that is converted into electrical power by using a turbine and a generator [7]. Pyrolysis is the thermal degradation of the waste in the absence of air, where the produced syngas can be used to generate electricity [6]. In the gasification process, it involves partial oxidation of the waste, again producing a syngas which is then used to generate energy [7].

Two of the basic categories of biomass waste materials are the agricultural residues and animal manure. Agricultural residues are by-products derived from agriculture harvesting or processing. These include rice straw, rice husk, corn cob, corn husk, bagasse, coconut husk, among others. In the Philippines, rice straw is a major agricultural waste that is produced in extremely large quantities and volumes and contains high moisture content. On the other hand, animal wastes such as cow dung, chicken manure and swine wastes are organic and combustible materials which can also be used as fuel or fertilizer for various applications.

According to [8], the proximate analysis on a dry basis of rice straw contains 75-85 % volatiles, 15-25 % fixed carbon and 0.1-0.7 % ash and the ultimate analysis resulted to 47-52 % carbon, 6.1-6.3 % hydrogen, 38-45 % oxygen, moisture of 10-20 % and small percentages of nitrogen, sulfur, chlorine and potassium with less than 0.2 %, 0.1 %, 0.02 % and 0.036-0.055 %, respectively. Its heating value is 18 MJ/kg.

The ultimate analysis of cow dung, on the other hand, includes 31.6 % carbon, 5.18 % hydrogen, 37.8 % oxygen, 6.12 % nitrogen, 19.3 % ash and 15 % moisture with a heating value of 11.4 MJ/kg [9].

The Ecological Solid Waste Management Act of 2000 (RA 9003) and Philippine Clean Air Act of 1999 prohibit open-field burning, including burning of rice straws. It causes air pollution and if done continuously will decrease the soil nutrient content and damage food resources for insects [10,11]. In the country, there are 15.2 Mt of rice produced yearly that leave 11.3 Mt of rice straw. To minimize the waste of post harvesting, rice straws are used as organic fertilizers to help the farmers save expenses from chemical fertilizers. According to [12], when straws are scattered in the field during land preparation, it maintains soil's nutrients and moisture. Every 5 t of rice straws can increase soil's nutrients such as nitrogen, phosphorus, potassium, sulfur, silicon, and carbon and preserve the biodiversity of microorganisms. This helps in nutrient cycling and efficient fertilizer utilization.

Rice straws are also used as mulch to protect the roots of the plants from heat and cold and reduce the evaporation rate. It also prevents weeds from growing in the paddy field. Rice straws are used as substrate for oyster mushroom production which is economically profitable for farmers and those engaged in agribusiness [12]. Wastes in this utilization of rice straw served as the main substrate for vermicomposting which is one of the best organic fertilizers. Cow dung is mainly used as fertilizer and in some cases as a source of biofuel.

Initiatives made from previous and current research consider some technological breakthroughs to the energy sector for production of green energy. However, current processing methods to exploit the rice straw and cow dung remain inadequate. Huge amounts of these materials are not fully utilized, some are just dumped in the rice fields where biological decomposition process continuously generates methane which is harmful to the environment. Environmental protection and material recycling are utmost concerns nowadays. For renewable energy resources utilization, the briquetting technology would enable agricultural wastes to be removed from the environment, thereby preventing environmental pollution.

Briquetting is the most known and widely spread technology of materials compacting. It converts low-bulk density materials into high-density fuel briquettes [13]. It is therefore in this light that this study considered the investigation of the viability of rice straw and cow dung as major raw materials in the briquetting process to maximize its full potential as a sustainable energy resource. It developed the appropriate engineering design and technology for the production of solid fuel briquettes using different agricultural wastes. It also established the best combination of raw materials for the briquetting process, determined the operating conditions, evaluated the performance of the briquetting system, and tested the properties of the solid fuel briquettes produced.

2. Materials and methods

A Conceive-Design-Implement-Operate (CDIO) model was employed in the completion of the project. It started from the conceptualization of the project, planning, designing until its implementation and operation.

The study consisted of four phases: design phase, fabrication phase, preliminary testing phase and final performance testing phase. In the design phase, the design requirements and specifications of the solid fuel briquetting system was established. Schematic representation was drafted indicating the different system components and dimensions of the proposed system. The 3D model was done using Solidworks to proportionately identify the best dimensions of the machine and simulate its intended functions. The fabrication phase covered the actual fabrication of the briquetting system in accordance with its design specifications. Close monitoring of the fabrication processes was observed to ensure the proper assembly of the system. Visual inspection was done as part of the quality monitoring process.

In order to establish the desired operating conditions of the fabricated system, preliminary test runs were conducted. In this stage, appropriate settings of the system operating parameters were established, which include the mass of feed, mixing speed, mixing time, compacting pressure, and briquetting time. Several modifications were considered to attain the maximum performance of the machine. The final tests focused on the performance evaluation of the machine in terms of mixing rate, briquetting rate, percent yield, and energy efficiency using the established settings and operating conditions. The samples of the briquette products collected during the performance evaluation were tested to determine their physical, mechanical and chemical properties.

2.1. Preparation of raw materials

The raw materials used for various performance tests of the study are rice straw, coco peat, saw dust, chicken manure, horse manure, cow dung collected from various farms located in Batangas province. These biomass materials were sun dried for two to three days to achieve the acceptable moisture content of around 10 % - 18 %. Several combinations of raw materials were tested.

2.2. Operating conditions of the system

Several important parameters were tested both in the preliminary and final performance evaluation of the system. For preliminary evaluation, the following parameters were established to serve as the operating conditions of the system.

2.2.1. Mass of feed

The input materials consist of agri-wastes (rice straw, coco peat and saw dust, corn husk), the animal manure (cow dung, horse manure and chicken manure) served as binder, and water. Different proportions by weight as presented in Table 1 are evaluated. The proportion that resulted in good quality briquettes was the proportion used in the final performance testing.

Table 1. Proportions of raw materials.

Mixture	Agri-wastes, g	Animal manure, g	Water, mL	Total, g
1	Sawdust, 900	Cow dung, 1500	2000	4400
2	Rice straw, 900	Cow dung, 1500	2000	4400
3	Coco peat, 900	Horse manure, 1500	2700	5100
4	Sawdust, 900	Horse manure, 1500	2700	5100
5	Sawdust, 1100	Chicken manure, 1560	2000	4660
6	Coco peat, 1100	Chicken manure, 1560	2000	4660
7	Corn husk, 900	Cow dung, 1500	2500	4900

2.2.2. Auxiliary parameters

Mixing speed refers to the speed of the mixer that results in a consistent mixture of the feed which includes agri-wastes, animal manure and water. Different mixing speeds were tested and the speed that produced the target consistency in the shortest time was the established mixing speed. The time needed to produce a consistent and homogeneous mixture with the corresponding mixing speed was set as the mixing time. Compacting pressure was established by testing different pressure settings necessary for the briquetting process. The pressure setting that produced good quality briquettes considering the different properties was the operating compacting pressure. The time needed to produce good quality briquettes with the set compacting pressure was measured. Briquetting time is the time elapsed from initial compression up to the time that the molder reached its maximum height.

2.2.3. Final performance testing

Series of tests were conducted to determine the following parameters such as the mixing rate which is the ratio of the mass of fed mixture and mixing time; briquetting rate which is the computed as the ratio of mass of acceptable briquettes and briquetting time; and the energy efficiency which is the ratio between the energy output that can be delivered from the produced briquettes and that of the energy input that was used in the processes involved in the briquetting system is termed as energy efficiency.

2.3. Evaluation of the properties of briquettes

The produced briquettes were evaluated in terms of their physical, mechanical and chemical properties.

2.3.1. Physical properties

The physical properties of the produced briquettes were evaluated in terms of dimensions (length and diameter), density, friability, and moisture absorption rate. The target length and diameter of acceptable briquette was set to 50 mm diameter and 50 mm length which is the designed dimensions of the molder. These dimensions were measured using a caliper after compaction. The density was determined by the ratio between the mass and the volume of each acceptable briquette. The mass of the acceptable briquette was measured using a digital weighing scale and its dimensions using a caliper. This water absorption test was performed using the method used in [14]. Five samples from each batch were used in the test. Each sample was immersed in 750 mL room temperature water for 5 min. The water absorbed by the five briquettes per batch were averaged to determine the mean value, which was used to determine the water resistance index (WRI). The water absorption was determined using the relation:

$$\%\,Water\ absorbed = \frac{water\ absorbed}{initial\ weight} * 100\%, \text{ and} \qquad WRI = 100 - \%\,Water\ absorbed \tag{1}$$

where the water absorbed was determined by subtracting the final weight of briquette after immersion and before immersion in water.

2.3.2. Mechanical properties

The mechanical properties of the produced briquettes were evaluated in terms of compressive stress and mechanical durability.

The compressive strength was carried out using a Universal Testing Machine. In this test, the briquette was subjected to continuous and progressive pressure until its fracture. The compression test reported the load relative to the deformation of the briquette and the maximum stress is calculated using this equation:

$$\sigma = \frac{2F}{\pi DL} \tag{2}$$

where σ is the maximum compressive stress in kg/cm^2, F is the maximum load in kg, D is the diameter of the briquette in cm and L is the length of briquette in cm.

Friability is a measure of the briquette's resistance to mechanical action which mainly occurs during handling and transportation of briquettes. From each sample group, 5 briquettes were exposed for friability measurements. The sample briquettes were placed 2 m above a concrete floor from which every briquette was dropped three times [15]. The mass of each briquette before and after the test was recorded. The Friability Index (FI) which is the measure of friability was calculated as the ratio of the mass retained after the test and the original mass of briquettes.

2.3.3. Chemical properties

The chemical properties of the produced briquettes were evaluated in terms of calorific value, ash content and moisture content. The calorific value was tested according to the ASTM D-5865 standard [16] while the ash content was determined according to the ASTM D-1102-84 standard [17]. Moisture content (MC) is the amount of water in solid fuel (briquettes) which is expressed as the percentage by weight of the dry or wet sample. For three groups of briquettes consisting of five briquettes, MC was measured using ASTM D 2016-74 methods [18]. In terms of wet basis, MC was computed using this equation:

$$MC_{wb} = \frac{W_w - W_d}{W_w} * 100\% \tag{3}$$

where: MC_{wb} is the moisture content on wet basis, W_w is the weight of wet briquettes (g) and $_{Wd}$ is the weight of dried briquettes (g). On dry basis, MC will be computed using this equation:

$$MC_{db} = \frac{MC_{wb}}{100 - MC_{wb}} * 100\% \tag{4}$$

3. Results and discussion

Figure 1 shows the designed and fabricated briquetting system.

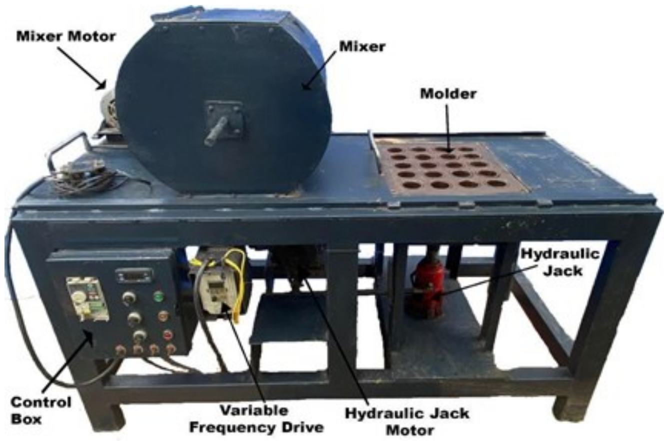

Figure 1. Briquetting system.

3.1. System components

The briquetting system consists of the following major components. Design of the molder is one of the important aspects that was considered during the designing phase. The number of holes, diameter of the hole and the depth of the hole served as the molder configuration. The plate material for molder to be used for fabrication was selected taking into consideration the resistance to corrosion as well the desired thickness.

The mixing chamber is semi-cylindrical in shape and is made up of galvanized steel. It is composed of twelve mixing hammers that move in a continuous rotational motion and has a total volume of 80,907 cm^3. The pre-heated and ground raw materials with the binding agent are loaded into this chamber for thorough and further mixing. It also prevents the feedstock from solidifying prior to the compression processes.

The molder is fabricated with twenty holes having uniform diameter that are capable of handling and containing mixed feedstock. It is made of steel plate with a 5 cm diameter hole and an 88 cm depth. The mixture is placed into this Molder 50 where the compression process takes place. The final output for the briquettes shall follow the cylindrical shape of the molder holes.

The hydraulic jack is a mechanical device composed of a hydrostatic press with its pump and cylinder chamber containing the hydraulic fluid. It applies great forces created by the pressure in the cylinder chamber. The compressive force or compacting pressure used to completely compress the feedstock placed in the molder is provided by this component. The maximum force input to the molder was ascertained to be 40.8 kg (400 N).

The mixing and molding processes are powered by two electric motors. The mixing chamber is powered by a three-phase induction motor which has a capacity of 0.2682 hp (200 W), while the molding process is powered by a 14 kg, three-phase induction motor with a capacity of 1 hp.

A variable frequency drive is a motor controller that changes the frequency and voltage of an electric motor's power supply. In the setup, a VFD with the following specifications is used: single to single phase, 220 V, 1.5 kW. A VFD for the mixing chamber motor is set to a frequency of 10 Hz. Meanwhile, a VFD for the hydraulic jack motor is set to a 30 Hz frequency.

The control box contains the switch for all the motors and variable frequency drives. Indicator lights are provided to help the operator distinguish whether a component is on or off.

Sunlight energy is captured by solar panels, also known as photovoltaics, which then transform it into electricity that can be utilized to power buildings or residences. These panels can be used to extend a building's electrical supply or offer power in outlying areas. For this study, four solar panels served as the primary energy source for the briquetting system's motors. With a surface area of 100 m^2, the four solar panels was able to provide at least 250 W of electricity for each panel.

Without being connected to the local utility grid, an off-grid solar inverter is made to operate totally on its own. The energy produced by solar panels is converted into alternating current, which is used by your appliances and for illumination, using an off-grid solar inverter. An off-grid inverter uses a battery bank rather than supplying AC energy to the grid. The off-grid solar inverter used in this study has a rated power of 3 kW and peak power of 9 kW.

The power coming from the solar array into the battery bank is controlled by a solar charge controller. It prevents the deep cycle batteries from being overcharged during the day and prevents the batteries from being drained at night by power running backwards to the solar panels. Although some charge controllers come with extra features like lighting and load management, their main function is to manage electricity. PWM and MPPT are the two available methods for solar charge controllers. They perform substantially differently from one another in a system. Even though an MPPT charge controller costs more than a PWM charge controller, doing so is frequently justified. For the machine, an MPPT-type solar charge controller is used. Moreover, the wiring diagram of the solar parts and components which serve as the energy source of the motors installed on the briquetting machine is shown in Figure 2.

3.2. Combination of raw materials

The raw materials used for various performance tests of the study are rice straw, coco peat, saw dust, chicken manure, horse manure, cow dung collected from various farms located in Batangas province. Several combinations of raw materials were tested as presented in Table 1.

3.3. Operating parameters

Several trials were conducted in order to establish the operating parameters of the briquetting system. Table 2 presents the established working parameters.

Table 2. Established operating parameters.

Parameters	Values
Mixing speed	10 Hz (600 rpm)
Mixing time	3 min
Compressive force	400 N
Briquetting speed	30 Hz (1800 rpm)
Compacting time	9 s

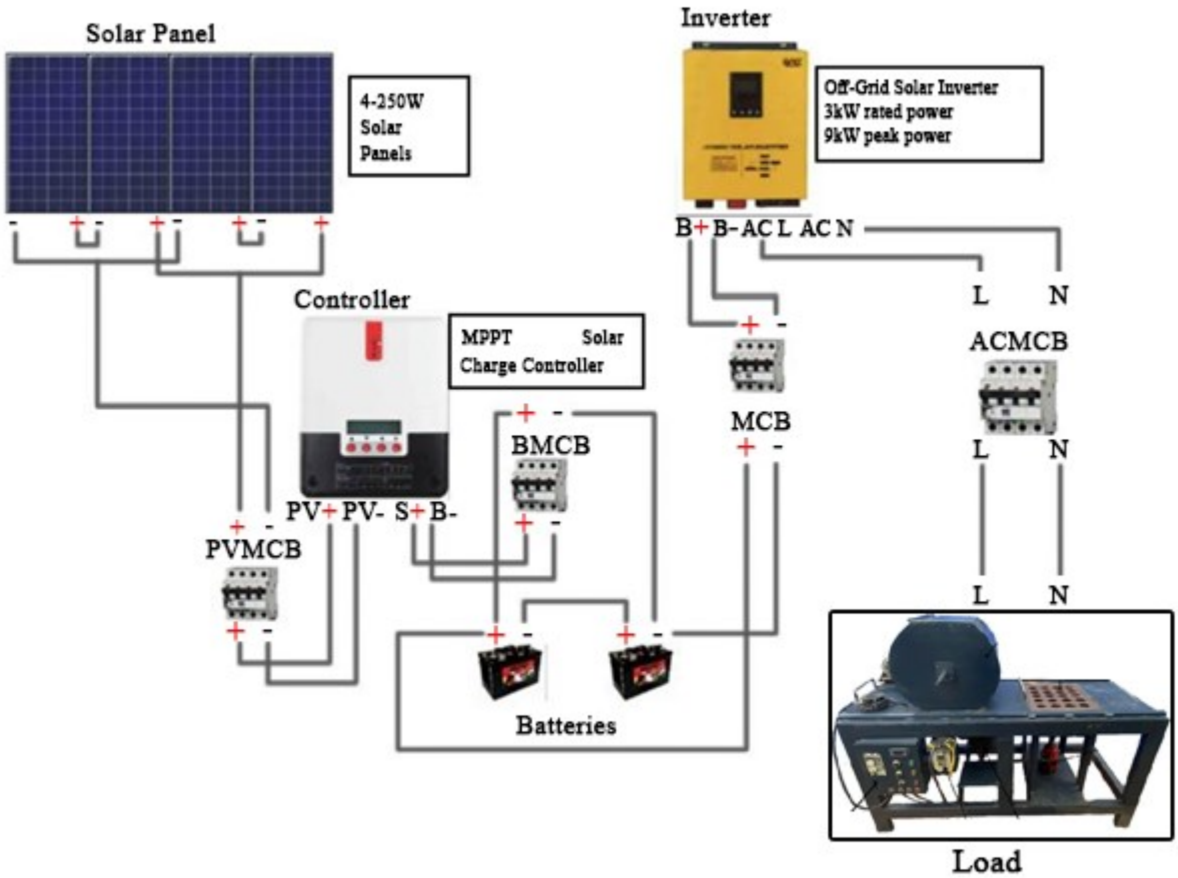

Figure 2. Wiring diagram of the solar panel with solar charge controller, battery, off-grid solar inverter, and load.

3.4. Performance testing results

Performance testing of the briquetting system was performed after achieving a successful trial test run using the established operating parameters. Tables 3 and 4 present the results of the testing.

Table 3. Performance testing results in terms of mechanical properties.

No.	Friability %	Average height, cm	Average weight, g (dry)	Mixing rate, g/s	Briquetting rate, briquettes/min
1	100	4.6	35.6	14.67	3.25
2	55	3.8	30.1	14.67	1.79
3	100	4.3	26.0	17.00	3.25
4	80	5.2	38.0	17.00	2.60
5	90	5.1	39.7	15.53	2.93
6	100	4.7	32.2	15.53	3.25
7	45	6	20.1	16.33	1.46

Table 4. Performance testing results in terms of chemical properties.

Performance parameters	Value
Energy efficiency	164.46 %
Calorific value	4256.12 J/kg
Ash content	2.26 %
Moisture content	19.81 %
Compressive strength	7.6 MPa

4. Conclusions

Size of agricultural wastes affect the properties of produced briquettes. The finer the particles, the better briquettes are produced. The amount of water to be added should be properly determined to produce more quality briquettes at a lesser time. The developed briquetting system is a viable project that can produce alternative solid fuels and can help in solid waste management of agricultural wastes and animal manure. In addition, the following are recommended. Further testing using other agricultural wastes and animal manure may be conducted. The processes involved may be further enhanced and automation is recommended. Research on characterization and optimization of raw materials can also be considered.

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