Iran. J. Environ. Health. Sci. Eng., 2011, Vol. 8, No. 4, pp.

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EVALUATION OF STABILITY PARAMETERS IN IN-VESSEL COMPOSTING OF MUNICIPAL SOLID WASTE

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Received 26 January 2011; revised 27 July 2011; accepted 28 November 2011

ABSTRACT

Composting is a reliable technology for production of stabilized organic matter that is suitable for agriculture, but this process should be carefully monitored with appropriate indices. Quality of compost is important from maturity and stability viewpoint, but in most compost factories proper attention is not paid to it. This study was designed to evaluate the stability indices in municipal solid waste composting, for selecting the best index in quality monitoring of the wastes. Processed and shredded municipal solid waste from Isfahan compost plant was used as raw material in an in-vessel composting process. A cylindrical reactor with 1 m height and 50 cm diameter made of Pyrex glass was designed. Air was supplied at a specifically flow rate 0.2 L/min.kg to maintain aerobic condition. NH_4^+/ NO_3 ratio, dehydrogenase enzyme activity (DA), pH, oxidation reduction potential (ORP or Eh) and specific oxygen uptake rate (SOUR) were used as stability indices. These parameters were measured during 40 days of composting process. Changes in these parameters during this period were surveyed and analyzed. Statistical analysis was carried out to choose best of them. Results showed that among the indices, SOUR can show the different stages of microbial decomposition and a numerical value for compost stability also SOUR value less than 2 mg O_2/gVS.h can show the full stability of compost.

Key words: In-vessel composting; Stability; Maturity; Municipal solid waste

INTRODUCTION

Compost production from municipal solid wastes in Iran has been considered for many years. The Quality of compost is important from maturity and stability viewpoint (Tiquia 2005; Gómez 2006; Bernal *et al.*, 2009) which unfortunately in most of compost factories proper attention is not paid to it (Heydarzadeh and Abdoli, 2009). There are few reports on compost maturity analyses using solid waste composts in developing countries and there are no standard procedures for determining compost maturity in these countries. However, with absence of reliable methods for determining the compost maturity, there are serious concerns about the use of composts with unknown maturation state (Ofosu-Budu and Hogarh, 2010).

Different methods are proposed for determining compost maturity. These can be broadly categorized into different groups as: physical (odour, temperature), chemical (C/N ratio, cation exchange capacity, nitrification), biological (plant bioassay germination test), microbiological (respiration analysis), spectroscopic (Infrared methods), humification (humic/fulvic acid

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content) and chromatographic (sephadex fractionation) (Zmora-Nahum and Markovitch, 2005; Aslam *et al*., 2008; Ko, Kim *et al*., 2008; Ofosu-Budu and Hogarh, 2010).

Although there is a wide range of literature on this subject, there is still controversy as to the parameters that can be used for defining the maturity of the composted products. For most developing countries, the application of methods based on spectroscopy and chromatography is quite complex and expensive for local compost producer (Ofosu-Budu *et al.,* 2010).

Stability is another indicative of degradation of organic material (Gómez 2006; Scaglia and Erriquens, 2007). If the material contains mainly recalcitrant or homus-like matter, it is not able to sustain microbial activity and therefore considered stable. Stability is not only an important compost quality characteristic but it can also be used for process performance monitoring and comparative evaluation of different composting systems (Gomez, 2006)

Several definitions for compost stability have been used: (Bernal *et al.*,2009) related stability to compost microbial activity; the UK Composting Association (2001) defined stability as 'the degree of biological decomposition that composting feedstocks have achieved'; Hue and Liu (1995) related stability to microbial activity and hence the potential for unpleasant odour generation (Bernal *et al*., 2009). Zmora (2005) defined stabilized compost which the rate of energy releases due to microbial degradation of the organic matter equals the rate of energy loss to the environment. Under these conditions, the temperature of the compost remains constant and the equals the ambient (Zmora-Nahum and Markovitch, 2005).

Many indices have been proposed to measure stability in compost (Rihani *et al*., 2010). The indices can be placed in two categories: first category includes on-site measurements, which are easy to perform such as temperature, pH, Eh, moisture, electrical conductivity and oxygen concentration within compost particles. The second category is laboratory analysis which are quite complex to carry out like: C/N ratio, NH_4^+/NO_3 ratio, Humic acid/Fulvic Acid ratio, organic matter, enzymatic activities, germination test and respiratory parameters (Barrena, *et al*., 2008; Kalamdhad *et al*., 2008; Khalil *et al*., 2008).

A suitable method for determining biological stability should be capable of numerically representing the actual point reached in the process of decomposition through the use of a measurement on a recognized Scale of values, with in turn enables the comparison of different decomposition processes. Among the different methods for determining compost stability, respirometric techniques are more reliable (Scaglia and Erriquens, 2007).

Few studies has been carried out in Iran about maturity and stability in compost. This study surveyed common indices of compost stability to choose the best index to evaluate the stability of compost produced from municipal solid wastes in Iran. On the other hand until recently, most of the articles on compost stability are available on traditional composting techniques such as windrows and static piles types of composting. Information on stability of compost with in Vessel techniques, for mixed municipal solid wastes is rather limited (Kalamdhad *et al*., 2008). Therefore in-vessel has been selected method in this study.

MATERIALS AND METHODS

Composting reactor

A cylindrical reactor with 1 m height and 50 cm diameter made of Pyrex glass was designed (Fig 1). A metallic perforated axis, connected to the air pump was placed in the center of the cylinder to supply air in the reactor. Separate gate was made in the center of the reactor for feedstock input, compost sampling and air output. The reactor was placed horizontally on metallic stand to rotate easier. A perforated disk was designed in lowest part of the reactor to collect leachate. The reactor was filled up to 75% of total volume. Total compost production duration was 40 days.

Composting materials

Processed and shredded (particle diameter less than 50 cm) municipal solid waste prepared for windrow in Isfahan compost plant, used as raw material for the reactor. The municipal solid waste contained different types of wastes that its characteristics are listed in Table1.

Table1: Characterization of the raw material

Density (kg/m3)	Moisture (%)	Organic carbon (g/kg)	Total solids (%)	Volatile solids (% TS)	Ash (% TS)	TKN (g/kg)	C/N
550	62.3± .82	344 ± 3.8	37 ± 0.35	89 ± 0.57	11 ± 0.45	11.8± 0.39	29± 1.2

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Sampling and analysis

For sampling, reactor was divided into three layers along the depth (upper, central and lower layers). Subsamples were collected randomly from these layers and combined and required amount of sample was taken for analysis. Final sample was shredded to less than 5 mm and analysis of samples was immediately conducted.

Air supply

Air from a compressor was supplied at a specifically flow rate of 0.2 L/min.kg (wet weight), to maintain aerobic conditions throughout the reactor. Optimum air flow rate (0.2 L/min.kg) was determined through initial pretests and according to the guideline values of air based on suggested in the literature. Compressor working timing during the day was calculated according to the amount of reactor waste volume and compressor flow rate. Air was injected through the central axis of the reactor (Bueno *et al., 2008)*.

Analyzed parameters

In this study, temperature, NH_4^+/NO_3 ratio, dehydrogenase enzyme activity, pH, Eh and SOUR were selected to assess the compost stability. Moisture, solids (volatile solids and ash), organic carbon, TKN (Total Kajeldahl Nitrogen) and C/N ratio of samples were measured also. All of the results were expressed as means of duplicate samples.

Analitical methods

- Moisture, ash and organic carbon: Temperature of 103-105 ⁰C was used for 24 hours to determine moisture content of samples. Volatile solid (VS) was determined as weight loss during dry combustion at 550 ⁰C for 2 hr in the furnace. Residue after combustion was reported as ash content. Total organic carbon was determined as %C = (%VS)/1.8 (Thompson, 2001; Abdullah and Chin, 2010). Each analysis was triplicated and the mean was calculated.

- Dehydrogenase activity: DA was determined according to standard procedures provided by US Department of Agriculture and US Composting Council (2001) and expressed as mg of triphenyl formazan (TPF) released per gram of Dry matter (Thompson 2001; Barrena, Vázquez *et al*. 2008).

- SOUR: specific oxygen uptake rate was determined according to the method described by Lasaridi and Stentiford (Lasaridi and Stentiford, 1998).

- pH and Eh: Analysis for pH and Eh were performed in the slurry of the dried sample: water ratio of 1:5. Mixture was stirred for 2 hr and decantation, the supernatant was taken. pH and Eh of the supernatant were measured using pH meter with ORP electrode (Thompson, 2001).

Statistical analysis

The relationship between analyzed parameters was evaluated by using Pearson correlation analysis. In order to define among all the parameters monitored those which are adapted for determining stability of the compost, a correlation matrix was carried out for temperature, pH, Eh, SOUR and DA.

RESULTS

Temperature

Temperature is one of the most important parameters of compost quality and reflects the microbial activity in composting process. Reaching the peak temperature is very important because the peak temperature of 50-60 ⁰C causes further degradation of organic matter and destruction of all pathogens (Ko *et al*., 2008). Temperature variation in the composting process

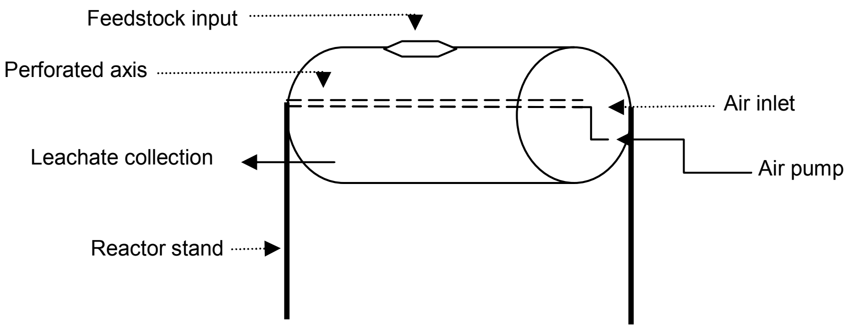

Fig. 1: Schematic diagram of pilot-scale in-vessel composting plant

Table2:Correlation matrix of all parameters monitored over the composting process

	Correlations					
	T	pH	Eh	NH_4/NO_3	SOUR	DA
T	1	-.488	-.011	.779	.876	.417
pH	-.488	1	.584	-.731	-.681	-.211
Eh	-.011	.584	1	-.193	.005	.301
NH_4/NO_3	.779	-.731	-.193	1	.882	.335
SOUR	.876	-.681	.005	.882	1	.393
DA	.417	-.211	.301	.335	.393	1

is shown in Fig.2. The maximum temperature of compost (56 ºC) was observed on the fifteenth day. Termophilic phase (temperatures above 40 ºC) continued until 10 Days and after that mesophilic phase began.

pH and Eh

The pH variations were studied during the days of composting (every two days). The relationship between pH variations and time is shown in Fig 3. As expected, the curve variation is ascending and at the end of the composting procedure, pH was in alkaline range.

Eh changes are shown in Fig. 4. This curve has irregular trend. Raw material had lowest Eh and highest value has been seen in days 5 and 25.

3.3 NH_4^+/NO_3 ratio

NH_4^+/NO_3 ratio variations were studied during the days of composting (every two days). NH_4^+/NO_3 ratio fluctuation is shown in Fig.5. There were many changes in curve and which was due to several reactions during the process occurred

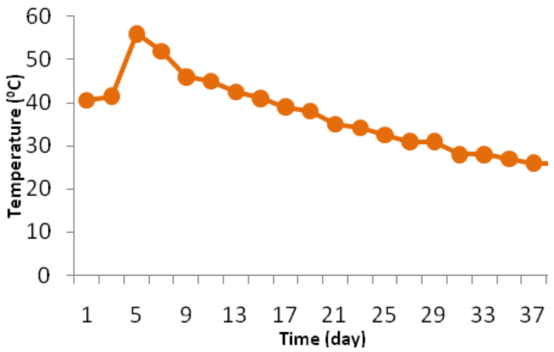

Fig. 2:Variations of compost temperature over time

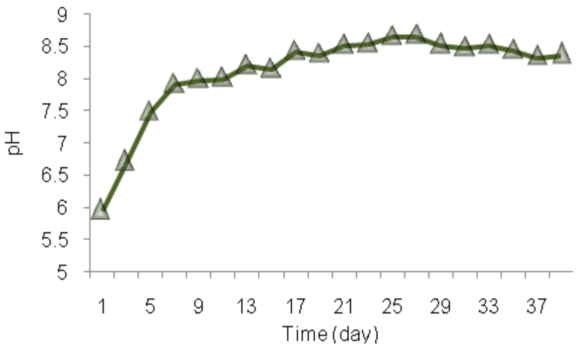

Fig. 3:Variations of compost pH over time

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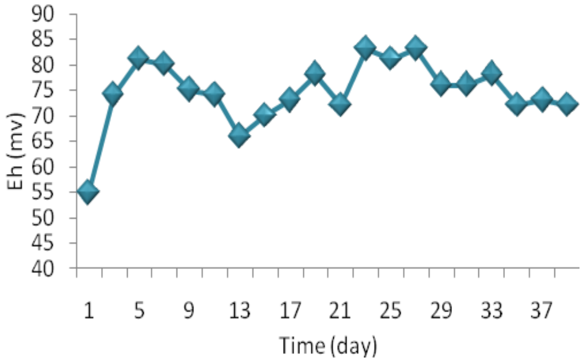

Fig. 4:Variations of compost Eh over time

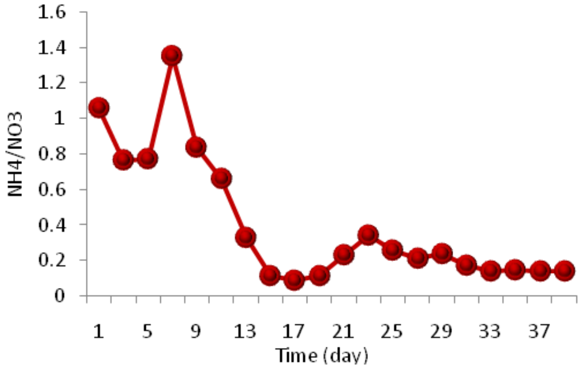

Fig. 5:Variations of compost NH_4^+/NO_3 ratio over time

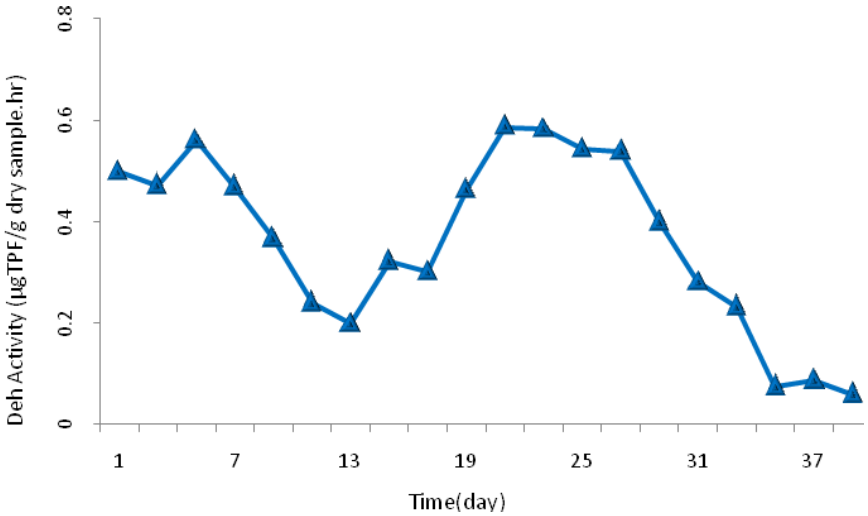

Fig. 6:Variations of compost DA over time

on nitrogen compounds. In this study, initial concentration of ammonia and nitrate were measured as 0.28 and 0.16 g/kg.

DA

Dehydrogenase enzyme was produced as a result of microbial activity. It is used as a microbial activity index in soil, but using this parameter in composting is also considered. DA was studied during the days of composting (every two days). Fig.6 shows the changes of dehydrogenase enzyme in which two peaks can be seen: the first in termophilic phase and the second in mesophilic phase.

SOUR

The SOUR changes were studied during the days of composting (every two days). SOUR changes are shown in Fig. 7 The maximum SOUR was observed in the first week and then decreasing trend was obtained.

Statistical analysis

A correlation matrix was carried out for temperature, pH, Eh, SOUR and DA (Table 2). With regard to temperature that shows obvious trend, the correlation analysis of the other parameters showed that SOUR shared high correlation coefficient (>0.87) at the significant level of $P<0.001$ in determining composting

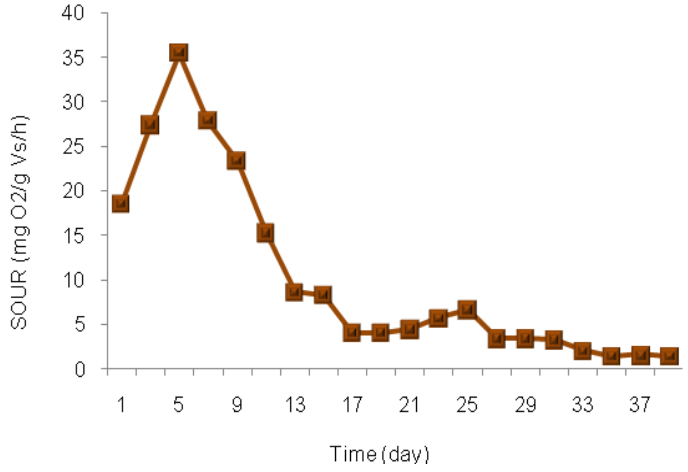

Fig. 7:Variations of compost SOUR over time

stability. NH_4^+/NO_3 ratio was the second parameter that was correlated with temperature in relatively high Pearson coefficient (>0.77), the coefficient was under 0.1 for Eh, which suggested tht Eh is an inaccurate index for evaluating compost stability of MSW. The highest correlation coefficient for SOUR indicated that this test was a precise method for compost stability determination.

DISCUSSION

Composting is a reliable technology for production of stabilized organic matter suitable to use in agriculture, but this process should be carefully evaluated with appropriate indices. Determining appropriate parameters for evaluation of compost stability, depending on the raw waste is important. There are different results from different studies that may be controversial, but most studies have concluded that two or more indicators are necessary to evaluate stability of the compost. In this study, some stability indices were studied in in-vessel composting of mixed municipal solid wastes. Variations of NH_4^+/ NO_3 ratio, dehydrogenase enzyme activity, pH, Eh and SOUR were measured for 40 days.

pH is a considerable effect on the composting process. Initial value of pH (5.95) showed production of organic acids during the first days of composting (Fig.3). The initial microbial degradation of food waste leads to the production of intermediate organic acids, which cause pH to decrease. After this short period, pH tends to increase and in termophilic phase, the amount of increase is high. After termophilic phase, pH change rate decreases is getting slow and the pH range remains relatively static. Ammonia is one of the most important reasons for increasing pH in termophilic phase (Kim *et al*., 2008; Elango*et al*., 2009). Ammonia volatilization could be one of the most important reasons for pH drops. As composting proceeds, the organic acids become neutralized and finished compost has neutral or alkali pH (Ko, Kim *et al* 2008; Lin 2008).

Eh had the highest value in termophilic phase (early days) and the middle of mesophilic phase (Fig.4). This is due to unstable intermediate compounds which were in the compost at the beginning of composting process (Khalil *et al*., 2008). After termophilic phase, Eh fluctuation was irregular. Anaerobic condition domination as a result of oxygen deficiency may be a reason for Eh drops, also high amounts of oxygen maybe a probable reason for Eh increase in mesophilic phase. Intense activity of bacterial and fungus is another reason for high amount of Eh. However, it seems that discontinuous aeration (in this study) has had considerable effect on Eh trend. Khalil and colleagues (2008) showed that Eh can be considered as an index to evaluate the maturity of compost. They found that the aeration does not have a direct impact on Eh changes and concluded that Eh evolution could be a useful

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index for directly on-site monitoring of green wastes composting *(Khalil et al.*, 2008).

Ammonia and nitrate concentrations in raw materials are different. It is demonstrated that nitrate production increases over time in an aerobic composting. At the beginning of composting process, ammonification occurs due to high microbial activity with decomposition of organic matter and causes production of large amounts of ammonia. Over the bio-oxidation step, the NH_4^+/NO_3 ratio fluctuates due to competition between ammonification and nitrification. NH_4^+/NO_3 ratio fluctuation is shown in Fig.5. At the beginning of the process, a significant decrease in NH_4^+/NO_3 ratio was observed. Ammonia volatilization as a result of rising temperature is the most important reason for NH_4^+/NO_3 ratio reduction in this stage. Nitrate measurements showed that nitrate changes at this stage was very low. High temperature reduces the activity of microorganisms responsible for nitrification. After termophilic stage, reducing the NH_4^+/NO_3 ratio refers to the increase in nitrate as a result of nitrification. Nitrification can be resumed after temperature decreases (Ko *et al.*, 2008). This study showed that NH_4^+/NO_3 ratio cannot be used as a compost maturity indice due to high fluctuations; some studies have suggested the contrary. For example(Ko *et al.,* 2008) suggested that NH_4^+/NO_3 ratio <1.0 could be appropriate in mature compost (Ko *et al*., 2008).

(Xiao and Zeng 2009) found that the dehydrogenase enzyme activity increases rapidly from 0.75 to 3.42 mg Triphenylformazan (TPF)/ g.day in the early days of composting and then decreasing trend starts which finally reaches to 0.45 mg TPF / g.day at the end of cooling (mesophilic) phase (Xiao and Zeng., 2009). Tiquia (2005) proposed that DA value of 35 µg TPF/g can be used for mature compost (Tiquia 2005). Barrena (2008) concluded that DA is a useful parameter to describe the biological activity of the whole composting process. He found that maximum values of DA were observed at the end of thermophilic stage or at the beginning of mesophilic stage. He also found a direct relationship between temperature changes and DA in the composting process (Barrena *et al*., 2008). High DA in mesophilic phase (Fig.6) is abnormal compared to other similar articles (Barrena *et al.,* 2008). It seems that the high microbial population (bacterial and fungus) activity continues in mesophilic phase and it causes high DA. With considering DA changes in whole composting process, DA could not be used as an ideal index to evaluate stability. But it is obvious that the lowest amount of DA (66 µg TPF/g dry matter.h) has been detected at the end of mesophilic phase (After 40 days). Thus it could be concluded that the stabilized compost has the lowest DA.

Respirometric indices such as SOUR have been used as a reliable indicator for determining stability in composting (Baffi *et al*., 2007). One research showed that SOUR value can be variable from 10 for raw material to 17.4 mgO_2/gVS.h during the bio-oxidation stage. They found that stabilized compost has SOUR value less than 2 mgO_2/gVS.h (after 20 days) (Xiao and Zeng, 2009). In a study by Scaglia and colleagues it was found that use of the SOUR index with samples characterized by a high biological stability should be considered with care due to a higher incidence of random errors (Scaglia and Erriquens, 2007). In fig.7 at the beginning, SOUR value was 18 mgO_2/gVS.h which increased to the maximum value as 35 at the termophilic or bio-oxidation phase. Then started to decline and at the end of process (40 days) reached less than 2 mgO_2/gVS.h that shows the compost was fully stabilized. As previous reports (Barrena *et al*., 2006; Xiao and Zeng ,2009; Scaglia and Erriquens, 2007; kalamdhad *et al*., 2008) have demonstrated, SOUR logical trend and its specific numerical values show that this index could be used as an ideal index for stability evaluation of composting process.

This study demonstared that the SOUR value less than 2 mg O2/gVS.h can show full stability of the compost.

ACKNOWLEDGEMENTS

This research was conducted with funding from the vice chancellery for research of Isfahan university of medical sciences (Grant No. 387258) as a PhD. Dissertation thesis. The authors wish to acknowledge Mr Farokhzadeh for technical support and Ms. Vahid Dastjerdi and Ms. Hatamzadeh, for their assistance and valuable advice.

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