MOISTURE CONTENT AND THERMAL BALANCE DURING COMPOSTING OF FISH, BANANA MULCH & MUNICIPAL SOLID WASTES

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Abstract

Temperature, moisture content, oxygen concentration in the airspace, and C/N ratio are the primary factors affecting the composting process (Haug, R. T. 1993; Ekinci, K., Keener, H.M., & Elwell, D.L. 2002). The overall aim of this study is to understand the effect of composting different types of wastes with different weights on temperature and moisture content during composting. The experimental trials involve an aerobic composting of fishery house wastes, municipal solid waste, banana plantations wastes and composted meat. Waste mix ratios were adapted following Carbon to Nitrogen formula. The compost material was left for more than 29 days of which more than 24 days of decomposition in barrel followed by 5-7 days piled up in open ground space and covered with nylon bags. Temperature at two depths 25 cm and 50 cm of top compost surface and moisture content were monitored throughout the experiments to control turnover frequency and water addition. A rapid increase in temperature was noticed indicating a marked microbial activity. There was a significant correlation between the moisture content and the temperature distribution within the pile. Higher temperature can be obtained by increasing size of the composting material or increasing volumetric mixing ratios of compost substrates or by trying other combinations with higher C/N ratios.

Keywords: Composting, Temperature, Moisture content, Agricultural Wastes, Seafood Wastes, Municipal Solid Wastes

Introduction

Millions of tons of wastes are generated each year from agricultural, municipal, and industrial sources. In Lebanon, Municipal Solid Waste (MSW) constitutes more than 90% of the total solid waste stream. The generation rate varies approximately from 0.8 Kg/capita/day to 1.2 Kg/capita/day (Sweep-net, 2014). The amount of waste is being increased day by day parallel to the increasing population in the world. The uncontrolled decomposition of organic solid waste can result in large-scale contamination of soil, water, and air (Ghosh, S., Viéitez, E.R., Liu, T., & Kato, Y., 1997).

Saida is an active fishing city with limited agricultural land (some wheat, vegetables, fruits especially citrus and banana). Saida has a fishing port, a small quay to receive commercial vessels and a fishery facility that sells fresh fish every morning. Fishery harvest output ranges from one to four tons per day. Of each ton of fish output, one third is considered as waste and sent for disposal along with other municipal solid waste of the city. As for banana sector, the annual banana output falls within 85,600 tons and 110,000 tons per year in South Lebanon. Banana production is increasing at the expense of cultivated areas for citrus production because of its economic value. Banana cultivation occupies at least 3,000 hectares. There is no exact official updated data on the total output waste generated from the banana agricultural sector since it is being burnt. Wastes from slaughterhouse which vary from season to season are dumped in open areas with other wastes without any treatment plan. The municipal wastewater treatment plant of Saida city has an anaerobic digester and an open area for compost maturation without being properly managed and controlled (no composting facilities). The Municipality is not benefiting from any economic return of compost products. It is also contributing to the environmental pollution of the city.

Composting is the biological decomposition of natural organic materials by soil organisms into stable organic matter (Hog Producers Sustainable Farming Group, 1996). The composted product has the advantage of improving soil structure, increasing soil organic matter, suppressing soil-borne plant pathogens and enhancing plant growth, (Fourti, O., Jedidi, N., & Hassen, A.M., 2011). It is the most practical, simple and inexpensive way to dispose of and recycle food scraps and yard waste which helps in improving and maintaining the environment (Fares, R., Fares, E., & De-Nardo, F., 2011).

The composting process can naturally occur with the involvement of microorganisms in MSWs. However, insufficient quantity or poor biodegradability of the indigenous microbial community used may easily lead to low composting efficiency and undesirable compost. (Bei-Dou, Xia,b, Xiao-Song, He, Zi-Min, Wei, Yong-Hai, Jiang, Ming-Xiao, Li, Dan, Li, Ye Lid, & Qiu-Ling Dang., 2012).

The suitability of the final product for use as fertilizer is determined by the composting process. This ensures that the process will be completed effectively from the microbiological point of view. The maximum temperature should be in the target of 55–60◦C to eliminate pathogens that are harmful to humans and plants. (Waszkielis, K.M., Wronowski, R. Chlebus, W., Bialobrzewski, I., Dach, J., Pilarski, K., & Jancazak, D., 2013).

Temperature, moisture content, oxygen concentration in the airspace, and C/N ratio are generally recognized as the primary factors affecting the composting process (Haug RT., 1993; Ekinci K. et al., 2002). In a typical completely mixed organic waste composting process, these factors are controlled by varying ingredient mix ratios, aeration, turning frequency, and occasionally by moisture addition. (Makan, A.H., Assobhei, O., & Mountadar, M., 2013).

Moisture content of the composting blend provides a medium for the transport of dissolved nutrients required for the metabolic and physiological activities of microorganisms (Liang, C., Das K.C., & McClendon, R.W., 2003). The moisture content of the composting material must be between 45 and 65% moisture content (Chen, L., Moore, A., & de Haro-Marti, M. D., 2012). The bacteria and fungi that do the composting live in a water layer around the organic particles. If the moisture content is below 45%, there is not enough water around the particles for the microorganisms to live, and if the moisture content is greater than 65%, the pores between the particles are filled with water, and the microorganisms cannot obtain enough oxygen (Chen et al., 2012). The rule of thumb is that if you can squeeze water out of the material, it's likely more than 70% moisture content and is too wet (Chen et al., 2012).

Turning is often cited as the primary mechanism of aeration and temperature control during windrow composting (Michel, F.C., Forney, L.J., Huang, A.J.F., Drew, S., Czu Prenski, M., Lindeberg J.D., & Reddy, C.A., 1996; Tiquia, S.M., 1996), while turning frequency is commonly believed to be a factor which affects the rate of composting as well as compost quality (Ogunwande, G. A., Osunade, J. A., & Ogunjimi, L. A., 2008)

In many studies, temperature has been shown to be a critical determinant of composting efficiency. Many researchers reported that the temperature range for optimal composting is between 52 and 60°C, whereas others suggested that lower temperatures might be more suitable for composting. In an outdoor biosolids composting experiment using insulated, aerated reactors, Campbell (1997) reported that biosolids piles heated to a maximum of 52–57°C in 9–11 days. (Liang et al., 2003)

Temperature is a very important factor since it ensures that the process will be completed effectively from the microbiological point of view. The maximum temperature should be around 55–60°C to eliminate pathogens that are harmful to humans and plants (Waszkielis et al., 2013). Microorganisms during composting stages are classified by their temperature growth preferences or tolerances. While classification of microorganism's growth by temperature preferences slightly differs across published research, microorganisms growing at 25-40ºC are mesophilic bacteria. Those growing above 45ºC are thermophilic bacteria (Madigan, M.T., Martinko, J.M., & Parker, J., 2000). Mesophilic organisms initiate the decomposition process. Mesophilic organisms rapidly break down the soluble readily degradable compounds of the waste and cause the rapid increase in compost temperature (Trautmann, N.M., Richard, T., & Krasny, M.E., 1996).

The overall aim of the study is to understand the effect of composting different types of wastes with different weights of temperature and moisture content during composting. Fish wastes and banana plantation wastes contribute to a substantial amount of waste generated in Saida city making it a likely candidate for investigations on the carbon and nitrogen amendments on the MSW. They will also contribute to reduce the accumulated wastes in the city and the environmental pollution. As such, sequential experimental trials were carried out to fulfill the objective of the study and to provide specific design and operational parameters for effective composting of MSW. The parameters to be investigated in this trial experiment are C/N ratio, moisture content and temperature. Accordingly, the research questions of this trial experiment are as follows:

1. To find a practical solution for the fishing area solid waste with banana (agriculture waste) instead of filling or burning?
2. To what extent the temperature profile of composting process is affected by the different waste mix of the compost material?
3. To what extent the temperature profile of composting process is affected by the moisture content of the compost material?

Materials & Methods

All composting experiments were performed in Saida wastewater treatment facility adjacent to the municipal solid waste site. This facility is on the sea side and is very close to Saida industrial city and Saineek river (Figure 1).

Figure 1: Site Location

Four vertical barrels of capacity 200 Liters fabricated from high density polyethylene (HDPE) cylindrical shape were used. The HDPE barrels have a diameter of 48 cm, height of 90 cm, capacity of 200 Liters and a weight of 5 Kilograms. For the purpose of this study, a total of 8 holes (1 centimeter diameter) were made at the approximate depths of 16, 38 and 64 cm from the top of each barrel. These holes were made using a drill to allow air movement and the drainage of excess moisture, thereby ensuring aerobic digestion inside the barrel. It can be considered as a variant of enclosed technology with small head space that enables the control of smaller volume of exhaust gases during the composting trial. The barrel has a conical-shaped plastic cover (with a metal belt) at the top to avoid infiltration of rain water and to protect the organic waste from the excess heat and sunlight.

Figure 2: The used barrels

When the two third of the barrel is filled with waste, the top of the barrel was covered with a black colored perforated nylon (to maintain temperature) then closed with barrel lid/cover and melt belt throughout the decomposition stages (24 days). The selected barrel type has multiple advantages from a practical point of view: 1- It provides insulation to maintain heating of compost material as self heating reactor. 2- It can be fully enclosed and requires little maintenance. 3- It can be easily moved around the facility as well as it enables easy mixing and turning of the compost materials.

A self-heating reactor may be defined as a reactor relying solely on microbial heat production to obtain process temperatures, and having no temperature control besides some external insulation (Mason, I.G. & Milke, M.W., 2005). Self-heating reactors have been extensively employed in composting research, especially for process evaluation and substrate compostability applications (Mohee, R. & Mudhoo, A., 2007). As such, they were used in the subsequent experimental trials. Fixed vertical perforated barrels are considered as variant of in-vessel composting systems or bioreactor. In-vessel composting requires less space, enables better control and high process efficiency than windrow composting (in open space). Yet, high temperatures which can result in greater bacterial and pathogen reductions (Franke-Whittle I.H. & Insam, 2013) might not be reached in in-vessel technologies compared to windrow composting.

Waste Types and Preparation

In order to decrease the pollution of the different types of accumulated waste, alternative composting of MSW with meat compost, fish wastes and banana plantation wastes were investigated in successive experimental trials.

In order to establish and maintain a microbial population in the compost pile, there must be moisture, oxygen, carbon to provide energy and nitrogen used for cell growth. In the selection of wastes, attention has been placed to earlier studies (Channey & David, 1991) and it has been recommended to compost fish wastes aerobically with a material that has a wide C/N ratio, which is fluffy enough to be well aerated to remove any malodors, which insulates heat; and which does not decompose fast enough to generate high heat. As such fish wastes are mixed in these experimental trials with different mix ratios of carbonaceous banana mulch wastes and municipal solid wastes to achieve a theoretical/ hypothetical carbon to nitrogen ratio goal within the range of 25:1 to 30:1. Fish wastes are rich in moisture and nitrogen. Banana mulch provides carbon, enables flow of air within its particles, absorbs odors and retains heat generated by the microbes.

Using banana mulch can help in keeping the integrity and porosity of the compost pile structure as well as promoting the aeration of the composting material pile. Composted meat does not have high carbon content as fresh mixed municipal solid waste and banana mulch; however, it was included in the initial experimental trials to help in keeping the integrity of the compost material. It is possible also that any slowly degradable carbon in the composted meat will not contribute to the generation of too much heat or high temperature profiles.

The experiment was conducted between April and December 2014. The experimental trials consist of aerobic composting of four waste materials: fishery house wastes, municipal solid waste, banana plantations wastes and composted meat. The composted meat is obtained from Beirut Slaughterhouse that has undergone an anaerobic digestion process. Shredded banana plantation wastes (stems/trunks and leaves) is secured by a local supplier that deals with the local fermenting facility in “Al Abbaseya” village , managed by the Association for the development of rural capacities (ADR). The mixed municipal solid waste is obtained from the Municipal Solid Waste Factory (MSWF) in Saida and was used as raw material in the composting trials. Fish wastes are obtained from the Saida Fishery Syndicate. Fish wastes are fresh chopped that has not underwent any type of composting.

a) Mulching of banana b) Fish wastes

c) During mixing d) Final product

Figure 3: Types of waste materials

All wastes were separately screened, sorted, manually shredded or chopped by experienced hired personnel at the wastewater treatment facility (Figure 3). After sorting and shredding, all the individual fresh /raw waste materials were placed in plastic boxes and mixed together as per the specified waste combinations for each experimental trial. To achieve waste material homogenization, initial water or moisture content was adjusted either by adding required amount of water or by drying the mixture under sun rays if there is excess moisture. Several attempts were conducted to get the right mixture of materials that will give the perfect recipe for composting. Mixing different types and sizes of organic materials provides a well-drained and arable compost pile. The more varied the materials going into the pile, the better chance of maintaining the proper C/N ratio and having an efficient decomposition. Table 1 shows the different mix ratios.

Table 1: Different Mix Ratios

	T.N%	T.C%	Barrel 1 (B1)				Barrel 2 (B2)				Barrel 3 (B3)				Barrel 4 (B4)			
			Weight (kg)	N	C	C/N	Weight (kg)	N	C	C/N	Weight (kg)	N	C	C/N	Weight (kg)	N	C	C/N
Fish waste	2.3	11.1	1	2.3	11.1		1	2.3	11.1		3	6.9	33.3		2	4.6	22.2	
Slaughterhouse waste	1.18	16.5	5	5.9	82.5		10	11.8	165		2	2.36	33		4	4.72	66	
Banana mulch	1.21	39.4	9	10.89	355		12	14.5	473		18	21.8	709		15	18.2	591	
Compost factory	1.23	31	10	12.3	310		2	2.46	62		2	2.46	62		4	4.92	124	
sum			25	31.39	758	24.15	25	31.1	711	22.87	25	33.5	838	25	25	32.4	803.2	24.79

Composting Process

Measuring the carbon and nitrogen content of each type of materials at was conducted in the Environment Core Laboratory of the American University of Beirut. Waste mix ratios were determined using the Carbon to Nitrogen formula developed by Tom Richard, Department of Agricultural and Biological Engineering, Cornell University.

$$R= \frac{Q1\ (C1\times(100\text{-}M1)+ Q2\ (C2\times(100\text{-}M2)+ Q3\ (C3\times(100\text{-}M3)}{Q1\ (C1\times(100\text{-}M1)+ Q2\ (C2\times(100\text{-}M2)+ Q3\ (C3\times(100\text{-}M3)}$$

Where:

R = C/N ratio of compost mixture

Qn = mass of material n ("as is", or "wet weight")

Cn = carbon (%) of material n

Nn = nitrogen (%) of material n

Mn = moisture content (%) of material n

Specified quantities of waste (based on selected mix ratios) for each experiment were initially mixed together on the ground then placed in the modified barrels (serving as bioreactors) all at once to ensure optimal C/N ratios and moisture contents throughout the pile. The modified barrels were filled to almost 2/3 height of mixed waste mixture. Black colored perforated nylon bags were placed on the top of the barrel to insulate against heat loss. The nylon bags were then covered by the barrel lid and metal belt to further avoid moisture penetration in rainy days. The compost material was left for a total of more than 24 of decomposition in barrel followed by 5-7 days piled up in open ground space and covered with nylon bags. Every two days, waste is taken out of the barrels and mixed on the ground then put back in the barrel and covered by nylon bags.

Moisture content

The decision to add water was based on subjective judgment and practical experience of the hired personnel. In case the mixing of the different wastes to compost resulted in a compost material with moist paste shape that remained intact when holding in hand palm, water is not needed. If the composting material is not intact, water is needed. Also, moisture content was monitored daily through laboratory tests (drying the sample for 24 hours in a 105-110ºC oven) during the experiments to control turnover frequency and water addition. Very low moisture content values would cause early dehydration during composting, which will stop the biological process, thus giving physically stable but biologically unstable composts. (Bertoldi, M.D., Vallini, G., & Pera, A., 1983; as cited in Liang, Das & McClendon, 2003; Makan et al., 2013).

Turning frequency

The composting material in all barrels was manually turned over at least twice a week during the first to 24th day of the incubation period.

Temperature

Temperature was monitored throughout the experiments to control turnover frequency and water addition. Major measurements were pH, moisture content, ash, elements (C, H, N, P, and K), bulk density and germination rate. Temperatures and ambient temperature were recorded as reference for turning pile frequency. During the composting process, temperature recordings were taken at two depths: 25 cm and 50 cm of top compost surface using Alla Brand handheld digital thermometer at the hours of 07:00 am and 04:00 pm.

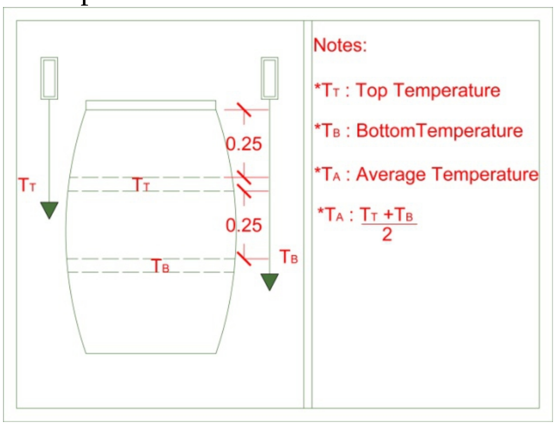


Figure 4: Temperature measurement locations

Two temperature recordings were taken per day. The average temperature 25cm from the top of the cover was 42.6ºC, while the average temperature 50cm from the top of the cover was 41.7ºC. The test of Homogeneity of Variances of temperature readings by microbial phase is not violated. The average & maximum recorded moisture contents were 79% & 56.65% respectively.

Odors

Rodent infestation and offensive odors were not noted in any of the composting trials.

Sampling and Analytical Methods

When the individual materials can no longer be identified and the pile resembles dark rich soil, the compost process is completed. It will smell sweet, woodsy, dark and earthy. It will crumble through your fingers. (Fares et al., 2011).

Due to the complexity of compost materials, the maturity assessment of the compost product generally requires a variety of indicators for integrated testing (Dong-lei, W., Ping, L., Yan-zhang, L., Guang-ming, T., & Mahmoud, Q., 2010).

Sampling was collected at day 28. Samples from mature compost material were taken in right to left manner in top surface, center, bottom and interior. Collected fresh compost product were mixed together in a bucket then a composite sample of around 500 grams was taken out using a grain shovel, placed in a zigzag bag and sent directly to the laboratory under ambient atmospheric conditions.

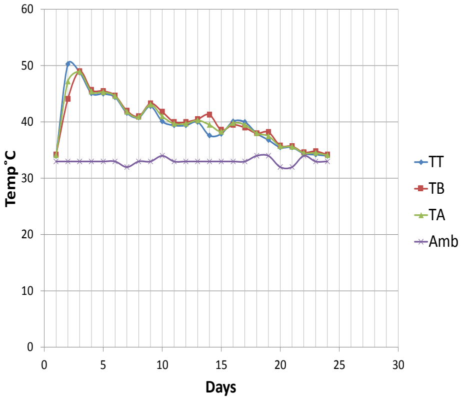
Fecal coliform and E-coli were determined using modified APHA Membrane Filtration 922 B, D method with limit of quantification of 10 colony forming units (cfu) per grams. Salmonella species were determined using ISO 6579 method (zero cfu /25 grs). pH was determined using APHA 4500-H method. Metal analysis was determined using ICP-MS (modified EPA 200-7/8). Total nitrogen and total carbon were measured using Thermo-Finnigan Flash EA 1112 Analyzer. The elemental composition of a compound is analyzed as weight percent of each element present in the compound. Flash EA 1112 analyzer operates according to the dynamic flash combustion (modified Dumas method) which produces complete combustion of the sample within a high temperature reactor, followed by an accurate and precise determination of the elemental gases produced using a thermal conductivity detector (TCD). A sample is weighed in a tin capsule. The sample enclosed in the tin capsule is introduced into the combustion reactor by an auto-sampler at a preset time. The sample is inserted in special furnace heated at 900 – 1000°C. An exact amount of pure oxygen is added to the system (at a precise time) to help in burning the organic or inorganic material, converting the sample into elemental (simple) gases. The reaction of oxygen with the tin capsule at elevated temperature generates an exothermic reaction which further raises the temperature to 1800 °C for few seconds. At this high temperature, both organic and inorganic substances are converted into elemental gases (N_2, NO_x, CO_2, and H_2O, SO_2) which after further reduction, are separated in a chromatographic column and finally detected by a highly sensitive thermal conductivity detector. The practical range of this determination is for nitrogen from 0.03% to 46% and for carbon from 0.04% to 72%.

Results and Discussions

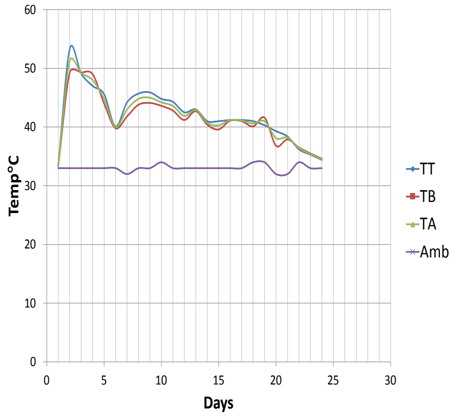
The monitoring of the pile is very important in order to ensure the optimum pile decomposition. The monitored factors are: temperature, moisture and odor (Fares et al., 2011)

Temperature

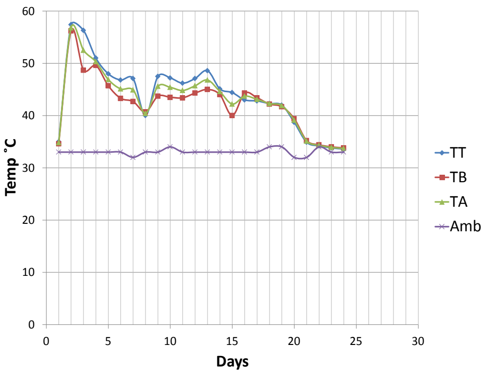
Because of the strong relationship of temperature with decomposition rate, temperature provides an important indicator of composting process efficiency (Haug RT., 1993; Ahn, H.K., Richard, T.L., & Choi, H. L., 2007). Temperature and humidity were controlled daily.



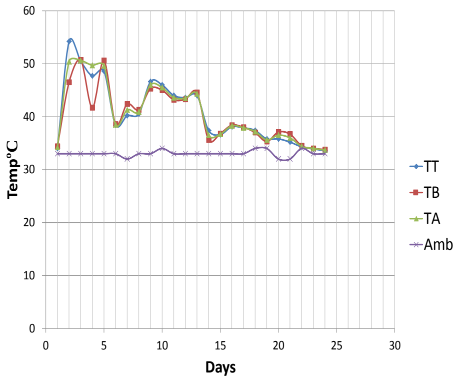
Barrel (1) B1



Barrel (2) B2



Barrel (3) B3



Barrel (4) B4

Figure 5: Ambient and measured temperatures for each pile

Figure 5 shows the ambient temperature and the measured temperatures within each pile during the composting process.(T_T=Temperatures at depth 25cm, T_B=Temperature at depth 50cm, T_A=Average temperature, Amb=Ambient temperature.)

After the initial filling of the bioreactors, a rapid increase in temperature was produced in all experiments, indicating a marked microbial activity. Temperatures rose rapidly to the thermophilic region (over 45°C) by day one, and reached 47.2°C, 51.3°C, 56.8°C & 50.4°C for B1,B2,B3&B4 respectively, which indicates that the temperature started with thermophilic temperatures (47.2 °C to 56.8 °C).

The composting piles temperature stayed over 40°C till day 20 for B2 & B3 mixtures, till day 18 for B1 & till day 14 for B4 mix. It is noticed that the temperature stayed above 40°C for a period of more than 14 days so it satisfied the regulatory requirement for the destruction of pathogens.

The temperatures during composting ranged between (34°C till 50.3°C), (33.5°C till 53.3°C) (33.6°C till 57.4°C) & (33.6°C till 54.2°C) for B1, B2, B3&B4 mixtures respectively. And as seen in Figure 5, temperature stayed over 40°C in all the experiments from the initial day.

The temperature has reached its maximum values of 50.3°C for B1 mix, T_T 53.3°C for B2 mix, T_T 57.4°C for B3 & T_T 54.2°C for B4 respectively. The broad range of optimum temperatures for composting process is from (45 to 65°C) (Sundberg, C., Smårs, S., & Jönsson, H., 2004). This allows a large variety of micro-organisms to participate in the process.

Moisture Content

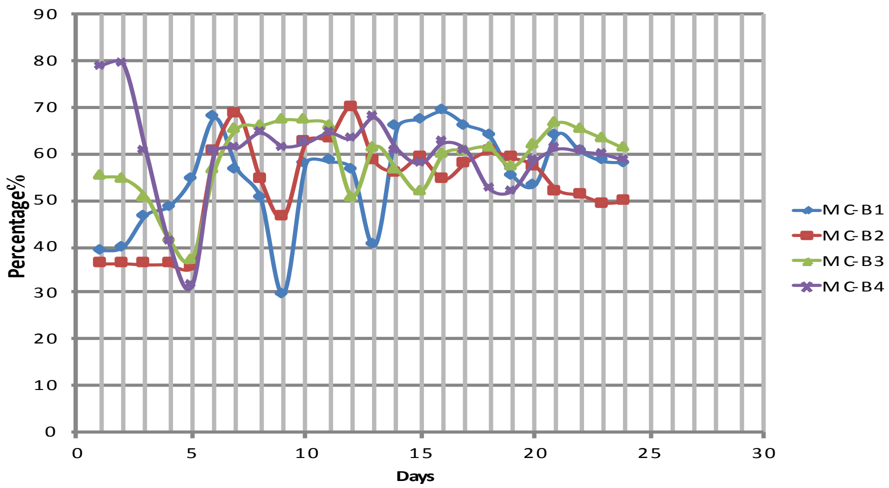


Figure 6: The variation of the moisture content for each pile during the composting process

The heat stored within the pile is dependent on moisture content (MC) of the composting material. Variations in the moisture content between

30% and 70% have an effect on the maximum temperature in the interior of the pile. For B1 at days (9 &13) MC dropped from (50.47 % to 29.73%), (56.66% to 40.13%), B2 at day (13) MC dropped from (69.91% to 58.26%), B3 at days (5 &15) MC dropped from (41.48% to 37.19 %),(56.35% to 51.77 %) & B4 at days (5 &15) MC dropped from (40.71% to 31.45%), (60.83 % to 57.83%) and water is added for B1, B2, B3 & B4 mix at days (9,13),(5,9),(5),(5) by (5.07,2.47), (3.62,0.93),(3.2), (4.64) respectively (Figure 6).

There was a significant correlation between the moisture content and the temperature distribution within the pile. For B2 by days (8&13), MC decreased (68.8% to 54.41%) & (69.91% to 58.26%) so (T_T=45.7°C > T_B=43.8°C) (T_T= 43°C > T_B= 42.7 °C). For B3 by days (5&12), MC decreased (41.48 % to 37.19%) & (66% to 50.72 %) so (T_T=48°C > T_B= 45.7°C) (T_T= 47.1°C > T_B=44.3°C). This means that when the moisture content is high, the temperature near the surface will be higher, and the high temperature zone will extend nearer to the surface than when the moisture content is low.

Character of the compost material

B1,B2,B3,B4 mixtures have different types of wastes with different weights mixture for experience: Fish (1,1,3,2)Kg, Banana (9,12,18,15)Kg, Meat (5,10,2,4)Kg, MSW compost (10,2,2,4)Kg respectively, as shown in Table 1. Temperature reached different maximum values for B1,B2,B3,B4 as follows (50.3°C, 53.3°C, 57.4°C & 54.2°C) respectively and as shown in figure.7 , observing that B3&B4 with higher weights of fish wastes had maximum temperature values. Concluding that temperature varies according to character of the compost.

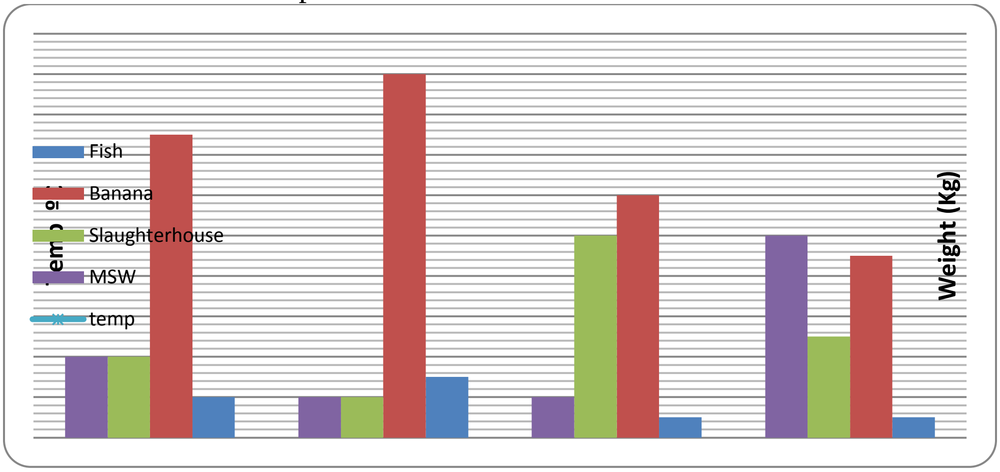


Figure 7: The weight of each type of wastes and the maximum temperature in each barrel

Turning for Aeration

A drop in temperature in the compost pile before the material is stabilized was observed at B1, B2, B3 & B4 mixtures for days (8,15),(6,15),(8,15),(6,15) respectively which indicates that the pile is becoming anaerobic The drop in compost pile temperature is not a sign that composting is complete, but rather an indication that the compost pile is entering another phase of the composting process and should be aerated or increasing moisture content is needed.

There were slight increases in pile temperatures immediately after each turning operation of aeration for B1 at day 8 from (40.9°C to 43.1°C) & day 15 from (38.3°C to 39.8°C), for B2 at day 6 from (40°C to 43°C) & day 15 from (40.3 °C to 41.2°C), for B3 at day 8 from (40.4°C to 45.6°C) & day 15 from (42.2°C to 43.7 °C) & for B4 at day 6 from (38.5°C to 41.3°C) & day 15 from (36.7°C to 38.3°C) .

Physical properties for the produced sampling

The compost product tended to have uniform dark crumbly appearance (dark brown to black) with little or non-recognizable pieces/components of used waste such banana leaves, soil like or earthy smell without obnoxious odor or with no distinctive smells to suggest instability (Figure 8).

B1: Tended to have red to golden color with aggregates.

B2: tended to have dark color with aggregates and moist.

B3 and B4: less aggregates than B1, B2 but with a lighter color.

Figure 8: Color differences between the mature compost

Chemical Properties for the product sampling

The results for testing the samples in AUB labs for each barrel compost showed that it reaches its maturity after 28 days (C/N results around 10 ratios) as shown in Table 2.

Table 2: The results from the AUB lab for the four samples

Samples No.	Job number	Date		Composting days	Chemical and elemental analysis				
					pH	T.C%	T.O.C%	T.N%	C/N ratio
B1	483	start	15\8\2014	28	46.3	23.5	25.3	1.87	12.567
		ends	11/9/2014						
B2	483	start	15\8\2014	28	52.2	22.7	18.6	1.92	11.823
		ends	11/9/2014						
B3	483	start	15\8\2014	28	50.6	25.5	25.8	2.2	11.591
		ends	11/9/2014						
B4	483	start	15\8\2014	28	47.1	25.1	25.7	2	12.55
		ends	11/9/2014						

Limitations of the study

These experimental trials in modified barrels are only pilot trials. Trial conditions (temperature and moisture profiles) might be achieved in full scale composting conditions (Mason & Milke, 2005). The different components of waste might change over time especially the MSW affecting reproducibility of results in these experiments trials.

Conclusion

All biological processes as well as reaction rate can be influenced by various factors during composting. Moisture content and temperature are among those factors which should be controlled and monitored carefully in the course of composting. In all experiments, after the initial filling of barrels bioreactors, a rapid increase in temperature was produced, indicating a marked microbial activity. Temperatures stayed above 40°C for a period of more than 14 days. It started with thermophilic temperatures (47 °C to 56.8 °C). The drop in compost pile temperature is not a sign that composting is complete, but rather an indication that the compost pile is entering another phase of the composting process, or might suggest anaerobic conditions within the composting material and suggests the need for aeration, but it is also a sign that the pile should be turned over and aerated or water is needed. After adding water or turning, the temperature will rise rapidly again and then experiences a gradual decline to ambient temperature range where the compost process can be considered nearly complete.

The temperature curve for different parts of the pile varies somewhat with the size of the pile, the ambient temperature, the moisture content, the degree of aeration, and the character of the composting material.

There was a significant correlation between the moisture content and the temperature distribution within the pile. This means that when the moisture content is high, the temperature near the surface will be higher, and the high temperature zone will extend nearer to the surface than when the moisture content is low.

Other combinations with higher C/N ratios will be tried in future studies to see if higher composting temperature readings can be obtained.

References:

Ahn, H.K., Richard, T.L., & Choi, H. L. (2007). Mass and thermal balance during composting of poultry manure—Wood shavings mixture at different aeration rates, *Process Biochemistry Journal*. 42 215-223. www.elsevier.com/locate/procbio

Bei-Dou, Xia,b, Xiao-Song, He, Zi-Min, Wei, Yong-Hai, Jiang, Ming-Xiao, Li, Dan, Li, Ye Lid, & Qiu-Ling Dang. (2012). Effect of inoculation methods on the composting efficiency of municipal solid wastes, *Chemosphere Journal* 88 744–750, www.elsevier.com/locate/chemosphere=

Bertoldi, M.D., Vallini, G., & Pera, A. (1983). The biology of composting, *Res*. 1, 157–176.

Chaney & David. (1991). Marine By-Products as Fertilizers, *the Juneau Economic Development Council*, (Vol. 2, No. 1)2121

Chen, L., Moore, A., & de Haro-Marti, M. D. (2012). Dairy Compost Production and Use in Idaho: *On-Farm Composting Management*, CIS 1190

Dong-lei, W., Ping, L., Yan-zhang, L., Guang-ming, T., & Mahmoud, Q. (2010). Nitrogen transformations during co-composting of herbal residues, spent mushroom, *J Zhejiang Univ-Sci B (Biomed & Biotechnol) 11*(7):497-505.

Ekinci, K., Keener, H.M., & Elwell, D.L. (2002). Composting short paper fiber with broiler litter and additives II: evaluation and optimization of decomposition rate versus mixing ratio, *Compost Science and Utilization Journal*, 10:16–28

Fares, R., Fares, E., & De-Nardo, F. (2011). Composting from A to Z, BEIRUT.

Fourti, O., Jedidi, N., & Hassen, A.M. (2011). Comparison of methods for evaluating stability and maturity of co-composting of municipal solid wastes and sewage sludge in semi-arid pedo-climatic condition, Centre des Recherches et des Technologies des Eaux, Laboratoire Traitement et Recyclage, Cité Mahrajène, Tunisie, 124-135.

Franke-Whittle I.H., & Insam. (2013). Treatment alternatives of slaughterhouse wastes, and their effect on the inactivation of different pathogens, *Microbiology journal*, 39(2): 139-151.

Ghosh, S., Viéitez, E.R., Liu, T., & Kato, Y. (1997). Biogasification of solid waste by two phase anaerobic fermentation. In: Proceedings of the Third Biomass Conference of the Americas. Pergamon Press.

Haug, R. T. (1993). The Practical Handbook of Compost Engineering. Lewis Publishers:USA.

Hog Producers Sustainable Farming Group. (1996). Composting Factsheet Series, Pacific Agricultural Research Centre (Agassiz), Agriculture and Agri-Food Canada; and *Resource Management Branch*, BCMA, 382.500-15

Liang, C., Das K.C., & McClendon, R.W. (2003). The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend, *Bioresource Technology* 86 131–137.

Madigan, M.T., Martinko, J.M., & Parker, J. (2000). Brock biology of microorganisms. *Upper Saddle River, NJ: Prentice Hall,* Madigan, Martinko and Parker 2000 is a book cited by many studies.

Makan, A.H., Assobhei, O., & Mountadar, M. (2013). Effect of initial moisture content on the in-vessel composting under air pressure of organic fraction of municipal solid wastes in Morocco. *Iranian Journal of Enviroment Health Sciences & Engineering*, 10:3

Mason, I.G., & Milke, M.W. (2005). Physical modelling of the composting environment: *A review. Part 1: Reactor systems. Waste Management Journal*, 25, 481–500.

Michel, F.C., Forney, L.J., Huang, A.J.F., Drew, S., Czu Prenski, M., Lindeberg J.D., & Reddy, C.A. (1996). Effects of turning frequency, leaves to grass mix ratio and windrow vs pile configuration on the composting of yard trimmings. Compost Science and Utilization 4: 26-43.

Mohee, R., & Mudhoo, A. (2007). Analysis of physical properties of an in-vessel composting matrix. Powder Technol., 155(1), 92- 99.

Ogunwande, G. A., Osunade, J. A., & Ogunjimi, L. A. (2008). Effects of Carbon to Nitrogen Ratio and Turning Frequency on Composting of Chicken Litter in Turned-Windrow Piles, *CIGR Ejournal*. Manuscript EE 07 016. Vol. X.

Sundberg, C., Smårs, S., & Jönsson, H. (2004). Low pH as an inhibiting factor in the transition from mesophilic to thermophilic phase in composting. *Bioresource Technology Journal* 95 (2), 145-150.

Sweep-Net. (2014). Country report on the solid waste management in Lebanon.
http://www.sweepnet.org/sites/default/files/LEBANON%20RA%20ANG%20WEB.pdf

Tiquia, S.M. (1996). Further composting of pig manure disposed from the pig-on-litter (POL) system in Hong Kong. Ph.D. Thesis. The University of Hong Kong Pokfulam Road, Hong Kong.

Trautmann, N.M., Richard, T., & Krasny, M.E. (1996). Composting in Schools. http://www.cfe.cornell.edu/compost/schools.html

Waszkielis, K.M., Wronowski, R. Chlebus, W., Bialobrzewski, I., Dach, J., Pilarski, K., & Jancazak, D. (2013). The effect of temperature, composition and phase of the composting process on the thermal conductivity of the substrate. *DOI: 10.1016/j.ecoleng*.09.024

Waszkielis, K.M., Wronowski, R. Chlebus, W., Bialobrzewski, I., Dach , J., Pilarski, K., & Jancazak, D. (2013). The effect of temperature, composition and phase of the composting process on the thermal conductivity of the substrate, *Ecological Engineering Journal*, 61 354–357.