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Eco Bar-Briq-Ues: Development of Sustainable Briquette from Sawdust and Paper Waste

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***Abstract*— *This research study aimed to develop sustainable briquettes from sawdust and waste paper as an alternative energy source. The experimental procedure followed ASTM standards to test the effectiveness of these raw materials in briquette production. After production, the briquettes underwent standard tests to characterize their physical, chemical, and mechanical properties. Results showed that Mixture 3, which contained a higher percentage of waste paper, had the highest density 0.537 g/cm3 as well as higher strength and durability, lasting an average of 3.6 drops. None of the mixtures, however, met the desired density criterion 0.90 – 1.30 g/cm3, thus limiting its possible efficiency as a source of fuel. Statistical analysis revealed significant differences in various properties among the mixtures, with a p-value of less than 0.001. The Kruskal-Wallis Test revealed that there is a significant difference in the dependent variable among the various groups as reflected by a p-value of less than 0.001. The post-hoc Dunn's test, with a Bonferroni adjusted alpha of 0.017, revealed that the mean ranks for the following pairs (Mixture 1 and Mixture 2, and Mixture 2 and Mixture 3) differ significantly. The comparison of the conventional briquettes with the experimental briquettes made from sawdust and waste paper revealed both strengths and weaknesses as a fuel source. While conventional briquettes proved more efficient, the experimental briquettes from recycled organic waste present a greener alternative, aligning with global initiatives to reduce waste and reliance on traditional biomass fuels. Recommendations include redesigning the briquette mold to create a central hole for improved combustion, expanding the parameters investigated, and optimizing the material mix and binder ratios, including trials with natural binders.*

***Keywords*—*Briquettes, Sustaianable energy, Waste management, Sawdust, Waste paper, Biomass, Renewabale energy, Briquette production, Binder-less briquettes, Briquetting, Manual briquette machine/compactor/press*.

I. Introduction

According to the World Health Organization's Household Air Pollution and Health Fact Sheet (2023), around 2.5 billion people, out of the estimated global population of 7.63 billion, depend on wood, kerosene, biomass, and coal for cooking in their homes. Consequently, there has been a rapid and extensive depletion of forests, resulting in an annual reduction of almost 3% of the global forest cover. Wood consumption is steadily rising, particularly in less technologically advanced nations worldwide (Aremu and Agarry, n.d). Deforestation is a significant issue that has a widespread impact on several nations globally, including the Philippines, where there is an increased scarcity of fuelwood for household cooking, leaving kerosene and gas as the significant cooking fuels (Dutch Green Business Group, 2024).

Increased energy demand has seen an increase in greenhouse gas emissions, consequently fast-tracking climate change and degradation of the environment (IPCC, 2020). Greenhouse gas emissions have a majority share in the Philippine energy sector, which obtains a majority of the energy from fossil fuels (DENR, 2019). Nevertheless, the country has committed to lofty targets for the reduction of greenhouse gas emissions as well as to transformation to a low-carbon economy (NEDA, 2017).

Charcoal briquettes, created by the compression of coal dust or tiny coal particles into a dense structure, have several benefits compared to conventional cooking fuels. They possess a greater energy density than firewood, burn more uniformly, and generate a reduced amount of smoke (Lee, 2022). Nevertheless, using charcoal briquettes also causes worries about air pollution and human health. Charcoal burning emits various pollutants, such as particulate matter, sulfur oxides, and nitrogen oxides, that may negatively impact respiratory health (Jelonek et al., 2020). Developing coal briquettes with low pollutant emissions and promoting clean combustion technologies is essential to mitigate the issues stated.

Alternatively, waste paper can bind agricultural residues to manufacture binder-less and smokeless briquettes. EMB-DENR stated on their National Solid Waste Management Status Report of 2018 that around 25% to 40% of global municipal solid trash annually comprises paper and paper products. Although the predominant global practice is to recycle these goods inside the paper industry, the procedure may be costly due to the necessities of sorting, deinking, and disinfections. The utilization of recovered waste paper often diminishes the quality of the resulting paper. Furthermore, the current state of waste paper recycling technology indicates that a certain proportion of waste paper remains unrecyclable due to technological and economic constraints (Wolska & Malachowska, 2023).

In this context, sustainable and renewable energy development is imperative. One of the potential directions in this context is the use of waste material, such as sawdust and paper waste, for the production of briquettes. Such waste materials are renewable, are in plenty, and can be used to produce a fuel of high energy density as a substitute for fossil fuels (Kumar et al., 2017).

Sawdust and paper waste are particularly attractive feedstocks for briquette production due to their high energy content and low ash production (Demirbas, 2009). However, the development of sustainable briquettes from these materials requires careful consideration of the production process, including the optimization of material composition, binder ratios, and compaction techniques (Kaliyan et al., 2011).

The fibers on the paper will used as a binder for the sample briquettes. Briquettes, created from natural or recycled materials, have minimal environmental impact. Sawdust is the sole component of wood briquettes, and they do not include any binders or additives. When burned, it does not release any hazardous compounds, indicating that it is carbon-neutral. Briquettes made from paper alone are another alternative for fuel source; however, they have the disadvantage of having a high ash concentration, which is a downside; for this study efforts will be made to produce a briquette from a mixture of sawdust and waste paper using locally fabricated manual briquette mold.

II. METHODOLOGY

A. Gathering of Raw Materials

The raw materials required for the production of briquettes were gathered from various sources. A total of 40 kilograms of used bond papers were collected from students of the Sanitary Engineering Department of Western Mindanao State University and from local government offices in Zamboanga City. The waste papers were prepared for the next stage of the briquette-making process by cutting/tearing them into smaller pieces, soaking, and compressing them into briquettes. Additionally, 40 kilograms of sawdust were collected from Perez Lumberyard in Barangay Tumaga, Zamboanga City, and were thoroughly checked and cleared of foreign objects like nails and plastic. Furthermore, 48 liters of tap water were collected from a faucet to soak the waste paper, which was the only available water supply at the location.

B. Preparation of Raw Materials

The raw materials, including waste paper and sawdust, underwent a series of preparation processes to ensure their suitability for briquette production. The waste paper was first cut into smaller pieces to enhance mixing and pulping. Then, it was soaked in 24 liters of water for three days to make it softer and release its fibers, which act as a binding agent. After soaking, the paper was blended into a slurry-like consistency and then compressed to drain excess water, leaving a damp pulp. Next, sawdust was added to the waste paper pulp in varying mixtures, including 50:50, 70:30, and 30:70, and mixed gradually to achieve a consistent texture.

C. Preparation of the Briquette Sample Mixtures

The preparation of the briquette sample mixture involved weighing sawdust and paper waste according to their required percent by weight. Three mixtures were prepared, namely Mixture 1 (50% sawdust, 50% waste paper), Mixture 2 (70% sawdust, 30% waste paper), and Mixture 3 (30% sawdust, 70% waste paper). The physical and chemical properties of the briquettes, including density, moisture content, ash content, boiling time, burning rate, and strength and durability, were tested according to standard test methods and criteria.

D. Molding of Briquettes

After the raw materials were mixed in their correct proportions, combining sawdust and paper waste. A briquette machine was then used to mold the mixture, ensuring consistency in the size and diameter of the resulting briquettes. Once molded, the briquettes were set aside for drying.

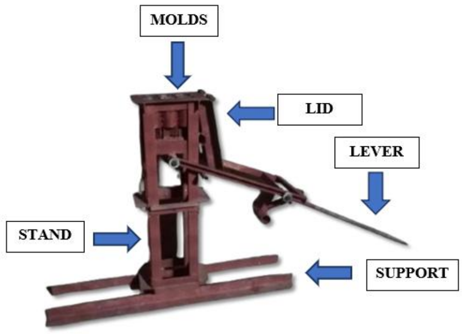

Figure 1. The actual briquette mold from the study of Tarroza (2024) used during the experiment

E. Sun-drying of Briquettes

To sun-dry briquettes, the freshly made briquettes were arranged and placed on a flat surface or clean ground, spread evenly to allow proper air circulation. They were then placed in a sunny, open area with good ventilation to maximize exposure to sunlight and airflow.

F. Oven-drying of Briquettes

To remove any additional moisture that may be present in the briquettes, the samples were placed inside an oven at a temperature of 110°C for a duration of fifty-five minutes, allowing for thorough drying and removal of excess moisture.

G. Testing of Briquettes

The briquettes produced in this study were manually tested in compliance with relevant ASTM standards to ensure their quality and performance. The main characteristics tested included moisture content, ash content, density, burning rate, boiling time, and strength and durability. The briquettes' density was calculated utilizing a formula based on their mass and volume, which was obtained with a digital scale. Moisture content was measured by oven-drying the briquettes and calculating the difference in weight. Ash content was calculated by weighing the ash produced by burning the briquettes. The burning rate was determined by measuring the duration of the flame when the briquettes were set on fire. Boiling time was measured by igniting the briquettes in a charcoal stove and timing how long it took for water to boil. Finally, the strength and durability of the briquettes were tested by dropping them from a height of 1.5 meters until they cracked or broke.

Physical Properties

Density

The first step in using a digital scale to measure the density of briquettes is to weigh the briquette. The sample briquette was placed on the weighing scale. After obtaining its mass, the

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next step is to determine the volume of cylindrical briquettes, using the formula:

$$V = \pi r^2 h \quad (1)$$

When the mass and volume are both measured and solved, the density can be determined through the formula as given by ASTM D6347/D6347M-05:

$$\rho_m = \frac{mass\ (g)}{volume\ (cm)} \quad (2)$$

Boiling Time

A briquette was put in the charcoal stove. One (1) liter of water was poured in an aluminum pot and was positioned above it. Afterward, a butane blow torch gun ignited the briquette. A digital timer was then utilized to count the time between when the briquettes were lit and the moment when the water was at its boiling point during the process of combustion.

Mechanical Property

Strength and Durability

To determine the strength and durability of a briquette sample, one must first determine a height of around 1.5 meters which is equivalent to 3 to 5 feet. The height was released to a hard or concrete surface; it was done in such a way that when it hits, it lands well. Then the dropping continues till the briquette cracks or breaks when it is dropped.

Chemical Properties

Moisture Content

In measuring the moisture content, first, weigh the sample briquette before oven-drying. After obtaining the weight of the sun-dried briquette, the briquettes are left inside an oven at 110°C for fifty-five (55) minutes to get rid of its excess moisture. The briquettes were then taken out of the oven and weighed on a weighing scale.

When the oven-dried weight and the dried weight of the briquettes are determined, moisture content can be calculated by using the following formula from ASTM D3173-03:

$$Moisture\ content = \frac{Dried\ weight - Over\ dried\ weight}{Dried\ weight} \, x\ 100\% \quad (3)$$

Moisture Content

In determining the ash content, the ash produced by the burned briquette used during the experiment was collected and weighed using a weighing scale. After determining the ash produced by the sample briquette, the ash content can be calculated using the following formula provided by ASTM D3174-12:

$$Ash\ content = \frac{Collected\ ashes\ (g)}{Original\ weight\ of\ briquette\ sample\ (g)} \, x\ 100\% \quad (4)$$

Burning Rate

To determine the burning rate of the briquette sample, the briquette was set on fire using a butane blow torch gun while a digital timer was used to measure and observe the duration of the flame in the briquette as it burns until it gradually extinguishes.

H. Data Analysis and Interpretation

The experimental briquette data was analyzed using a computer program after collecting the test results. A normality test was conducted using the Shapiro-Wilk Test to determine if the data was normally distributed. If the data was normal, an ANOVA analysis was performed to compare the means of briquettes from different waste material percentages. If the data was not normal, a Kruskal-Wallis Test was used instead. The analysis was facilitated by Microsoft Excel's Data Analysis Toolpak and the Statistical Package for the Social Sciences (SPSS), with a significance level of $\alpha = 0.05$.

III. Result and Discussion

The three (3) different briquette mixtures labeled as Mixture 1, Mixture 2, and Mixture 3 that were used in the experiment, each composed of varying amounts of sawdust and waste paper. Mixture 1 has an equal ratio of sawdust and waste paper, Mixture 2 has a greater ratio of sawdust, while Mixture 3 has a greater ratio of waste paper. The briquettes have a somewhat rough and uneven texture, and they also vary slightly in their color and shape. Briquettes produced from Mixture 1 is brownish-gray in color and has a rough, irregular surface. It is packed with sawdust particles and waste paper fibers, which are visible easily. Meanwhile, briquettes produced from Mixture 2 is browner in color and contains more noticeable sawdust particles and less trace of fibers from the waste paper. Lastly, briquettes produced from Mixture 3 is lighter in color and smoother in texture. It has a finer texture than the earlier briquettes, with more exposed fibers from the waste paper and fewer sawdust particles.

Figure 2. The three (3) different briquette mixtures

The table presented below shows the overall ranking of all the samples (Mixture 1, Mixture 2, and Mixture 3) used in developing an alternative briquette. The results were obtained after evaluating all the samples according to their parameters and standards. The scoring is from 1 to 3, 1 being the lowest and 3 being the highest.

TABLE 1. Overall Ranking of the Experimental Briquettes in terms of the Tested Parameters

Parameters	**Ranking**		
	Mixture 1	**Mixture 2**	**Mixture 3**
Density	1	2	3
Boiling Time	2	1	3
Strength and Durability	2	1	3
Moisture Content	1	3	2
Ash Content	2	3	1
Burn Rate	1	2	3
Total Score	**9 (Lowest)**	**12**	**15 (Highest)**
Final Ranking	**3rd**	**2nd**	**1st**

Table 1 assesses the three (3) mixtures (Mixture 1, Mixture 2, and Mixture 3) on the basis of the six (6) parameters (density, boiling time, strength and durability, moisture content, ash content, and burning rate), with rankings where 3 is the highest and 1 is the lowest. Rank highest overall Mixture 3 scores the highest overall with a total score of 15, superior performance in the boil time, density, burn rate, and strength and durability plus moderate moisture contents that make clean combustion ideal, while mixture 2 ranks as the second with a total score of 12, due to excellent moistures and good ash content while poor in terms of boil times. Mixture 1 ranks the lowest with a total score of 9 since it performs poorly in moisture content, density, and burn rate.

The properties of briquettes, which include density, boiling time, strength and durability, moisture content, ash content, and burn rate, are essential in briquette production as they determine its overall performance and efficiency. Density affects the compactness of the briquette. Boiling time measures how quickly a briquette can generate heat. Strength and durability ensure that the briquettes can withstand handling, storage, transportation, and combustion without breaking, Moisture content affects the combustion efficiency, allowing for faster ignition and cleaner burning. Ash content indicates the amount of non- combustible material left after burning. Finally, burn rate determines how quickly the briquette ignites and gives off heat, as well as how long does it takes for the briquette to be fully extinguished. Balancing these briquette properties is important for producing briquettes that are cost-effective, efficient, and suitable for various applications, whether for cooking, heating, or industrial uses.

TABLE 2. Tabulated Data for Comparison Between A Traditional Briquette and A Sawdust and Wastepaper Briquette

Parameters	Mixture 3 (Experimental Briquette)	Traditional Briquette (Wood)	Traditional Briquette (Charcoal)
Density	0.54 g/cm3	1.1 to 1.4 g/cm³	0.5 to 0.9 g/cm³
Boiling time	57.86 minutes	10 to 30 minutes	15 to 30 minutes
Strength and Durability	3.6 drops	5 to 10 drops	10 to 20 drops
Moisture Content	8%	6% to 12%	4% to 8%
Ash Content	28%	0.5% to 2%	8% to 10%
Burning Rate	73 minutes	60 to 120 minutes	180 to 300 minutes

Table 2 provides a comparison of the properties of three (3) types of briquettes: Mixture 3 (Experimental Briquette), Traditional Wood Briquettes, and Traditional Charcoal Briquettes. The performance of each briquettes is evaluated based on density, boiling time, strength and durability, moisture content, ash content, and burning rate, with compliance to standard requirements noted.

In terms of density, Mixture 3 recorded a value of 0.54 g/cm3 which is below the acceptable standard range of 0.90 to 1.30 g/cm3, resulting in a failed remark. In contrast, Traditional Wood Briquettes (1.1 to 1.4 g/cm³) and Traditional Charcoal Briquette (0.5 to 0.9 g/cm³) aligned with expected ranges. For boiling time, Mixture 3 took 57.86 minutes, significantly longer than the expected ranges of 15 to 30 minutes. The boiling time for Traditional Wood Briquettes ranges from 10 to 30 minutes, and for Traditional Charcoal Briquette it ranges from 15 to 30 minutes. The experimental briquette clearly indicated inefficiency and earning another failed remark. Traditional briquettes performed much better, since it only consumed a shorter time for the water to boil.

When assessing its strength and durability, Mixture 3 withstood 3.6 drops, which is also below the acceptable range of 4 to 5 drops. This contrasts with the Traditional Wood Briquettes, which withstood 5 to 10 drops, and the Traditional Charcoal Briquette, which demonstrated superior strength by withstanding 10 to 20 drops.

On the other hand, Mixture 3 moisture content which is 7% fell within the acceptable range of 1% to 22%, passing the criterion along with the traditional briquettes, which also met their respective moisture ranges.

For ash content, Mixture 3 recorded a very high value which is 28%, far exceeding the standard requirement of 3% to 18%, leading to another failed remark. Traditional Wood Briquette exceptionally well in this parameter with only 0.5% to 2% ash content, while Traditional Charcoal Briquette also met the acceptable range with 8% to 10%.

With regards to its burning rate, Mixture 3 lasted 73 minutes, which is within acceptable range of 1 to 3 hours, indicating steady burning but potentially insufficient heat output. Traditional Wood Briquettes burned for 1 to 2 hours, while Charcoal Briquettes offered a longer burn time of 3 to 5 hours, showcasing their efficiency for prolonged use.

IV. CONCLUSION

The evaluation of the briquettes' physical properties indicated that Mixture 3 showed maximum density at 0.537 g/cm3, indicating improved compacting and binding due to a higher percentage of waste paper. However, none of the mixtures conformed to the standard density of 0.90-1.30 g/cm3, which adversely affected the fuel efficiency. Statistical analysis (Kruskal-Wallis Test) showed a significant difference with a test statistic of 21.004 and a p-value of < 0.001, confirming that the mixtures varied significantly in their compactness. The evaluation of the mechanical properties of the briquettes revealed that Mixture 3 demonstrated superior strength and durability, withstanding an average of 3.6 drops, while Mixture 2 performed the poorest, surviving only one drop. However, all mixtures fell below the acceptable standard of 4 – 5 drops, indicating structural weakness. Kruskal-Wallis Test results indicated significant differences in strength with a test statistic of 23.771 and a p-value of < 0.001, highlighting that some mixtures were much weaker than expected. The evaluation of the chemical properties of the briquettes shows that Mixture 3 had the lowest ash content 40.8% but still failed to meet the standard range 3% - 18%. Its moderate moisture content 7.6% supports efficient burning aligning with the industry standards 1% - 22%. The evaluation of the combustion of the briquettes shows that Mixture 3 exhibited the shortest boiling time 57.856 minutes and an acceptable burn rate 73.40 minutes, making it the most efficient fuel among the three (3). Yet, boiling time remains outside the standard range 15 – 30 minutes, reflecting insufficient combustion efficiency. Kruskal-Wallis Test showed significant differences with a test statistic of 22.199 and a p-value of <0.001, indicating notable variations in how long each mixture burned. The statistical analysis of sawdust and waste paper briquettes, using normality tests, Kruskal-Wallis, and ANOVA, confirmed significant differences in physical, mechanical, and chemical characteristics. While traditional briquettes demonstrated superior efficiency and durability, the experimental briquettes made from recycled organic waste offer a more sustainable alternative. Despite some limitations, these briquettes contribute to reducing waste and dependence on traditional biomass fuels, aligning with global efforts toward environmental sustainability and renewable energy solutions.

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