Characterization of Waste Pellets as An Environmentally Friendly Alternative Fuel Solution: Waste Management at Bali State Polytechnic

Ida Ayu Anom Arsani[1], I Made Rajendra[2], and I Made Sudana[3]

[1,2,3] Mechanical Engineering Department, Politeknik Negeri Bali, Bali, Indonesia
ayuanomarsani@pnb.ac.id

Abstract. Pellets made from waste have great potential as an environmentally friendly alternative fuel. These waste pellets have diverse chemical compositions, with carbon and hydrogen content providing good calorific value. The physical properties of the pellets, such as density, moisture, and mechanical durability, meet the standards for optimal combustion efficiency. Waste pellets can offer a sustainable solution to waste management issues and support the transition towards renewable energy. This research aims to characterize pellets produced from waste as an environmentally friendly alternative fuel solution. The characterization of the pellets will be conducted through three stages of testing: proximate analysis, ultimate analysis, and bomb calorimetry. The results of the study show that some test parameters have met the requirements, including moisture and ash content. However, volatiles, fixed carbon, and sulfur have not met the requirements. The calorific value has been met by the 10%, 20%, 30%, and 40% plastic variations.

Keywords: Renewable Energy, Waste Management, Waste Pellet

1 Introduction

The development of environmentally friendly alternative energy sources has become increasingly urgent. One solution currently being developed is waste pellets, which hold great potential as an eco-friendly alternative fuel. Waste pellets are products derived from the composting or processing of organic and inorganic waste. These pellets offer a range of potential benefits, particularly in the context of waste management and energy conservation. With careful characterization, waste pellets can be utilized as an efficient and environmentally friendly fuel. The chemical content of these pellets can affect their calorific value and fuel efficiency, necessitating further research to better understand their characteristics.

Research by (Harun & Afzal, 2015) characterized the chemical composition of waste pellets to determine the carbon, hydrogen, nitrogen, sulfur, and oxygen content. This analysis provided essential information about the combustion potential and calorific value of the waste pellets. According to (Prvulovic et al., 2014), characterization is a crucial parameter for assessing the quality of these pellets. The chemical and thermal

A. A. N. G. Sapteka et al. (eds.), *Proceedings of the International Conference on Sustainable Green Tourism Applied Science - Engineering Applied Science 2024 (ICoSTAS-EAS 2024)*, Advances in Engineering Research 249,
https://doi.org/10.2991/978-94-6463-587-4_20

indicators are determined by the content of several chemical elements in the pellets, ash content, moisture content, and the energy value of the pellets.

A popular method for processing organic waste and biomass today is the Technology for Waste Management at the Source (TOSS). This method converts organic waste and biomass into biofuel in the form of biomass pellets. These biomass pellets can serve as an alternative to coal for various purposes. The process involves biodrying, shredding, and pelletizing. The resulting biomass pellets are a solid fuel with a calorific value or higher heating value (HHV) of approximately 3000-4000 kcal/kg, depending on the type and composition of the biomass (Brunner et al., 2021; Sari et al., 2015) . Several studies related to the development of waste pellets as an alternative fuel have shown significant potential for their use as an alternative energy source (Alpian et al., 2023; Apriyanto & Thohirin, 2022). Pellets, in the form of small granules, contain 2500-4000 kcal/kg of calorific value (Fadli et al., 2019), which can then be utilized in large-scale power generation by co-firing with coal. The technology applied involves combustion, where the pellets serve as fuel, and the heat generated is used to heat boilers that produce steam to drive power generation turbines.

The use of waste pellets also helps reduce dependence on fossil fuels, while simultaneously providing a solution to reduce the volume of solid waste. By harnessing previously unusable waste, we can generate clean and renewable energy. This aligns with global commitments to reduce greenhouse gas emissions and combat climate change. Therefore, the characterization of waste pellets as an alternative fuel holds significant potential in supporting the sustainable development agenda. In the industrial context, waste pellets can also be used as raw materials in production processes, replacing more expensive and environmentally harmful conventional raw materials. The use of waste pellets not only offers a solution for waste management but also contributes to resource efficiency and the reduction of the industrial carbon footprint.

Mechanical characterization of pellets refers to the process of identifying, measuring, and analyzing the mechanical properties of the pellets. This includes various parameters used to evaluate how well the pellets can withstand load, stress, abrasion, and other conditions. Pellet characterization is conducted through proximate and ultimate analyses, which aim to determine the physical and chemical properties of the pellets. Characterization is highly influenced by the properties of the raw materials, as pellets under different conditions will exhibit different characteristics (Onochie et al., 2017; Winaningsih et al., 2023).

Currently, waste management is a serious concern due to the increasing volume of waste, necessitating proper processing and disposal to prevent environmental pollution. Bali State Polytechnic (PNB), as one of the vocational higher education institutions, is also committed to managing waste generated within the campus area through a waste bank to realize a Green Campus. The utilization of waste into pellets has not yet been developed as one of the outcomes of waste processing at PNB. Characterizing waste pellets is an important initial step in making this alternative fuel a competitive and sustainable option for the future.

2 Methodology

2.1 Research Design

This research is observational, involving the testing of waste pellet samples using several laboratory methods to determine their characteristics. The characteristics are assessed through three tests:

a) Proximate Analysis: This is the process of determining the composition or content of the main components present in the waste pellets.
b) Ultimate Analysis: This is a detailed analysis process to determine the chemical composition of a sample, including the major elements it contains. In the context of waste pellets, ultimate analysis can be conducted to determine the content of carbon, hydrogen, nitrogen, sulfur, oxygen, and other elements in the pellet samples.
c) Bomb Calorimeter Testing: This is a standard method for determining the calorific value or energy content of fuel, solid fuels, pellets, or other combustible materials. This procedure is commonly used to assess the energy efficiency of various types of fuels and is also utilized in research, product development, and quality control.

The following is a waste-to-pellet processing scheme using the TOSS method (Brunner et al., 2021). It is shown in Figure 1.

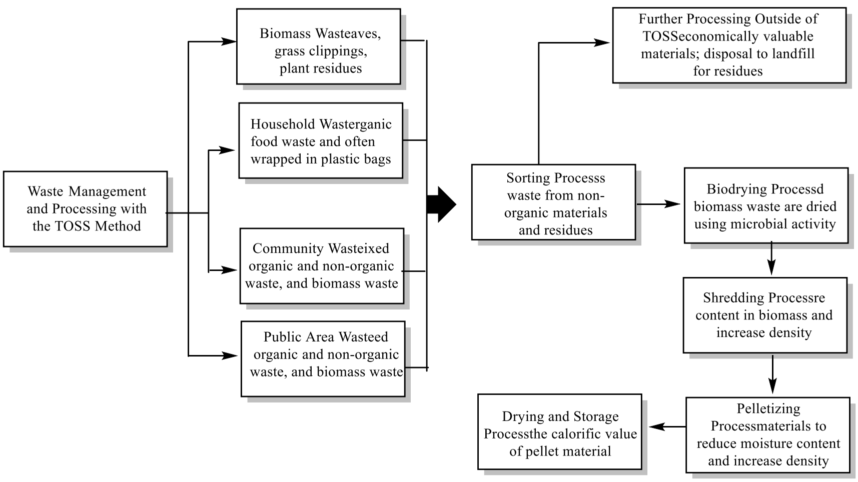

Figure 1. Scheme for waste processing into pellets using the TOSS Method

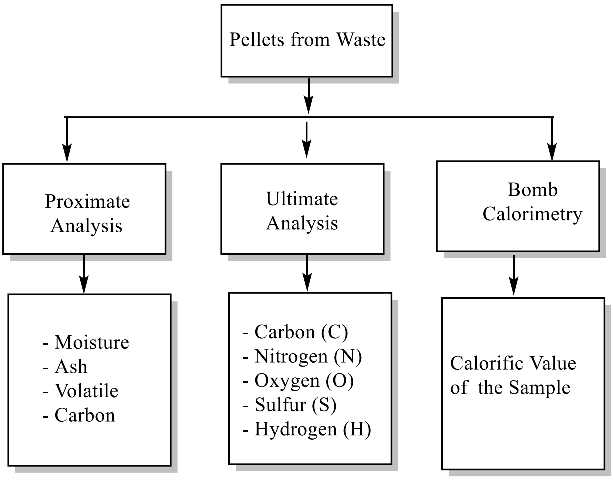

Figure 2. Procedure for testing waste pellets

2.2 Tools and Materials

The main equipment used in the research consists of three tools corresponding to the testing methods described above. The equipment includes:

a) Proximate analysis using the Leco Thermo Gravimetric Analysis (TGA) 701,
b) Ultimate analysis using the Leco CHN 628 elemental analyzer with an O-type 628S add-on, and
c) Calorific testing using an Oxygen Bomb Calorimeter

Figure 3. Testing equipment

Proximate testing on the Leco TGA-701 was conducted using the ASTM D7582 MVA-biomass method, where the temperature measurement parameter was set at ± 2°C, and the microbalance sensitivity at 0.0001g, under a continuous nitrogen gas flow at 10 mL/min. The ultimate testing was performed using the ASTM D4239 reference standard method, while the calorific value was determined using the ASTM D240 method. The chemical elements of C, H, N, and O were tested with LECO determinator CHN add-on O type 628. Data analysis was carried out through data interpretation, where, after obtaining the proximate and ultimate values, the results were compared with the standards or expected values for the type of waste pellets being studied. For example, good proximate and ultimate values would indicate a high energy content and minimal contaminants.

3 Result and Discussion

3.1 Waste Processing Stage into Pellets

The process of converting waste into pellets consists of several stages, including collection, sorting of organic and inorganic materials, followed by shredding, and the formation of waste pellets. This activity involves sanitation workers managed by the UPT-PP Management of Bali State Polytechnic. The waste management system implemented includes collection using bins distributed throughout the campus. The collected waste is sorted into organic and inorganic materials. Organic waste, such as leaves and small branches, is shredded and fermented into planting media. In general, the waste collected consists of 60% organic material, which is due to the abundance of leaves from the trees growing on campus. The inorganic waste, on the other hand, mainly consists of food packaging plastics. The utilization of organic waste as planting media has not been fully optimized, so most of the organic waste, food waste, and plastic are categorized as residual waste, which is then disposed of at the landfill.

Figure 4. Waste processing activities into pellets

Utilizing waste as a fuel source in the form of pellets is done by varying the composition between organic and inorganic materials. All the waste is shredded and sun-dried to reduce the moisture content before being made into pellets. In this study, five variations were made, namely pellets with plastic weight compositions of 10%, 20%, 30%, 40%, and 50%. To determine the content within the pellets, proximate, ultimate, and LHV tests were conducted, with the test results showed in Table 1.

Table 1. Sample test results

Pellets	Proximate (% wt)				Bomb calorimeter (k.cal/kg)	Ultimate (% wt)				
	Moisture	Volatile	Ash	Fix carbon	LHV	C	H	O	N	S
MSW 10%	0.5	99.18	0.25	0.06	2,770	47.9	8.11	33.7	6.23	4.06
MSW 20%	3.51	96.16	0.27	0.07	2,660	47.1	9.5	32.9	6.74	3.76
MSW 30%	1.51	99.80	0.01	0.17	2,620	48.2	7.6	34.6	5.08	4.52
MSW 40%	0.13	99.49	0.32	0.05	2,600	46.5	8.3	33.1	8.33	3.97
MSW 50%	1.07	99.47	0.01	0.13	2,130	47.4	8.9	33.4	6.04	4.26

3.2 The Potential of Waste Pellets as Fuel

The processing of waste into solid fuel aims to reduce the increasing accumulation of waste. However, as a solid fuel, waste pellets must meet specific requirements, particularly in terms of energy content and minimal moisture content. Based on the results of the proximate tests in the Table 1, the moisture content increases from MSW 10% to MSW 20% and 50%. This progression demonstrates the critical role moisture plays in combustion performance. Volatile matter is consistently high across all samples, ranging from 96.16% (MSW 20%) to 99.80% (MSW 30%). Ash content is very low across the samples, with the highest being MSW 40% (0.32%) and MSW 30% showing the lowest (0.01%). Low ash content is beneficial because it indicates fewer incombustible residues, leading to less operational cleanup and higher fuel efficiency during combustion.

Fixed carbon is quite low across all samples, with MSW 30% having the highest at 0.17% and MSW 40% the lowest at 0.05%. The low fixed carbon content implies that a smaller portion of the sample will combust more slowly, contributing minimally to the total energy output. The LHV is highest for MSW 10% at 2,770 k.cal/kg and decreases as moisture content increases, with MSW 50% having the lowest LHV at 2,130 kcal/kg. Higher moisture content lowers LHV because more energy is required to evaporate the water during combustion, reducing the net energy yield. This makes MSW 10% a more efficient fuel source compared to MSW 50%.

Based on the results of the Ultimate tests, the carbon content is fairly consistent across the samples, ranging between 46.5% (MSW 40%) and 48.2% (MSW 30%). Carbon is the primary component contributing to heat during combustion, so higher carbon content (MSW 30%) correlates with better energy potential. However, the variation is minor, so it doesn't drastically affect energy outcomes. Hydrogen content ranges from 7.6% (MSW 30%) to 9.5% (MSW 20%). Higher hydrogen content increases the heating value as hydrogen burns to form water vapor, contributing to the overall calorific value. MSW 20%, with 9.5% hydrogen, would release more energy compared to others. Oxygen content is relatively stable, with MSW 30% showing the highest (34.6%) and MSW 20% the lowest (32.9%). High oxygen content in the fuel can result in self-oxidation, which might lower the net heating value of the fuel. Nitrogen content varies significantly, from 5.08% (MSW 30%) to 8.33% (MSW 40%). High nitrogen levels, especially in MSW 40%, can lead to the formation of nitrogen oxides (NOx) during combustion, contributing to air pollution and requiring additional emission control. Sulfur content varies between 3.76% (MSW 20%) and 4.52% (MSW 30%). Higher sulfur content (MSW 30%) can lead to sulfur oxide emissions, contributing to acid rain and equipment corrosion. Thus, the presence of sulfur in higher concentrations necessitates better pollution control mechanisms during combustion.

According to SNI 8966:2021 on solid fuel (Sihombing & Darmawan, 2021), the requirements for solid fuel are as follows: moisture content in the range of < 15-25%, ash content < 15-25%, volatile matter ≤ 65-75%, fixed carbon > 15-5%, sulfur content ≤ 1.5%, and calorific value of 4777-2389 k.cal/kg. Based on these values, the moisture and ash content of all five variations have met the requirements. However, the volatile matter, fixed carbon, and sulfur content in all five variations have not met the requirements. For calorific value, only the 50% plastic variation did not meet the requirements, while the others did. Observing the trend of decreasing calorific value with increasing plastic composition indicates that organic waste (biomass) has a higher calorific value compared to plastic.

Based on the results of this study, the waste at Bali State Polytechnic does not fully meet the requirements for solid fuel according to SNI. This finding is also supported by other researchers who have noted that certain types of biomass in organic waste do not meet the criteria for solid fuel (Brunner et al., 2021).

4 Conclusion

A study to determine the potential of waste as solid fuel (pellets) at Bali State Polytechnic has been conducted. The results of the study show that some test parameters have met the requirements, including moisture and ash content. However, volatiles, fixed carbon, and sulfur have not met the requirements. The calorific value has been met by the 10%, 20%, 30%, and 40% plastic variations.

Acknowledgment

This research was funded by the DIPA Fund of Politeknik Negeri Bali in 2024 with Contract No. 02014/PL8/AL.04/2024.

References

Alpian, A., Supriyati, W., Luhan, G., & Surasana, I. N. (2023). Karakteristik pelet kayu laban (Vitex Pubescen) sebagai bahan bakar alternatif terbarukan. *Jurnal Penelitian Hasil Hutan*, *41*(1), 27–34. https://doi.org/10.55981/jphh.2023.679

Apriyanto, A., & Thohirin, M. (2022). Kaji eksperimental konversi biomassa sampah menjadi bahan bakar terbarukan menggunakan proses torefaksi. *Teknika Sains: Jurnal Ilmu Teknik*, *7*(1), 42–52. https://doi.org/10.24967/teksis.v7i1.1593

Brunner, I. M., Norhidayat, A., & Brunner, S. (2021). Pengolahan sampah organik dan limbah biomassa dengan teknologi olah sampah di sumbernya. *Jurnal Serambi Engineering*, *6*. https://doi.org/10.32672/jse.v6i3.3120

Fadli, M., Kamal, D. M., & Adhi, P. M. (2019). Analisis swot untuk direct co-firing batubara dengan pellet sampah pada boiler tipe Cfbc. *Jurnal Poli-Teknologi*, *18*(3 SE-Articles), 271–280. https://doi.org/10.32722/pt.v18i3.2391

Harun, N. Y., & Afzal, M. T. (2015). Chemical and mechanical properties of pellets made from agricultural and woody biomass blends. *Transactions of the ASABE*, *58*(4), 921–930. https://doi.org/10.13031/trans.58.11027

Onochie, U., Obanor, A., Aliu, S., & Igbodaro, O. (2017). Proximate and ultimate analysis of fuel pellets from oil palm residues. *Nigerian Journal of Technology*, *36*(3), 987–990. https://doi.org/10.4314/njt.v36i3.44

Prvulovic, S., Gluvakov, Z., Tolmac, J., Tolmac, D., Matic, M., & Brkic, M. (2014). Methods for determination of biomass energy pellet quality. *Energy and Fuels*, *28*(3), 2013–2018. https://doi.org/10.1021/ef402361k

Sihombing, A. L., & Darmawan, R. (2021). Karakteristik sampah lama (*mining landfill waste*) tempat pemrosesan akhir sebagai bahan bakar jumputan padat. *Seminar Nasional Penelitian Dan Pengabdian Masyarakat*, 24–28.

Sari, S., Yenie, E., & Elystia, S. (2015). Studi timbulan, komposisi dan karakteristik fisika dan kimia (*proximate analysis*) sampah non domestik di Kecamatan Tampan Kota Pekanbaru. *Teknik Lingkungan*, *31*(2), 259–264.

Winaningsih, I., Suramta, S., & Mala, Y. (2023). Karakterisasi pelet pupuk organik berbahan eco enzyme. *KOVALEN: Jurnal Riset Kimia*, *9*(3), 258–265. https://doi.org/10.22487/kovalen.2023.v9.i3.16541