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EFFECT OF AIRFLOW ON MOISTURE REMOVAL OF ROTARY BIODRYING REACTORS

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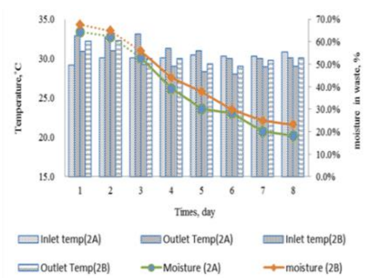
Graphical abstract



Abstract

Biodrying is the process to reduce moisture from municipal solid waste (MSW) by using the heat from aerobic bio-degradation. The typical process parameters are aeration, temperature during the process, initial moisture of waste, and temperature and relative humidity of the inlet air. This study aimed to investigate the effects of air flow rate and the supplied direct airflow duration on the rotary biodrying process for drying the high initial moisture content households solid waste, allowing satisfied energy content biofuel. The MSW from the Karai subdistric, kratumban samutsakorn province were used as a substrate. Biodrying process was performed in 8 trails with various air volumes from 0.20 to 0.45 m3/hr.-kg dry weight (dw). It was found that the increased airflow rate was not linearly proportional to the weight loss. The hydrolytic stage period (2 days) before supplied high air flow in aerobic stage could more increase moisture removal efficiency for rotary biodrying than increase double air flow rate only. The end product was sufficiently homogeneous and heating values 18,024 – 24,260 kJ/kg.

Keywords: MSW, rotary biodrying reactor, water removal, air flow rate, hydrolytic stage

1.0 INTRODUCTION

Biodrying was a variation of aerobic decomposition, used within Mechanical-Biological Treatment (MBT) plants to dry and partially stabilize Municipal Solid Wastes (MSW). Drying technique which relies on the biological activity of microorganisms, both bacteria and fungi to reduce the moisture content of wet biomaterial waste while preserving calorific value [1, 8]. It was a significant alternative for treating MSW [12]. Currently, most studies of biodrying processes focus on the aerobic technology, which removes water mainly as vapor by high temperatures and adequate ventilation [14]. After biodrying, the refuse can be used as a source of energy, i.e., fuel, [1, 11] suitable for safe and economical combustion in a biomass boiler [6].

The study of Sugni [11] examined the influence of alternate air flow on the process of biodrying. At appropriate air supply level, high temperature of composted waste (60 °C) was obtained. By the lack of mixing and one direction of air supplement contribute to the appearance of temperature gradients, resulting in a lack of homogeneity in the moisture and energy content of the final product.

Air flow rate influencing biomass temperature in drying process, while the degree of organic matter degradation affects the calorific value and stability of the final product [1]. In biodrying, the main drying mechanism was convective evaporation, using heat from the aerobic biodegradation of waste components and facilitated by the mechanically supported airflow. The daily inversion of airflow could achieve MSW drying in very short times (8–9 days) and leads to a homogeneous final product [11]. Zhang [14], in order to improve the water content reduction and accelerate biodegradation of MSW with high water content, supplemented a hydrolytic stage prior to aerobic degradation and inoculated the biomass with the bio-drying products as leachate. In this study, a combined hydrolytic-aerobic biodrying technology was introduced to remove water from MSW.

The total water removals were depended on the ventilation frequency and the temporal span in the hydrolytic stage that should not be prolonged more than 4 days. Resulted for the study of Zhao[16] showed a higher air-flow rate (0.0909 m3/ hr.-kg) led to lower temperature than the lower one (0.0455 m3/ hr.-kg) by 17.0% and 13.7% for turning frequency at every 2 and 4 days. The doubled air flow rate resulted in improvement of total water removal ratio by 2.86% (19.5 g/ kg initial water) and 11.5% (75.0 g/ kg initial water) for turning frequency at every 2 and 4 days respectively, indicating that there was no remarkable signs advantage for water removal with high air-flow rate, even with high turning frequency. The study of Colomer-mendoza [3] showed the increased airflow rated was not linearly proportional to the weight loss of MSW.

However, the airflow rate on biodrying system was studies at static system [1, 7and 11]. There were a few studies in continuous or semi-continuous agitation and controlled aeration within a rotary biodrying reactor of MSW [2, 10], specifically configured and optimized for biodrying. This may provide an alternative approach and significant advantages compared to conventional, static methods of MBT by maximizing microbial activity and heat generation at limiting moisture contents, reducing process retention times, enhancing particle size reduction and improving the homogeneity of the treated end product for use as a fuel. However, effect of airflow rate on rotating biodrying process information still insufficient. This study aimed to investigating the effects of air flow rate and duration on the rotary bio-drying process for drying the high initial moisture content of MSW, allowing obtain biofuel of satisfactory energy content.

2.0 EXPERIMENTAL

2.1 Characteristics of MSW Feedstock

The characteristic of MSW for Administrative Organization of Tumbon (AOT) Karai will be observed for chemicals properties and composition such as bulk density, size distribution, and moisture content of raw MSW.

The raw MSW was collected from dumping area of Karai AOT and grinded by hammer mill then sorted with screening size 50 mm. The remains on the screen were collected for preparing feedstock and the grinded MSW which smaller than 50 mm were rejected. The bulky waste such as carpet, yard waste whose size that bigger than 250 mm was rejected by hand. Only MSW size between 50 – 250 mm was used as feedstock for laboratory rotary biodrying process.

2.2 Experimental Equipment

The scheme of the laboratory scale biodrying process used for developing the experiment was presented in Figure 1.

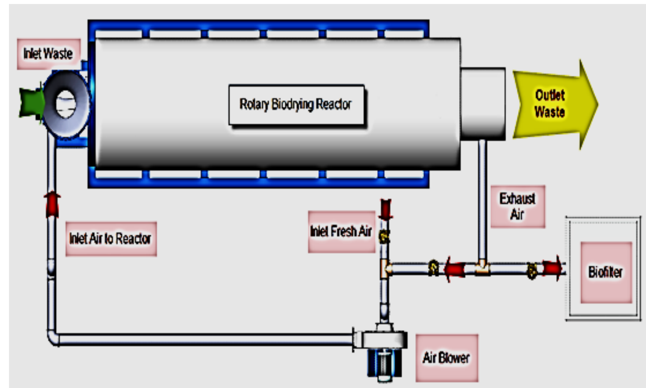


Figure 1 Scheme of the Rotary Biodrying Process

The reactor tank was made of steel at capacity 2,000 liters, the diameter is 1,200 mm and the length is 1,800 mm. The 4 lifter was installed at the internal wall with the height of 200 mm for mixing and turning waste. The leachate drain pipe and thermocouple were installed at the outer wall of the steel column. This steel column will be wrapped by the 25-mm-thick of rock wool for thermal insulation. At the base frame, the drives and supporting roles will be installed with other peripheral equipment and power supply. The biofilters were used to reduce odor impact in the laboratory.

2.3 Experimental Setup and Operation

In this experimental set up, the MSW feedstock was filled until the half of reactor which the total weight approximately 250 kg. The retention time for biodrying process was 8 days [2]. The reactor turning frequency was fixed at 1.5 rpm. Air blower was supplied air into the reactor at the center line of horizontal tank reactor. The air flow rate was controlled by valve and measured by flow meter. The air flow rate was varies at 0.35-0.45 m^3/hr.-kg $_{(dw)}$ or 0.16-0.25 m^3/hr.-kg $_{\text{wet weight(ww)}}$ for high air flow rate and 0.20-0.25 m^3/hr.-kg($_{dw}$) or 0.06-0.08 m^3/hr.-kg $_{(ww)}$ for low air flow rate (Table 1).

The temperature and humidity of inlet and outlet air were continuously measured twice a day by humidity/temperature meter model DIGICON HT-776. The temperature of composting biomass and inner reactor was continuously monitored in every 15 minutes by using a digital thermometer at three different locations inside the reactor; at its center and at its two ends. The experimental data was recorded by data logger which the means of the readings was reported.

The experiment investigation was consists of two stages; the hydrolytic and the aerobic stages. For hydrolytic stage, the reactor was only rotate without aeration and the operating period was 0, 2, 4, and 8 day. Following by aerobic stage with ventilation frequency at 48 times/ day (run 20 minute, stop 10 minute) and the operating period was 8, 6, 4, and 0 day (Table1). The operating time of the biodrying process was automatically controlled by a timer program as shown in Table 1.

Table 1 The rotary biodrying experiment setups [a]

Trial	Experimental (days)		Turning frequency	Air Supply Rate for Aeration Stage			
	Hydrolytic stage	Aeration Stage		Reactor A (High air flow rate)		Reactor B (Low air flow rate)	
			(rpm)	m^3/hr.-kg $_{(dw)}$	m^3/hr.-kg $_{(ww)}$	m^3/hr.-kg $_{(dw)}$	m^3/hr.-kg $_{(ww)}$
1	0	8	1.5	0.35 - 0.45	0.16 - 0.25	0.20 - 0.25	0.06 - 0.08
2	2	6	1.5	0.35 - 0.45	0.16 - 0.25	0.20 - 0.25	0.06 - 0.08
3	4	4	1.5	0.35 - 0.45	0.16 - 0.25	0.20 - 0.25	0.06 - 0.08
4	8	0	1.5	0.0	0.0	0.0	0.0

2.4 Sampling and Parameter Analysis

100 g of samples were collected from three different locations, mainly from the mid span and two end terminals of the reactor, using a composite sampling method to minimize disturbance of the adjacent materials**.**

The samples were dried in an oven (105 ℃, 24 hr.) in order to determine their moisture content following the ISO5068-1 standard. Dried waste was grinded in a mill till 98.75% of the particles could pass through a 2 mm sieve. The heating value of samples was determined by a Bomb Calorimeter®, in accordance with ASTM E711-87(2004).

2.5 Statistical Analysis

All statistical analysis was performed using SPSS 16.0 by SPSS Inc. In all cases, significance was defined by $P<0.05$. Test for significant difference in each condition were tested using a One-way ANOVA.

3.0 RESULTS AND DISCUSSION

The temperature conditions for this experiments were in range of the mesophilic micro-organisms growth between 20-45 °C [17]. The results of moisture content in the reactors were presented in the Table 2.

3.1 Moisture Removal and Duration Time

According to the result of four trials, the moisture removal efficiency was between 60% - 83%. In biodrying, the main drying mechanism was evaporation and convection, using heat from the aerobic biodegradation of waste components and facilitated by the mechanically supported airflow. In these experiments, the moisture removal was preceded in two steps: water evaporated from biomass surface to ambient air through the bed voids as vapor then carried away from the vicinity of waste mass surface with the bulk of convective air stream.

A notable increased in exhaust air temperature results from the biological heat that carries out with the air stream [11]. For the trial 4A and 4B, the moisture removal efficiency was 60% - 65% by only rotation. While the other three aerated experimental trials, the moisture removal efficiency was between 78% - 83%. The initial water content of MSW was 54% - 66% w/w will be decreased to 18%-23% w/w via the drying process.

In the other works, the semi-industrial rotary drum bioreactor was achieved a moisture reduction from 40% to 20% with less than 7 days operation [8]. The commercial process cycles were completed within 7 – 15 days, with mostly loses of water 25-30% w/w, leading to moisture contents of less than 20% w/w [10]. Furthermore, more than 82% of moisture removal of initial gardening waste at high humidity ambient air can be removed by greenhouse biodrying process [3].

3.2 Effects of Air Flow Rate on Moisture Removal

For trial 1A (high air flow rate) and 1B (low air flow rate), the airflow rate was 0.41 m^3/hr.-kg $_{(dw)}$ and 0.23 m^3/hr.-kg $_{(dw)}$. The initial moisture of raw MSW was 0.56 and 0.66 kg $_{water}$ /kg $_{(ww)}$. The final moisture content was 0.19 and 0.23 kg $_{water}$/kg $_{(ww)}$ as shown in Table 2.

The total moisture removal efficiency of trial 1A was 82.2% which consists of air convection 27.6% and rotation 54.6%. The moisture content was reduced from 66% to 28% on the 3rd day of trial. When the moisture content in reactor was lower than 30%, the moisture reduction rate was slowly declined (Figure 2) due to the reduction of microbial decomposition rate.

The highest decomposition rate was achieved at 50% of moisture content [4]. The optimum moisture content for decomposing was between 40% - 60 % and decreasing within 3 days based on the daily turning in the rotary drum [5]. In early day of operation, the outlet air temperature was higher than the inlet air temperature then slightly declined due to biodrying activity. However, the exhaust air temperature was increased and higher than inlet air temperature on 7th and 8th day of operation. Biodegradation and biodrying were inversely correlated; fast biodrying produced low biological stability and vice versa [1].

Table 2 Moisture content of MSW biomass in rotary biodrying reactor [a]

Reactor	Air Supply		Moisture content		Moisture removal efficiency					
	Duration (day)	Flow Rate m³/hr.-kg (dw)	Initial of trial kg water/kg (ww)	Final of trial kg water/kg (ww)	Total		Air convection		Rotation	
					kg water	%	kg water	%	kg water	%
Trial1A	8	0.41	0.55	0.19	112.77	82.2%	37.85	27.6%	74.92	54.6%
Trial1B	8	0.23	0.66	0.23	128.84	78.3%	27.71	16.8%	101.13	61.4%
Trial2A	6	0.45	0.64	0.18	133.72	83.0%	59.13	36.7%	74.59	46.3%
Trial2B	6	0.20	0.68	0.23	135.99	80.5%	19.65	11.6%	116.33	68.9%
Trial3A	4	0.36	0.54	0.21	118.12	79.6%	32.75	22.1%	85.37	57.5%
Trial3B	4	0.25	0.66	0.23	135.49	82.1%	23.62	14.3%	111.87	67.8%
Trial4A	0	0.00	0.61	0.40	91.61	60.4%	0.00	0.0%	91.61	60.4%
Trial4B	0	0.00	0.59	0.37	96.74	65.9%	0.00	0.0%	96.74	65.9%

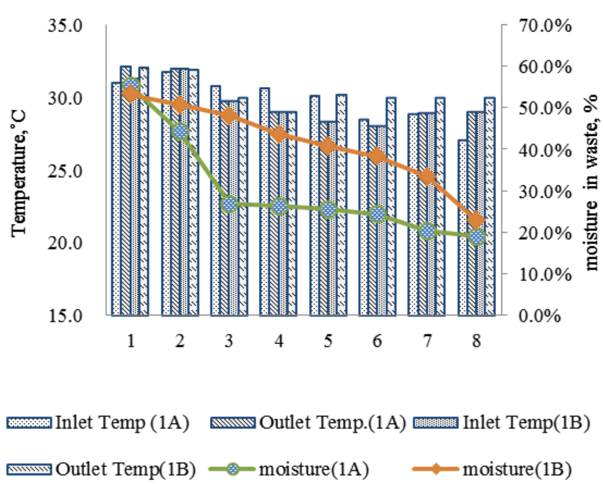


Figure 2 Temperature profile and moisture content of Trial 1A and Trial 1B

Trial 1B gave 78% of the total moisture removal efficiency which consists of air convection 17% and rotation 61%. The moisture content of waste was less than 30% in 8th day of operation indicated that the current rate air flow rate was inadequate to remove the remained moisture in MSW and the biodegradation still working as resulted of higher temperature exhaust air than inlet air. Trial 1A was significantly effective in moisture removal than trial 1B along this trial ($P<0.05$, $F=16.44$).

On the first two days of trials 2A (high air flow rate) and 2B (low air flow rate) was a hydrolytic stage and the followed by six days an aeration stage with air flow rate 0.45 m³/hr.-kg (dw) and 0.20 m³/hr.-kg (dw). The initial moisture value was 0.64 and 0.68 kg water/kg (ww). The final moisture value was 0.18 and 0.23 kg water/kg (ww), as described in Table 2.

The trial 2A gave 83% of total moisture removal efficiency which consists of air convection 37% and rotation 46%. For trial 2B, the total moisture removal efficiency was 81% which consists of air convection 12% and rotation 69%.

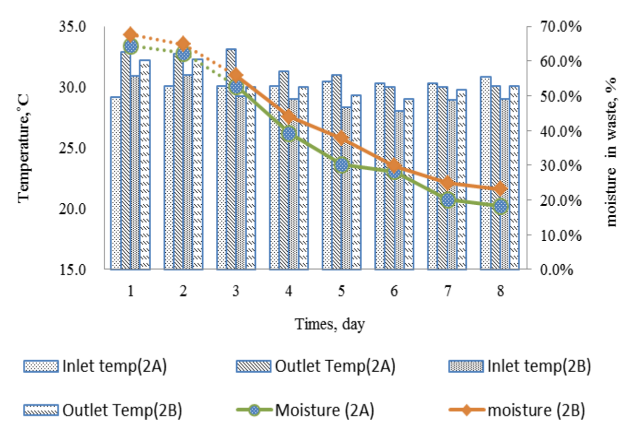


Figure 3 Temperature profile and moisture content of Trial 2A and Trial 2B

In trial 2A, the exhaust air temperature was 2-3 °C higher than ambient temperature on the 2nd and 3rd day of the operation. On the 3rd day operation, air were supplied into the reactor at the high air flow rate which caused in decreasing of the exhaust air temperature from 35°C to 30°C. After the 5th day of the operation, the exhaust air temperature was dropped down and maintained below the inlet air temperature till the end of the operation period. The moisture content in waste was reduced rapidly when supplied air flow and decreased slightly to 20% when the moisture content was lower than 30% on the 5th to the end of trial (Figure 3). The first two days of hydrolytic stage could remove the moisture content from MSW higher than the other trials. However, Zhang reported that the optimum hydrolytic temporal span time should not excess more than 4 days [16].

For Trial 2B, the exhaust air temperature was 1-2 °C higher than ambient temperature throughout 8 days of operation. The moisture content in waste was reduced rapidly due to effect of air flow but decreased slowly to 30% at the 6th day and 23% at the 8th day of the operation (Figure 3) which resembled with high air flow rate trial (2A). At the low the air flow rate, the moisture was insufficient to remove from the MSW due to lacking of air flow. The result of trial 2A and trial 2B revealed that the moisture content significant decreased along the 8 days of process ($P<0.05$, $F=37.94$).

Trial 3A (high air flow rate) and 3B (low air flow rate), the first four days of trial was a hydrolytic stage and the remained four days of trial was in an aeration stage. Air flow rate was set at 0.36 m^3/hr.-kg $_{(dw)}$ and 0.25 m^3/hr.-kg $_{(dw)}$. The initial moisture content was 0.54 and 0.66 kg $_{water}$ /kg $_{(ww)}$ and the final moisture content was 0.21 and 0.23 kg $_{water}$/kg $_{(ww)}$, as described in Table 2. The total moisture removal efficiency of 3A was 80% which consists of air convection 22% and rotation 58%. For trial 3B, the total moisture removal efficiency was 82% which consists of air convection 14% and rotation 68%.

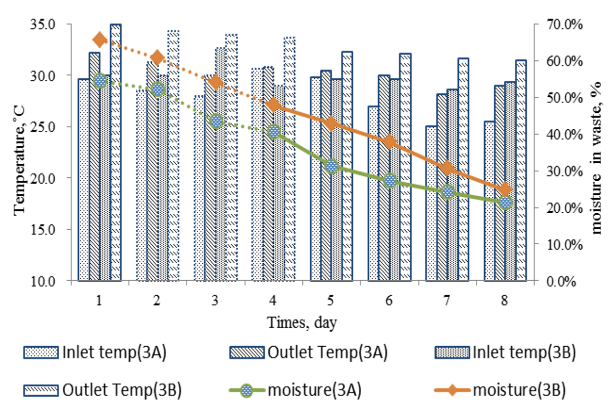


Figure 4 Temperature profile and moisture content of Trial 3A and Trial 3B

The trial3A and 3B, the exhaust air temperature was 2-3°C higher than inlet air temperature and maintained throughout 8 days of operation. The moisture content was decreased lower than 30% on the 5th day of operation and slowly reduced to 21% at the 8th day of 3A trial. For trial 3B, the moisture content was decreased lower than 30% on the 8th day of operation as shown in Figure 4. There was a significant decreasing of the moisture content throughout the 8 days of operation ($P<0.05$, $F=16.64$). However, the exhaust air temperature still higher than an inlet air temperature due to insufficient of aeration stage to removed the moisture from MSW during the process (Figure 4).

The results effect of high airflow rate and low air flow rate with moisture content removal efficiency showed positive significant difference ($P<0.05$, $F=38.45$). Thus it can be noted that the two rate of air supplied was affected on the moisture content of rotary biodrying reactor. Consistent with the report of the effect of double air flow rate improved the total water removed but not linearly proportional to water removed or water loss [3, 16]. The result of high airflow rate led to lower exhaust temperature for all trial [16].

3.3 Effect of Hydrolytic Time for Water Removal

The result of the moisture content removal efficiency which done by the rotation in hydrolytic stage only was 60% of total efficiency. The final moisture content in MSW was 40% as shown in Figure 5. Which mean the hydrolytic stage and rotation without air supply was inadequate to reduce the moisture content in MSW within 8 days of the operation.

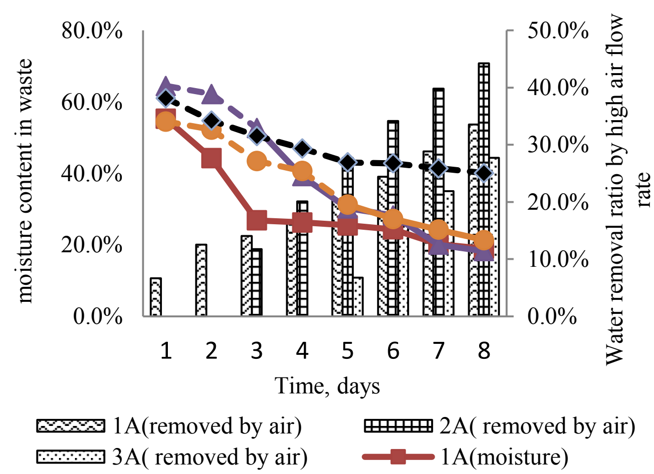


Figure 5 Water removal and Hydrolytic time Trial1A, Trial 2A, and Trial 3A

When moisture content in MSW was more than 30 %, under an aerobic stage and high air flow rate, the moisture content was depreciate rapidly. In contrast, the declined rate was slightly when moisture content in MSW was less than 30% [5]. The percentage of water removal by air convection without hydrolytic stage (1A) was 33.6% of total water removed in an experiment. In trial 2A and 3A, the percentage of water removal by air convection was 44.2% and 27.7% of total water removed in an experiment, respectively (Figure 5).

At low air flow rate, the decline rate of moisture content was declined slightly throughout 8 days of trial. The percentage of water removal by air convection was 21.5% of total water removed. In trial 2B and 3B, moisture content removal efficiency was slightly decreased in the hydrolytic stage and decrease more rapidly when supplied the air flow into the reactor. The percentage of water removal by air convection was 14.5% and 15.7%, respectively (Figure 6).

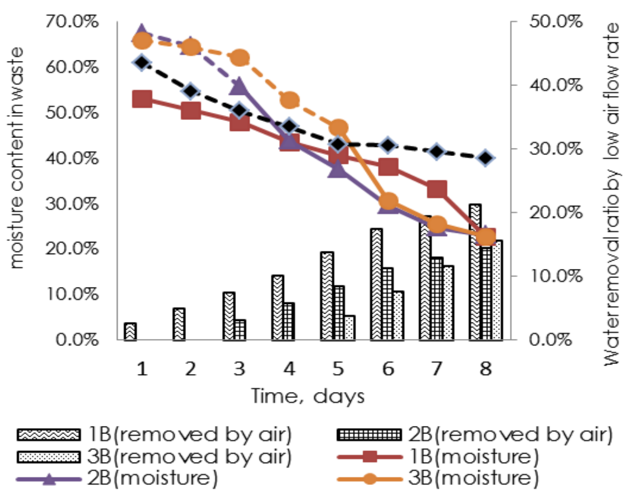


Figure 6 Water removal and Hydrolytic time of Trial1B, Trial 2B, and Trial 3B

The hydrolytic stage may be supplemented to destruct the cell wall or membrane with a less organics consumption [14]. The suitable hydrolytic span time of these experiments was 2 days before the aerobic stage with high air flow rate which suitable for reduce the moisture content up to 83% from initial moisture content at the water removal efficiency was 44.2%. Similar to rotary drum bio-reactor with the semi-continuous agitation that the most effective moisture removal with high air flow rate to reduce the MSW temperature due to the utilization of thermal energy stored in the MSW [10].

In this study, the MSW with initial moisture content between 0.54–0.68 kg $_{water}$/kg $_{(ww)}$ were used as the media of rotary biodrying. In trial 1, 2 and 3, moisture removal efficiency was obtained between 79% - 83%. While the trial 4 (without air flow) moisture removal efficiency between 60%-65%. The reduction of moisture content trend was resembled with the study of Adani [1] and Sugni [11]. Nevertheless, the final moisture content of the end product was equal to 190 - 230 g $_{water}$/kg $_{ww}$ with air flow rate. The calorific value of the end product was 18.03-24.26 kJ/g waste was observed which similar to Adani [1], Skourides [10], Sugni [11] and Zawadzka [13].

4.0 CONCLUSION

A proper control of biodrying process parameters makes it possible to dry MSW in a short period. In this work, The MSW was biodried in reactors for 8 days. A weight loss between 40% and 57% and a volume reduction between 40% and 60% was reached. Furthermore, the combined 2 days hydrolytic stage before aerobic stage with high air flow rate resulted in a high weight loss. At higher airflow, weight loss was greater than lower airflow but not in a linear proportional. The hydrolytic stage had a positive influence for biodrying of wastes, but only below 4 days. Therefore the hydrolytic stage reduced the airflow required as well as the energy needed for the aeration.

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