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CHARACTERIZATION OF MUNICIPAL SOLID WASTE AS AN ENERGY SOURCE IN THE GASIFICATION PROCESS

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Abstract. Municipal solid waste (MSW) poses significant environmental challenges if not managed effectively. The composition and quantity of MSW are closely linked to the socioeconomic structure of a given area. This study aimed to assess the feasibility of utilizing raw materials from Denpasar's MSW for gasification processes. Samples were collected, segregated, processed, and dried for analysis. Various physical and chemical properties were examined, including moisture content, volatility, fixed carbon, elemental composition, and calorific value. Proximate analysis on dry base sample revealed that the MSW contained 12.45% moisture, 54.68% volatile matter, 13.05% fixed carbon, and 19.82% ash. Ultimate analysis showed the following elemental composition: 64.46% C, 11.5% H, 18.3% O, 0.5% N, and 0.05% S, with a calorific value of 11.99 MJ/kg. Based on these findings, the implementation of a waste-to-energy program utilizing gasification processes for waste management is recommended.

Keywords: Municipal Solid Waste, Proximate Analysis, Ultimate Analysis, Gasification.

1. INTRODUCTION

The rapid growth in population and urbanization, coupled with increased industrial development, has led to a surge in global energy demand [1]. The continuous reliance on fossil fuels to meet these energy requirements has been proven to cause significant environmental damage [2]. The combustion of fossil fuels, primarily composed of hydrocarbons, releases CO2 and contributes to the rise in greenhouse gas emissions [3]. This greenhouse effect is a major driver of climate change, resulting in global warming. Consequences of rising global temperatures include crop failures and health issues related to heat waves [4]. Moreover, the current rate of fossil fuel extraction to meet global demand is expected to deplete reserves within this century [5]. These pressing concerns have spurred the development of sustainable, renewable energy sources, including the utilization of waste as an environmentally friendly alternative.

Municipal solid waste (MSW) has emerged as a critical issue due to increasing population and consumption patterns [6]. Generated from various human activities in residential, agricultural, and industrial sectors, MSW can lead to severe environmental problems if not managed effectively. Global MSW production reached 2.01 billion tons in 2016 and is projected to escalate to 2.59 billion tons by 2030 and 3.40 billion tons by 2050 [7]. The composition of MSW varies significantly based on the economic status of communities. Middle- and low-income areas typically produce more organic waste, including food scraps, plant materials, and agricultural residues that are biodegradable. In contrast, high-income regions generate a larger proportion of recyclable waste such as paper, glass, plastic, and metal [8]. Despite concerted efforts to reduce, reuse, and recycle materials, a substantial amount of waste still requires disposal in landfills [9]. However, the continued reliance on landfills presents limitations and can lead to new challenges, including odor issues and health risks [10]. Therefore, effective waste management necessitates well-designed handling programs and infrastructure to mitigate negative impacts on the environment and public health. As the search for viable alternatives to fossil fuels intensifies, waste has emerged as a promising renewable energy source. The large and consistent volume of waste generated can potentially replace traditional energy sources. Various fuels, including syngas, methane, hydrogen, bio-oil, and biodiesel, can be derived from different waste treatment technologies. Thermochemical and biochemical processes are widely employed to convert waste into energy [11]. Gasification, a thermochemical process, offers a more environmentally friendly approach to waste management. This technique converts MSW components into useful gases such as methane (CH4), hydrogen (H2), and carbon monoxide (CO) for use as fuel [12]. The gasification process involves several stages: drying the biomass to remove water, pyrolysis to separate biomass components, partial oxidation with limited oxygen supply to generate heat, and reduction to produce syngas - a mixture of CO, H2, and CH4.

MSW is inherently heterogeneous, with its calorific value fluctuating based on the conditions of the source area. Utilizing it as a feedstock for the gasification process presents a promising solution to both mitigate energy shortages and address the challenges posed by MSW accumulation [13]. This study aims to examine the composition of MSW in Denpasar to assess its feasibility as a feedstock for the gasification process, potentially paving the way for more sustainable waste management and energy production practices.

2. METHODS

The testing procedure begins with sample preparation, as shown in Figure 1. Sample collection starts with pinpointing the source location in the Denpasar area. The city's dense population and relatively strong economic development have made waste management a pressing issue for the government. MSW, specifically household waste, is transported from various sources to temporary facilities for collection. The diverse composition of municipal solid waste (MSW), characterized by non-flammable materials and high moisture content, requires a meticulous selection process. This ensures that the MSW utilized in testing and subsequent applications is suitable. Effectively addressing this challenge entails sourcing MSW from trustworthy providers. The initial preparation involves homogenizing the raw materials through manual sorting to segregate non-combustible materials like stone, metal, and glass. Organic components are then chopped and sifted to achieve a consistent grain size. For the sample to be used, a sifting test is conducted using a mesh sieve with a size of 40 – 60 mesh to obtain particles ranging from 0.2 to 0.3 mm.

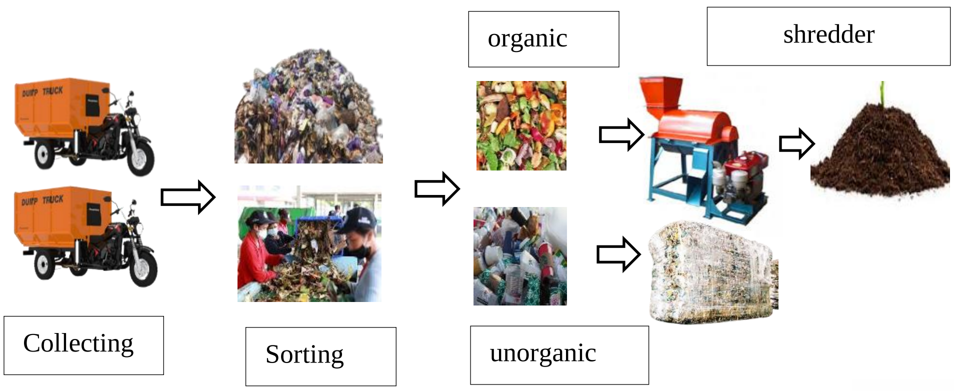

Figure 1. Collecting and preparing MSW procedure

The testing phases conducted include proximate analysis, ultimate analysis, and calorific value testing. These tests are carried out at the NRCE Lab, located at the Faculty of Engineering, Udayana University. Proximate analysis is used to determine the concentration of constituents such as moisture, ash, fixed carbon, and volatile matter in municipal waste fuel. The ASTM D7582 BIOMASS technique is employed, utilizing a test apparatus of type LECO TGA 701. The proximate testing stage begins with a drying procedure to find out the moisture content of the Msw. This involves weighing the sample, approximately one gram, and drying it at 105°C until its weight remains constant, with the difference in weight indicating the moisture content. The sample is then heated to roughly 950°C for seven minutes in an oxygen-free environment to conduct the volatile test. The remaining weight after heating indicates the non-volatile material. To quantify the ash level, the sample is heated in a furnace to 750°C until all organic elements burn, leaving only residues. The weight of the residual ash represents the ash content. Once the moisture content is reduced, the remaining portion of the material comprises volatile matter, while the ash represents fixed carbon.

To analyze the C, H, N, S, and O content in MSW samples, the ultimate test was conducted using the LECO CHN628 instrument, which involved multiple primary phases. To ensure uniformity, the sample is initially prepared, then dried until it attains a constant humidity level, and finally, it is pulverized into a fine powder. The sample is weighed using an analytical balance to achieve the required 0.5 grams. The LECO CHN628 appliance utilizes two-stage combustion to reach high temperatures of up to 1050 °C while operating in a pure oxygen atmosphere. The combustion gases (CO_2, H_2O, and NOx) are measured with an infrared or conductivity thermal detector, eliminating the requirement for chromatographic separation and allowing for quick and accurate analysis through aliquot dosing and combustion gas handling devices. Processing the data retrieved from the detector yields the weight percentage of each element in the sample.

The bomb calorimeter test was conducted to determine the calorific value of MSW fuel using the LECO Oxygen Bomb Calorimeter. The test involved conditioning dry samples into fine powders, compacting a 1-gram sample, and placing it on a nickel cup in the bomb calorimeter filled with oxygen at a density of 30 Psi, which was then submerged in water. The sample was ignited using an incendiary wire connected to the bomb terminal, initiating combustion in a pure oxygen atmosphere. The heat generated by the combustion was absorbed by the water surrounding the bomb. The increase in water temperature in the calorimeter was measured using a high-resolution digital thermometer. This temperature increase was then used as a reference for calculating the calorific value of the MSW sample.

3. RESULTS AND DISCUSSION

3.1 Proximate analysis

The proximate analysis results of the MSW sample are presented in Figure 2. The result obtained the composition of moisture, volatile materials, ash, and fixed carbon components. Each component has an impact on the quality of syngas produced in the gasification process [14]. Since MSW varies in composition, the moisture content, ash, volatile material content, and elemental compositions will differ accordingly. The moisture content was found to be 12.45% (dry base measurement). The low moisture content percentage is attributed to the sample preparation process, which involved preliminary selection and drying of the samples, leading to a reduction in their moisture content. Moisture plays a critical role in the gasification process of MSW and can significantly impact the system's efficiency, energy output, and overall performance [15]. During the gasification process, the production of H_2O in the reactor increases, leading to the water-gas shift reaction ($CO + H_2O \rightarrow CO_2 + H_2$) and the steam reform process, resulting in higher H_2 and CO_2 content. However, this process requires heat, which can inhibit and lower gasification temperature. Dilution of H_2, CO, and CH_4 concentrations can also reduce the calorific value and energy potential of syngas, ultimately decreasing the overall efficiency of the gasification process. The water content test data indicate that MSW can be used as a raw material for gasification processing.

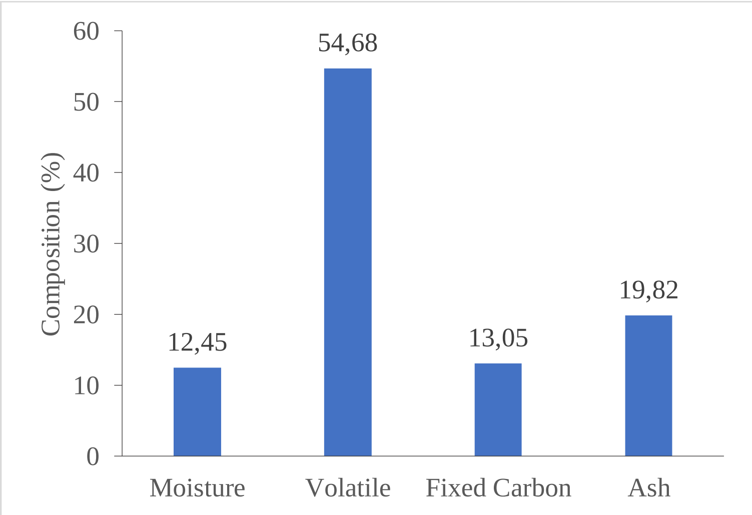

Figure 2. Proximate testing of MSW

The volatile matter of the fuel is crucial in gasification. The high volatile composition indicates the high biomass content of MSW. It vaporizes into gases like H_2, CO, CO_2, CH_4, and hydrocarbons when heated without combustion. Higher volatile content enhances syngas production, especially H_2, and CO, even at lower temperatures during pyrolysis [16]. However, excessive volatility can increase tar formation, complicating the process and requiring additional cleaning. Managing volatile matter is essential to maximize syngas output while minimizing tar-related issues. Ash is the non-combustible residue left after MSW is gasified, made up of minerals like silica, alumina, calcium, and metal oxides. Some ash components, like alkali metals, can catalyze gasification reactions, boosting H_2 and CO production. However, high ash content absorbs heat, lowering gasification temperatures and reducing H_2 and CO output, while increasing CO_2 and CH_4 levels [17]. Additionally, low-melting-point ash can cause tar formation, disrupting the gasification process. High ash content also requires more energy to maintain temperature, reducing syngas quality and efficiency. The results of the bomb calorimeter test indicated that the MSW sample had a calorific value of 11.99 MJ/kg. This high value suggests that MSW contains a significant amount of flammable materials. This finding aligns with Mukherjee's research [18], which states that the calorific value of MSW typically ranges from 11 MJ/kg to 12 MJ/kg. This calorific value is considered suitable for fuel in the gasification process, which can generate syngas. These syngas can then be utilized as a direct energy source or converted into other fuels.

3.2 Ultimate analysis

The ultimate analysis in Figure 3 provides the percentage of C, H, N, S, and O in the municipal waste sample. The findings show that C, O, and H are the main elements of MSW. C, O, and H in MSW, directly affect syngas production, energy output, and gasification efficiency [19]. N is an element that produces harmful gases like ammonia (NH_3) and nitrogen oxides (NOx). N can dilute the syngas and reduce the quality of the resulting gas. S contributes to the formation of hydrogen sulfide (H_2S) and sulfur dioxide (SO_2). These sulfur compounds are corrosive and toxic, necessitating their removal from the syngas to prevent damage to downstream equipment and reduce environmental impact.

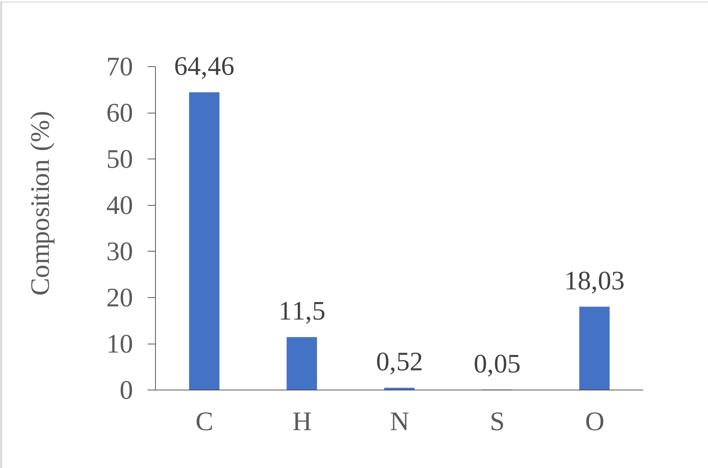

Figure 3. Ultimate testing of MSW

C plays a pivotal role in MSW as it influences the gasification process, directly affecting syngas production, energy output, and gasification efficiency [20]. The exothermic oxidation of carbon ($C + O_2 \rightarrow CO$) helps to sustain the temperature of gasification, thereby promoting endothermic reactions such as the Boudouard reaction and the water-gas reaction. With limited oxygen or air, C is oxidized into CO. In the Boudouard reaction, C reacts with CO_2 to produce CO. In contrast, in the water-gas reaction, C reacts with H_2O to yield H_2 and CO. The concentrations of CO and H_2 have an impact on the calorific value of produced syngas. MSW containing a high C content tends to generate syngas with a higher calorific value, thereby enhancing the overall gasification efficiency. The reaction is :

Oxidation $$C + \frac{1}{2}O \rightarrow CO \quad (1)$$

Boudouard reaction $$C + CO_2 \rightarrow 2CO \quad (2)$$

Water-gas reaction $$C + H_2O \rightarrow CO + H_2 \quad (3)$$

The O content in MSW significantly affects combustion and oxidation reactions during gasification. A higher O content in MSW can also influence the stoichiometry of the gasification process, producing CO_2 and H_2O [21]. This has the potential to reduce the calorific value of syngas and the efficiency of syngas production. Conversely, H enhances syngas' calorific value since H_2 is a very energetic fuel component. A higher H content in MSW generally leads to a higher concentration of H_2 in the syngas, which enhances its overall quality as a fuel. Several tests conducted in various locations, including Osogbo, Chattogram City, and Morocco [22,23,24], have shown that the composition of the elements from the proximate and ultimate analyses yielded comparable results. Additionally, when compared to Cassius' research [25], which reported a low heating value of 4.6 MJ/kg, the findings from this test indicate that the material is suitable for use as raw material in the gasification process

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4. CONCLUSION

The proximate and ultimate analyses of MSW indicate that elements such as volatiles and carbon, present in high percentages, have a positive impact on syngas production and calorific value. Moreover, the composition of components such as moisture content, ash, hydrogen, and oxygen is sufficient to support the gasification process. Elements like nitrogen and sulfur, which can potentially reduce the quality of syngas and lower the calorific value, are present only in small percentages. It is important to note that the sample preparation process, including sorting and drying, significantly affects the composition of these elements. Based on these findings, MSW from the sampled source is recommended for use as a raw material in the gasification process.

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