

Process of changing municipal solid waste into RDF using rotary bio-drying

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Abstract

Refuse Derived Fuel (RDF) is produced by significantly reducing the moisture content of Municipal Solid Waste (MSW). By using bio-drying process inhabited the heat from the degradation process of organic waste. The MSW size was reduced to be less than 3 inches in order to have a thorough circulation of air. This study aimed to investigate the effects of rotation speed and initiate preheat time on the rotary bio-drying process for drying the high initial moisture content households solid waste, allowing satisfied energy content biofuel. The density was 212 kg/m^3 , air inlet was $0.075 \text{ m}^3/\text{hr/kg}$, with the rotation rate at 0.1, 0.2, 0.3, 0.4 rpm, preheating at 45°C for 6, 9, 12 hours in 8 days, respectively. As a result, preheating at 45°C for 12 hours, rotating speed at 0.4 rpm, with the air inlet at $0.075 \text{ m}^3/\text{hr/kg}$, resulting in the reducing of the moisture content to 13%, and the increasing of the heating value to 4,588.91 kcal/kg, which was higher than standard RDF at 3,820.80 kcal/kg. Rotary bio-drying process can improve the quality of the waste within a short period of time. The RDF with high heating value is required in the industrial sector for use as fuel in the manufacturing.

Keywords:

Refuse Derived Fuel; Rotary Bio-drying; Dewatered Municipal Solid Waste, Drying MSW.

1. Introduction

In 2017, Thailand produced approximately 27.37 million tons of municipal solid waste (about 75,000 tons per day). This indicate that per capita production of MSW has increased to, 1.13 kg per person per day [1]. Municipalities dispose the waste in sanitary landfills. Since open dumping is the disposal method selected by municipalities, environmental problems such as leachate contamination, bad odor, proliferation of pests and scattering of dry solid waste are most possible. Inadequate waste collection, insufficient waste treatment and leachate at disposal sites, as mentioned previously, can become major environmental problems. and Possible groundwater contamination and the absence of groundwater monitoring; health danger for waste pickers who are exposed to unsanitary conditions; and lack of means for separation of hazardous waste raising risk of hazardous waste contamination of landfill area and water resources are additional major concerns.

Especially for MSW that consist of organic wastes from households and agricultural activities, which have a high-water content, bio-drying is a good way to tap their energy content. Bio-drying is a drying process wherein heat is generated by the biological activities of microorganisms, bacteria and fungi, thereby reducing the moisture content of the wet organic wastes, producing fuel from the MSWI (Refuse Derived fuel; RDF) [2]. Biological conversion of organic matter may be able to produce solid fuels, Refused-Derived Fuel or RFD, that can be used in power plants, cement kilns and other combustion plants [2-3].

Biological processing generates heat by degrading a part of the easily degradable organic matter, and the heat is sufficient to evaporate a significant fraction of the water in the MSW received. This increases the heating value. As a result, the municipal solid waste is stabilized regarding further degradation, as microbial degradation is inhibited by the reduction of the water content to lower than 25%, and which ceases at values below 10 % [4]. Appropriate control of aeration operational parameter (e.g., air-flow rate and direction) operations during the aerobic stage with fix ventilation flow rate of $0.075 \text{ m}^3/\text{kg}\cdot\text{m}^2\cdot\text{hr}$. [5] and at temperatures can achieve a high bio-drying efficiency [6]. The rotating drum ensures homogenization and fluffing of the materials. As a result of thorough aeration, other emissions from rotating drum are low. Removal of inert materials is more effective after leaving the rotating drum, because the compost is drier and well homogenized [7].

In previous research, the retention time in the rotating drum system ranged from 1 to 10 day [7], the rotational speed rates from 0.1 to 1.0 rpm [8], and the rotation was either continuous or intermittent.

This study aimed at investigating the influence of the rotation rate with fix ventilation flow rate of $0.075 \text{ m}^3/\text{kg}\cdot\text{m}^2\cdot\text{hr}$ on temperature increase of bio-drying process and moisture removal.

2. Methods and Materials

2.1. Characteristics of Waste Feed Stock

The MSW feedstock was sampled from Nong Bua Community, Mueng District, Kanchanaburi Province, Thailand. It comprised of 32% (w/w, wet weight) kitchen waste, 26% (w/w) agriculture waste, 12% (w/w) Paper, 16% (w/w) Plastics, and 14% (w/w) others. The initial water content was 68%. The characteristics of raw MSW such as bulk density, size distribution, and moisture content were determined.

The raw MSW was collected from the dumping area of Nong Bua Community. It was then sorted by screening sizes smaller than 3 inches. Bulky wastes such as carpets, yard wastes, and other wastes bigger than 3 inches were manually separated and rejected. Only MSW of suitable sizes, less than 3 inches, were used for the laboratory rotary bio-drying process.

2.2. Experimental Equipment

The bio-drying experiments were performed in a laboratory horizontal column reactor, as shown in Fig 1. The reactor tank was cylindrical steel sheet with a diameter of 120 cm and the length of 120 cm., with an insulated exterior. The tank, as shown in Fig 2 consisted of two layers to separate the leachate from MSW. A leachate drainage vent was installed in the lower part of the reactor. The air outlet was installed at side of tank. The reactor has a spindle mount with two set of gears for variable speed using a 0.2 kW 220-volt motor. Ambient inlet air was supplied by whirlpool pump. The flow meter and variable flow valve were installed between pump and reactor.

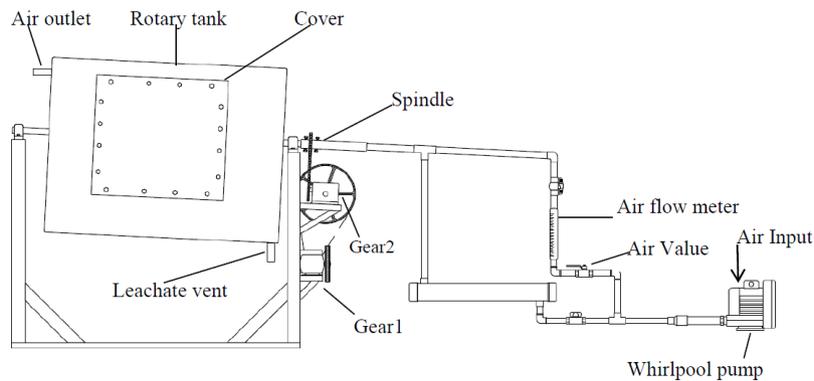


Fig. 1 Schematic representation of the rotary bio-drying reactor.

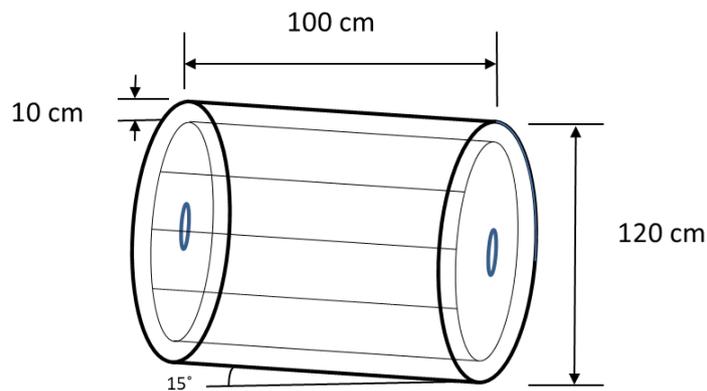


Fig. 2 Sieve tank in Rotary.

2.3. Experimental Setup and Operation

In this experimental set up, MSW feedstock was fed until the reactor is more than half-full. The total weight was approximately 133 kg, given an estimated density of 212 kg/m^3 [9]. The retention time for bio-drying process was 8 days [6]. Rotation rate was reduced, using reduction gear, to 0.1, 0.2, 0.3, 0.4 rpm. Inlet air was supplied by a whirlpool pump at flow rates $0.075 \text{ m}^3/\text{hr.kg}_{\text{wet waste}}$. [10]. Aeration has an influence on the biomass temperature and the bio-drying process for converting the municipal solid waste to refuse-derived fuel (RDF).

Table 1 Operation conditions of bio-drying.

Condition	unit	Trial 1	Trial 2	Trial 3	Trial 4
Ventilation flow rate	m ³ /kg.m ² .hr	0.075	0.075	0.075	0.075
preheat time	hr.	-	-	-	-
preheat temperature	°C	Ambient temperature	Ambient temperature	Ambient temperature	Ambient temperature
Rotation rate	rpm	0.1	0.2	0.3	0.4

Condition	unit	Trial 5	Trial 6	Trial 7	Trial 8	Trial 9	Trial 10
Ventilation flow rate	m ³ /kg.m ² .hr	0.075	0.075	0.075	0.075	0.075	0.075
preheat time	hr.	6	6	6	6	9	9
preheat temperature	°C	45	45	45	45	45	45
Rotation rate	rpm	0.1	0.2	0.3	0.4	0.1	0.2

Condition	unit	Trial 11	Trial 12	Trial 13	Trial 14	Trial 15	Trial 16
Ventilation flow rate	m ³ /kg.m ² .hr	0.075	0.075	0.075	0.075	0.075	0.075
preheat time	hr.	9	9	12	12	12	12
preheat temperature	°C	45	45	45	45	45	45
Rotation rate	rpm	0.3	0.4	0.1	0.2	0.3	0.4

2.4. Experimental Monitoring

The process was monitored every day for temperature and air flow rate. The temperature was monitored using thermometers, with the sensors installed inside the tank in three positions, as shown in Fig. 3. The data collected were directly saved on a computer.

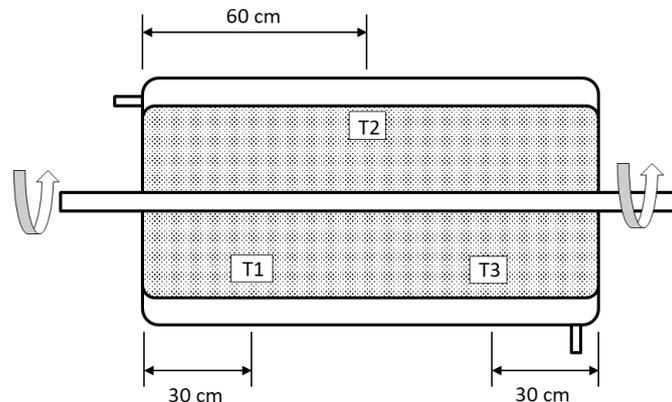


Fig. 3 Installation location of the thermometers.

Thus, the temperature and humidity of inlet and outlet air were continuously measured twice a day using the humidity/temperature meter model i-Button. The temperature of composting biomass and inner reactor was continuously monitored every 15 minutes using digital thermometers at three different locations inside the reactor at its center and at its two ends. The data from the experiment were recorded by a data logger which also the means by which the readings were reported.

2.5. Sampling and Analytical Methods

The samples of fresh wastes were collected from two different spots and were mixed together inside the reactor tank. A composite sample was obtained and analyzed for parameters shown on Table 2.

Table 2 Parameter and analytical methods.

Parameter	Unit	Analytical methods
Bulk Density	kg/m ³	ASTM E 1109-86
Moisture content	% by weight	ASTM E 790
Heating Value	MJ/kg	ASTM E 711
Ash content	% by weight	ASTM E 830-87

3. Results

3.1. MSW characteristic

The raw MSW collected from Nong Bua Community, Mueang District, Kanchanaburi Province amounted to 28,083 tons of waste. This was from 14 rai of waste land where there was 14 tons of new wastes per day and collected three times (average and standard deviation).

Table 3 MSW characteristic.

Waste	Weight of component (kg.)	Percent of componen	Average Weight (%)	SD	Average Percent(%)
Food waste	28 – 35	22.05 – 25.55	32	3.60	24.06
Agricultures	13 – 20	9.63 – 14.60	16	1.54	12.03
Paper	8 – 18	5.84 – 13.33	12	5.29	9.02
Plastic	14 – 19	10.22 -14.07	16	2.64	12.03
Textile	12 – 15	8.89 – 10.95	13	1.73	9.78
Tiles	18 – 25	13.14 – 19.69	21	3.60	15.79
Wood	7 – 14	5.19 – 10.22	10	3.20	7.52
Rubber	4 – 9	3.15 – 6.67	6	2.60	4.51
Other	3 – 10	2.96 – 7.09	7	4.02	5.26
Total			133		100

MSW feedstock was comprised of 24.06% (w/w, wet weight) food waste, 12.03% (w/w) agriculture waste, 9.02% (w/w) Paper, 12.03% (w/w) Plastics, 9.78% (w/w) textile waste, 15.79% (w/w) tiles waste, 7.52% (w/w) wood waste, 4.51% (w/w) rubber waste, and 5.26% (w/w) others.

The range of moisture content in the waste was 70-51%, with an average of 68%. This was because the average composition of municipal solid waste mostly comprised of organic food waste that contains high level of moisture. The range of heating value of wet waste was 669.21-1,959.84 kcal/kg, an average value of 812.61 kcal/kg.

3.2. Effect of rotation speed and initiate preheat time

The experiments had 16 trials, which were divided into 4 groups. All experiments took 8 days, and the define constant air flow rate was 0.075 m³/hr.kg_{wet waste} throughout the experiments.

Group 1 rotation rate at 0.1, 0.2, 0.3, 0.4 without initiate preheat.

Table 4 Effect of rotation speed and without initial preheating of system performance.

Trial	Moisture content				Heating value			
	Initial (%)	SD.	Final (%)	SD.	Initial (kcal/kg)	SD.	Final (kcal/kg)	SD.
1	68	1.00	38	3.61	812.61	99.51	2,868.06	225.90
2	51	2.65	30	2.62	1,959.84	189.71	3,441.68	176.18
3	64	2.00	28	1.00	1,099.42	137.82	3,585.08	73.02
4	68	2.65	15	3.46	812.61	199.01	4,421.60	234.58

Table 5 Results of group 1 Ash content and Bulk density.

Trial	Ash content (%)	SD.	Bulk Density (kg/m ³)	SD.
1	7.68	1.62	83.82	26.72
2	5.26	1.67	66.18	14.92
3	6.08	0.90	61.76	21.44
4	5.22	1.42	33.09	11.12

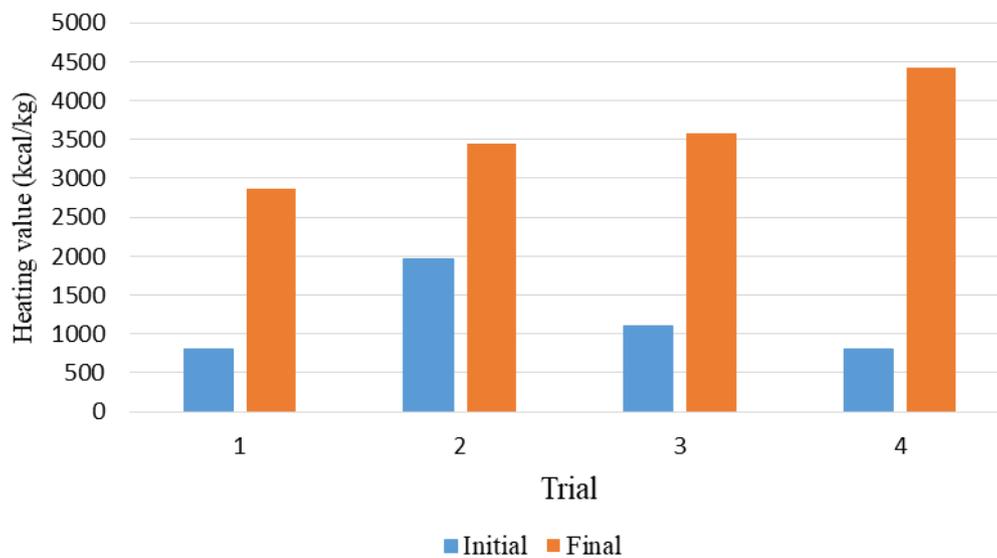


Fig. 4 Heating value trial 1-4.

The graph given in Fig. 4 shows effect on heating values of the waste, at different rotation rates of 0.1, 0.2, 0.3 and 0.4 rpm. The results revealed that how increasing heating values influenced moisture reduction. Trial 1-4 had created efficiency heating value at 252.94%, 75.61%, 226.08% and 444.12% respectively.

Group 2 rotation rate at 0.1, 0.2, 0.3, 0.4 rpm and initiate preheat 45 °C in 6 hr.

Table 6 Effect of rotation speed and initiate preheat 45 °C in 6 hr. of system performance.

Trial	Moisture content				Heating value			
	Initial (%)	SD.	Final (%)	SD.	Initial (kcal/kg)	SD.	Final (kcal/kg)	SD.
5	68	1.73	36	3.61	812.61	124.19	3,035.37	245.29
6	59	3.00	29	2.65	1,457.93	209.16	3,537.28	162.68
7	63	1.00	26	1.73	1,171.12	77.76	3,680.68	124.19
8	60	2.00	15	2.65	1,386.23	137.46	4,373.80	169.57

Table 7 Results of group 2 Ash content and Bulk density.

Trial	Ash content (%)	SD.	Bulk Density (kg/m ³)	SD.
6	7.60	0.59	63.96	5.90
7	6.25	0.74	57.35	7.60
8	6.44	0.58	32.09	11.95

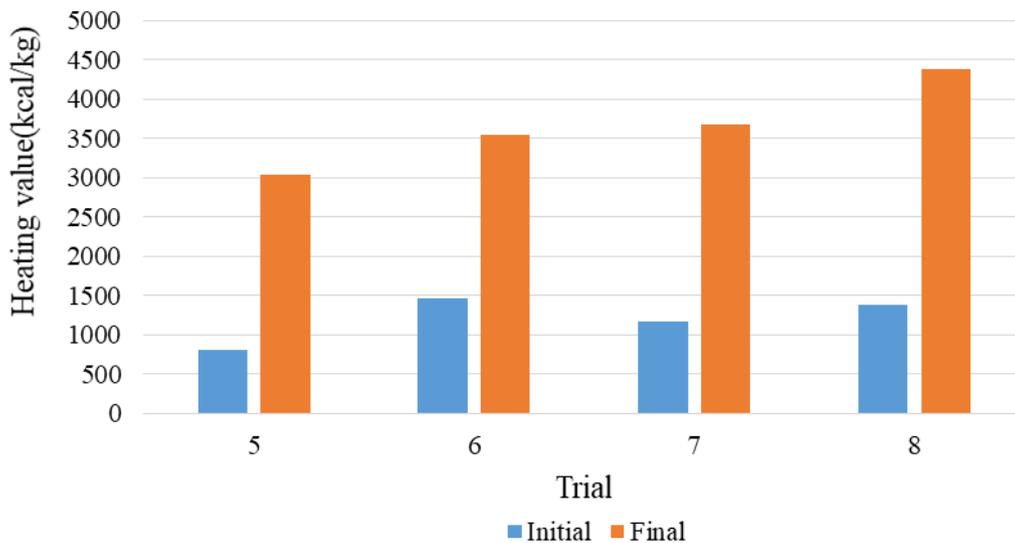


Fig. 5 Heating value trial 5-8.

The graph given on Fig. 5, shows the effect on the heating value of the wastes, at different rotation rates 0.1, 0.2, 0.3 and 0.4 rpm, but with initial preheating to 45 °C in 6 hr done on the wet wastes. The result revealed that increasing heating value influenced moisture reduction. Trial 5-8 had created efficiency heating value at 273.53%, 142.62%, 214.28% and 215.51% respectively.

Group 3 rotation rate at 0.1, 0.2, 0.3, 0.4 rpm and initiate preheat 45 °C in 9 hr.

Table 8 Effect of rotation speed and initiate preheat 45°C in 9 hr. of system performance.

Trial	Moisture content				Heating value			
	Initial	SD.	Final	SD.	Initial	SD.	Final	SD.
	(%)		(%)		(kcal/kg)		(kcal/kg)	
9	65	2.00	35	2.65	1,051.62	107.77	3,059.27	145.21
10	66	2.65	30	2.65	956.02	180.97	3,453.63	176.18
11	65	3.61	24	2.65	1,051.62	250.39	3,847.99	185.65
12	67	1.00	14	2.65	908.22	90.49	4,469.40	176.18

Table 9 Results of group 3 Ash content and Bulk density.

Trial	Ash content (%)	SD.	Bulk Density (kg/m ³)	SD.
9	7.53	0.90	75.39	12.53
10	6.04	0.19	64.62	10.77
11	5.36	0.25	51.69	32.02
12	5.64	0.57	30.16	3.28

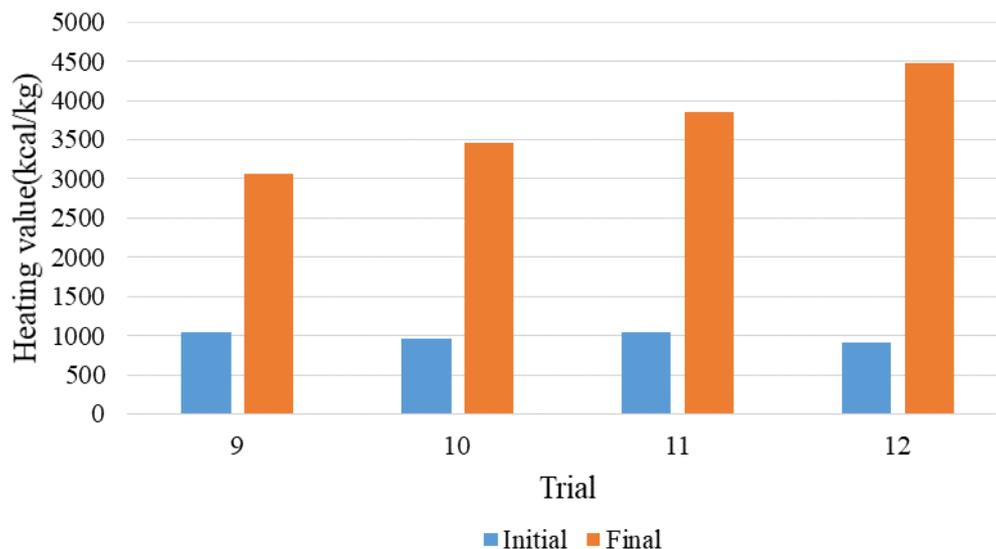


Fig. 6 Heating value trial 9-12.

The graph given on Fig. 6 shows the effect on the heating values of the waste at different rotation rates of 0.1, 0.2, 0.3 and 0.4 rpm, with initial preheating of the wet wastes to 45°C in 9 hr. The result revealed that increasing heating value influenced moisture reduction. Trial 9-12 had created efficiency heating value at 190.91%, 261.25%, 265.91% and 392.10% respectively.

Group 4 rotation rate at 0.1, 0.2, 0.3, 0.4 rpm and initiate preheat 45°C in 12 hr.

Table 10 Effect of rotation speed and initiate preheat 45°C in 12 hr of system performance.

Trial	Moisture content				Heating value			
	Initial (%)	SD.	Final (%)	SD.	Initial (kcal/kg)	SD.	Final (kcal/kg)	SD.
13	61	1.73	29	2.00	1,290.63	124.19	3,489.48	131.63
14	65	4.00	27	1.00	1,051.62	251.81	3,632.88	60.15
15	62	4.36	22	2.65	1,254.78	304.52	4,015.29	185.64
16	63	3.00	13	1.00	1,171.12	203.27	4,588.91	96.50

Table 11 Results of group 4 Ash content and Bulk density.

Trial	Ash content (%)	SD.	Bulk Density (kg/m ³)	SD.
13	5.43	0.69	64.67	10.76
14	6.72	0.90	60.21	17.21
15	5.84	0.28	49.06	16.86
16	6.88	0.61	28.99	12.34

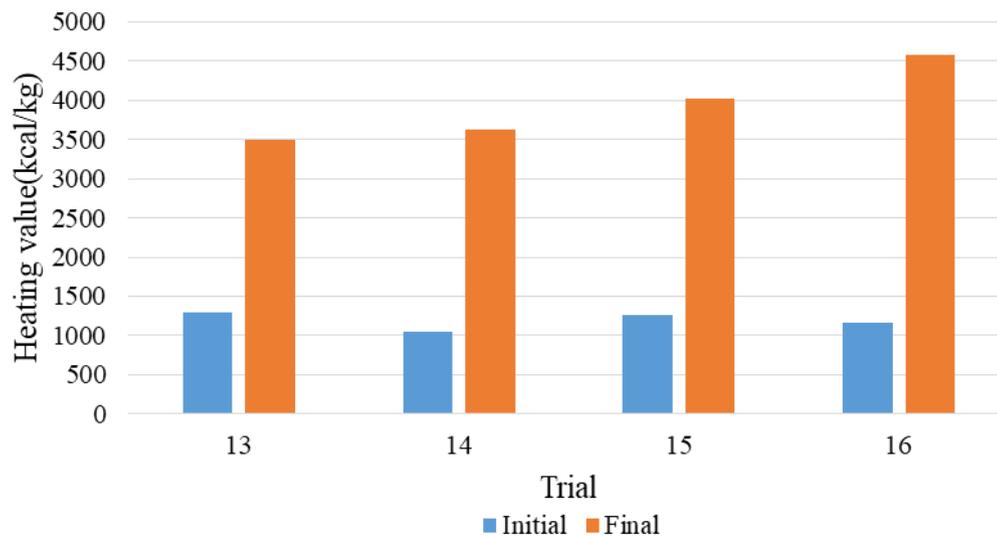


Fig. 7 Heating value trial 13-16.

The graph given in Fig. 7 shows the effect on heating values of the waste, at different rotation rates of 0.1, 0.2, 0.3 and 0.4 rpm, with initial preheating of the wet wastes to 45°C in 12 hr. The result revealed that increasing heating value influenced moisture reduction. Trial 13-16 had created efficiency heating value at 170.37%, 245.45%, 219.99% and 291.83% respectively. Particularly for Trial 16, the final heating value obtained for dried MSW was 4,588.91 kcal/kg or 19,199.99 kJ/kg which considered as heating value for Class 2 according to “Standard CEN/TS 15359:200G”.

4. Discussion

4.1. Effect of rotation rate on bio-drying

For MSW bio-drying, water removal was expected to consume energy as little as possible to preserve more energy for refuse derived fuel [11], while waste confronts more challenge for water removal due to the adverse properties including low biodegradable organic substances, high moisture and poor porosity. So, in waste bio-drying degradation should be enhanced as far as possible and the resulting energy loss was trivial compared with its contribution to water removal [12].

Bio-drying of MSW allows for lower energy consumption in removal of water from wet organic wastes, thus producing RDF (refused-derived fuel) with higher energy content. Bio-drying allows efficient removal of moisture from wet wastes despite of having very high moisture content, low biodegradable organic substances and poor porosity. [12]

From the results, it showed that with a “ventilation flow rate” of $0.075 \text{ m}^3/\text{kg}\cdot\text{m}^2\cdot\text{hr}$ and rotation rate of 0.1rpm provide the best effect on attaining best drying temperature and moisture content removal. The slow rotation rate prevented rapid moisture removal. Moisture should not less than 35-40% for effective bio-degradation and bio-drying as it provides the desirable moist working environment needed by the microorganisms. During the bio-drying process the heat generated evaporation [7]. If the speed is increased, evaporation will also increase, consequently higher amount of moisture will be removed. If moisture in the system is less than 35-40%, the bio-drying process will decrease and temperature also decrease, respectively.

Temperature declines with decreasing moisture, as a result, the moisture content at day 8 at a speed of 0.4rpm with a minimum moisture content of 1% 5 (Standard Deviation 3.46) produced RFD with a heating value of 4,421.60 kcal/kg (Standard Deviation 234.58), which is higher than the NETL standard of 2,865.6-3,820.8 kcal/kg [13].

4.2. Effect of preheat time on bio-drying

Bio-drying, which similar to composting, aims at removing or reducing moisture from biodegradable waste that has high water content, thereby increasing treatability and allow utilization of the bio-dried material as high-value solid fuel. Bio-drying is the utilization of the heat released during the decomposition of biodegradable waste to reduce the moisture content and produced partially stabilize organic waste. The removal or reduction of moisture contents in bio-drying process involves evaporation of water through the heating generated by the aerobic decomposition of the organic material [7]. Bio-drying process can produce temperatures of more than 55°C during the decomposition process.

The bio-drying process enhances the evaporation process to remove out more moisture [2,11]. Moisture content is the single critical parameter for evaluating the efficiency of bio-drying process [14]. The moisture content influences microbial activity, by creating a suitable environment for the growth of bacteria. This was achieved by preheating at 45°C for 6, 9, and 12 hours. Preheating produced good bacterial growth, which lead to more efficient f organic degradation, and resulting to rapid heating and better dehydration. The humidity of the waste decreased as the moisture content decreased below 40%. A decrease in the growth rate of bacteria also decreased heat generation. If initial moisture content is low, microbial activity will slow down due to insufficient moisture content, and consequently, the drying performance also decreases [9].

The results of the experiments and research showed that the assembly should be rotated at a speed of 0.4 rpm and with 12 hours of pre-heating. Heat generation on day 2 resulted to a temperature of 53°C ,

and moisture content reduced below 40%. The temperature decreased gradually, until day 8., when the final moisture content was 13% (Standard Deviation 1.00), heating value was 4,588.91 kcal/kg (Standard Deviation 96.50), This is also higher than the NETL standard of 2,865.6-3,820.8 kcal/kg [13].

5. Conclusion and suggestions

A proper control of bio-drying process parameters makes it possible to dry MSW in a short period of time to a desirable RFD moisture level. In this research, the MSW was bio-dried in reactors for 8 days. Although the convection heating process and moisture content reduction were slower, this slower rotation and the preheating provided adequate conditions for the effective bio-degradation of the MSW by increasing the degradation temperature. On the other hand, when the rotation speed is increased, moisture content decreased rapidly. Heating was faster, but the heating time reduced. Hence, there was insufficient moisture content to produced suitable conditions for biodegradation. With moisture content reduced, the temperature inside the rotary tank correspondingly dropped. The slower process done under this research can increase heating value from 1,171.12 kcal/kg to 4,588.91 kcal/kg and decrease moisture content from 63 % to 13 % within a period of 8 days.

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