

Evaluation Process of Municipal Solid Waste Composting for Methane Gas Generation

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Abstract

One of the most versatile and remunerative techniques for handling biodegradable solid wastes is composting. A large variety of such wastes of plant, animal, and synthetic origins can be gainfully composted, at scales varying from a household bin to a large industry. Compost also has an inexhaustible market as a soil conditioner and fertilizer. Apart from being a source of nitrogen, phosphorus, potassium, and other nutrients for plants, compost is also believed to suppress soil-borne diseases in plants. These virtues make composting an ideal option for processing the enormous quantities of biodegradable solid wastes that are generated in ever increasing quantities. An in-vessel composting system was investigated in this survey. in a 20 L composting tank using 5 kg of a simulated food waste mixture including potatoes, carrots, beef, steamed rice, leaves, and garden soil as the composting raw material. Physical and chemical parameters were measured throughout the composting period. The result proved that anaerobic in-vessel composting can process large amounts of wastes reducing starting weights to 70%.

Keywords: Municipal Solid Waste; Composting; Fertilizer; Methane Gas.

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1. Introduction

The term municipal solid waste (MSW) describes the stream of solid waste generated by households, commercial establishments, industries and institutions. MSW consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint and batteries. It does not include medical, commercial and industrial hazardous or radioactive wastes, which must be treated separately (**Farrel and Jones, 2009**).

Unexploited materials resulting from human and animal activities, which may be in solid, liquid, or gaseous form, are generally called waste. With the rapid social and economic development and degree of industrialization, the amount of waste generation has gradually increased. In general, the greater the economic prosperity and the higher the percentage of the urban population, the greater the waste (**Rajaratne & Panagoda Arachchige Kumara 2014**). Municipal solid waste in Baghdad Governorate mainly includes solid waste released from homes, restaurants, shops, factories and farms. The accumulation of this waste has led to the creation of a clear environmental problem that has clearly become apparent in the streets and roads of the city and has led to the distortion of its beautiful image.

What causes concern is the lack of sound remedial methods and technologies to solve this problem at the present time, despite their availability in other countries, because their application in the city requires capabilities that are not available under the influence of the circumstances that the country is currently going through, as the methods for disposing of municipal solid waste remain limited to simple methods such as open burning of waste in collection areas or throwing it in landfills that are not equipped with means to protect the surrounding environment from its spread, and this harms the individual and the environment together. To reduce the burden of environmental problems on the city of Baghdad, the idea of this research was directed to include

recycling some components of municipal solid waste by performing anaerobic digestion process. The production of MSW is an inevitable consequence of today's consumer society. Finding safe, sustainable and cost-effective alternatives to the disposal of MSW in landfills represents a major challenge to the waste management industry.

Recycling and composting are seen as attractive waste management options, providing that there are few negative effects on the environment, however, we are still a long way from diverting MSW into these processes. For example, in the USA only 33% of the MSW generated is composted and recycled with the rest either being landfilled (54% of total) or combusted for energy recovery (13% of total) (EPA, 2008). It is known that the largest fraction of municipal wastes is organic in composition. These organic wastes can be classified according to their biodegradability:

- 1) Water-soluble constituents, including sugars, starches, amino acids, proteins and various organic acids.
- 2) Hemicellulose and cellulose, which are condensation products of five and six carbon sugars, and glucose.
- 3) Fats, oils and waxes, which are esters of alcohols and higher fatty acids.
- 4) Lignin, a material present mainly in some paper products and lignocelluloses, a combination of lignin and cellulose.

Biogas typically refers to a gas produced by the biological breakdown of organic matter in the absence of oxygen and it is considered a type of biofuel. Gas is produced from the anaerobic digestion or fermentation of biodegradable materials (biomass, manure, sewage, solid waste). The following table shows the typical composting of biogas.

Table 1: Typical composting of biogas

Matter	%
CH ₄	50-57
CO ₂	25-50
N ₂	0-10
H ₂	0-1
H ₂ S	0-3
O ₂	0-2

The objective of the current study is to:

- 1) Preparation of organic fertilizer
- 2) Detection of methane gas as a biofuel
- 3) Municipal solid waste weight reduction

2. Materials and Methods

2.1. Manufacturing composting system

The digesting cell started in November till December 2025. Day 1 is defined as November 5/2025; the end of day 27 is defined as December 2/2025. The digester cell was filled with 5Kg of different Domestic waste and 50% water, that is 2.5 L of Water. The digester cell was operated anaerobically.

1. The composting system consisted of a drum composter of (20 L) capacity. (**As shown in Figures 1 and 2).**



Figure 1: An in-vessel composting reactor.



Figure 2: The in-vessel composting reactor with raw materials.

2. A Temperature Thermometer was installed in the reactor to measure temperature during the process, as shown in **Figure 3**.



Figure 3: Thermometer installation.

3. An opening valve was installed at the top of the reactor to collect evolving gases as shown in **figure 4**.



Figure 4: An opening valve.

2.2. Raw materials

1. Bio-degradable (organic) waste was segregated at the household level to be used as feed material for the compost tank.
2. The Food Waste (FW) was collected from the daily normal kitchen waste. FW was mainly food remaining in plates after lunch consisting of potatoes, carrots, beef, steamed rice, cooked soybean. Leaves were added as a bulking agent and as a source of nitrogen, while garden soil was added to provide more desired microorganisms.
3. All the raw materials were minced into pieces of <0.005 m in diameter using a food processor (Brown, China), and mixed well before the composting reaction began. Leaves were added as a bulking agent and as a source of nitrogen, while garden soil was added to provide more desired microorganisms [Lin et al., 2008]. Chicken dung was added as a rich source of nitrogen. The use of soil in a compost pile is optional, however, in most cases, organic yard wastes such as grass clippings or leaves contain enough microorganisms to cause decomposition [Bass et al., 1994].
4. **Figure 5** indicates raw materials used in the reactor (a: potatoes, b: carrots, c: beef, d: steamed rice, e: leaves, and f: garden soil).



Figure 5: Raw materials used in the reactor (a: potatoes, b: carrots, c: beef, d: steamed rice, e: leaves, and f: garden soil)

2.3. Equipment and reagents used

Reagents used in this study were distilled water, Vario AM tube test reagent set LR (Lovibond/ Germany), Vario Ammonia Cyanurate F5 ml (Lovibond/ Germany), Vario Ammonia Salicylate F5 ml (Lovibond/ Germany), Phosphate No.1 LR tablet (Lovibond/ Germany) and Phosphate No.2 LR tablet (Lovibond/ Germany). **Table 2** lists equipment used in compost analysis.

Table 2|: Equipment used in compost analysis.

#	Function	Type	Origin
1	Multi Direct Photometer for multi-parameter analyses (water test Equipment)	Lovibond	Germany
2	pH meter	Inolab WTW series	Germany
3	Centrifuge	PLC series	Taiwan
4	Analytical balance accurate to 0.001g	(Sartorius BL210S)	Germany
5	drying oven	Hamilton	USA
6	distilled water generator	GFL	Germany

2.4. The process of composting

1. The moisture content of the feedstock is important to ensure reaction continuity. The difference between required and available moisture contents was adjusted by sprinkling tap water on the surface of the composting mixture introduced through the upper valve, and mixing the content thoroughly by rolling the reactor. pH, and temperature were taken at regular intervals throughout the composting period. In addition, Nitrogen, and Phosphorous content, were

carried out for examining the quality of the composted product for each run. Two replicates were conducted.

2. At the end of composting the formed end-product was collected from the bottom layer by shearing the bottom of the vessel bioreactor. The collected compost was then mixed sufficiently and spread outside the bioreactor to form a pile. Two representative samples were collected from different points within the pile. The final sample was formed after mixing the two samples together to form a homogeneous material. From this homogeneous material two samples were selected from which a series of parameters were evaluated [Rihani et al., 2010]. The average value of each parameter was calculated from the average value of the two separate samples.

2.5. Analytical Procedure

The standard methods followed for testing and evaluating compost and composting feedstock material were determined according to the test method Composting Council [TMECC, 2002]. Laboratory analyses included measurements of moisture content, pH, water soluble nitrogen as N and in NH_4 and NH_3 , phosphorous as P and in P_2O_5 and PO_4^{-3} .

1. Samples of about 50 g were collected and dried in an oven at 105 °C for 24 h; the loss of weight was taken as the moisture content.
2. For measuring the compost pH, raw samples were mixed with deionized water at a weight ratio of 1:10. The mixture was shaken for 1 h and then allowed to settle under quiescent conditions; pH of the clear supernatant was measured in the top clear liquid with a pH meter.
3. Nitrogen in NH_3 and NH_4 and phosphorus as P in P_2O_5 and PO_4^{-3} were analyzed using Multi Direct Photometer for multi-parameter analyses (water test Equipment). All tests were summarized in **Table 3**.

Table 3: Tests summary undertaken in this study.

Tested item	Methods
Moisture content	Determined by drying 50 g of sample at 105 °C for 24 h. Moisture content is expressed on a wet weight basis (mass water/wet mass).
N ₂ , NO ₃ , NH ₂	Multi-direct
pH	Measured by dissolving 10 g of compost sample (<1 mm) in 100 mL of distilled water, under stirring at 150 rpm for 1h in a horizontal shaker at room temperature using a bench top pH/temperature meter (Inolab WTW series).
Total phosphorous as P ₂ O ₅	The determination of phosphorous (P ₂ O ₅) by using the UV-Visible spectrophotometer

Biogas formed was measured by “liquid displacement method”. The schematic diagram of experimental laboratory set up as shown in **Figure 6**.

1. Methane content in the generated biogas was measured by a liquid displacement system.
2. The biogas is a mixture of carbon dioxide, methane, hydrogen sulphide and nitrogen gas [Ludington, 2005] and [Kaparaju et al., 2008]. The amount of hydrogen sulphide is less than 1% [Lettinga, et al., 1988]. The amount of nitrogen is difficult to estimate although it can be measured with gas chromatography (GC). [Juanga et al., 2005], [Bonn, 2008] and [Nadhem, 2009].

In liquid displacement method the carbon dioxide and methane composition of the biogas measured by taking a 50 ml of biogas sample in a large syringe and pushing the biogas slowly

(over 10 minutes) through a 0.5L glass bottle liquid displacement system containing a strong solution of NaOH (4 g/l). As the biogas passes through this high pH solution, the CO₂ of the biogas is converted to carbonate and absorbed into the liquid; only the methane passes through the solution and an equivalent volume of alkaline solution is pushed out of the glass bottle. The volume of alkaline solution that pours out of the bottle divided by the volume of biogas injected is equal to the fraction of methane in the biogas [Van Lier, 1997] and [Nadhem, 2009].

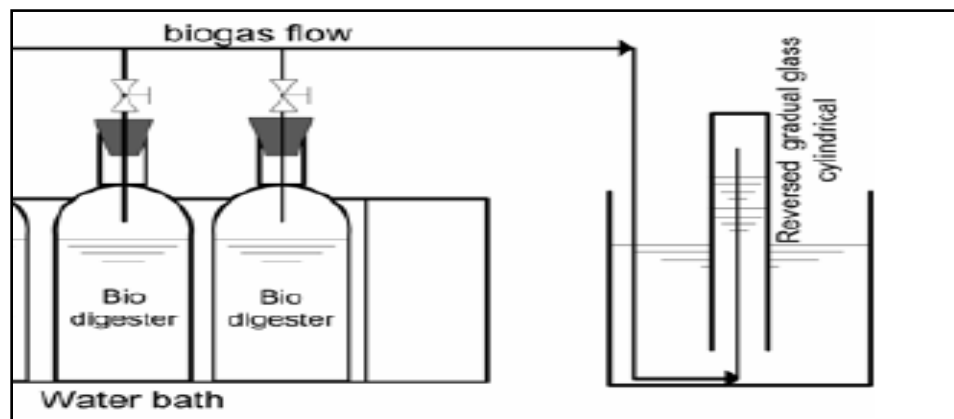


Figure 6: Schematic diagram of two laboratory batch assessment of anaerobic digestion

3. Results and discussion

3.1. Temperature profiles

Temperature is the easiest parameter to assess as well as the most commonly used parameter to describe the evolution and state of composting processes [Keener et al. 2000]. The temperature of the composting mixture in run rose soon after beginning the experiment and reached 48 ± 2 °C within 10 to 15 days (Figure 7). The variations of composting temperature followed the typical patterns of anaerobic composting reactions. The temperature increased to the thermophilic level (above 50 °C) within 15 to 20 days, which indicated that the indigenous microorganisms could easily utilize the organic materials in the amended food waste.

The thermophilic phase lasted more than 20 days, and then the temperature slowly dropped to a normal level. Although rapid raise in temperatures corresponds to natural self-heating of the organic mixture, the initial mixtures largely influence the temperature increase via their nutrient balance and their content of easily biodegradable organic fractions. This increase in temperature with time is consistent with previous reports [Benson et al., 2007] and [Barlaz et al., 2010].

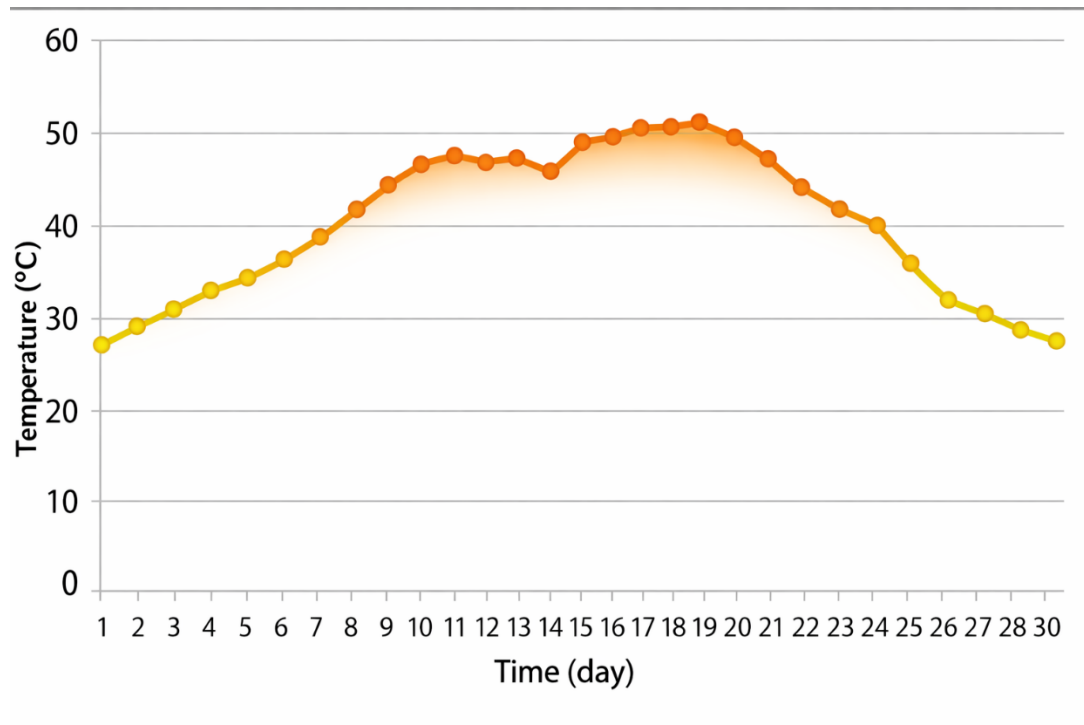


Figure 7: Temperature profiles for anaerobic composting processes in-vessel.

3.2. The changes in pH

The changes of pH are shown in **Figure 8**. The pH had its lowest value at day 4. The final pH level in the vessel reactor was about 7.0.

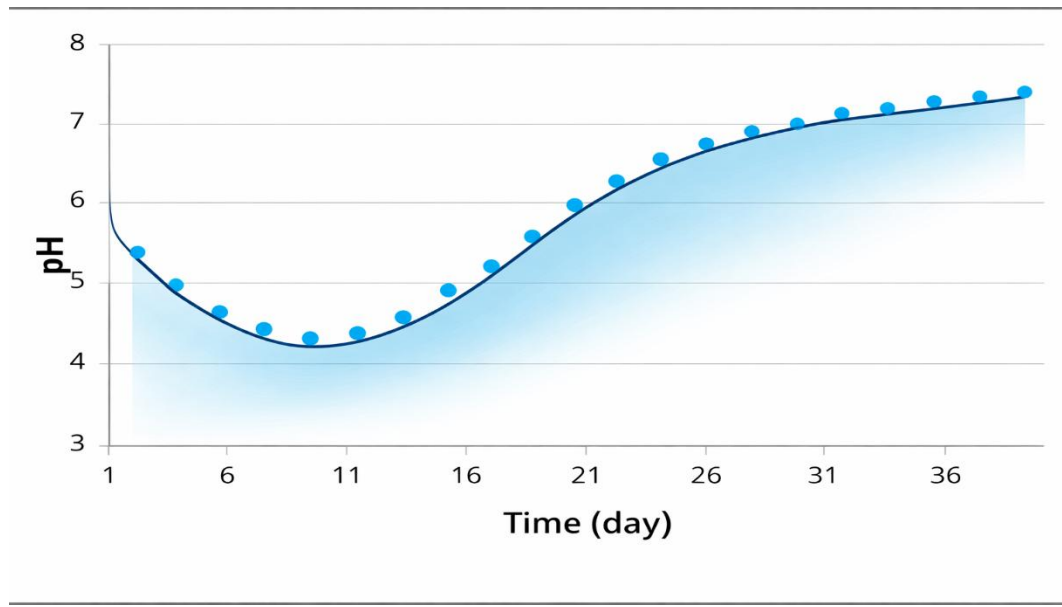


Figure 8: pH profiles of the composting processes in-vessel.

3.3. Moisture content

The moisture content tended to decrease due to the combination of high temperature levels and anaerobic state during the thermophilic phase, and was controlled by applying water, humidifying the compost mass. The initial moisture content (63.5 % of wet weight) was reduced to reach an average moisture content of 40 remaining above the minimum moisture content of 40% suggested by [Haug, 1993]; [Liang et al., 2003] and [Petric et al., 2009] for optimal composting conditions. After that, no significant changes in parameters have been observed. According to Sadaka and Engler [Sadaka and Engler, 2003], water content is one of very important parameter affecting digestion of solid wastes. There are two main reason i.e. (a) Water enables the movement and growth of bacteria facilitating the dissolution and transport of nutrient; and (b) water reduces the limitation of mass transfer of non-homogenous or particulate substrate.

3.4. Evolution of compost characteristics

3.4.1. matter loss

The compost turned out to be 1.5 kg out of 5kg. Thus, the mass reduction is $(5.0 - 1.5/5.0)*100\% = 70\%$

3.4.2. Compost quality

For a product to be marketable, it must meet the requirements of the user. The following criteria have been found to be of particular importance to compare with commercial compost [Knox and Robinson, 2007] and [Hargreaves et al., 2008]. To evaluate the quality of the final compost, the electrical conductivity content index and heavy metal content of the product quality is generally considered to be the most important of the factors that affect the validity of compost. Quality of the product is a function of the physical, chemical, and biological characteristics [Inbar, et al., 1993]. The concentration of nitrogen was relatively low in final compost suggesting that nitrogen was lost during composting upon opening the digesters. Losses of nitrogen in this composting process were governed mainly by volatilization of ammonia due to high pH and temperatures values of the substrate.

Nitrogen was 1.23 mg/l as NH_4 , 0.95 mg/l as N, and 1.16 mg/l as NH_3 which can be considered as an indicator of a high degree of compost stabilization [Abu el wafa et al., 2008] and [Haroun et al., 2009]. Phosphorus as P_2O_5 reached 1.65 mg/l, 0.72 mg/l as P and 2.21 mg/l as PO_4 during compost maturation, which are higher than the recommended levels. **Table 4** presents the findings of this study, in which a comparison was made between MSW composts with respect to their physical and chemical characteristics.

Table 4: Physical and chemical properties of the compost produced in this study and the compost quality standards.

Characteristic	Compost of this study	Permissible Concentrations of Trace Elements in Compost Additions to Soil	
		Washington State, USA*	British Columbia State, Canada**
Appearance	1) dark color 2) Uniform particle size 3) Pleasant earthy odor 4) Absence of clumps 5) No visually identifiable contaminants	--	--
Moisture content <50%(for ease of transport)		30-60 %	45%
Available nutrients (NP)mg/l	0.95 N 1.65 P ₂ O ₅	3.6 N 2.57 P ₂ O ₅	2.6 N 1.5 P ₂ O ₅
pH	7.2	6.5- 8.0	6.5-8.0

*[Cal Recovery System, 1990], **[British Columbia, 1993]

3.4.3. Gas production and composition

The largest fraction of gas had probably been lost from the compost by volatilization. It was proven by observing high temperatures during composting period. The ammonium ion is volatilized and the resulting ammonia gas is lost during the aeration of the composting mass. The

composition of methane produced was equals 68% of the total gas produced. Biogas production is very slow at the beginning and at the end period of observation. This is predicted due to the biogas production rate in the digester is directly corresponds to specific growth rate of methanogenic bacteria in the bio digester [Nopharatana et al., 2007]. After 23 days observation, biogas production tends to decrease and this is predicted due to stationary phase of microbial growth The rate of methane gas produced agreed with other results of researchers [Lo et al., 1984]; [Luengo and Alvarez, 1988] and [Carneiro et al., 2008].

4. Conclusions

The main findings of the current research are:

1. The 5 kg turns to be 1.5 kg and indicating a successful reduction in solid waste quantities.
2. The length of the composting process was 27 days in the vessel and two weeks of curing.
3. In-vessel composting produces very little odor and minimal leachate. Conversion of organic material to compost took few weeks. Once the compost comes out of the vessel, however, it required a few more weeks for the microbial activity to stabilize and to cool the pile.
4. The temperature of the composting mixture in both runs rose soon after beginning the experiment and reached 48 ± 2 °C within 10 to 15 days
5. The final pH levels was around 7.0
6. The initial moisture content (63.5 % of wet weight) was reduced in all experiments to reach an average moisture content of 40%.
7. Mean **loss of dry matter** of 70 %
8. Nitrates as ammonia reached at 1.16 mg/l on the 27 day of the process, during compost maturation, which can be considered as an indicator of a high degree of compost stabilization.

9. Phosphorous as P_2O_5 was 1.65 mg/l on the 27 day of the process, which coincide with recommended level of the USA and British compost quality standard.

10. Biogas production is very slow at the beginning and at the end period of observation.

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