The potential of bio-drying process in improving quality of the processed waste from the mechanical biological treatment for industrial heating systems

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Abstract

This research has an objective to improve the quality of the waste after the mechanical biological treatment (MBT) by using the bio-drying process. The waste after MBT has high moisture content and low heating value because municipal solid waste (MSW), a major source of the waste, lacks proper waste segregation. This make the processed waste unsuitable for being used as refuse-derived fuel (RDF) in waste-to-energy generation and industrial heating systems. Bio-drying is the process that utilizes aerobic decomposition of microbes such as bacteria and fungi on the biomass content of the waste after MBT. The effects of operational parameters such as temperature, humidity and heating value of the waste after MBT before and after applying the bio-drying process were studied. High-quality RDF should have a minimum heating value of 5,000 kcal/kg and maximum moisture content of 30%. The results revealed that the waste after MBT before applying the bio-drying process has the lower heating value (LHV) of 2,451 kcal/kg and moisture content of 53%, while after applying the bio-drying process, with an airflow rate of 750 m^3/hour in every 3 hours/day for 20 days in a closed system, has the LHV of 9,047 kcal/kg and moisture content of 5%. The power used in these experiments was equivalent to electricity cost of 351 THB, while the revenue generated from selling the processed waste as RDF for waste-to-power generation is 750 THB/ton. The bio-drying process can improve the quality of the waste after MBT with low power consumption within a short period of time. The bio-drying process is a solution for tackling the waste management crisis and global warming by providing a sustainable waste management model for the future.

Keywords: *Bio-drying, refuse-derived fuel, MBT*

1. Introduction

Thailand's waste management problem is worsening as the country currently has 28 million tons of accumulated waste and the number is still increasing [1]. Although this waste has potential to be used as refuse-derived fuel (RDF), the country's lack of waste segregation results in a waste with high moisture content (55.89%) due to contaminations [2]. Mechanical Biological Treatment (MBT) approach is a part of integrated solid waste management concepts and was developed to pre-treat residual waste in order to reduce its volume and environment impacts in landfills. In MBT there are two processes. First Mechanical Treatment, where Pre-sorted solid waste is cut and mixed in a rotating drum for about 45 minutes. After finishing this homogenization, materials are moved to outdoors. Second, is Biological Treatment, the waste pile is set on a ventilation layer made of wooden pallets and drain pipes, while the surface is covered with bio-filter material made of coconut shells. The period for biological stabilization and degradation of organic materials is 9 months. [3]. To diminish moisture content from waste, the MBT is utilized to encourage decomposition of biomass content. This method consists of mechanical and biological processes which mix and dry waste in an open space such as a landfill for a long period of time. However, the processed waste still has a low heating value and high moisture content because Thailand's weather is predominantly tropical (high temperatures and rains). Therefore, a method capable of improving the quality of processed waste greatly helps the industrial sectors using RDF for heat generation, thus solving the looming waste management crisis. Bio-drying is the process that employs aerobic decomposition of microbes such as bacteria and fungi on biomass content of processed waste consisting of carbon, nitrogen and other substances. The by-products of the decomposition are heat, carbon dioxide and water. Heat produced from the decomposition process can diminish the moisture content of waste, which results in increased heating values. The equation (1) shows a chemical reaction of aerobic decomposition [4]. Researchers have reported increased heating values and decreased humidity of sewage sludge and paper pulp using bio-drying [5] and biomass content extracted from the MSW is useable as fertilizer [6]. Bio-drying can reduce the moisture content of waste from 73.0% to 48.3%[8] by controlling operational parameters such as humidity, temperature and airflow rate for appropriate aerobic decomposition of microbes[9].

Industries that need heat generation in their manufacturing processes, such as the cement industry, demand 40% of heat generated from waste due to RDF has a high heating value equal to the coal.

In addition, the price of coal is 3,000 BHT/ton which is higher than RDF which cost 1,000 BHT/tone [16]. RDF to be used in the cement industry must have low heating value (LHV) above 4,685 kcal/kg, moisture content, chlorine and sulfur not more than 12%, 0.6% and 0.2% respectively.

Moreover, the level of cadmium, chromium, mercury and lead must not be higher than the minimum level fixed by the EU [11]. The researchers reported that in the 50 kg reactor, bio-drying can decrease the moisture content of waste from 66.5% to 24.1% and increase the heating value from 1,210 kcal/kg to 3,420 kcal/kg [12]. However, studies [8] [9] [12] found that bio-drying was efficient for reducing the moisture content of waste or sludge by appropriate airflow rate control and the characteristics of material. Most studies have been done using small scale reactors due to the volume of material and locations. Thailand's lack of proper waste segregation results in the mixing of dry, wet and plastic waste. Its tropical climate also creates difficulties for maintaining the humidity levels of waste. Furthermore, it takes 9 months for processed waste to become usable as a RDF. These obstacles make MBT not practically sufficient to convert MSW to RDF for waste-to-power generation. Therefore, bio-drying, which takes a very short period of time to improve the quality of the waste after MBT can be used effectively. The by-products of our experiments have the LHV higher than 5,000 kcal/kg and moisture content lower than30% which is in accordance with the requirements of industrial heating systems. So, this process can effectively be used to develop waste to energy and to promote the use of renewable energy from waste, solving Thailand's waste management crisis.

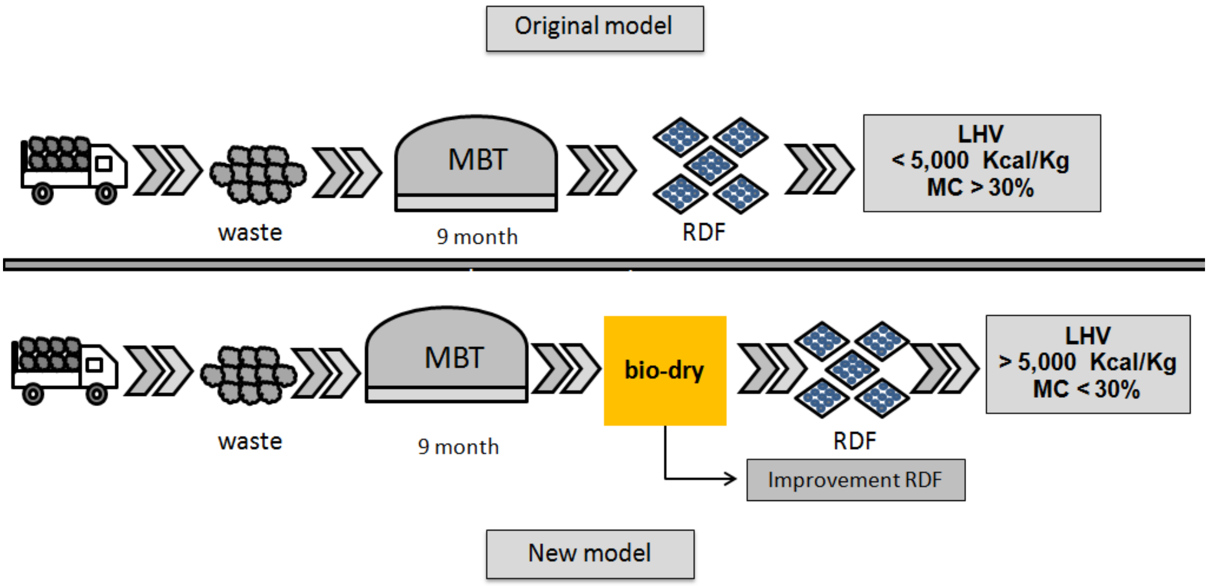


Figure 1 A model for improvement in the quality of RDF from the MBT by using the bio-drying process

Municipal Solid Waste + O2→ CO2+ H2O + Heat (1)

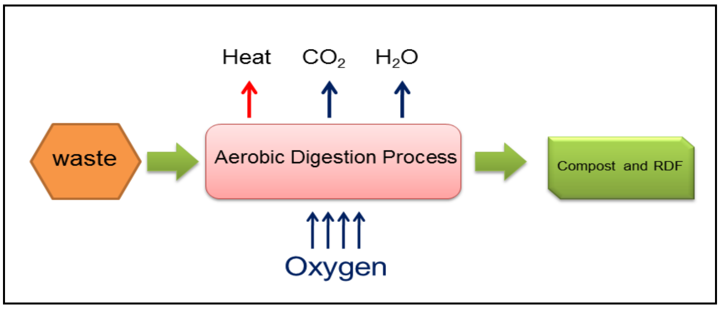


Figure 2 A schematic of aerobic decomposition

2. Materials and methods

2.1 Bio-drying process

The Bio-drying was performed in a close system inside the building. The aeration system installed comprised blowers connected to an air pipe on the ground. The waste after MBT was dumped on an air pipe and covered by a vinyl sheet having Check Valves to control excess air and evaporation. Temperature sensors were installed at different levels as shown in fig. 4 and connected to a data logger for monitoring. Aeration was controlled by a digital timer to provide optimum conditions for bio-drying. A rim weight overlaid the cover sheet to block the air leaking out of the system as shown in fig. 3.

2.2 Waste composition and density analysis

25 kg from 100 kg of waste after MBT were collected by using the quartering method. Then, Separate waste piles were classified into the following categories; plastic, paper, textiles, metal, glass/ceramics, rubber, pebble, bones, wood and unclassified. Waste composition was calculated based on the proportion of waste from each category to the total weight. Waste density was calculated by filling the waste into a known volume container.

$$Waste\ composition = \frac{Weight\ of\ waste\ from\ each\ category}{Total\ Weight} \times 100 \quad (2)$$

2.3 Lower heating value (LHV) and moisture content analysis

LHV is the amount of heat generated from combustion of waste in pure oxygen. In this study, 1 kg of processed waste from the MBT was collected and cut into small pieces of 6 mm^2 with Retsch SM300, burned 1 gram of this waste in a bomb calorimeter KIKA model C5001. Two grams of the waste were used in a humidity analysis machine Sartorius MA 150 at 110 C^o. The dehydrated sample was weighted and the moisture content was calculated according to the following equation.

$$Moisture\ content(\%) = \frac{(a-b)}{a} \times 100 \quad (3)$$

a = weight before dehydration b = weigh after dehydration

2.4 Experimental procedures

The experiments were performed at a pyrolysis plant of a landfill owned by Phitsanulok municipality in Bangrakam district, Phitsanulok Province. First, 100 kg of processed waste was collected from the MBT and chose only 25 kg by quartering method, then classified the waste into each category and calculated the waste composition according to the equation (2).

Second, installed an aeration system using PVC pipes of size 0.025 x 4 m (diameter x length). The holes were made on two sides of the PVC with a distance of 20 cm each. The PVC was connected to an air pump of 1 horse power, 750 watts, 220V and 2800 RPM. The air was pumped into a container with a velocity of 750 m^3/hr for 8 hours each. The system was controlled by a digital timer. Third, 2,000 kg of waste was collected after MBT that had been left in the landfill for 9 months and dumped it on the air pipe (PVC) to make a pile, the pile size was 3x2x1.5 meter (length x width x height). Then, covered the pile with a vinyl sheet with a size of 5 x 7 m (width x length). Then, 9 check valves were installed with a diameter of 0.05 m to control heat and humidity as shown in fig. 3. Finally, three Pt100 thermocouples were installed at the upper, middle and lower levels and connected to a data logger for measuring temperatures inside a bio-drying process according to fig. 4. Temperature data was collected every hour and 0.5 kg of waste was collected from the upper, middle and lower levels on the day 10th, 15th and 20th for waste composition and moisture content analysis. The experiment was continued until the waste had the LHV above 5,000 kcal/kg, moisture content less than 30% or the temperature inside bio-drying process was same as ambient temperature.

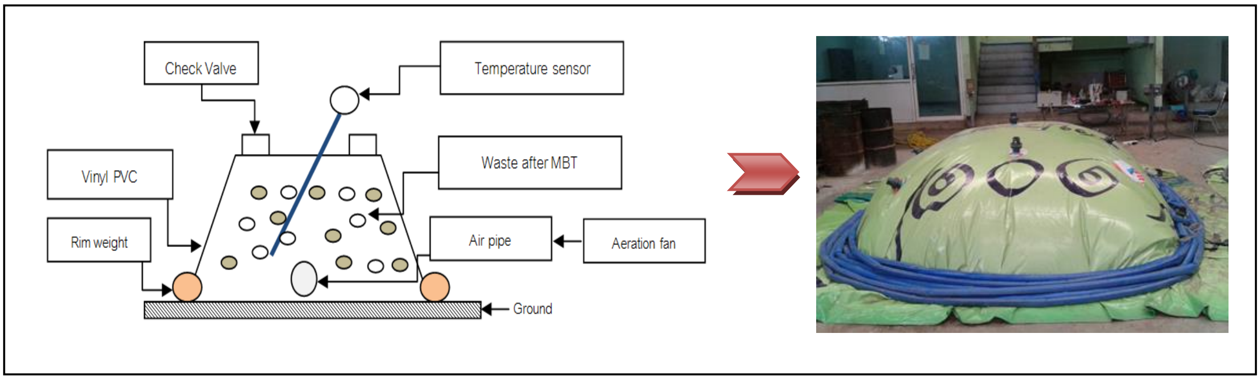


Figure3 Bio-drying process

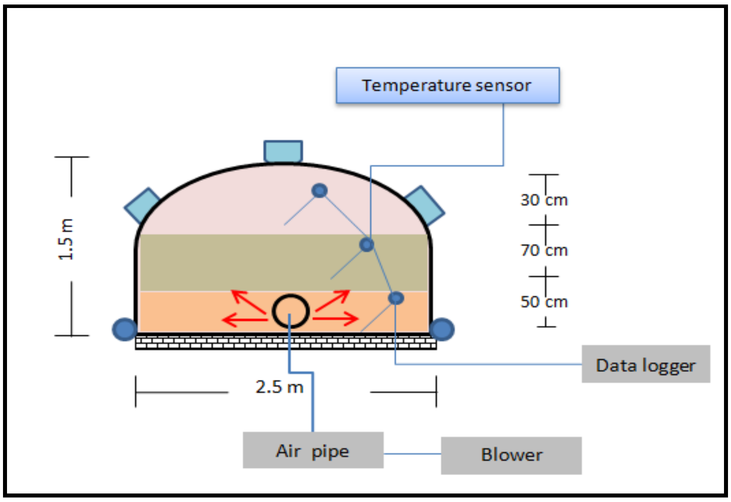


Figure 4 System installation and data monitoring

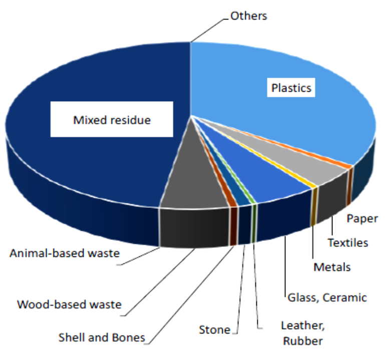
3. Results and Discussion

3.1 Waste composition

The processed waste from the MBT system that had been left in the landfill for 9 months had a high moisture content of 53.5%. According to Table 2, plastic waste is 34.6% and the remaining 47.6% is decomposable biomass as shown in Figure 5. The mixed residue has C/N proportion of 14.51 and this indicates that the waste can be decomposed faster if it is exposed to proper air flow and humidity.

Table 1 C/N proportion of processed waste from the MBT system

Name	N(%)	C(%)	S(%)	H(%)	C/N
Mixed residue	1.04	15.10	0.31	1.98	14.51
Wood-based waste	0.89	40.68	0.40	5.66	46.07
Paper	0.70	39.09	0.26	5.73	56.35



Composition	Composition ratio (%)
Plastics	34.6 %
Paper	0.7 %
Textiles	3.8 %
Metals	0.6 %
Glass, Ceramic	5.1 %
Leather, Rubber	0.4 %
Stone	1.1 %
Shell and Bones	0.7 %
Wood-based waste	5.4 %
Animal-based waste	0.0 %
Mixed residue	47.6 %
Others	0.0 %

Figure 5 Waste composition of processed waste from the MBT system after 9 months

3.2 Temperatures of the bio-drying process

The temperatures inside a waste container indicate the status of the bio-drying process. The temperature of the waste was 38.25 ºC at the beginning and decreased after 2-3 days when microbes began the re-fermentation processes. The inner temperature continued to rise to 34-36 ºC from the 5th to the 9th day, while the ambient temperature was 30-32 ºC. After that, the inner temperature dropped to the same level as the ambient temperature as reported in the works of [12][7][13]. The temperature of the lower level (B3) was higher than the middle level (B2), or the upper level (B1) and the ambient temperature (amb) as shown in the Graph 1. When the middle level (B2) and the upper level (B1) were dehydrated faster than the lower level (B3), this encouraged decomposition of microbes. This indicates that when the temperature inside the waste container is higher the ambient temperature (amb) decomposition was still functioning.

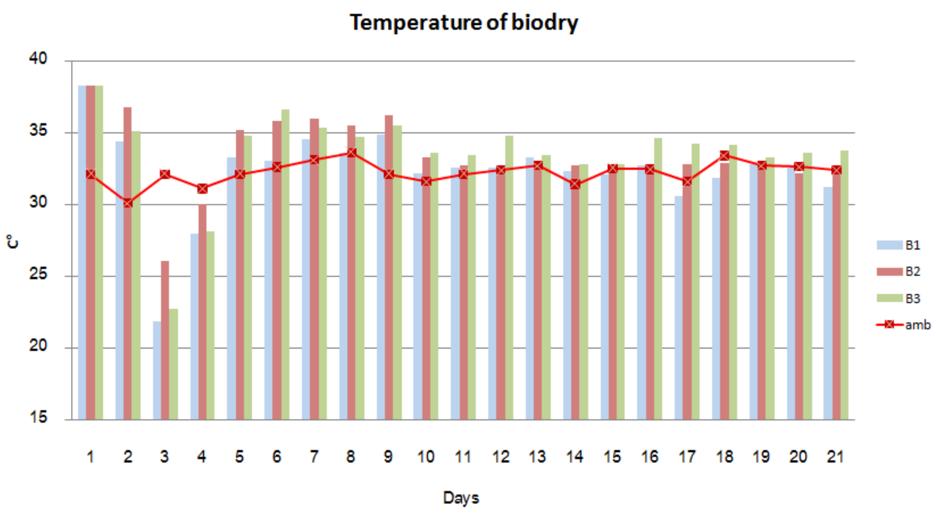


Figure 6 The temperatures inside a waste container (B1: upper, B2: middle, B3: lower)

3.3 Lower heating value (LHV), moisture content, and electricity charge analysis

LHV of RDF is crucial for price setting. In this study, the processed waste from the MBT system has a LHV around 2,541 kcal/kg and a moisture content of 53.50% in the beginning. The waste improved by the bio-drying process has a LHV of 4,930 kcal/kg and humidity 27.39% after 15 days and LHV 8,018 kcal/kg and humidity 8.41% after 20 days. According to the results, the bio-drying process has potential to improve the quality of waste after MBT to become usable as the RDF with LHV more than 5,000 kcal/kg and moisture content less than 30%. The experiment revealed that 20 days operation utilizes 351 Baht of electricity. In Thailand, purchasing of RDF is dependent on the LHV. If LHV is more than 5,000 kcal/kg, buyers pay more than 100 bath/ton. For every increase of LHV 1,000 kcal/kg were shown in the Table 2.

Table 2 LHV, moisture content, mass, aeration, electricity charge within 20 days of experiment

Detail	Raw waste	after BD(10 day)	after BD(15 day)	after BD(20 day)
Mass(kg)	1,985	-	-	883
Moisture content (%)	53.50%	40.39%	27.39%	2.67%
Low heating value (kcal/kg)	2,541	3,997	4,930	9,434
Mass(kg)	Raw waste	after 20 day	Lost weight	% Lost weight
Biodrying	1,985	883	1,102	56%
Aeration (m^3/hr)	750			
Electricity charge (baht)	351			

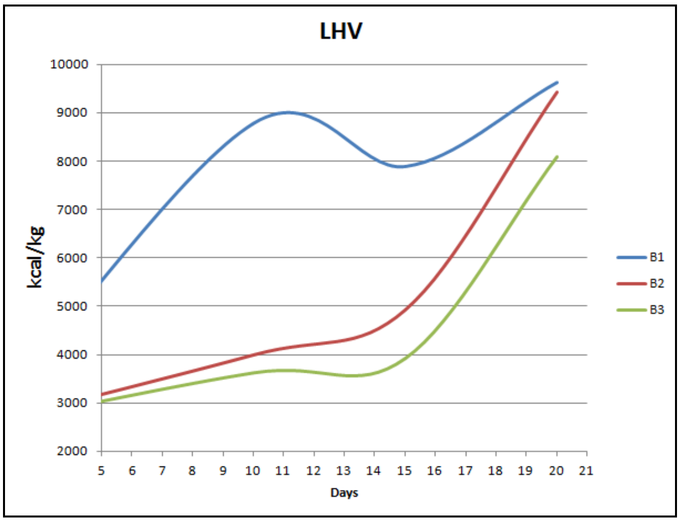


Figure 7 LHV of waste during applying the Bio-drying processes
(B1: upper, B2: middle, B3: lower)

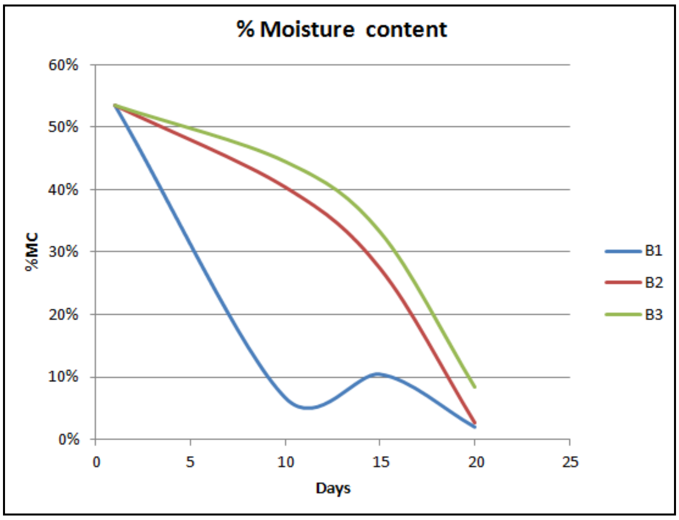


Figure 8 Moisture content during applying the Bio-drying processes
(B1: upper, B2: middle, B3: lower)

According to Figure 7 and 8, the LHV of the waste in the bio-drying process was increasing while moisture content was decreasing over time. This result corresponds with the findings of [12] who used bio-drying to improve waste quality by focusing on organic waste in the reactor. The LHV and moisture content of B1 were better than those at B2 and B3. It was also shown that moisture moves from below to above. During the first period, the LHV and moisture content at B1 were high but then steadily decreased as moisture content from B2 and B3 moved up. On day 15, the moisture content was 15%, and LHV was 7,809 kcal/kg. The second table shows the initial weight of the waste which was 1,985 kg. After 20 days, the level of heat increased and while moisture content decreased resulting in the loss in weight to 883 kg. The weight lost was 1,102 kg or 56% which was mostly water or moisture.

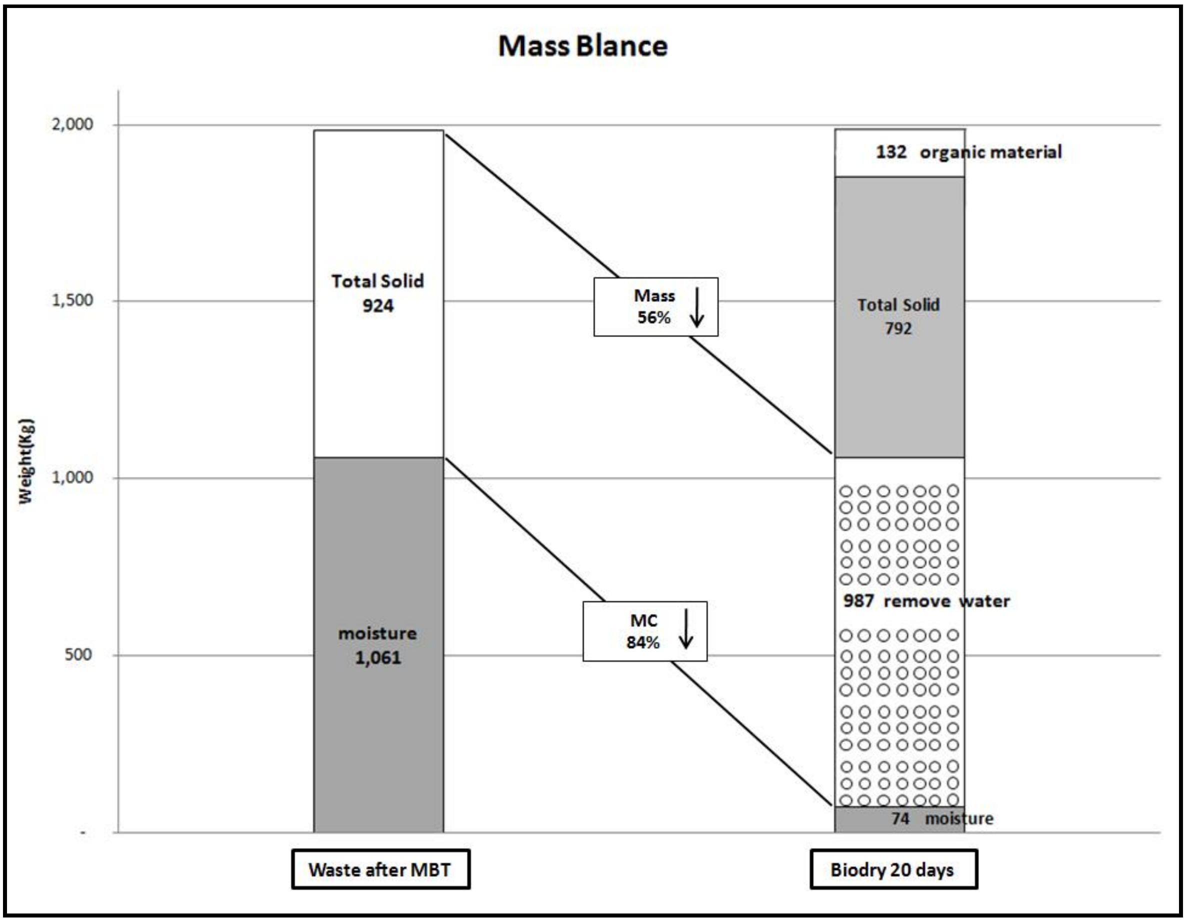


Figure 9 The balance of mass in the bio-drying process

From the Figure 9, the balance of mass in the bio-drying process during the 20 days shows that the system can reduce up to 84% of the moisture content in waste that was processed with the MBT. In the second table, the efficiency of the bio-drying process was evident as the weight of the waste decreased to 883 kg from the initial weight of 1,985 kg.

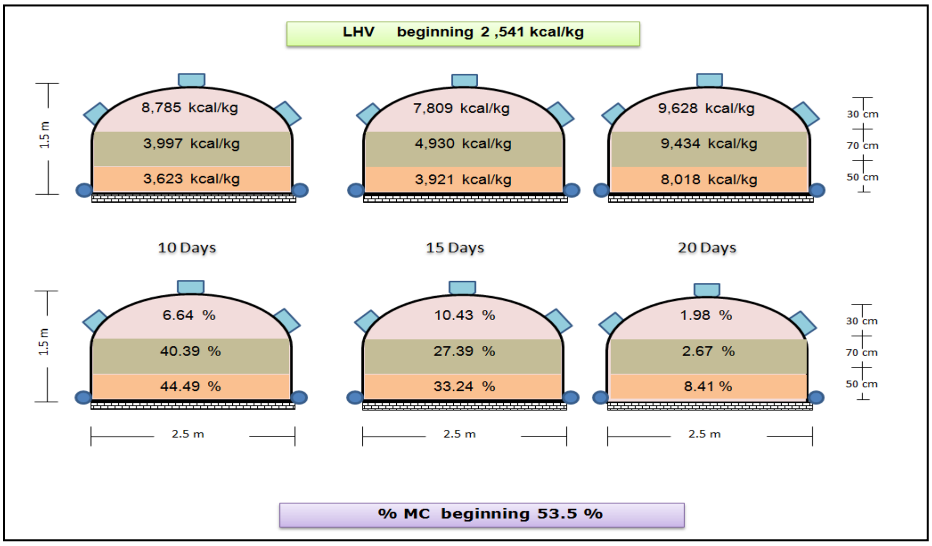


Figure10 The LHV and the moisture content of the processed waste in the bio-drying process

By studying the LHV and the moisture content in the 1.5-meter high bio-drying process, waste at the 50- meter thick lower layer, 70-meter thick middle layer, and 30-meter thick upper layer, and by sampling on day 10, 15, and 20 as shown in the Figure10, during the first 10 days, the moisture content in the upper layer decreased by 6.64% leading to LHV of 8,785 kcal/kg. However, the middle and lower layers still had high moisture content of 40.39% and 44.49% with LHV 3,623 kcal/kg and 3,397 kcal/kg respectively. On day 15, the moisture content in the lower and middle layers decreased to 33.24% and 27.39%, but the moisture in the upper part was found to be increasing to 10.43%. This shows that the moisture content had moved to the upper part. The LHV on day 15 also increased to 3,921 kcal/kg and 4,930 kcal/ kg. At day 20, the waste became drier judged by the decrease in moisture content in the three layers of the waste to 8.41%, 2.67%, and 1.98% respectively. The LHV in the upper layer is as high as 9,628 kcal/kg and 9,434 kcal/kg in the middle layer, and 8,018 kcal/kg in the lower layer. This shows that within 20 days, the bio-drying process can increase LHV above 5,000 kcal/kg and decrease moisture to less than 30%. If LHV becomes more than 8,000 kcal/kg maximum purchase price can be 750 Bath /ton, making RDF salable which is a better option than open dumping, saving the land and reducing the budgets for solid waste management.

4. Conclusion

According to the results, the bio-drying process has potential for improving the quality of processed waste from the MBT, since it can increase LHV from 2,541 kcal/kg to 9,434 kcal/kg and decrease moisture content from 53% to 2.67% within a period of 20 days. The bio-drying process requires a short period of time and low power consumption to convert high moisture content waste into the RDF with LHV higher than 5,000 kcal/kg and moisture content less than 30% which is suitable for industrial heating systems. Operational parameters such as resident time, air flow rate and weather should be explored further for application of the bio-drying process in a large scale system as our study only conducted the experiments in a closed system with controlled parameters. However, for the use of bio-drying in the industrial sector a large scale pilot project should be developed. A system size of up to 20 tons with a drying time of 30 days can be explored. The RDF with high LHV is required in the industrial sector and hence this project can attract investment.

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