Organic Solid Waste in Vessel Composting System

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ABSTRACT

Low-level microbial activity due to the production of organic acids is a recognized problem during the initial phase of food waste composting. Increasing such activity levels by adjusting the pH values during the initial composting phase is the primary objective to be investigated. In this study, sodium acetate (NaoAc) was introduced as an amendment to an in-vessel composting system. NaoAc was added when the pH of the compost mixture reached a low level (pH < 5), the addition increased pH to 5.8. This had a positive effect on the degradation of organic materials i.e. the formation of methane gas compared to the results without NaoAc addition.

The results also proved that anaerobic-aerobic in-vessel composting could reduce the large amounts of wastes by 33% -30%.

However the addition of NaoAc had no significant influence on temperature profile, bulk density, electric conductivity (EC), moisture contents, Nitrogen, phosphorus, potassium (NPK) and heavy metals (Cu, Cd, Ni, Pb) during the composting process, in fact heavy metals and (NPK) were below the maximum permissible levels of the Japanese organic farming and the USDA and US Compost Council standards .

To assess the performance of the composting process, two small-scale digesters were used with fixed temperature. Maximum methane content of 68±1% and 75±1% by volume of the generated biogas was achieved in the run without and with NaoAc respectively.

The germination index was 84.8 % which proved that the stabilized compost obtained in this research is of the “mature" kind and it is satisfactory for agricultural use according to the organic farming recommended by the Japanese Ministry of Agriculture, Forestry and Fisheries, and USDA and US Compost Council standards.

Keywords: compost, sodium acetate, biogas, mature compost, germination test, solid waste management.

تدبيل النفايات الصلبة العضوية باستخدام النظام المغلق

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الخلاصة

ان ظاهرة انخفاض الفعالية الميكروبية بسبب تولد الاحماض العضوية خلال المرحلة الاولية من عملية هضم المواد العضوية في الفضلات الصلبة سواء كانت هوائية اولاهوائية لهي ظاهرة شائعة ومعروفة ولطالما عانت منها التفاعلات اللاهوائية

للمادة العضوية . ولذلك كان الهدف الاساسي لهذا البحث زيادة الفعالية البكتيرية لهضم النفايات العضوية عن طريق ايجاد طريقة لضبط حامضية وسط التفاعل . فتم استعمال خلات الصوديوم كمادة معدلة الى وسط التفاعل، على ان يتم اضافتها بمجرد هبوط الحامضية لما دون 5 ومن ثم دراسة ما لهذه الاضافة من تاثير على الفعالية البكتيرية من خلال انتاج غاز الميثان ونوعية السماد العضوي الناتج . ادت اضافة خلات الصوديوم الى ارتفاع في درجة الحامضية الى 5.8 وقد كانت لهذه الزيادة اثرها الايجابي على تحلل المادة العضوية اي تولد كمية اضافية من غاز الميثان بكمية محسوسة قياسا الى تلك الكمية المنتجة بدون اضافة خلات الصوديوم.

كذلك اثبتت النتائج ان الهضم اللاهوائي –الهوائي في حيز محدود قادر على هضم كميات كبيرة من النفايات مختصرا حجمها الى 30-33% من حجمها الابتدائي. كما أثبتت النتائج ان اضافة خلات الصوديوم لم تكن ذات تاثير ملحوض على شكل مخطط الحرارة (Temperature Profile) ولا على الكثافة الكلية و التوصيلية الكهربائية ومحتوى الرطوبة وتراكيز النتروجين والفسفور والبوتاسيوم (NPK) والعناصر الثقيلة (Cu, Cd, Ni, Pb) اثناء عملية الهضم ، بل ان تراكيز العناصر الثقيلة وال (NPK) بقيت دون المحدادت الامريكية والبريطانية لمواصفات النوعية للسماد العضوي.

كذلك تم اعداد مفاعلات بايولوجية مصغرة وبحجم 1لتر في المختبر وبتثبيت الظروف المناسبة لتسهيل عملية التخمر لانتاج غاز الميثان . بلغت اعلى نسبة حجمية في انتاج غاز الميثان 68±1% و 75±1% للنمط بدون اضافة خلات الصوديوم كبفر وللنمط مع الاضافة على التوالي . واخيرا بلغت النسبة المئوية للانبات 84.8 مشيرة الى ان نوعية السماد العضوي المنتج في هذه الدراسة يمكن ان يصنف تحت الصنف الناضج "Mature" وهو مناسب للانبات والزراعة وحسب توصيات وزارةِ الزراعة والغابات والثروات السمكيةِ اليابانيةِ للزراعة العضوية وكذلك حسب معايير النوعية الأمريكية للسماد العضوي .

الكلمات الرئيسية

سماد عضوي ، خلات الصوديوم ، الغاز العضوي ، سماد عضوي ناضج ، اختبار الاستنبات، ادارة النفايات الصلبة .

1. INTRODUCTION

Food waste is the largest component of municipal waste streams after the recyclables are separated. It is associated with high disposal costs, **McDonnell, 1999**. Composting is a promising alternative treatment method for food waste that enables the valuable organic contents of food waste to be reused, **Kim et al., 2008**.

In recent years, composting has been presented as an environmental friendly and sustainable alternative to manage and recycle organic solid wastes, with the aim of obtaining a quality organic product, known as compost, to be used as organic amendment in agriculture. When mixed with soil, compost increases the organic matter content, improves the physical properties of the soil, and supplies essential nutrients, enhancing the soil's ability to support plant growth, **Iyengar, 2006.**

Compost can also be applied to the soil surface to conserve moisture, control weeds, reduce erosion, improve appearance, and keep the soil from gaining or losing heat too rapidly, **Swan, et al., 2002**.

Composting may be defined as a biological degradation of organic materials under controlled aerobic conditions. The process may be used to stabilize wastewater solids prior to their use as a soil amendment or mulch in landscaping, horticulture, and agriculture, **Lin et al., 2008**. To handle large volumes of municipal waste, the process of decomposition has to be speeded up. The microorganisms in the waste are given an environment, which allows them to grow rapidly and work at peak efficiency in breaking down the waste.

To do this, the microorganisms need air, water and nutrients, **Iyengar, 2006**.

When biodegradable organic solid waste is subjected to anaerobic decomposition, a gaseous mixture of Methane (CH_4) and Carbon dioxide (CO_2) known as biogas could be produced under favorable conditions. The decomposition of the waste materials is mainly done by the fermentation process, which is carried out by different group of microorganisms like bacteria, fungus, actinomycetes etc. **Swan, et al., 2002**.

Due to the presence of short-chain organic acids that are not only produced from raw materials, but also generated during the initial phase of batch composting pH will be lowered, inhibiting microbiological activity, **Nakasaki et al., 1993, Beck-Friis, et al., 2001, Reinhardt, 2002; Beck-Friis et al., 2003** and **Lin. et al., 2008**. Therefore, inhibiting the adverse effect of organic acids, i.e., controlling pH during the initial composting phase, is the primary issue to be resolved.

Anaerobic composting, while accepted elsewhere, has failed in our country due primarily to the odor nuisance, the time involved in producing a stable product and space requirements. While the aerobic process is characterized by a minimum odor nuisance and rapid decomposition when compared to the older anaerobic process. Still aerobic process has not yet been proven satisfactory and as of this date, there are no installations using this process, in operation in this country, except on an experimental or pilot plant basis.

In this research, an amendment material, sodium acetate (NaoAc), is introduced to the food waste composting process in order to resolve the difficulties noted above. NaoAc as a buffer salt combined with the acetic acids produced in the initial composting process can form NaoAc/HoAc a buffer solution in the composting reactor. Buffer solutions are potentially pH control amendments because of their capability to resist change in ambient pH and maintain it at a desired level, **Liang et al., 2006**.

However, few studies have examined the use of buffer salts for regulating the pH of the composting process. In addition, the effect of pH control amendments on the production of biogas has also been investigated. Therefore, the objective of this research is to examine the effect of NaoAc on the food waste composting process under controlled experimental conditions, quality of the final compost, as well as estimating the percentage of biogas generated due to organic solid waste degradation.

1.1 Compost Phases

The process starts with the oxidation of easily degradable organic matter; this first phase is called decomposition. The second phase, stabilization, includes not only the mineralization of slowly degradable molecules, but also includes more complex processes such as the humification of ligno-cellulosic compounds. From a technical point of view, the composting process is stopped at a phase in which the remaining organic matter present is relatively in large quantities (more than 50% of the starting amount); otherwise the process would continue, until all of the organic components are completely mineralized. The main product is called compost, which may be defined as the stabilized and sanitized product of composting, compatible, and beneficial to plant growth **Diaz et al., 2007.**

2. MATERIALS AND METHODS

2.1 Raw Sample

The Food Waste (FW) was collected from daily normal kitchen waste. FW was mainly food remaining in plates after lunch consisted 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, **Lin et al., 2008**.

2.2 In-vessel Composting Reactor

The composting system consisted of a cylindrical vessel metal tank (200 L) with an easy mechanism for turning the compost, as shown in **Fig.1**. A perforated steel screen was installed 10 cm above the reactor bottom, to recover leachate formed in the bottom section and through an opening valve.

A pressure gage was installed in the top of the reactor to measure the pressure of the gases produced while, temperature and humidity sensors with platinum probe were installed in the center inside the reactor. All the raw materials were minced into pieces of <5 mm in diameter using a food processor (Brown, China), and mixed well before the reaction began. To compare and analyze the effects of NaoAc on the composting processes, two experimental treatments were carried out in sequence. In Run B, NaoAc salt was added to the compost mixture; Run A was conducted as a control treatment without NaoAc addition. The detailed composition of raw materials for the compositing processes is summarized in Table 1.

The digesting process started in April until June; 2012. Day 1 is defined as April 22/ 2012. The digester cell was filled with 66.67 kg of different simulated food waste and 0.6 kg of sodium acetate as a buffer. The digester cell was operated anaerobically from day 1 to 5, and then air was introduced through day 6 to start the aerobic process.

For Run B, 600 g of NaoAc, was added to the compost mixture on day 4 immediately after sampling, when the pH had decreased to a relatively low level (pH < 5), **Giannis, et al., 2012**.

Temperature, pH, and moisture content were taken at regular intervals throughout the composting period. In addition, germination tests, NPK, and heavy metal analyses were carried out for examining the quality of the composted product for each run. Two replicates were conducted for each analysis.

Mixing was achieved by turning the arm of the screw by hand to ensure sufficient contact between bio-waste and the bacteria inside the digester, **Donovan et al., 2012**. Composting is essentially completed when mixing no longer produces heat in the pile, **Giannis, et al., 2012**.

At the end of each composting trial of 20-25 days, the formed product was collected from the bottom layer of the bioreactor and spread outside to form a pile. Six representative samples were collected from different points within the pile. The final sample was formed after mixing the six samples together to form a homogeneous material. From the homogeneous material two samples were selected from which a series of parameters were evaluated, **TMECC, 2002**.

2.3 Analytical Procedure

The standard methods followed for testing and evaluating compost and composting feedstock material were determined according to Test Methods for the Examination of Composting and Compost, **TMECC, 2002**.

Laboratory analyses included measurements of moisture content, pH, volatile solids, water soluble total Kjeldahl nitrogen (TKNW), NH_4^+, NH_3, phosphorous as P_2O_5 and PO_4^{-3}, potassium, electrical conductivity, heavy metals, and germination test.

Samples from the compost of about 50 g were collected and dried in an oven at 105 ^oC for 24 h; the loss of weight was taken as the moisture content. The oven-dried sample was further heated at 550 ^oC for 2h for the determination of volatile solids. pH of the clear supernatant was measured for the top clear liquid of the sample with a pH meter.

The water-soluble extract was prepared by mixing 10 g of sample with 100 ml of deionized water, then shaken for 2 h, and centrifuged at 3000 rpm. The supernatant was then filtered through a filter paper Whatman No. 1, **TMECC, 2002**. Nitrogen as total N, NH_3 NH_4^+, potassium and phosphorus as P_2O_5 and PO_4^{-3} were analyzed using Multi Direct Photometer for multi-parameter analyses. The electrical conductivity of the compost was analyzed once daily using EC meter.

Heavy metals of water-soluble extract samples were analyzed by Atomic Absorption Flame Emission Spectrophotometer (GBC scientific equipment Sens AA).

Germination test was performed for 48 h at 25^{o}C in the dark with 20 radish seeds placed on a 9 cm filter paper What man No. 1 soaked with 4 mL of compost extract and placed in a Petri dish, **Bertran et al., 2004**. Moreover, the germination test was repeated with deionized water as a control, and extract of commercial compost. The following equations were used to calculate the relative seed germination, relative root growth, and germination index (GI), **Zucconi et al., 1981** and **Tiquia et al., 1996.**

$$\text{Relative Seed Germintation \%} = \frac{No.of\ seeds\ germinated\ in\ compost\ extract}{No.of\ seeds\ germinated\ in\ control\ extract}\ x100 \qquad (1)$$

$$\text{Relative Root Growth \%} = \frac{Mean\ root\ length\ in\ compost\ extract}{\sqrt{Mean\ root\ length\ in\ control}}\ x\ 100 \qquad (2)$$

$$\text{Germintation Index (GI)\%} = \frac{Relative\ Seed\ Germintation\ x\ Relative\ Root\ Growth}{100}\ x\ 100 \qquad (3)$$

Two plastic bottles one liter each were modified and used as digesters. The mouth of each was supplied with an airtight rubber stopper and an outlet to permit gas collection in a suitable glass bottle filled with 0.1 M of NaOH. Each digester was set up at several combinations of environmental conditions that play the main role in the efficiency of the anaerobic digestion process and biogas production. These conditions were temperature, starting pH and moisture content.

The temperature of the biodigesters was maintained at a constant value in a water bath (50^{o}C), thermostatically controlled as shown in **Fig. 2**.

Biogas formed was measured by “liquid displacement method”. The schematic diagram of the experimental laboratory set up is shown in **Fig.3.**

Sampling proceeded until composting temperature was almost near ambient temperature and stand still **Gumaa, 2009**. Laboratory analyses included measurements of moisture content and temperature of the composted materials, which were recorded daily during the composting period. Composition of food samples used in the study is presented in **Table 2.**

The biogas is a mixture of carbon dioxide, methane, hydrogen sulphide and nitrogen, **Liang, et al, 2006**. The amount of hydrogen sulphide is less than 1%, **Kaparaju et al., 2008**. The amount of nitrogen is difficult to estimate although it can be measured with gas chromatography, (GC) **Juanga et al., 2005** and **Bonn, 2008**.

2.4 Laboratory Simulation

In order to study the influence of NaoAc addition on biogas production, two laboratory biodigesters in series was investigated spontaneously. In digester b, NaoAc salt was added to the mixture; digester a was conducted as a control treatment without NaoAc addition. The procedures held were as followed: the raw material mixture;

Composition of biogas was 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 CO_2 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 as shown in **Fig. 3**.

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, **Juanga et al., 2005; Bonn, 2008** and **Gumaa, 2009.**

3. RESULT AND DISSCUSSION

Results are based on parameters used to assess the anaerobic-aerobic mixed solid waste conversion, NaoAc addition, and methane gas production.

3.1 Temperature Profiles

The temperature of the composting mixture in both runs rose soon after beginning the experiment and reached 63 ± 2^oC within 20 to 25 days, corresponding to an average increase rate of 2°C/ day as shown in **Fig. 4.**

The temperature increased to the thermophylic level (above 50 °C) within 13, 7 days in Run A, Run B respectively, indicating that the indigenous microorganisms could easily utilize the organic materials in the amended food waste.

The thermophylic phase lasted more than 15days in Run A and 20 days in Run B, and then the temperature slowly dropped to a normal level. The duration of the thermophylic phase in Run B was relatively longer than that in Run A. The increase in temperature with time is consistent with previous reports of, **Benson et al., 2007**.

The overall average ambient temperature during this research was 40 ± 3^oC, indicating that exothermic reactions in the digester contributed considerable beneficial heating. For the batch digester the system was located in a water bath adjusted at 50 ^oC. This relatively high temperature would be expected to facilitate digestion. It also shows that the cell is capable of retaining heat that is generated during decomposition to withstand sudden electric cutoff.

It is clearly shown that composting proceeded more rapidly in the laboratory plastic biodigesters than in the large tank in both runs a and b due to the relatively optimal conditions i.e., under control and suitable surrounding environment. Temperature profiles for run a and run b are shown in **Fig. 5.**

3.2 The Changes of pH

The changes of pH are shown in **Fig. 6.** The pH had its lowest value at day 4 in all runs. The addition of NaoAc raised the pH value in Run A because NaoAc is an alkaline salt that forms a buffer solution through combining with acetic acids present in the composting material. This partially neutralized the acids and tended to maintain a relatively stable pH (5-5.8) level. However, maximum pH levels in the reactor with the addition of NaoAc were around 9.1, while in the control reactor was about 7.0.

3.3 Moisture Content

The moisture content tended to decrease due to the combination of high temperature levels and aeration during the thermophylic phase and was controlled by applying water (humidifying) the compost mass. The initial moisture content 63.5 % of the wet weight was reduced in all experiments to reach an average moisture content of 40±5% of the wet weight, remaining above the minimum moisture content of 40% suggested by **Liang et al., 2003** and Petric **Petric et al., 2009** for optimal composting conditions. After that, no significant changes in parameters have been observed.

3.4 Electric Conductivity

Fig. 7 shows the variation of electrical conductivity with time. The electrical conductivity slightly increased on day 1. Since decomposable compounds were easily released in the solution, the soluble ions in the water extract may increase slightly at the beginning of the composting process. The electrical conductivity was in the range of 2 to 3 dS/m during composting.

The initial EC increase could be caused by the release of mineral salts such as phosphates and ammonium ions through the decomposition of organic substances, **Fang and Wong, 2000**. As the composting process progressed, the volatilization of ammonia and the precipitation of mineral salts could be the possible reasons for the decrease of EC at the later phase of composting, **Beck et al., 2003.**

4. EVOLUTION OF COMPOST CHARACTERISTICS

4.1 Organic Matter Loss

Dry matter losses mainly occurred during the first 13 days **TMECC, 2002** but varied among composting runs, with a mean loss of dry matter of 32 ± 9% and a coefficient of variation of 15.6 %.

4.2 Compost Quality

The concentration of nitrogen was very low in the 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 (that is because of the addition of NaoAc) and high temperatures values of the substrate. Agitation and aeration rate may have also affected the rate of ammonia volatilization, **Beck et al., 2003**. However, as composting was developing nitrates concentration presented a significant increase which can be explained by the activity of autotrophic nitrobacteria which oxidize ammonium compounds into nitrates in the presence of oxygen-rich environment, **Benson, et al., 2007** and **Chroni et al., 2009**.

Nitrates reached 0.6 mg/l and 2.84 mg/l on the 40th day of the process, for Run A and B respectively, which can be considered as an indicator of a high degree of compost stabilization. Phosphorous as P_2O_5 reached 3.1 and 4.5 mg/kg on the 40th day of the process, for Run A and B respectively, which are higher than the recommended levels, while potassium as K_2O reached 3.12± 0.03 mg/kg for both runs. Results of Run A were expressed in **Table 3**.

4.3 Heavy Metals

Metal concentrations were below the maximum permissible levels of organic farming recommended by the Japanese Ministry of Agriculture. The maximum permissible levels for organic farming in Japan are 2 mg/kg mercury, 5 mg/kg cadmium, 50 mg/kg arsenic, 600 mg/kg copper, and 1800 mg/kg zinc, **Japanese Ministry of Environment, 2005**. As may be concluded, the quality of the current compost meets the requirements of USDA and US. Composting Council, **TMECC, 2002** as shown in **Table 3**.

4.4 Germination Test

Maturity of compost may be evaluated with the use of the cress seed germination bioassay, which is sensitive to excessive salinity or the presence of phytotoxic simple organic acids or phenol compounds, **Chroni, et al. 2009** and **Donovan, 2012**. One of the most significant germination tests is that reported by **Zucconi et al., 1981** and **Zucconi et al.1985**, and many later tests were developed from this.

The results of germination shows 86.5% relative seed germination and 98% root growth; the calculated value of germination index (GI) is 84.8% which is better than the suggested value of 60% for cress reported by Diaz **Diaz et al., 2007**. On the other hand, poor relative seed germination of 50.9%, root growth 16.4%, and GI 8.3% values were observed upon analyzing a commercial compost extract.

Table 5 gives values for very mature, mature and immature composts **TMECC, 2002**, which shows that the obtained compost can be classified as mature compost.

5. GAS PRODUCTION AND COMPOSITION

It was impossible to assess the impact of NaoAc addition on methane production in both runs A and B in the large tank; therefore, two-laboratory biodigesters of two liters each were used spontaneously as biodigesters (a and b). In digester b, NaoAc salt was added to the raw material mixture; digester a was conducted as a control treatment without NaoAc addition. Experiments were held in the Environmental Engineering Department laboratory in Baghdad University.

The largest fraction of gas probably had been lost from the compost by volatilization. The total volume of methane produced was 68±1% of the total gas produced with the absence of NaoAc, where the production reached 75±1%for the NaoAc-amended compost, indicating that the addition of NaoAc had effectively increased the extent of methane gas production due to effective material degradation.

Biogas production is very slow at both, the beginning and at the end period of observation. This is predicted due to the biogas production rate in the digester is directly corresponded to the specific growth rate of methanogenic bacteria in the biodigester, **Nopharatana et al., 2007**. After 27 days observation, biogas production tends to decrease due to the stationary phase of microbial growth.

The rate of methane gas produced agreed with other results of researchers, **Lo et al., 1984**, **Nopharatana et al., 2007** and **Kaparaju et al., 2008.**

6. CONCLUSIONS

The characteristics of the wastes composted and the temperature profiles obtained indicate that composting is a suitable technology to treat food wastes and to recycle them into stabilized and sanitized soil amendment. The final compost produced in this study was satisfactory for its agricultural application in terms of pH, electrical conductivity as a salt content index, germination test and heavy metal contents.

The main findings were:

1. In-vessel composting can process large amounts of waste without taking much space or cost as other solid waste management methods. In addition, it can accommodate virtually any type of

organic waste (e.g., meat, animal manure, bio solids, food scraps). The length of the composting process was 35 days in the vessel and two weeks of curing out of the vessel. The residuals after composting were about 33% of the original weight for run A and slightly less for run B 30%, i.e. the 66.6 kg turned to be 20.7 kg in the vessel B, indicating successful reduction. The bulk density of the composting materials was 750 kg/m^3 at day 1, and kept on decreasing after each mixing trial to reach 390 kg/m^3 of day 12. Almost equal for both runs.

2. The temperature of the composting mixture in both runs rose soon after beginning the experiment and reached 63 ± 2^oC within 20 to 25 days, corresponding to an average increase rate of 2 °C/ day. The duration of the thermophylic phase in Run B of 20 days was slightly longer than that in Run A of 15 days.
3. It was clearly shown that composting proceeded more rapidly in the laboratory plastic biodigesters than in the large vessel due to the relatively optimal conditions i.e., under control and suitable surrounding environment.
4. Final pH levels in reactors B was around 9.1, while the control reactor was about7.
5. Electrical conductivity slightly increased on day 1, as the composting process progressed, the volatilization of ammonia and the precipitation of mineral salts caused EC reduction at the later phase of composting. Overall, electrical conductivity was in the range of 2 to 3 dS/m for both runs.
6. The initial moisture content (63.5 % of wet weight) was reduced in all experiments to reach an average moisture content of 40±5 % of the wet weight.

6.1 Compost Maturity

Compost maturity was evaluated using certain indices; the levels of indices were relatively stable in the latter part of the composting period, and they remained constant.

1. Nitrates as ammonia reached 0.6 mg/l and 2.84 mg/l on the 40th day of the process, for Run A and B respectively, which can be considered as an indicator of a high degree of compost stabilization.

2. Phosphorous as P_2O_5 was 3.1 and 4.5 mg/l on the 40th day of the process, for Run A and B respectively, which are higher than the recommended levels. Potassium as K_2O reached 3.12 ± 0.03 mg/kg for both runs that is within the recommended level of the USA compost quality standard, **TMECC, 2002**.

3. The metal concentrations in this study were below the maximum permissible levels for organic farming recommended by the Japanese Ministry of Agriculture, **Japanese Ministry of Environment, 2005** and the recommended levels of the USDA and US Composting Council standards, **TMECC, 2002**.

6.2 Gas Production and Composition

In all cases, a peak in gas emissions was observed in coincidence with the thermophylic stage. In fact, gas emissions may be proposed as an indicator of the biological activity of composting materials, **Liang, et al., 2006**. Results showed:

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

2. The total volume of methane produced was 75±1% of the total gas produced in run a and 68±1% of the total gas produced in run b, indicating that the addition of NaoAc had effectively increased the extent of methane gas production due to effective material degradation.

6.3 Germination Test

The results showed that relative seed germination = 86.5%, relative root growth =98%, and GI=84.8%. The obtained compost can be classified as mature compost, **TMECC, 2002**. This stabilized compost can be finally considered very satisfactory for agricultural use.

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Figure 1. In-vessel composting reactor.

Figure 2. Laboratory batch digesters of anaerobic digestion to estimate the generated biogas.

Figure3. Gas collection by displacement.

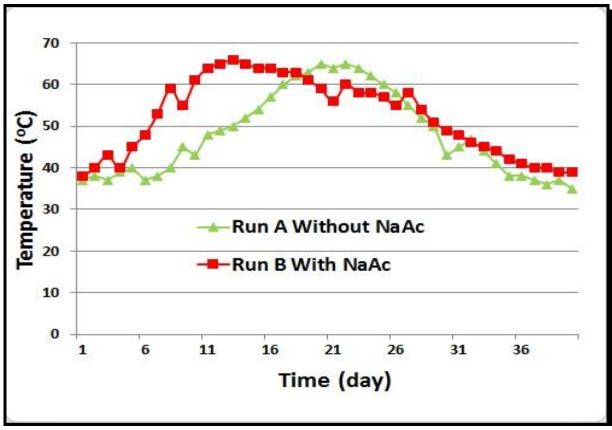

Figure 4. Temperature profiles through composting process.

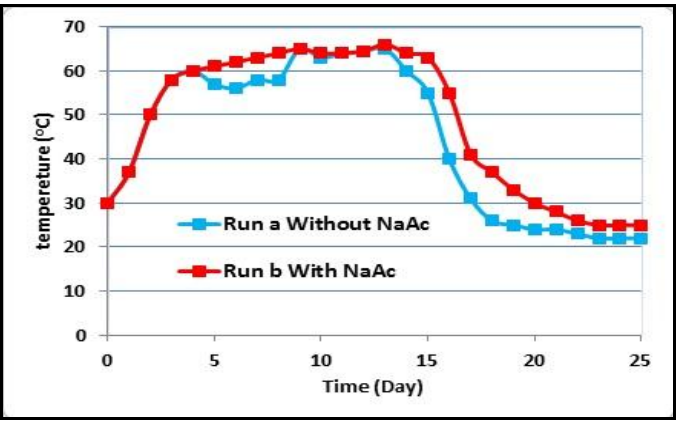

Figure5. Temperature profiles in simulated digester.

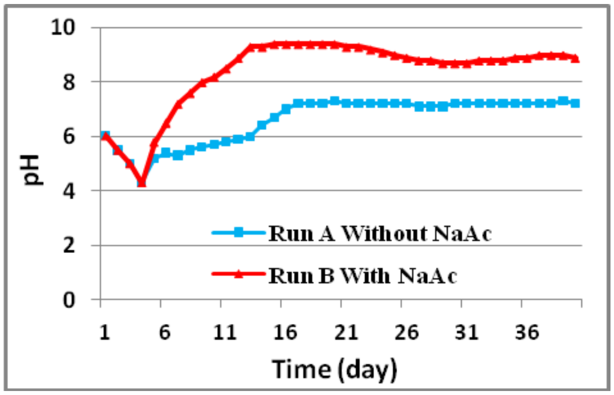

Figure 6. pH profiles of the composting processes.

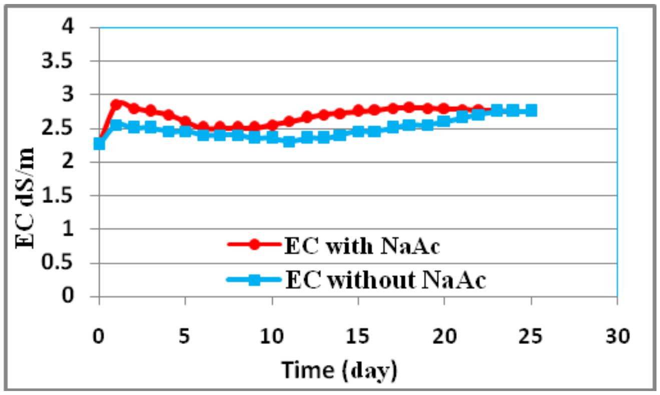

Figure 7. Variation of electrical conductivity during composting.

Table 1. Raw material for the compositing processes in the vessel.

Item (kg)	Run A	Run B
Potato	8.46	8.46
Carrot	13.06	13.06
Meat	2.34	2.34
Soybean	13.06	13.06
Steamed rice	13.34	13.34
Soil	13.34	13.34
Leaves	3.06	3.06
Water	4.66	4.66
NaoAc	0	0.60

Table 2. Raw materials for batch digesters lab-size.

Item (g)	Run a	Run b
Potato	74.1	74.1
Carrot	114.3	114.3
Beef	20.4	20.4
Soybean	114.3	114.3
Steamed rice	116.7	116.7
Soil	116.7	116.7
Leaves	26.8	26.8
Water	41	41
NaoAc	0	5.83

Table 3 Characteristics of run A compost and compost quality.

Heavy metal (mg/kg, dry weight)	Run A compost	TMECC 2002 Max.
Pb	110	150
Zn	--------	1400
Cu	28	750
Ni	35	210
Cd	0.54	2
Moisture content	40.2 %	30-60 %
Electrical conductivity (EC) dS/m	2.75	4.7
Available nutrients (NPK)mg/kg	1.1 N 3.1 P_2O_5 3.12 K_2O	1.6 N 2.57 P_2O_5 8 K_2O
C/N	20/ 25	20/30

Table 4. Outcomes of germination.

parameter	Compost extract of in-vessel lab-scale reactor	Commercial compost extract
Total seeds	75	75
Germinated seeds	45	33
Mean root length (cm)	0.98	0.85
%Relative seed germination	86.5	50.9
%Relative root growth	98	16.4
%Germination index	84.8	8.3

Table 5. Compost maturity Indices **TMECC, 2002.**

Method	Units Rating		
	Very Mature	Mature	Immature
NH4- : NO3-N Ratio	< 0.5	0.5 - 3.0	> 3
Total NH3-N ppm, dry basis	< 75	75 - 500	> 500
%Seed Germination	> 90	80 - 90	< 80
Plant Trials % of control	> 90	80 - 90	< 80