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Impact of Feedstock Density on Biodrying for Enhancing Heat Retention and Moisture Reduction

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Abstract

This study examines the effect of varying feedstock densities on the performance of biodrying processes to enhance waste management efficiency. Three different densities of wet-refuse-derived fuel 3 (wet-RDF3) from Bangkok's On Nut Transfer Station were tested using lysimeter reactors with constant aeration rates (0.6 m^3/kd.day). Results revealed that a moderate density (230 kg/m^3) achieved the highest temperature integration index (7218.01°C) and demonstrated effective moisture reduction and minimal volatile solids consumption. The higher densities improved heat retention and prolonged thermophilic conditions, optimizing the biodrying process. These findings highlight the importance of feedstock density in biodrying, suggesting that optimal density can significantly improve waste drying efficiency and produce better quality refuse-derived fuel. This approach offers a sustainable solution for waste management, particularly in developing countries.

Keywords : Refuse-Derived Fuel; Temperature Integration Index; Waste Management; Thermal Performance; Volatile Solids Consumption

Introduction

The increase in municipal solid waste (MSW) is unavoidable due to population growth, where everyone produces their own. The prediction of waste generation in low-income countries, especially in Asia, accounts for 0.5-0.9 kg/capita/day until 2050 [1]. This condition has a potential environmental problem if the waste generated piles up without further processing. Especially in developing countries, the widespread types for managing waste are open dumping and untreated landfills [2-4]. This is undertaken because the operation is easy and cheap. However, proper sustainable waste management is needed to develop in developing countries.

One reliable waste management method is biodrying technology. In its implementation, biodrying has been applied to produce biodried waste capable of reuse as an alternative fuel [5]. This process aims to produce treated waste with high low heating value (LHV) and low moisture content (MC) and subsequently be applied to the cement industry and power plants. Biodrying is a biological drying process that utilizes microorganisms in the waste to degrade the materials' organic fraction and water content. Biodrying applications have been widely applied in developing countries because of low operation expenses. In waste management, the types of material commonly used are MSW, kitchen waste, dewatered sludge, and other materials that have organic fractions [6-8].

Several parameters are affecting the biodrying process's performance, such as the initial MC of feedstock, the operational conditions involving aeration rate (AR) supply, and the kind of material used to produce bioheat for evaporation [9-11]. This experiment was set up under different feedstock densities in three trials. Itsarathorn *et al.* (2023) evaluated the relationship between density variations and AR supply in the biodrying of wet-RDF2. According to their findings, 232 kg/m^3 density was the optimal condition at AR0.5, and 250 kg/m^3 was the efficient outcome at AR0.6. Furthermore, Tom *et al.* (2016a) conducted biodrying on mixed MSW with different initial MC and density conditions. This was carried out to evaluate how well biodrying works in waste management to lower the amount and volume of MSW [12].

RDF2, a coarse RDF, involves coarsely shredding or cutting combustible waste. RDF3, a fluff RDF, separates non-combustible components and shreds the remaining waste to a size smaller than 2 inches for 95% of the material. This creates differing air/void ratios, impacting air distribution and temperature retention during biodrying. Despite these differences, no study has ever focused on the effects of varying densities in wet-RDF3. Addressing this gap could optimize biodrying performance by providing crucial insights. This study aims to investigate the effect of different densities and their changing on the biodrying performance based on temperature integration (TI) index and biodrying index (BI) value, which led to the efficient biodried product in LHV and MC during the process.

Methodology

Feedstock Preparation and Analysis

The feedstock used in this experiment was wet-RDF3 from On Nut Waste Transfer Station, Bangkok, Thailand. A wet-RDF3 is a kind of shredded RDF2, with the air classifier, magnetic separator, and fine shredder primarily consisting of plastic [13]. The wet-RDF3 from the stockpile was sampled for 1.5 kg to measure the chemical properties before the biodrying (the same treatment as the product after biodrying). Furthermore, a thermogravimetric analyzer was used to measure MC and volatile solid (VS) content in the feedstock and biodried product following the ASTM D7582 standard. The LHV also was analyzed using a bomb calorimeter according to the ASTM D2015 standard. Three different conditions were set up in this experiment through lysimeter reactor, designated as L1, L2, and L3, respectively.

This experiment was set up with a constant AR supply and various densities. The constant AR of 0.6 m^3/kg.day was chosen based on previous findings where different ARs (0.2, 0.4, and 0.6 m^3/kg.day) were tested. The 0.6 m^3/kg.day rate produced the best results, yielding the highest low heating value (LHV) and lowest moisture content (MC) [14, 15]. For this experiment, the objective was to investigate the effect of variations in initial feedstock density on biodrying performance while maintaining a constant AR. The initial condition during the experiment is shown in Table 1.

Table 1 Initial condition of feedstock

Conditions	L1	L2	L3
Density (kg/m^3)	208.86	230.00	250.00
Weight (kg)	50.1	55.8	60.1
High (m)		1.20	
AR (m^3/kg.day)		0.6	
MC (%)		47	
LHV (kcal/kg)		3,119	

Lysimeter Description

The biodrying experiment used three lysimeters, with each being 1.5 m high, 0.5 m deep, and 0.5 m wide. A perforated metal plate was placed above the ventilation pipe at the bottom side of the reactor to help material distribute air. The ventilation pipe, condensation pipe, and centrifugal pump to provide airflow were installed at the system's base. A U-trap pipe was installed at the legs of the lysimeter to collect leachate. The gas measuring inside the system was recorded through the pipe. More details on the installation location and design are shown in Figure 1.

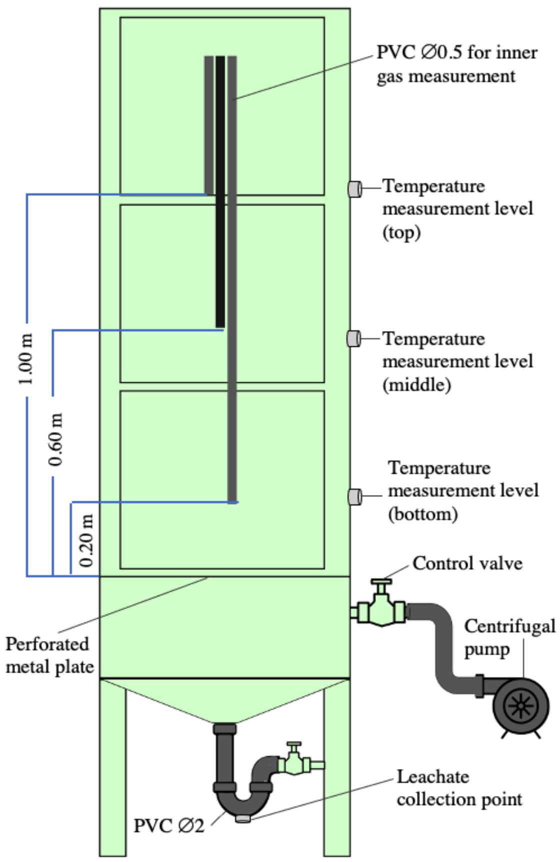


Figure 1 Schematic design of lysimeter

Experimental Monitoring

The temperature was measured using a thermocouple connected to cables at three locations (Figure 1), and another probe was placed in the surrounding environment to record the ambient temperature. The temperature data was recorded hourly using a midi-data logger (Graphtec GL220). Those data were subsequently used to determine the temperature integration (TI) index. The TI index can be calculated using the following equation:

$$\mathbf{TI} = \sum_{t=1}^{n}(t_s - t_{amb})\ x\ \Delta t \qquad (1)$$

Where t_s is sample temperature at time t (ºC), t_{amb} is ambient temperature at time t (ºC), and Δt is the difference between the measured time points.

A hoist and a digital scale were used to measure daily weight reduction. The following equation describes the weight loss:

$$\boldsymbol{weight\ loss}\ (\%) = \frac{\Delta w}{w_i}\ x\ 100 \qquad (2)$$

Where Δw is the change in weight of the dried product relative to the initial material weight (kg) and w_i is the initial material weight (kg).

Gas measurements were taken using a Biogas 5000 portable gas analyzer (Geotech, UK). Carbon dioxide (CO_2) and oxygen (O_2) levels were measured daily in the morning during the biodrying process. For CO_2 exhaust gas measurement, the value was determine using information from direct gas measured by Biogas 5000, and with the following equation:

$$\Sigma CO_{2\ exhaust} = Av\ x\ A\ x\ CO_{2\ measurement} \qquad (3)$$

Where Av is the air velocity (m/s), A is the cross-sectional area of the pipe (m^2), and CO_2 measurement is the value recorded by the Biogas 5000 instrument (%).

O_2 utilization refers to the amount of O_2 microorganisms required to degrade organic matter. The amount of O_2 utilization is based on the total mass remaining on the day of each measurement, as it relates to the remaining nutrient supply needed by the microbes. The calculation method to determine O_2 utilization (volume in m^3) was adopted by Contreras-Cisneros (2021) in the following equation:

$$\Sigma O_{2\ u} = \left(\frac{O_{2amb} - O_{2ex}}{O_{2amb}}\right) x\ V \qquad (4)$$

Where O_2amb is the O_2 concentration in the surrounding environment (%), O_2ex is the oxygen concentration in the exhaust pipe recorded by the Biogas 5000 portable gas analyzer (%), and V is air volume in the day (m^3). Air volume can be determined using the following equation:

$$V = \frac{AR}{Wt} \qquad (5)$$

Where AR is the exact aeration rate flowed based on air velocity when the monitoring daily (m^3/kg.day), and Wt is the waste mass at the monitoring (kg).

For biodrying index (BI) determination, parameter used was MC reduction and VS consumption. To find VS consumption was adopted method from Li *et al.* (2022) in the following:

$$VS\ consumption\ (\%) = \frac{\Delta VS}{VS_i} x100 \qquad (6)$$

Where ΔVS is subtraction VS between initial and final, and VS_i is initial VS.

Statistical analysis

The correlation test was used to determine the relationship between two parameters, and single-factor ANOVA was used to analyze the variance in temperature with a confidence level of 95% ($p<0.05$). Both statistical tests were conducted using Microsoft® Excel for Mac Version 16.77.1 Software.

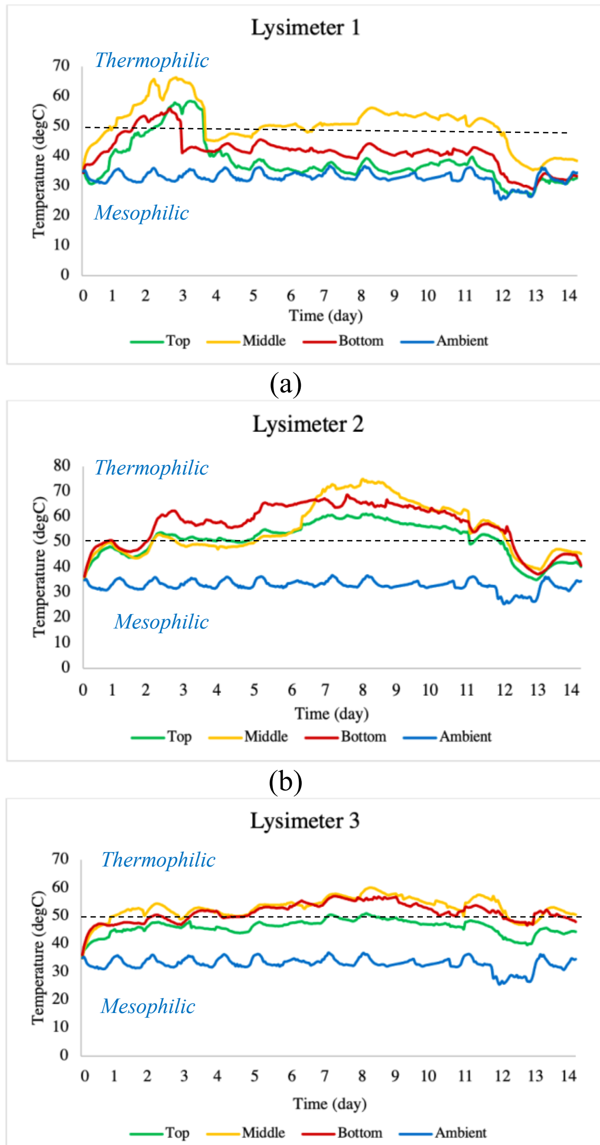
Results and Discussion

Temperature Profile

Temperature evolution

Temperature is a parameter that indicates microbial activity in degrading organic matter. The heat produced is a byproduct of microbial metabolism–heat metabolic. The highest temperature achieved by L1 on day 3 of the experiment was 65°C. This maximum temperature was reached more quickly than in other trials. A sudden significant drop in temperature (with a difference of 20°C) occurred on day 4. After that, it entered the stable phase at a moderate temperature and was maintained under thermophilic conditions, this study used 50°C as the starting point for the shift from the mesophilic to the thermophilic phase [4], in the middle layer and mesophilic conditions in the top and bottom layers. The maintaining temperature occurs from day 5 to 12. The temperature evolution trend in L1 is shown in Figure 2(a).

In L2, the highest temperature was obtained in the bottom layer from day 1 to 6. Upon entering the HP, the middle layer showed the highest temperature trend. The maximum temperature reached was 74°C in the middle layer and occurred for two days (days 8 and 9). If the heat in the system is a byproduct of aerobic degradation, then in L2, microbial growth occurs maximally from day 7 to 12. The temperature evolution trend in L2 is shown in Figure 2(b).



(c)

Figure 2 Temperature evolution trend in each layer of (a) L1, (b) L2, and (c) L3

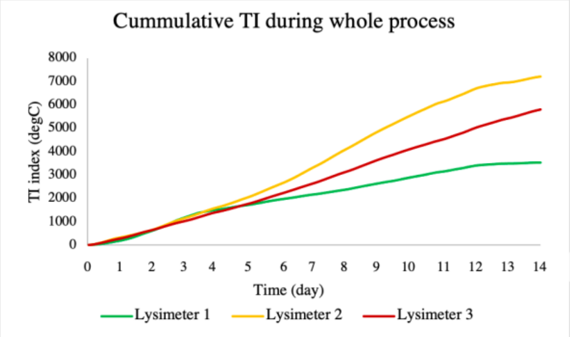
Meanwhile, in L3, the temperature in the middle and bottom layers was extremely high. The remaining maintained temperature was also under thermophilic conditions from day 3 to 11. The temperature range during this time was 49.5-47.9°C, with a slight decrease in temperature (to 53°C) entering day 12. The temperature evolution trend in L3 is presented in Figure 2(c). This trial had almost no declining phase, suggesting that aerobic degradation still occurred and was not completed by day 14.

Similar findings were reported by Tom *et al.* (2016b), who conducted biodrying experiments of mixed solid waste with different densities (density Case A > Case B) under the same airflow supply. They reported that the temperature profile in Case A reached a higher maximum temperature (65°C < T < 70°C) compared to the maximum temperature in Case B (55°C < T < 60°C). Based on physical assessments, this occurred because a high density can hinder the system in the reactor from returning to the surrounding temperature [16]. Based on the availability of organic matter in the waste, the highest temperature can be achieved if degradation continues. This was reported by Hao and Jahng (2019), who analyzed the levels of organic substances in bulking agents during the biodrying of dewatered sludge. Degradation occurs when volatile solids are consumed, with the degradation ability ranked as lipid > hemicellulose > protein. The highest temperature obtained in the experiment with bulking agents contained more lipids and hemicellulose, reached 70°C, and was maintained at around 65°C until the final experimental day. This result indicated a higher degradation process because lipids and hemicellulose are more easily degraded than proteins [17].

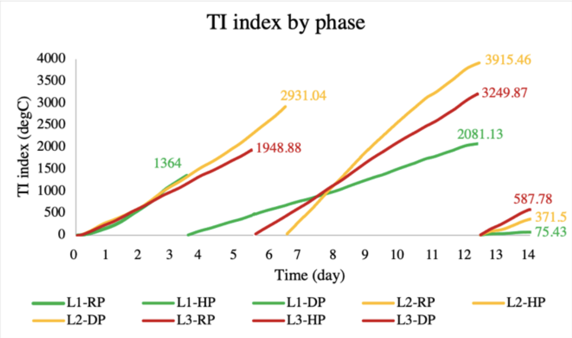
Temperature integration index

The largest cumulative TI value was obtained from the L2, which was 7,218.01°C. This temperature achievement was significantly higher compared to the other two trials. The next most considerable TI value was in the L3 experiment, which reached 5,803.67°C. The lowest one obtained in L1 is 3,524.43°C. The higher TI value obtained from the higher density trial due to the system maintaining thermophilic conditions for longer than L1 during the process. The L1, which has the lowest density, made it easier to escape the temperature from the system, so the temperature recorded in the system was relatively low. The cumulative TI trend in the whole process is presented in Figure 3(a), and the TI index by phase is shown in Figure 3(b).

From the three separate phases of TI, all trials show the maximum TI value obtained during HP. This was caused by the longer retention time and heat produced within metabolic reaction considering material's type. Trial L2 with moderate density achieved greatest value. A similar finding was found in Itsaratorn *et al*. (2023), which revealed that moderate density during biodrying of wet-RDF2 for five days obtained the highest TI value at 2,108.10°C. Their TI value is smaller than this experiment's because of the different retention times during biodrying. Furthermore, Payomthip *et al.* (2022) reported that the highest TI reached 365°C during the biodrying of shredded MSW over seven days. Their higher TI obtained was consistent with the temperature evolution.



(a)



(b)

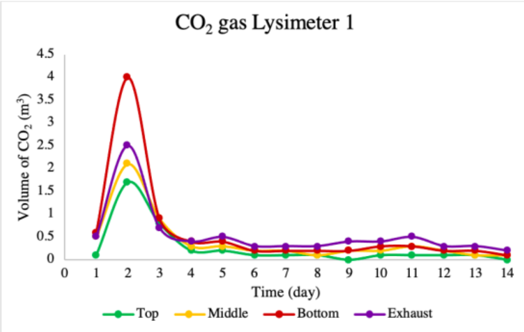
Figure 3 Cumulative TI index of (a) whole process, and (b) by phase

The effective condition to show biodrying performance based on the TI index was in moderate to high obtained value. Suppose the concept of biodrying is utilized as much as heat generated from the degradation of organic materials. In that case, a high TI value indicates maintaining control during the process. However, each trial was set up in this experiment with different density and mass-loaded conditions. So, one of the rationales that the higher-density trials have a greater TI value is that the denser waste and the capability to provide more organic to degraded. Yuan *et al.* (2019) conducted that biodrying with additional bulking agents causes the highest TI value due to material density. The increasing density effect decreases free air space and leads to low heat loss in the system [8].

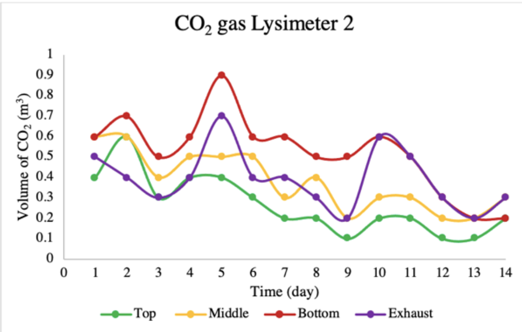
CO_2 Production

The trial with higher densities showed significant value of CO_2 levels in the inner gas measurement. The CO_2 levels increased on day 2 in the L1 trial, corresponding to the maximum temperature achieved during that period. The CO_2 concentration then decreased on day 3 and continued to decline until the end of the experiment. The process in L1 was finished when the experiment stopped. Meanwhile, the L2 and L3 produced more CO_2 than the L1. This condition might occur because the availability of organic fraction was higher along with increased density. Reports show that denser waste can provide more organic and lead to more VS consumption [8]. The CO_2 production trend in each experiment is presented in Figure 4.

A similar finding was reported by Itsarathorn *et al.* (2023), who conducted biodrying experiments on RDF2 with different densities (232, 250, 270 m^3/kg) under the same AR supplied (0.6 m^3/kg/day). His experiments found that the largest CO_2 was produced by experiments with a density of 270 m^3/kg. Furthermore, Sutthasil *et al.* (2022) revealed that the availability of more organic fractions is a factor that influences the speed of CO_2 production in aerobic degradation because organic acts as a substrate that microorganisms digest. This was very likely in this study when an increase in feedstock density caused the amount of waste loaded into the lysimeter reactor to increase, and a large amount of waste increased the availability of organic material [18].



(a)



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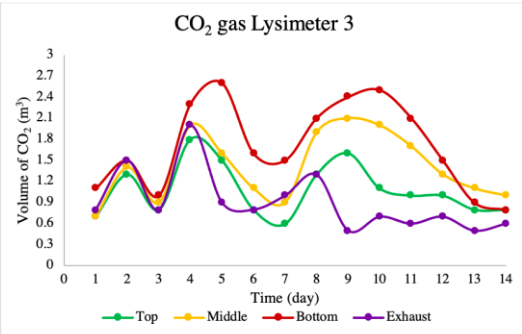

(c)

Figure 4 CO_2 production in each layer of (a) L1, (b) L2, and (c) L3

O_2 Utilization

The representation shows how much O_2 is utilized during aerobic degradation by the microorganism. The calculation of O_2 utilization is necessary since O_2 is a crucial component in the success of aerobic degradation. This compares the volume of O_2 used and CO_2 produced [19]. In some literature, O_2 utilization is closely related to the amount of CO_2 produced during biodrying. However, in this experiment, there was a very weak correlation in one of the three phases based on temperature evolution. The correlation between O_2 utilization and CO_2 production is shown in Table 2, and the trend of O_2 utilization is shown in Figure 5.

As an optimum condition for aerobic degradation, which occurs under thermophilic, the O_2 should be uptake high due to thermal assistance when the system enters HP, which can stimulate microbial growth more than natural thermal effects. Increased biogenic heat can reduce external heat energy consumption.

Table 2 Correlation of O_2 utilization and CO_2

Trial	RP		HP		DP	
	r	Stdv.	*r*	Stdv.	*r*	Stdv.
L1	0.99	±4.70	0.34	±1.53	0.23	±0.80
L2	0.55	±2.92	0.81	±2.06	0.97	±1.69
L3	0.93	±7.72	0.74	±3.23	0.36	±2.92

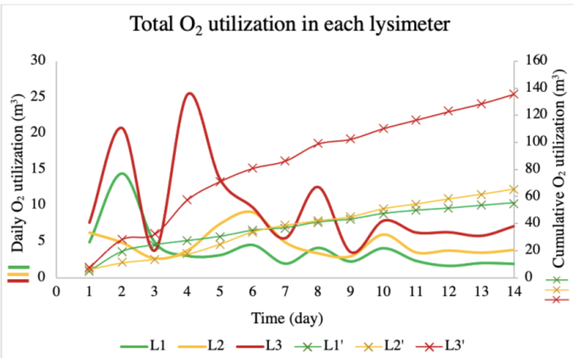

Figure 5 Total O_2 utilization during biodrying

For L1, the trend was consistent with CO_2 production and maximum temperature reached to describe the degradation condition. Özbay *et al.* (2021) revealed the significance of O_2 in aiding aerobic microbes during biodrying, which enhances the effectiveness of the drying process. This highlights the crucial role O_2 plays in establishing suitable conditions for microbial action and the decomposition of organic matter [7]. Furthermore, Payomthip *et al.* (2022) monitored O_2 levels during the biodrying process and highlighted the significance of this parameter in understanding the dynamics of biodrying. However, for L2 and L3, the O_2 trend did not always match the CO_2 production. It may occur because of the density effect. Huiliñir *et al.* (2020) measured the behavior of dynamic respiration index (DRI) on the dewatered secondary sludge biodrying, which is represent the O_2 consumption for enhance microbial activity. Higher DIR values were favorable conditions for microbial growth, which was similar to this experiment and related to organic mass in the system [20].

Weight Loss and Density Changes

Weight loss is described as the MC successfully evaporating and the organic fraction being broken down into gases–the water removal phenomenon. In the L1 trial, the maximum weight loss was achieved on day 3. This trend followed the maximum temperature produced in the system and CO_2 production in the inner gas. The L2 trial reached a maximum on days 5 to 7, during which the HP and the highest CO2 production were entered. While in the L3 trial, the maximum weight loss occurred on day 4, and the greater CO_2 production occurred. Daily weight loss in each trial is shown in Figure 6.

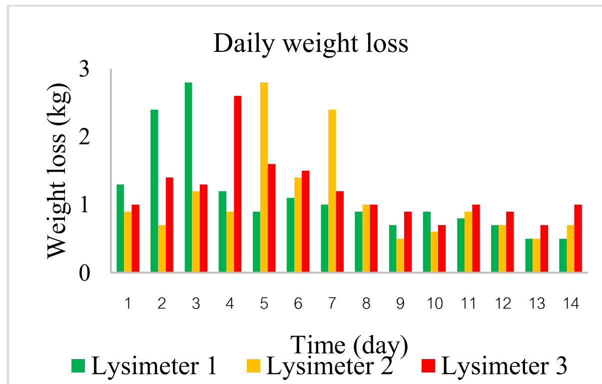

Figure 6 Trend of daily weight loss

Besides evaporation, which reduces the weight and volume of waste, in many cases of biodrying, especially for waste rich in organics, the leachate production also influences the weight loss. This occurs because water vapor condenses after it reaches its maximum temperature and turns into leachate. This study implements the negative ventilation system (suction airflow) to force more leachate. However, this study's cumulative leachate production was less than 1 L for each trial. The total volume of leachate produced in L1, L2, and L3 were 640, 169, and 450 mL, respectively. Bhatsada *et al.* (2023) revealed that water removal mainly occurs due to bioactivity, and the water phase changes as water vapor evaporation during biodrying. In their experiment, the low leachate generation caused leachate to be a nominal proportion of the water balance in the system with less removal [21]. Bosilj *et al.* (2023) experimented on the sample with a higher initial MC, which led to a more significant overall mass loss. Most samples had a mass loss that occurred on day 2 of the experiments. The rate then stabilized to a lower level (around 0.3-0.4 kg/day). However, this experiment showed that maximum loss occurred on day 4. This happened due to variations in organic content compared to [11] study.

Density changes were obtained through daily weight loss and waste height reduction measurements. Density affects the free-air space (FAS) in the waste pile in the reactor. This FAS affects the distribution of heat resulting from the degradation of organic matter, which subsequently affects the water vapor evaporation rate to leave the system. Higher density limits FAS availability and leads to higher temperatures being trapped in the waste pile [8]. Due to enhanced FAS, typical bulking agents support organics degradation and water migration [22]. Their results showed that suitable feedstock, with appropriate bulk density, affects bio-heat generation, extracellular polymeric substances (EPS) release, and potentially contributes to the maturity of the biodried product.

For this experiment, the density changes between the initial and final occurred not too much in all trials. The final percentage changes in L1, L2, and L3 were 6.64, 3.22, and 3.94%, respectively. The initial density in L1, L2, and L3 was 195, 226, and 240 kg/m^3. This relatively small change in density can be attributed to the nature of RDF3, which primarily consists of plastic. As the moisture content in RDF3 decreases, the plastic components tend to dry out and may expand slightly. This behavior is different from wet plastics, which can become compact when they retain moisture. The reduction in moisture allows RDF3 to retain some of its bulk, preventing significant compaction and leading to only minor changes in density throughout the biodrying process. The trend of daily density change is shown in Figure 7.

Based on the trend in Fig. 7, each trial has a change in density increase. L1 and L2 trials showed an increase in the early stages of the biodrying process. Meanwhile, the L3 trial showed an increase after day 5. L2 and L3 had the same density on days 4 to 5, where both trials entered a phase of maintaining high temperatures during that time. Unlike trial L1, the significant decrease in density occurred until the last day of the process. This can be stated as consistent with the trend of temperature changes, in which L1 reached its maximum temperature only for three days of the experiment.

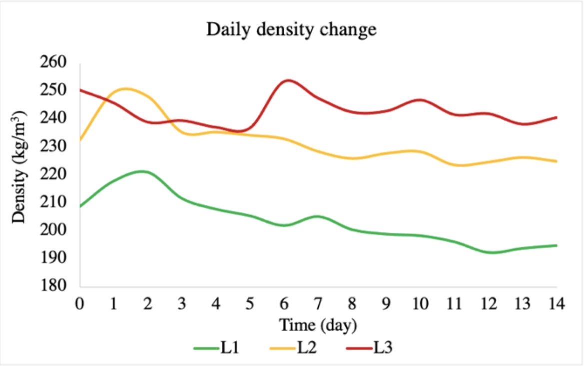

Figure 7 Daily density change

Despite the density changes, the trial with a higher initial density still resulted in a higher final density in the experiment. This can be explained by the fact that FAS critically affects the high-temperature resistance experienced by L2 and L3. The degradation process in L3 might have been still undergone until the last day of biodrying stopped. The temperature and CO_2 production were also still relatively high in L3.

Moisture Content and Low Heating Value

The moisture reduction is related to the effectiveness of evaporation of water molecules during the biodrying process. Suppose numerous water molecules are successfully released from the system. In that case, the moisture reduction will also be considerable, positively impacting the final LHV value obtained. In this second experiment, the highest moisture reduction was achieved in L1, with a final MC value reaching 15%. Daily moisture reduction has been investigated in this study, with the manual calculation adopted from Ham (2020). The detailed pathways equation is shown in Table 3, and the trend of daily moisture reduction in each trial is shown in Figure 8. Xu *et al.* (2023) highlighted that optimal nutrient utilization (C/N ratio) promotes microbial growth, leading to faster decomposition of organic matter and the release of water. This study emphasizes the impact of density on heat retention, which can significantly influence the moisture reduction rate. However, optimizing the biodrying process affects microbial degradation, producing high-quality biodried products with fine LHV [23].

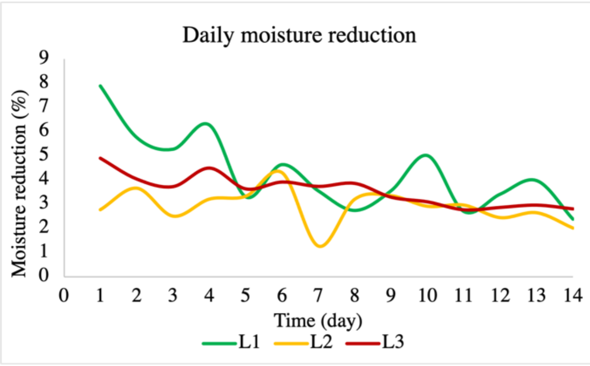

Figure 8 Daily MC reduction in each trial

The declining graph in L1 was very significant until the last day of the biodrying process. As cumulative, the MC percentages for L1, L2, and L3 were 68, 43, and 55%, respectively. This final MC value affected the LHV obtained, where L1 had the largest LHV. If we return to the initial meaning of biodrying, which is a biological drying process that utilizes metabolic heat from aerobic degradation [4]. So, the sufficient AR supply is a factor that enhances the degradation. However, if excessive aeration is intended to accelerate the process, the drying that occurs may not be biodrying. This was what might have happened in the L1 trial. Looking back at the cumulative TI and temperature evolution, a significant temperature decrease occurred rapidly on day 3. In addition, CO_2 production also sharply decreased during that period. The drying process from the excess AR supply subsequently helps significantly decrease MC and the large final LHV. The LHV values for each experiment are presented in Table 4.

Some studies mentioned the relationship between MC and LHV. Sagala *et al*. (2018) reported that the final LHV of RDF can reach 3,000 kcal/kg or more with an MC below 20%, which indicates that the drying process can significantly enhance the LHV value of RDF by reducing its MC. Furthermore, Dharmasyah (2023) reported that processed fluff RDF presented an LHV of 4,708 kcal/kg with a low MC of 2.1%, which confirms the potentially high LHV values that can be achieved in RDF when the MC is effectively reduced.

Biodrying Index

This parameter is related to water losses and volatile solid (VS) removal. The amount of BI is closely related to the material and the operational condition. A higher BI value indicates that the experiment is the most effective for removing water because the system can escape as much water vapor as possible with measly organic consumption. This condition is good when the system preserves more carbon, which would affect the final LHV obtained. Normally, materials with high organic content undergo significant VS consumption during degradation [24, 25]. Li *et al.* (2022) reported that VS consumption of kitchen waste during biodrying was 26.26%, with an MC reduction of 34.47%. Furthermore, Wang *et al.* (2024) reported that VS consumption of biodrying sludge was 8.79%, Similar to this experiment with unrich organic matter, the VS consumption is not over 10%. The VS information before and after biodrying is shown in Table 5.

Table 3 Equations for daily moisture reduction [26]

Contents	Symbols	Unit	Equations	Remarks
Water vapor pressure	pv	Pa	$pv = RH\ x\ pvs$	RH = direct humidity measured
Saturated water vapor pressure	pvs	Pa	$pvs = 6.1078\ x\ 10^\wedge \frac{7.5\ x\ T}{T + 237.3}$	T = temperature (°C)
Specific humidity	SH	%	$SH = \frac{0.622\ x\ pv}{Ptotal - pv} x100$	P total = standard atmosphere, 101,325 Pa
Estimated dry feed mass	m_d	kg	$m_d = 1 - \left(\frac{RH}{100}\right) x\ m_f$	m_f = daily mass measured
Daily moisture reduction	ΔMC	%	$\Delta MC = SH\ x\ m_d$	

The greatest BI value for this study was obtained from the L1. Meanwhile, the largest VS consumption was obtained from L2. The availability of organic matters in the feedstock influenced big or small amounts of VS consumption. As mentioned in the CO_2 production section, higher-density trials have denser waste, which provides more organic availability. It was very reasonable that the less VS consumed, the greater the BI value produced [27-29]. This finding was reinforced by Payomthip *et al.* (2022), who reported that the highest BI value was reached with the maximum moisture removal (65.6%) and lowest VS consumption (2.87%). That condition obtained the greatest LHV (4,938 kcal/kg). Furthermore, Cao *et al.* (2024) reported the highest BI value from a trial that has the highest LHV (5,843 kJ/kg) and maximum moisture removal (61.71%) simultaneously. Quan *et al.* (2023) reported that a biodrying sludge pile exhibited a significantly higher BI due to more efficient water removal and less VS consumption. Similarly, the L2 condition provided high-temperature evolution in this experiment, resulting in maximum VS loss.

Table 4 LHV and MC changing after biodrying

Trial	LHV (kcal/kg)		Change (%)	MC (%)		Change (%)
	Before	After		Before	After	
L1		6,020	(+) 93		15	(-) 68
L2	3,119	4,931	(+) 58	47	27	(-) 43
L3		5,628	(+) 80		21	(-) 55

Table 5 Information on VS before and after biodrying

Trials	Volatile solid (%)		ΔVS	VS consumption (%)	MC reduction (%)	BI value
	Initial	Final				
L1		43.42	6.14	12.0	68	5.67
L2	49.4	40.96	8.60	17.4	43	2.47
L3		41.81	7.78	15.7	55	3.50

Conclusion

This study demonstrated that varying feedstock densities significantly influence the efficiency of the biodrying process. Among the tested densities, a moderate density (230 kg/m³) achieved the highest temperature integration index (7218.01°C). However, exhibited superior moisture reduction and minimal volatile solids consumption was reached in the lowest density trial (208.86 kg/m³). These findings highlight the critical role of feedstock density in optimizing the biodrying process, suggesting that careful density adjustment can enhance heat retention and extend thermophilic conditions. Consequently, this leads to more efficient drying and higher-quality refuse-derived fuel production. The results of this study provide valuable insights for developing sustainable waste management strategies, particularly in developing countries where efficient and cost-effective solutions are crucial. Future research should explore the long-term impacts of different feedstock compositions and densities on biodrying performance and evaluate the economic feasibility of large-scale applications. By continuing to refine these methods, the potential for significant environmental and economic benefits in waste management can be realized.

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