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# Micro-scale Biodrying of Municipal Waste for Refuse Derived Fuel (RDF) Production

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**Abstract**

*The quantity and types of municipal solid waste (MSW) continue to increase worldwide, driven by rapid urbanization and population growth. This study explores the biodrying process as a sustainable approach to convert MSW into refuse-derived fuel (RDF), offering an alternative renewable energy source. Biodrying, a biological phase within the mechanical–biological treatment (MBT) system, removes moisture through microbial activity supported by controlled aeration. The experiment evaluated different aeration rates (0, 6, and 8 L/min) and residence times (7, 14, and 21 days) to assess their impact on the quality of RDF. Higher aeration enhanced drying performance and increased the calorific value up to 4260 kcal/kg, while longer residence time improved moisture reduction and heating efficiency. However, the non-aerated condition (0 L/min) demonstrated greater process stability and energy efficiency, achieving 4044 kcal/kg with lower operational demand. Thus, while forced aeration improved RDF quality, the passive (non-aerated) setup represented the most energy-efficient operating condition. The optimal configuration non-aerated condition (0 L/min) and 7-day residence time produced RDF with 8.2% moisture, 1.0% ash, 76.5% volatile matter, and 14.3% fixed carbon. The resulting RDF complied with SNI 8966:2021 Class II solid fuel standard, equivalent to low-grade brown coal (<7000 cal/g). These findings indicate that passive biodrying without forced aeration can effectively enhance RDF quality with minimal energy input. The process demonstrates a simple, low-cost, and energy-efficient strategy for transforming mixed municipal waste into renewable solid fuel, supporting the circular economy and sustainable energy goals.*

**Keywords:** *garbage; Refuse Derived Fuel (RDF); biodrying; aeration*



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## INTRODUCTION

Sugarcane bagasse, a biomass waste rich in lignin (22.4%), cellulose (45.3%), and hemicellulose (22.1%), represents a promising source for carbon dot (CD) synthesis (Yang *et al*., 2017). Rapid urbanization and economic growth have intensified municipal solid waste (MSW) generation, aggravating environmental and public health pressures. In Pontianak, Indonesia, waste generation reaches ~400 tons day$^{-1}$, increasing from 144,651.25 tons in 2021 to 146,560.7 tons in 2022, with approximately 66% comprising organic fractions (Badan Penelitian dan Pengembangan Provinsi Kalimantan Barat, 2021). Conventional practices such as landfilling and small-scale incineration are inadequate and generate secondary pollution, including greenhouse gas emissions ($CO_2$, $NO_x$, $SO_2$) and leachate (Gunarathne *et al*., 2024; J. Wang & Qiao, 2024). Within the waste-to-energy framework, conversion of MSW into refuse-derived fuel (RDF) offers a viable alternative to fossil fuels in cement and power industries, with reported calorific values of landfill-derived fractions ranging from 10.4–21.8 MJ kg$^{-1}$ (Cheela *et al*., 2021) particularly relevant for biomass-rich tropical waste streams.

Biodrying, a Mechanical–Biological Treatment (MBT) process, is a critical pre-treatment for high-moisture MSW, utilizing microbial metabolic heat to reduce moisture below 20% while preserving calorific value (Chaerul & Fakhrunnisa, 2020; Komunikasi *et al*., 2020). It is more energy-efficient and environmentally favorable than thermal drying.

During biodrying, several coupled biological and physicochemical phenomena occur simultaneously. Indigenous aerobic microorganisms degrade biodegradable organic fractions through aerobic metabolism, producing metabolic heat via exothermic reactions. The generated heat is transferred throughout the waste matrix, facilitating moisture evaporation and vapor migration from the solid phase to surrounding air. Consequently, microbial degradation, heat transfer, and mass transfer collectively govern drying efficiency and RDF fuel quality, where reduced moisture generally increases energy density and calorific value (Velis *et al*., 2009).

Biodrying performance depends on operational parameters, notably aeration rate and residence time, which regulate microbial activity, heat generation, and evaporation kinetics (Bhatsada *et al*., 2023; Itsarathorn *et al*., 2023; Payomthip *et al*., 2022). The addition of a bulking agent enhances drying efficiency and calorific value (Widyarsana & Wulandari, 2025). In this study, sawdust was employed due to its high carbon content, favorable density, high combustion potential, and sulfur-retention capacity (Yuan *et al*., 2017). To optimize biodrying for MSW–sawdust mixtures, this study evaluated aeration rates (0, 6, 8 L min$^{-1}$) and residence times (7, 14, 21 days), assessing RDF quality through proximate and calorific analyses to determine optimal conditions in accordance with SNI 8966:2021.

## MATERIALS AND METHODS

### Materials

The feedstock consisted of Municipal Solid Waste (MSW) from Pontianak and sawdust, which served as a bulking agent to enhance porosity and calorific value. After manual removal of non-combustible materials, such as glass and metal, the combustible fractions (organic, paper, and plastic) were mechanically shredded to ensure size and shape homogeneity and increased surface area.

### Methods

The biodrying process was performed in a 20 L high-density polyethylene (HDPE) tank processor (3 kg capacity) equipped with an air compressor and flow meter to control the aeration, with leachate was discharged through the bottom outlet. A factorial design evaluated three aeration rates (0, 6, and 8 L min$^{-1}$), applied intermittently (15 min every 2 h), over retention times of 7, 14, and 21 days. The feedstock comprised a 50:50 mixture of shredded municipal solid waste: food waste (30%), twigs (12.4%), paper (11.8%), plastic (15.6%), rubber (3.3%), and fabric (6.3%), and sawdust, supplemented with a bioactivator. After biodrying, material was milled to 32 mesh, blended with 10% starch binder and 400 mL water, pelletized into 5 mm RDF, and sun-dried for two days. RDF quality was assessed according to SNI 8966:2021 focusing on proximate and calorific characterizations based on ASTM standards.

The proximate compositions, comprising moisture content (MC), ash content, volatile matter (VM), and fixed carbon (FC), were analyzed to evaluate RDF quality. All proximate analysis values were expressed on a wet basis (as-received basis). Fixed carbon was calculated by difference according to:

$$FC\ (\%) = 100 - (MC + Ash + VM) \qquad (1)$$

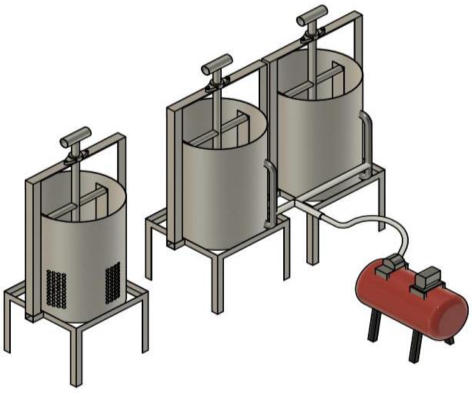

Figure 1. Schematic design of the agitated biodrying processor system

## RESULTS AND DISCUSSION

### *Temperature and Moisture*

Temperature is critical in biodrying as it governs organic degradation and water evaporation rates. Optimal thermal conditions accelerate moisture removal by enhancing microbial metabolic activity, thereby preserving the calorific value of the refuse-derived fuel.

The observed temperature profile reflects the progression of microbial activity during biodrying. The temperature increases during the early stage (day 1–7) suggests active biodegradation of readily degradable organic fractions, which promotes heat accumulation and accelerated moisture removal. However, the maximum temperature remained within the mesophilic range (up to 36 °C), indicating that biological activity was insufficient to reach thermophilic conditions, likely due to the limited reactor size and heat dissipation in the open system. As biodrying progressed, the gradual decline in temperature after day 7 may be attributed to reduced biodegradable substrate availability and lower moisture content, both of which limited microbial metabolic activity and heat generation (Adani et al., 2002; Tambone et al., 2011).

In contrast, suboptimal temperatures hinder microbial efficiency and overall drying performance (Orozco-Álvarez et al., 2025; Yuan et al., 2017). The heat generated by waste decomposition process will be used to assist the evaporation of water molecules contained in the waste and on the surface of the waste. The basic principle of biodrying is to reduce the water content using heat generated by microorganisms decomposing organic waste, assisted by aeration. Table 1 shows that the waste temperature decreased until day 6, after which it stabilised between days 7 and 21, exhibiting no significant fluctuations.

The temperature increase observed during biodrying can be attributed to aerobic microbial degradation of biodegradable organic matter, which releases heat through exothermic reactions. A simplified representation of carbohydrate-rich organic degradation in municipal solid waste can be expressed as follows (Zaman et al., 2018):

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{Heat}$$

During aerobic biodrying, microorganisms utilize biodegradable organic substrates and oxygen, producing carbon dioxide, water vapor, and metabolic heat. The generated thermal energy elevates matrix temperature, enhances moisture evaporation, and improves drying efficiency within the waste matrix.

Microbial heat generation during biodrying may be enhanced by maintaining conditions favorable for aerobic biodegradation, including sufficient oxygen availability, suitable moisture content, biodegradable organic substrate, and adequate waste porosity. However, excessive aeration may also increase convective heat loss, thereby reducing internal heat accumulation within the waste matrix. In the present microscale biodrying system, passive aeration under the 0 L min$^{-1}$ condition likely retained metabolic heat more effectively while still allowing oxygen diffusion through material porosity, contributing to improved drying performance.

Table 1. Temperature and moisture observed during the biodrying process

| Day | Aeration Flow Rate | | | | | |
|---|---|---|---|---|---|---|
| | 0 L/m | | 6 L/m | | 8 L/m | |
| | T (ºC) | M | T (ºC) | M | T (ºC) | M |
| 1 | 36 | WET+ | 36 | WET+ | 36 | WET+ |
| 2 | 33 | WET+ | 32 | WET+ | 32 | WET+ |
| 3 | 32 | WET | 32 | WET+ | 33 | WET+ |
| 4 | 30 | WET+ | 31 | WET+ | 30 | WET+ |
| 5 | 29 | WET | 30 | WET | 30 | WET |
| 6 | 28 | WET | 28 | WET | 28 | WET |
| 7 | 28 | WET | 29 | WET | 29 | WET |
| 8 | 28 | DRY | 29 | WET | 28 | DRY |
| 9 | 29 | DRY | 30 | DRY | 29 | DRY |
| 10 | 29 | DRY | 30 | DRY | 30 | WET |
| 11 | 29 | DRY | 29 | DRY | 29 | DRY |
| 12 | 28 | DRY | 28 | DRY | 28 | DRY |
| 13 | 29 | DRY | 28 | DRY | 29 | DRY |
| 14 | 30 | DRY | 30 | DRY | 30 | DRY |
| 15 | 29 | DRY | 29 | DRY | 29 | DRY |
| 16 | 29 | DRY | 29 | DRY | 29 | DRY |
| 17 | 29 | DRY+ | 29 | DRY | 28 | DRY |
| 18 | 28 | DRY+ | 28 | DRY+ | 28 | DRY |
| 19 | 27 | DRY | 27 | DRY+ | 27 | DRY+ |
| 20 | 28 | DRY+ | 28 | DRY+ | 28 | DRY+ |
| 21 | 29 | DRY+ | 30 | DRY+ | 29 | DRY+ |

The interplay between microbial metabolism, heat generation, and moisture removal determines biodrying efficiency and RDF quality (Latosińska et al., 2022; Payomthip et al., 2022). Metabolic heat from aerobic degradation promotes moisture evaporation through aeration and residence time, although a minor fraction may percolate as leachate (Chungam et al., 2025). The temperature rise on day 1 indicated the onset of active decomposition. Despite the potential to reach thermophilic conditions (45–75 °C) that enhance stabilization and drying (Orozco-Álvarez et al., 2025), only mesophilic temperatures were achieved (maximum 36 °C) due to limited pile height and an open reactor design that facilitated heat dissipation; thermophilic conditions would require improved insulation and higher waste loading. Extended aeration and retention enhanced moisture removal, reduced ash content, and improved volatile matter, fixed carbon, and calorific value (Izaty et al., 2018). Temperature peaked on day 7 due to intensified microbial activity (Lwin et al., 2024), declined by day 14 as moisture decreased, and stabilized by day 21, indicating metabolic attenuation and process completion (Hu et al., 2023). The final temperature (29–30 °C) met the SNI 19-7-30-2004 maturity standard (25–35 °C), confirming attainment of the DRY+ condition and substantial moisture reduction.

## Proximate Analysis of Biodrying Process

### *Water Content in Biodrying*

The initial moisture content was 60.7%. The greatest reduction occurred at 6 L min$^{-1}$, reaching 18.9% after 21 days, whereas 8 L min$^{-1}$ yielded the lowest reduction (54.9% after 7 days). Overall, 6 L min$^{-1}$ outperformed 0 and 8 L min$^{-1}$, indicating optimal aerobic conditions for microbial metabolism, heat generation, and convective moisture removal.

A B C

Figure 1. Biodrying results before RDF production, with (A) Aeration Rate 0 L/min, (B) 6 L/min, (C) 8 L/min

Adequate aeration enhances evaporation through improved oxygen supply and heat transfer; however, excessive moisture depletion suppresses microbial activity and slows further biodegradation. Mechanical airflow thus maintains aerobic conditions while removing water vapor. Insufficient aeration (0 L min$^{-1}$) restricts oxygen and limits biologically driven drying, whereas excessive aeration (8 L min$^{-1}$) dissipates heat and reduces microbial effectiveness (Yang et al., 2017). Consequently, biodrying at 6 L min$^{-1}$ was biologically dominant, while 0 and 8 L min$^{-1}$ were governed mainly by physical evaporation. The visualization of biodrying results before RDF production is shown in Figure 2. The overall biodrying performance before RDF production is illustrated in Figure 3 and Figure 4.

As shown in Figure 3, moisture content consistently declined from day 7 to day 21 across all treatments, reflecting progressive microbial attenuation as the waste matrix dried (Yang et al., 2017). This trend follows the bacterial growth curve — lag, exponential, and stationary phases (Manna et al., 2024). The early stage (days 1–4) showed limited activity and minor drying; the mid-stage (days 5–14) corresponded to exponential growth with moderate moisture loss; and the final stage (days 15–21) marked stationary conditions, where drying shifted predominantly to physical evaporation due to nutrient depletion and reduced metabolic activity. Residence time further determines final moisture reduction, with longer durations enhancing water loss. The addition of a bulking agent (sawdust) improved porosity and free-water absorption (Yuan et al., 2019). The optimal condition, 6 L min$^{-1}$ aeration with 21 days of residence time, produced the lowest final moisture content (18.9%), confirming the combined influence of balanced aeration, sufficient retention time, and bulking agent addition on biodrying performance.

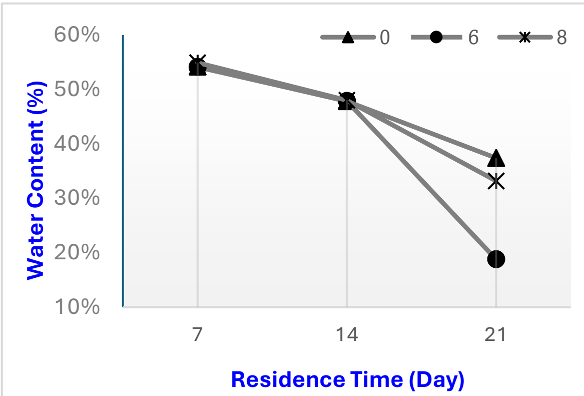


Figure 2. Water content changes during biodrying treatment at aeration rates of 0, 6, and 8 L/min over residence times of 7, 14, and 21 days

### *Ash Content in Biodrying*

Ash content represents the inorganic, non-combustible residue remaining after thermal decomposition and inversely correlates with calorific value; higher ash dilutes the combustible fraction and lowers RDF quality (Nasiri et al., 2023;Lieskovský et al., 2017;Sarquah et al., 2023). As shown in Figure 4, aeration rate and residence time significantly influence ash content during biodrying. The lowest value (0.3%) was observed at 6 L min$^{-1}$ for 14 days and at 8 L min$^{-1}$ for 14 and 21 days, whereas the highest (0.9%) occurred at 0 L min$^{-1}$ for 14 days, indicating that insufficient aeration limited microbial degradation and heat generation.

Appropriate airflow (6–8 L min$^{-1}$) enhances aerobic activity, moisture removal, and organic matter stabilization, thereby reducing the relative inorganic fraction. Longer residence time further decreased ash percentage due to continued mass and moisture loss during biodrying (Ardhianti et al., 2017).

The ash fraction primarily comprises minerals such as Ca, Mg, and P, and its overall low level reflects the limited inorganic content of the feedstock. In general, ash variation during biodrying is closely associated with moisture dynamics driven by microbial heat rather than direct microbial conversion of mineral components. Nevertheless, ash content remains an important fuel-quality indicator because elevated ash levels reduce calorific value and carbon content. The slight increase observed at 6 L min⁻¹ on day 21 may be attributed to ambient moisture reabsorption during the decline of biological activity. Overall, low ash contents (≈0.3%) were obtained at aeration rates of 6–8 L min⁻¹ with residence times of 14–21 days, indicating that adequate aeration combined with sufficient retention promotes effective stabilization during biodrying.

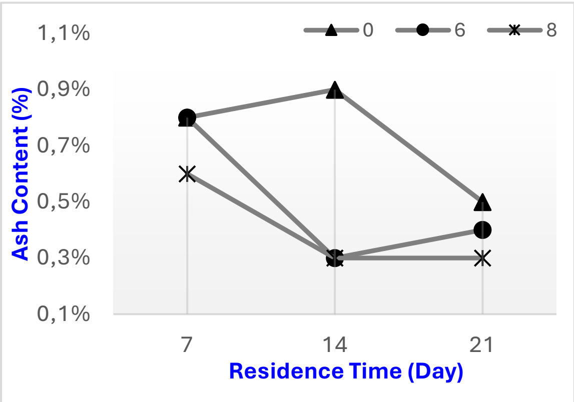


Figure 4. Changes in ash content during biodrying at aeration rates of 0, 6, and 8 L/min over residence times of 7, 14, and 21 days.

***Volatile Matter in Biodrying***

Figure 5 shows that variations in aeration rate and residence time during the biodrying process of solid waste mixed with sawdust significantly affect the volatile matter content. Because biodrying effectively reduces moisture and ash, the remaining material tends to retain a higher proportion of volatile compounds. The results indicate that volatile matter generally increased on days 14 and 21 across most aeration treatments.

Before pelletization, the lowest volatile matter content (32.9%) was observed at an aeration rate of 6 L min⁻¹ with a residence time of 7 days, whereas the highest value (71.3%) occurred at the same aeration rate after 21 days. Only minor changes in volatile matter were detected during the early stage (days 1–7), corresponding to the microbial lag phase, when microbial populations are still adapting to the substrate and metabolic activity remains limited. During the subsequent exponential phase, microorganisms proliferate rapidly and actively decompose biodegradable organic matter. Although part of the organic fraction is consumed during microbial metabolism, the relative proportion of volatile matter in the remaining material may increase due to concurrent reductions in moisture and ash content. Therefore, variations in volatile matter reflect the combined influence of microbial degradation, aeration efficiency, and overall mass reduction during the biodrying process (Prahara & Kristanto, 2019).

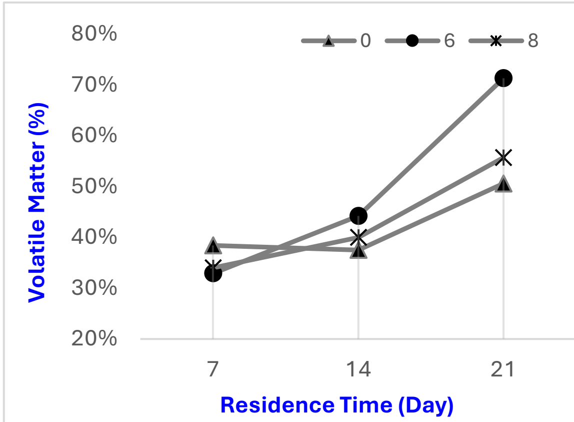


Figure 5. Changes in volatile content during biodrying at aeration rates of 0, 6, and 8 L/min over residence times of 7, 14, and 21 days.

***Fixed Carbon in Biodrying***

Figure 6 demonstrates that aeration rate and residence time significantly affected the fixed carbon content of the biodried MSW–sawdust mixture. Prior to pelletization, the highest fixed carbon value (66.3%) was obtained at an aeration rate of 6 L min⁻¹ after 7 days, whereas the lowest value (9.3%) occurred at the same aeration rate after 21 days. In general, fixed carbon decreased with increasing residence time across all aeration treatments.

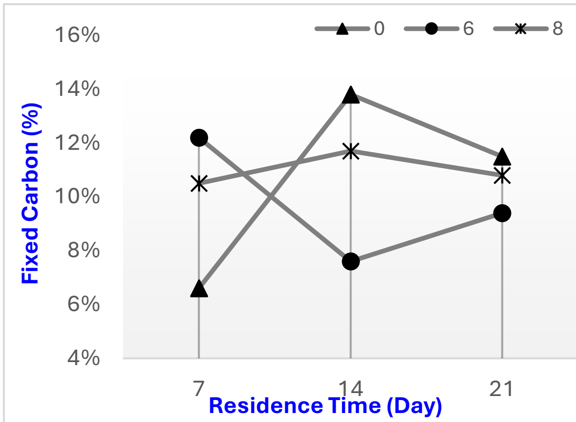


Figure 6. Changes in fixed carbon content during biodrying at aeration rates of 0, 6, and 8 L/min over residence times of 7, 14, and 21 days.

This trend reflects the progressive degradation of carbonaceous organic matter during biodrying. As microbial activity intensifies under aerobic conditions, biodegradable carbon compounds are oxidized and converted into metabolic products such as carbon dioxide, water vapor, and heat. Adequate aeration enhances oxygen supply and microbial metabolism, thereby accelerating the decomposition of organic substrates (Bhatsada et al., 2023). Consequently, longer residence times allow continued microbial oxidation of carbon-containing materials, resulting in a reduction in fixed carbon content.

Fixed carbon is calculated as the residual fraction remaining after subtracting moisture, ash, and volatile matter from the total mass. Therefore, the observed decline in fixed carbon with increasing residence time reflects progressive biochemical degradation and mass loss during biodrying.

Extended retention allows continued microbial oxidation of carbonaceous substrates, which gradually reduces the fixed carbon fraction. Nevertheless, the relatively high fixed carbon value (66.3%) observed at an aeration rate of 6 L min$^{-1}$ after 7 days indicates that moderate aeration combined with shorter residence time can better preserve carbon-rich material prior to pelletization, representing the most favorable condition for fixed carbon yield.

***Proximate Analysis and Caloric Value RDF-5***

Figure 7 presents the physical appearance of RDF-5 pellets produced from biodried municipal solid waste mixed with sawdust under different aeration rates. The pellets were formed after the biodrying process followed by pelletization and additional sun drying. As shown in Figure 7A–C, all treatments successfully produced cylindrical pellets with relatively uniform shapes and compact structures, indicating that the biodried material possessed adequate binding and densification characteristics for pellet formation.


Figure 7. Physical appearance of RDF-5 pellets produced after biodrying under aeration rates of 0 L min$^{-1}$ (A), 6 L min$^{-1}$ (B), and 8 L min$^{-1}$ (C).

Differences in surface texture and compactness among the pellets may be associated with variations in moisture content and particle cohesion resulting from different aeration conditions during biodrying. Pellets produced under different aeration treatments exhibited slightly different structural appearances, reflecting the influence of biodrying conditions on the physical properties of the feedstock prior to pelletization.
Overall, the visual appearance of the RDF-5 pellets indicates that the biodrying process effectively conditioned the waste mixture for densification, enabling the production of stable solid fuel pellets suitable for handling and storage.

***Water Content in RDF-5***

Figure 8 shows that all RDF pellets met solid refuse fuel standards, confirming the effectiveness of biodrying followed by two-day sun drying prior to pelletization. The highest moisture content (8.2%) was observed at an aeration rate of 0 L min$^{-1}$ with a residence time of 7 days, whereas the lowest value (2.5%) was obtained at 8 L min$^{-1}$ for 14 days and at both 0 and 8 L min$^{-1}$ for 21 days. These results demonstrate that aeration rate and residence time significantly influence drying efficiency during RDF preparation. Lower moisture content contributes to a higher calorific value and improves the fuel quality of RDF (Halim & Muhammad, 2025).

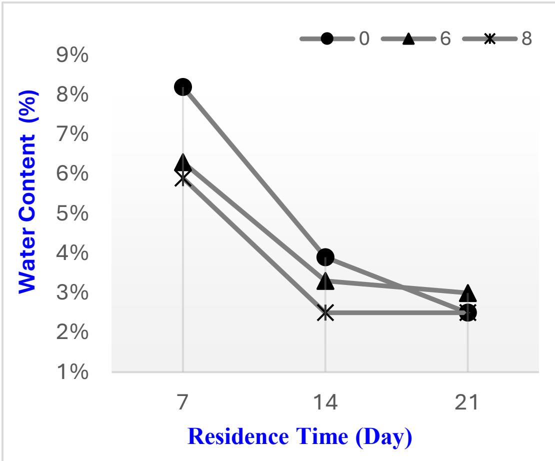


Figure 8. Changes in water content of RDF-5 at aeration rates of 0, 6, and 8 L min$^{-1}$ over residence times of 7, 14, and 21 days

The differences in moisture content before and after pelletization were mainly attributed to additional sun drying after pellet formation, although storage conditions and ambient climate may also influence the moisture level (X. Yang et al., 2024). Although adhesive addition introduces a small amount of water, the binder can enhance pellet density and reduce pore size, which may affect moisture retention (Anukam et al., 2021). The most favorable condition for RDF-5 production was observed at 0 L min$^{-1}$ with a residence time of 21 days, yielding a moisture content of 2.5%. Overall, all RDF-5 samples exhibited moisture contents below 20%, thereby satisfying the Class 2 solid fuel pellet requirement specified in the 2021 Indonesian National Standard.

***Ash Content in RDF-5***

The highest ash content (1.5%) was observed at 6 L min$^{-1}$ with 14 days of residence time, whereas the lowest value (0.8%) occurred at 0 L min$^{-1}$ for 21 days and 6 L min$^{-1}$ for 7 days, indicating that aeration rate, retention time, and adhesive addition influence RDF-5 ash levels. As shown in Figure 9, the ash content of

RDF-5 varies with aeration rate and residence time during the biodrying process. The highest ash content (1.5%) was observed at an aeration rate of 6 L min⁻¹ with a residence time of 14 days, whereas the lowest value (0.8%) occurred at 0 L min⁻¹ for 21 days and at 6 L min⁻¹ for 7 days. These results indicate that aeration rate, residence time, and adhesive addition influence the ash content of RDF-5.

The slight increase in ash content associated with adhesive addition can be attributed to the starch binder, which consists mainly of amylose and amylopectin. Although starch is predominantly organic, it may produce minor inorganic residues after combustion. Ash represents the non-combustible fraction of biomass and plays an important role in fuel performance, as elevated ash levels can hinder heat transfer and oxygen diffusion during combustion, thereby reducing calorific value. Consequently, ash content is inversely correlated with heating value and the overall energy potential of RDF (Suryawan et al., 2022; Cheela et al., 2021).

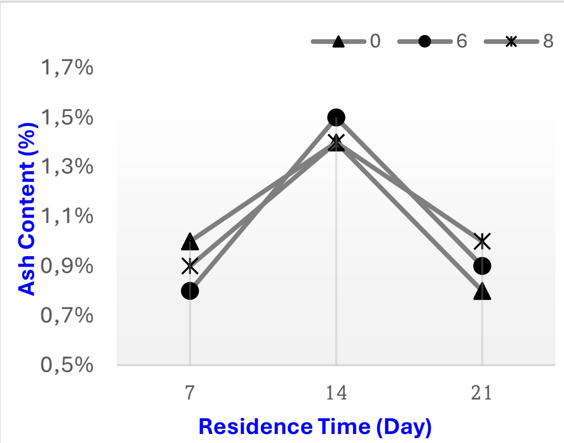


Figure 9. Changes in ash content of RDF-5 at aeration rates of 0, 6, and 8 L min⁻¹ over residence times of 7, 14, and 21 days.

Minor deviations in ash content observed at residence times of 7 and 14 days were likely caused by sampling variability and did not significantly affect the overall trend. Based on the RDF ash analysis, the most favorable condition was obtained at 0 L min⁻¹ with a residence time of 21 days, yielding an ash content of 0.8%. This value is well below the maximum limit of 20% specified in the Indonesian solid fuel quality standards, indicating that all RDF-5 samples produced in this study meet the required ash content criteria.

### *Volatile Matter in RDF-5*

Figure 10 illustrates the influence of aeration rate and residence time on the volatile matter content of RDF-5 produced from mixed municipal solid waste and wood powder. Biodrying reduced moisture and ash fractions, thereby increasing the relative proportion of volatile compounds in the resulting RDF. The highest volatile matter content (86%) was observed at an aeration rate of 8 L min⁻¹ with a residence time of 14 days, whereas the lowest value (76.6%) occurred at 0 L min⁻¹ with 7 days of residence time. These results indicate that operational conditions during biodrying affect the distribution of volatile components even when the feedstock composition remains constant (Chaerul & Fakhrunnisa, 2020).

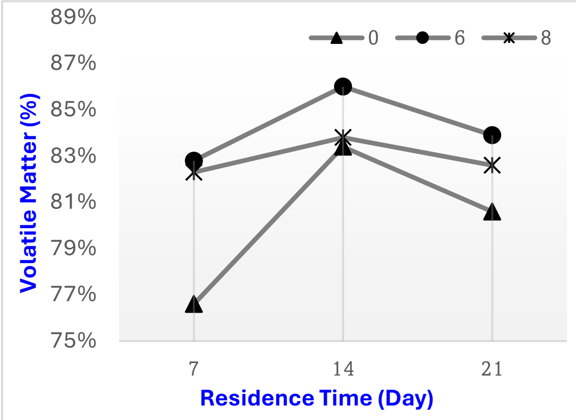


Figure 10. Changes in ash content of RDF-5 at aeration rates of 0, 6, and 8 L min⁻¹ over residence times of 7, 14, and 21 days.

Higher aeration rates can accelerate heat and moisture removal, which may suppress microbial activity and limit the degradation of volatile organic compounds, thereby increasing the relative volatile fraction. Therefore, balanced aeration is important to maintain effective microbial activity while ensuring suitable RDF quality (Yuan et al., 2019). In addition, the use of starch adhesive during pelletization may slightly increase the volatile fraction due to its combustible organic composition. Nevertheless, the volatile matter values obtained in this study remained within acceptable limits. The most favorable condition for RDF-5 production was observed at 0 L min⁻¹ with 7 days of residence time, yielding a volatile matter content of 76.6%. This value falls within the standard range of 50–80% specified by the Indonesian Ministry of Industry, confirming that all RDF-5 samples comply with national fuel quality requirements.

### *Fixed Carbon in RDF-5*

Figure 11 presents the effect of aeration rate and residence time on the fixed carbon content of RDF-5 produced from municipal solid waste mixed with sawdust. The highest fixed carbon value (16.1%) was obtained under the biodrying condition of 0 L min⁻¹ with a residence time of 21 days, whereas the lowest value (9.2%) occurred at an aeration rate of 6 L min⁻¹ with a residence time of 14 days. These variations are closely associated with changes in moisture and volatile matter, which determine the remaining proportion of solid carbon in the material.

Fixed carbon represents the fraction of fuel that remains after moisture and volatile components are released during combustion. Consequently, its content is strongly influenced by the relative amounts of water and volatile matter present in the fuel and generally exhibits an inverse relationship with volatile matter content. As moisture decreases during biodrying, the concentration of carbonaceous solids tends to increase, leading to higher fixed carbon values. This behavior is consistent with theoretical principles indicating that fixed carbon is determined by the progressive reduction of moisture, ash, and volatile fractions in biodried materials and the resulting RDF pellets (Inegbedion, 2022).

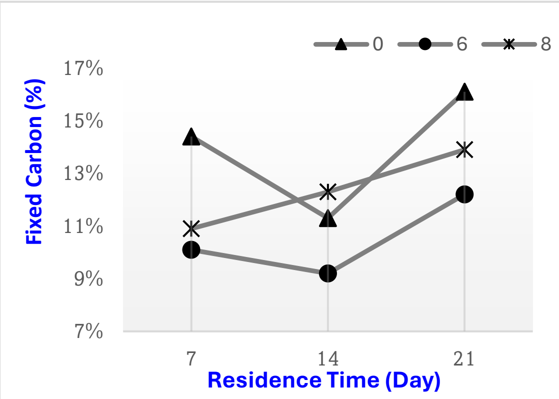


Figure 11. Changes in fixed carbon content of RDF-5 at aeration rates of 0, 6, and 8 L min$^{-1}$ over residence times of 7, 14, and 21 days.

Across all aeration treatments (0, 6, and 8 L min$^{-1}$), fixed carbon content generally increased from day 7 to day 21, reflecting progressive drying and stabilization of the biomass-derived material. Minor deviations from this trend were observed on day 14 at aeration rates of 0 and 6 L min$^{-1}$, which may be attributed to temporary fluctuations in environmental conditions during sampling that affected moisture redistribution and measurement consistency.

The most favorable condition for fixed carbon enrichment was observed at 0 L min$^{-1}$ with a residence time of 21 days, yielding a fixed carbon value of 16.1%.

The superior performance observed under the 0 L min$^{-1}$ condition may be associated with improved heat retention during microscale biodrying. Although increased airflow generally enhances moisture transport in conventional drying systems, excessive aeration may also increase convective heat dissipation, limiting heat accumulation within the waste matrix. Since biodrying relies on biologically generated heat to facilitate moisture evaporation, excessive airflow (6 and 8 L min$^{-1}$) may have reduced drying efficiency by dissipating thermal energy faster than it was produced. In contrast, passive aeration at 0 L min$^{-1}$ likely retained microbial metabolic heat more effectively while still permitting oxygen diffusion through material porosity, thereby promoting moisture reduction and fixed carbon enrichment (Adani et al., 2002; Tambone et al., 2011; Velis et al., 2009).

This condition is beneficial for improving the calorific value of RDF, as fixed carbon contributes directly to the fuel's energy content. According to SNI 8966:2021, the minimum fixed carbon requirement for solid refuse fuel is 10%, and all RDF-5 samples produced in this study satisfied this national quality standard. These findings are consistent with previous studies reporting that longer retention times during biodrying promote fixed carbon enrichment and improve the calorific value of municipal solid waste-derived fuels (Itsarathorn et al., 2023) and (Bhatsada et al., 2023).

### ***Proximate Analysis and Caloric Value RDF-5***

Calorific value (CV) represents the amount of energy released during fuel combustion and is an important parameter for evaluating the quality and combustion efficiency of refuse-derived fuel (RDF). Fuels with higher calorific values generally exhibit better ignition and combustion performance (Awad et al., 2017).

This observation is consistent with previous studies indicating that calorific value is inversely related to moisture content. The calorific value results of RDF-5 produced under different aeration rates and residence times are presented in Table 2. Three samples were selected for calorific value testing based on their compliance with the Indonesian National Standard (SNI 8966:2021) for solid fuel. Most proximate parameters satisfy the SNI requirements, while volatile matter values slightly exceeded the recommended range; therefore, samples with volatile matter values closest to the standard range were selected for calorific value analysis.

The measured calorific values were 4044 kcal kg$^{-1}$ at an aeration rate of 0 L min$^{-1}$ with a residence time of 7 days, 4260 kcal kg$^{-1}$ at 6 L min$^{-1}$ with a 7-day residence time, and 4184 kcal kg$^{-1}$ at 8 L min$^{-1}$ with a residence time of 21 days. All measured values exceeded the minimum SNI requirement of ≥3585 kcal kg$^{-1}$, indicating that the biodrying process successfully improved the energy potential of the produced RDF.

The relatively high calorific values obtained in this study are closely related to the reduction in moisture content during biodrying. Lower moisture levels increase the effective energy density of the fuel because less heat is required to evaporate water during combustion.

Although microbial activity during biodrying may partially consume biodegradable organic matter, excessive organic loss was likely limited in the present study due to the relatively short residence time and mesophilic operating temperature. Unlike composting, biodrying primarily aims to reduce moisture content while preserving combustible fractions. Therefore, the reduction in moisture content likely exceeded the loss of organic matter, resulting in increased energy density and improved calorific value of the RDF produced.

Biodrying enhances fuel quality by utilizing microbial metabolism to decompose organic matter under controlled aeration conditions, typically within 14–21 days, thereby reducing moisture and stabilizing the waste matrix. Previous research has reported that biodrying can substantially increase the calorific value of municipal solid waste through moisture reduction and stabilization of combustible fractions (Tambone et al., 2011).

Although microbial metabolism during biodrying may partially consume biodegradable organic matter, excessive degradation of combustible fractions was likely limited in the present study due to the relatively short residence time and mesophilic operating temperature. Unlike composting, biodrying aims to reduce moisture content while preserving energy-rich combustible components. Therefore, the reduction in moisture content likely exceeded the loss of organic matter, resulting in increased energy density and improved calorific value of the RDF produced (Tambone et al., 2011).

Among the tested conditions, the highest calorific value (4260 kcal kg$^{-1}$) was achieved at an aeration rate of 6 L min$^{-1}$ with a residence time of 7 days, corresponding to a relatively low moisture content of 6.3%. Although the moisture content continued to decrease at higher aeration rates, the calorific value slightly declined under the 8 L min$^{-1}$ treatment.

This may be attributed to excessive aeration, which accelerates physical drying but may reduce microbial activity during the later stages of biodrying (days 14–21). Reduced microbial activity can alter the balance of organic components, leading to slightly higher ash fractions and lower volatile contributions compared with the moderate aeration condition.

Overall, while the highest calorific value was obtained at 6 L min$^{-1}$, the most balanced RDF-5 quality, considering moisture, ash, volatile matter, and fixed carbon, was achieved under the 0 L min$^{-1}$ treatment with a residence time of 21 days. Under this condition, all proximate parameters satisfied the requirements for Class 2 solid fuel according to SNI 8966:2021.

The calorific value obtained in this study is comparable to values reported in previous RDF research. For instance, (Rania et al., 2019) reported calorific values of approximately 4800 kcal kg$^{-1}$ for RDF produced through a pyrolysis-based process, whereas (Zaman et al., 2021) for RDF derived from municipal solid waste. In the present study, starch flour was used as a binder during pelletization. Although binders may slightly reduce calorific value due to additional moisture and thermoplastic components that require energy for evaporation, starch-based adhesives can also contribute to the energy content of RDF because of their carbon-rich composition. This factor likely supports the relatively high calorific values obtained in this study.

Figure 12 illustrates the proposed biodrying mechanism observed in this study. Biodrying performance was governed by coupled biological, heat transfer, and mass transfer processes, where microbial degradation generated heat that promoted moisture evaporation and vapor migration. In microscale biodrying systems, effective drying depends on the balance between biologically generated heat and heat

Table 2. Proximate composition and calorific value of RDF-5 produced at different aeration rates and residence times

| Aeration Rate / Residence Time | | Water Content (%) | Ash Content (%) | Volatile Matter (%) | Fixed Carbon (%) | Calorific Value (kcal/kg) |
|---|---|---|---|---|---|---|
| Indonesian National Standard (SNI 8966:2021) | | ≤20 | ≤20 | 50-80 | ≥10 | ≥3585 |
| 0 L/min | 7 Day | 8.2 | 1.0 | 76.4 | 14.4 | 4044 |
| | 14 Day | 3.9 | 1.4 | 83.4 | 11.3 | - |
| | 21 Day | 2.5 | 0.8 | 80.6 | 16.1 | - |
| 6 L/min | 7 Day | 6.3 | 0.8 | 82.8 | 10.1 | 4260 |
| | 14 Day | 3.3 | 1.5 | 86.0 | 9.2 | - |
| | 21 Day | 3.0 | 0.9 | 83.9 | 12.2 | - |
| 8 L/min | 7 Day | 5.9 | 0.9 | 82.3 | 10.9 | - |
| | 14 Day | 2.5 | 1.4 | 83.8 | 12.3 | - |
| | 21 Day | 2.5 | 1.0 | 82.6 | 13.9 | 4184 |

dissipation, explaining the superior performance observed under the 0 L min$^{-1}$ condition.

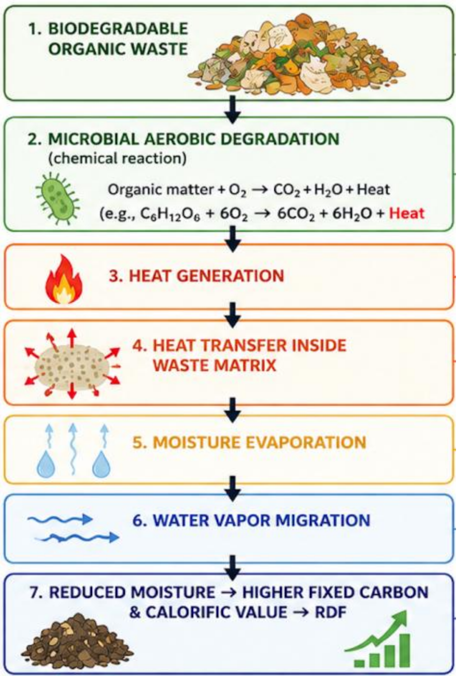


Figure 12. Schematic illustration of the biodrying mechanism during RDF production from municipal solid waste (MSW), showing microbial heat generation, heat and mass transfer, moisture evaporation, and the influence of aeration on drying performance and RDF quality.

The moisture evaporation process during biodrying requires heat for water vaporization and may be expressed as equation (2).

$$\boldsymbol{Q_{evap}} = \boldsymbol{m_v} \times \Delta \boldsymbol{H_{vap}} \quad (2)$$

where
$\boldsymbol{Q_{evap}}$ is the heat required for water evaporation (J)
$\boldsymbol{m_v}$ is the mass of water evaporated during biodrying (kg)
$\boldsymbol{H_{vap}}$ is the latent heat of vaporization of water, $\boldsymbol{H_{vap}} \approx \boldsymbol{2.26 \times 10^6 J/kg}$ (Ummah, 2019).

The transfer of water vapor from the waste matrix to the surrounding air, expressed as the volumetric evaporation rate $\boldsymbol{m_v}$ (kg m$^{-3}$ s$^{-1}$), is driven by the vapor concentration gradient between the solid surface and the surrounding air and may be described by the following simplified mass-transfer equation (Velis et al., 2009):

$$\boldsymbol{m_{evap}^{m}} = \boldsymbol{k_m} \,.\, \boldsymbol{a_v} .\,[\, \boldsymbol{C_{sat}}\,(\boldsymbol{T}) .\, \boldsymbol{a_w} - \boldsymbol{C_v}] \quad (3)$$

where
$\boldsymbol{m_{evap}^{m}}$ **:** is the volumetric water evaporation rate (kg m$^{-3}$ s$^{-1}$)
$\boldsymbol{k_m}$ : the mass transfer coefficient (m s$^{-1}$)
$\boldsymbol{a_v}$ : is the specific evaporation surface area per unit volume of the waste bed (m$^2$ m$^{-3}$, equivalent to m$^{-1}$),
$(\boldsymbol{C_{sat}})(\boldsymbol{T})$ : is the saturated water-vapor concentration at the bed temperature (kg m$^{-3}$)
$\boldsymbol{a_w}$ : is the water activity of the material (dimensionless)
$\boldsymbol{C_v}$ : is the actual water-vapor concentration in the surrounding air (kg m$^{-3}$)

Together, these equations demonstrate that biodrying performance is governed by the balance between biologically generated heat, which provides the energy required for water evaporation, and mass transfer, which removes water vapor from the waste matrix to the surrounding air.

## CONCLUSION

This study demonstrates the biodrying process as an effective method to convert mixed municipal solid waste (MSW) into refuse-derived fuel (RDF) with a relatively low energy input. The results show that both aeration rate and residence time during the biodrying process significantly influence the resulting fuel properties. Among the evaluated conditions, the most favorable RDF-5 quality was achieved in a non-aerated condition (0 L/min) with a residence time of 21 days, yielding a solid fuel with moisture, ash, volatile matter and fixed carbon contents of 2.5%, 0.8%, 80.6%, and 16.1%, respectively. The calorific value of the RDF-5 exceeds 4000 kcal kg$^{-1}$. These characteristics satisfy the requirements of SNI 8966:2021 for Class 2 solid refuse fuel, indicating that the produced RDF possesses suitable properties for energy recovery applications. Overall, the results suggest that passive biodrying can serve as a simple and cost-efficient approach for improving the fuel quality of municipal solid waste, thereby supporting sustainable waste valorization and alternative energy production.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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## REFERENCES

Adani, F., Baido, D., Calcaterra, E., & Genevini, P. (2002). The influence of biomass temperature on biostabilization–biodrying of municipal solid waste.

Bioresource Technology, 83(3), 173–179. https://doi.org/https://doi.org/10.1016/S0960-8524(01)00231-0

Anukam, A., Berghel, J., Henrikson, G., Frodeson, S., & Ståhl, M. (2021). A review of the mechanism of bonding in densified biomass pellets. Renewable and Sustainable Energy Reviews, 148, 111249. https://doi.org/10.1016/j.rser.2021.111249

Ardhianti, C., Sudarno, & Purwono. (2017). Pengaruh Aerasi Terhadap Karakteristik Lindi Hasil Pengolahan Sampah Sayuran dengan Metode Biodrying (Studi Kasus: Sawi Putih). Jurnal Teknik Lingkungan, 6(1), 1–10.

Awad, O. I., Mamat, R., Ibrahim, T. K., Hagos, F. Y., Noor, M. M., Yusri, I. M., & Leman, A. M. (2017). Calorific value enhancement of fusel oil by moisture removal and its effect on the performance and combustion of a spark ignition engine. Energy Conversion and Management, 137, 86–96. https://doi.org/10.1016/j.enconman.2017.01.009

Bhatsada, A., Patumsawad, S., Towprayoon, S., Chiemchaisri, C., Phongphiphat, A., & Wangyao, K. (2023). Modification of the Aeration-Supplied Configuration in the Biodrying Process for Refuse-Derived Fuel (RDF) Production. Energies, 16(7), 3235. https://doi.org/10.3390/en16073235

Chaerul, M., & Fakhrunnisa, A. (2020). Refuse Derived Fuel Production through Biodrying Process (Case study: Solid Waste from Canteens). Jurnal Bahan Alam Terbarukan, 9(1), 69–80. https://doi.org/10.15294/jbat.v9i1.24609

Chaerul, M., & Wardhani, A. K. (2020). Refuse Derived Fuel (RDF) dari Sampah Perkotaan dengan Proses Biodrying: Review. Jurnal Presipitasi : Media Komunikasi Dan Pengembangan Teknik Lingkungan, 17(1), 62–74.

Cheela, V. R. S., John, M., & Dubey, B. (2021). Quantitative determination of energy potential of refuse derived fuel from the waste recovered from Indian landfill. Sustainable Environment Research, 31(1), 24. https://doi.org/10.1186/s42834-021-00097-5

Chungam, B., Ishimori, H., Vinitnantharat, S., Towprayoon, S., Chiemchaisri, C., & Wangyao, K. (2025). Application of Electrical Resistivity Measurements for Continuous Monitoring of the Municipal Solid Waste Biodrying Process. Recycling, 10(2), 32. https://doi.org/10.3390/recycling10020032

Gunarathne, V., Phillips, A. J., Zanoletti, A., Rajapaksha, A. U., Vithanage, M., Di Maria, F., Pivato, A., Korzeniewska, E., & Bontempi, E. (2024). Environmental pitfalls and associated human health risks and ecological impacts from landfill leachate contaminants: Current evidence, recommended interventions and future directions. Science of The Total Environment, 912, 169026. https://doi.org/10.1016/j.scitotenv.2023.169026

Halim, N. A., & Muhammad, N. (2025). Investigation of moisture content and higher heating value in refusederived fuel from agricultural residues using statistical modelling. AIMS Energy, 13(1), 1–12. https://doi.org/10.3934/ENERGY.2025001

Hu, Z., Hao, Z., Lei, H., Guo, Y., Chen, Q., Zhang, W., & Rao, P. (2023). Effect of Bulking Agents on Dewatered Sludge Biodrying Followed by Thermal Drying. Processes, 11(5). https://doi.org/10.3390/pr11051392

Inegbedion, F. (2022). Estimation of the moisture content, volatile matter, ash content, fixed carbon and calorific values of saw dust briquettes. MANAS Journal of Engineering, 10(1), 17–20. https://doi.org/10.51354/mjen.940760

Itsarathorn, T., Towprayoon, S., Chiemchaisri, C., Patumsawad, S., Phongphiphat, A., Bhatsada, A., & Wangyao, K. (2023). The effect of aeration rate and feedstock density on biodrying performance for wet refuse-derived fuel quality improvement. International Journal of Renewable Energy Development, 12(6), 1091–1103. https://doi.org/10.14710/ijred.2023.56035

Izaty, F. N., Putra, H. P., & Lokahita, B. (2018). Analisis Karakteristik dan Komposisi Sampah Zona 1 TPA Piyungan Bantul Sebagai Bahan Baku RDF. Jurnal Universitas Islam Indonesia.

Latosińska, J., Żygadło, M., & Dębicka, M. (2022). The Biological Drying of Municipal Waste in an Industrial Reactor–A Case Study. Energies, 15(3), 1039. https://doi.org/10.3390/en15031039

Lieskovský, M., Jankovský, M., Trenčiansky, M., Merganič, J., & Dvořák, J. (2017). Ash Content vs. the Economics of Using Wood Chips for Energy: Model Based on Data from Central Europe. BioResources, 12(1),1579–1592. https://doi.org/10.15376/biores.12.1.1579-1592

Lwin, Y. N. N., Bhatsada, A., Towprayoon, S., Patumsawad, S., Sutthasil, N., & Wangyao, K. (2024). Aeration Optimization for the Biodrying of Market Waste Using Negative Ventilation: A Lysimeter Study. Clean Technologies, 6(4), 1519–1536. https://doi.org/10.3390/cleantechnol6040073

Manna, K., Bhattacharjee, R., Majumder, P., Acharjee, J., & Paul, K. (2024). A Composite Review on: Microbial Culture and Growth Curve of Bacteria. Acta Scientific Microbiology, 7(3), 27–30. https://doi.org/10.31080/asmi.2024.07.1355

Nasiri, S., Hajinezhad, A., Kianmehr, M. H., & Tajik, S. (2023). Enhancing municipal solid waste efficiency through Refuse Derived Fuel pellets: Additive analysis, die retention time, and temperature impact. Energy Reports, 10, 941–957. https://doi.org/10.1016/j.egyr.2023.07.039

Orozco-Álvarez, C., Gervacio-Hernández, A., Moreno-Rivera, M. de L., Piña-Guzmán, B., & Robles-Martínez, F. (2025). Microbiological and Physicochemical Characterization During Biodrying of Organic Solid Waste. Processes, 13(1), 78. https://doi.org/10.3390/pr13010078

Payomthip, P., Towprayoon, S., Chiemchaisri, C., Patumsawad, S., & Wangyao, K. (2022). Optimization of Aeration for Accelerating Municipal Solid Waste Biodrying. International Journal of Renewable Energy Development, 11(3), 878–888. https://doi.org/10.14710/ijred.2022.45143

Prahara, L., & Kristanto, G. A. (2019). Utilization of non-woven geotextile as insulation on bio-drying reactor. IOP Conference Series: Earth and Environmental Science, 311(1). https://doi.org/10.1088/1755-1315/311/1/012053

Rania, M. F., Lesmana, I. G. E., & Maulana, E. (2019). Analisis Potensi Refuse Derived Fuel (Rdf) Dari Sampah Pada Tempat Pembuangan Akhir (Tpa) Di Kabupaten Tegal Sebagai Bahan Bakar Incinerator Pirolisis. SINTEK JURNAL: Jurnal Ilmiah Teknik Mesin, 13(1), 51. https://doi.org/10.24853/sintek.13.1.51-59

Sarquah, K., Narra, S., Beck, G., Bassey, U., Antwi, E., Hartmann, M., Derkyi, N. S. A., Awafo, E. A., & Nelles, M. (2023). Characterization of Municipal Solid Waste and Assessment of Its Potential for Refuse-Derived Fuel (RDF) Valorization. Energies, 16(1). https://doi.org/10.3390/en16010200

Suryawan, I. W. K., Septiariva, I. Y., Fauziah, E. N., Ramadan, B. S., Qonitan, F. D., Zahra, N. L., Sarwono, A., Sari, M. M., Ummatin, K. K., & Wei, L. J. (2022). Municipal Solid Waste to Energy: Palletization of Paper and Garden Waste into Refuse Derived Fuel. Journal of Ecological Engineering, 23(4),64–74. https://doi.org/10.12911/22998993/146333

Tambone, F., Scaglia, B., Scotti, S., & Adani, F. (2011). Effects of biodrying process on municipal solid waste properties. Bioresource Technology, 102(16),7443–7450. https://doi.org/10.1016/j.biortech.2011.05.010

Ummah, M. S. (2019). Fundamentals of Heat and Mass Transfer, 8th Edition. In Sustainability (Switzerland) (Vol. 11, Number 1).

Velis, C. A., Longhurst, P. J., Drew, G. H., Smith, R., & Pollard, S. J. T. (2009). Biodrying for mechanical–biological treatment of wastes: A review of process science and engineering. Bioresource Technology, 100(11),2747–2761. https://doi.org/10.1016/j.biortech.2008.12.026

Wang, J., & Qiao, Z. (2024a). A comprehensive review of landfill leachate treatment technologies. Frontiers in Environmental Science, 12(September). https://doi.org/10.3389/fenvs.2024.1439128

Widyarsana, I. M. W., & Wulandari, S. (2025). Study of the effect of a bulking agent on the biodrying of municipal solid waste. Archives of Environmental Protection,83–90. https://doi.org/10.24425/aep.2025.154759

Yang, B., Hao, Z., & Jahng, D. (2017). Advances in biodrying technologies for converting organic wastes into solid fuel. Drying Technology, 35(16), 1950–1969. https://doi.org/10.1080/07373937.2017.1322100

Yang, X., Zhang, Y., Sun, P., & Peng, C. (2024). A review on renewable energy: Conversion and utilization of biomass. Smart Molecules, 2(4). https://doi.org/10.1002/smo.20240019

Yuan, J., Li, Y., Wang, G., Zhang, D., Shen, Y., Ma, R., Li, D., Li, S., & Li, G. (2019). Biodrying performance and combustion characteristics related to bulking agent amendments during kitchen waste biodrying. Bioresource Technology, 284, 56–64. https://doi.org/10.1016/j.biortech.2019.03.115

Yuan, J., Zhang, D., Li, Y., Chadwick, D., Li, G., Li, Y., & Du, L. (2017). Effects of adding bulking agents on biostabilization and drying of municipal solid waste. Waste Management, 62, 52–60. https://doi.org/10.1016/j.wasman.2017.02.027

Yusuff, A.S., Popoola, L.T. and Ibrahim, I.S., (2025). Adsorptive removal of anthraquinone dye from wastewater using silica-nitrogen reformed eucalyptus bark biochar: Parametric optimization, isotherm and kinetic studies. Journal of the Taiwan Institute of Chemical Engineers, 166, p.105503. https://doi.org/10.1016/j.jtice.2024.105503

Zaman, B., Oktiawan, W., Hadiwidodo, M., Sutrisno, E., & Purwono. (2018). Bio-drying Technology of Solid Waste to Reduce Greenhouse Gas. E3S Web of Conferences,73,05019. https://doi.org/10.1051/e3sconf/20187305019

Zaman, B., Oktiawan, W., Hadiwidodo, M., Sutrisno, E., & Purwono, P. (2021). Calorific and greenhouse gas emission in municipal solid waste treatment using biodrying. Global Journal of Environmental Science and Management, 7(1), 33–46. https://doi.org/10.22034/gjesm.2021.01.03