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ORIGINAL PAPER

Initial air pressure influence on in-vessel composting for the biodegradable fraction of municipal solid waste in Morocco

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Abstract This study aimed to determine the initial air pressure influence on the in-vessel composting for the biodegradable fraction of municipal solid waste in Morocco. For this purpose, representative composting mixture was prepared in which C/N ratio was 26 and moisture content was 70 %. The in-vessel bioreactor was designed and used specially to evaluate the initial air pressure effect on composting process in this study. Thus, daily changes of internal air pressure and temperature were monitored, and physicochemical properties of different composts obtained were also analyzed and compared. Experimental results showed a significant increase in internal pressure corresponding to the initial air pressure of 0.6 bar and a slight increase for the other initial air pressures. The initial air pressure which equal to 0.6 bar allowed maximum value of temperature and final composting product with good physicochemical properties as well as higher organic matter degradation and higher gas production. Composts obtained from experiments under 0.4 and 0.8 bar showed good maturity levels and may also be used for agricultural applications.

Keywords Air pressure · Biodegradation · Bioreactor · In-vessel · Municipal solid waste · Maturity

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Introduction

The amount of waste is being increased day by day parallel to the increasing population. In 2000, Morocco has produced 6.5 million tons of municipal solid waste, of which 4.5 million tons of waste from urban areas and 2 million tons of waste from rural areas (D.E. 2001). Organic wastes resulting from the solid wastes have a negative impact on the environment and human health. Besides landfill, incineration, pyrolysis, biogas processes and composting are used to stabilize and recycle organic wastes. In Morocco, produced wastes are characterized by a percentage of 70 % of organic fraction and 70 % of moisture content (D.E. 2001). Thus, composting is one of the suitable treatments for this type of waste.

The main factors in the control of a composting process include environmental parameters (temperature, moisture content, pH and aeration) and substrate nature parameters (C/N ratio, particle size and nutrient content) (Diaz et al. 2002; Zaman 2013). Aerobic composting is the decomposition of organic substrates in the presence of oxygen (Liang et al. 2003). Oxygen is essential for the microbial activity in composting since it is an aerobic process. However, aeration is defined as “the most important factor in composting systems” (Diaz et al. 2002). The principal aeration methods providing O_2 during composting are physical turning of the mass, natural convection and forced aeration.

Composting period of organic matter varies from 10 days to 3 months (Wong and Fang 2000). In order to reduce the composting time, new approaches like faster reaction rate, smaller composting area and introduction of biodegrader are essential. Recent research has shown that the growth of aerobic microorganism and fermentation of organic substances accelerates the composting process, and reduces composting time (Velan et al. 2005). Moreover, the in-vessel composting system has advantages over the windrow system because it requires less space and provides better control than windrows; it involves high process efficiency (Cekmecelioglu et al. 2005). Thus, food wastes have been successfully composted for those purposes (Chang et al. 2006).

According to extensive literature research, there is no study that involves in-vessel composting under air pressure. The aim of the study of composting under pressure is to enhance the intake of necessary oxygen for microorganisms to degrade organic matter. The intake of oxygen was made at once; an initial quantity of air was injected into the bioreactor at the beginning of the experiment in the pressurized form. Alternatively, continuous aeration in opened bioreactors (Kulcu and Yaldiz 2004) was substituted by air pressure in closed bioreactors. In this study, a laboratory-scale bioreactor was specially designed to examine initial pressure effect on composting performance of organic fraction of municipal solid waste (OFMSW). The bioreactor is supplied with an air compressor for different initial air pressures (0.2, 0.4, 0.6, 0.8 and 1 bar). Thus, effects of initial air pressure on composting of OFMSW in Morocco were determined. Moreover, physicochemical properties of different composts obtained (moisture, mass transformed into gas Δm, pH, electrical conductivity (EC), organic matter content OM, total organic carbon (TOC), total Kjeldahl nitrogen (TKN) and ammonium nitrogen $NH_4^+ - N$) were also analyzed and compared. The research carried out throughout this study was conducted in water and environment laboratory, Faculty of science at the University Chouaib Doukkali of El Jadida, Morocco, during the first half of 2010.

Materials and methods

Composition of OFMSW

For the representativeness of the study, mean OFMSW composition should be the nearer as possible to the reel world composition. The purpose of this section is to determine the mean reel composition of OFMSW in Morocco. Sorting followed by a statistical study is the classical method used for determining the composition of a mixed waste (Sharma and McBean 2009). Furthermore, it is very difficult to adopt this method for organic waste and especially in national scale. Organic waste is inseparable either in the landfill or in the same bin. They often have the same color after oxidation. In this study, an approximate method based on the average consumption of organic products in the country was adopted. In general, main Moroccan consumption of organic products consists of vegetables, fruits and tea products (85 %) with an average annual consumption of 5,841,440, 2,076,946 and 138,740 t, respectively (Eurostat, 2009). Thus, the average annual consumption per person is about 167 kg of vegetables, 60 kg of fruit and 4 kg of tea products, while means of total consumption of these three products is 231 kg/habitant/year. Furthermore, experiments with representative quantities showed that vegetables, fruits and tea products generate, respectively, 17, 30 and 160 % of waste. Thus, the final composition of the OFMSW obtained from the average annual consumption, the amount of waste per species and population in 2006 (34,859,364) is 37 % of vegetable waste, 35 % of fruit waste, 13 % of tea products waste and 15 % of other wastes.

Description of the bioreactor (design)

Figure 1 shows the laboratory-scale bioreactor which was specifically designed and used for waste composting in this study. The bioreactor was a vertical metallic cylinder of 15 L. The metal used was in steel covered by an anticorrosive paint. The metal thickness was 1 mm. The bioreactor was designed with an opening in the upper face for waste introduction. The lid of the upper surface contained a valve to inject and remove air, a manometer to monitor pressure inside the bioreactor and a copper tube. A multi-thermometer was used to monitor temperature inside the compost. Sealing was ensured by a rubber gasket.

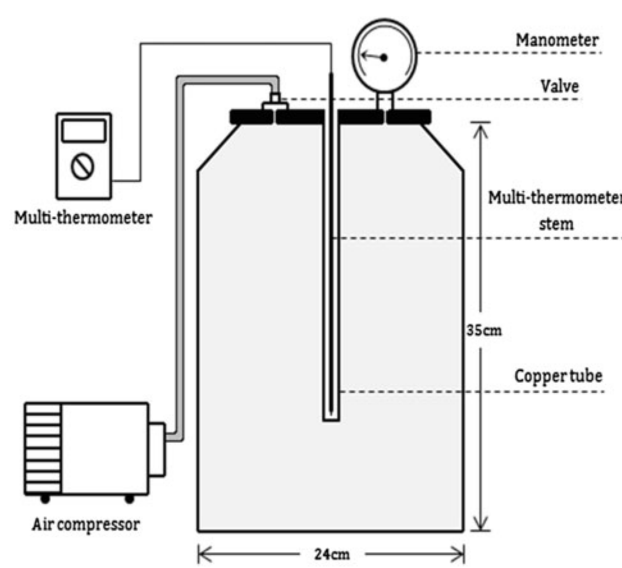

Fig. 1 Laboratory-scale bioreactor

Waste preparation and experimental design

Representative composting mixture was prepared based on composition established in section "Composition of OF-MSW." Each species was separately weighed, manually hashed and added to mixture. The obtained waste was then homogeneously mixed. The particle size of the mixture was 5 mm, and the initial C/N ratio was 26, which does not require any adjustment with other products. The biodegradability of organic waste is dependent on its C/N ratio. Larsen and McCartney (2000) have found an optimal biodegradation with C/N ratio equal to 29. More generally, it appears that C/N between 25 and 40 allows a satisfactory composting (Sadaka and El.Taweel 2003; Leclerc 2001). In addition, initial moisture of mixture was about 70 % and within the suggested range of 50–80 % for efficient composting as has been reported by several studies (Richard et al. 2002; Ahn et al. 2008). Some of physicochemical properties of initial mixture were determined, and the values were respected for the reproducibility of the experiment. Table 1 shows the average of triplicate values for selected physicochemical properties of initial mixture.

A sample of 5 kg of prepared waste was weighed and placed into bioreactor. After closing the bioreactor, air was injected through the valve. An air compressor supplied the bioreactor until initial pressure desired. Feeding the bioreactor was made every day. The formed gases during the degradation process were evacuated at the end of the day. Then, the bioreactor was fed a second time and so on until compost stabilization. Thus, five triplicate experiments were performed for different initial air pressures (Table 2). The composting process took about 10 days after stabilization. The final compost was then removed from the bioreactor and set for a natural maturation. Finally, the mass transformed into gas, Δm, was calculated by the difference in masses before and after each experiment, and the required indicator values of the process were measured.

Table 1 Selected physicochemical properties of initial mixture

Parameter	Initial mixture
pH	6.38
Moisture content (%)	70
Electrical conductivity (EC) (mS cm^{-1})	7.2
Organic matter (OM) (%)	92.4
Total organic carbon (TOC) (%)	46.2
Total Kjeldahl nitrogen (TKN) (%)	1.82
C/N ratio	25.9
$NH_4^+ - N$ $\left(mg\ kg^{-1}\right)$	315

Table 2 Initial air pressure for different experiments

Experiment number	Initial pressure in the bioreactor (bar)
Experiment 1	$P1 = 0.2$
Experiment 2	$P2 = 0.4$
Experiment 3	$P3 = 0.6$
Experiment 4	$P4 = 0.8$
Experiment 5	$P5 = 1$

Analytical methods

The moisture content of sample was measured after drying at 105 °C for overnight. The dried sample was ground and then used in analysis. The organic matter was calculated from the ash after igniting a sample of 20 g dry weight at 550 °C for 6 h. The water-soluble extract was prepared by the following procedure: 10 g of sample was first mixed with 100 ml of deionized water, then shaken for 2 h and centrifuged at 3,000 rpm. The supernatant was then filtered through 0.45 μm membrane filters. TOC and TKN were measured by the Walkley–Black method and semi-micro Kjeldahl method, respectively. pH and EC were measured in the condition of solid-to-water mixture (weight:volume = 1:10). Values were directly read on pH-522 WTW meter and EC-214 conductivity meter, respectively. Ammonium nitrogen, $NH_4^+ - N$, was measured by the spectrophotometry of salicylic acid and sodium hypochlorite (Lu 2000). Temperature in the bioreactor was measured using a Multi-stem digital thermometer (ST–9283B). Evolution of internal pressure was followed using a manometer (0–2.5 bar) to measure gas pressures.

All analyses were triplicated in order to ensure reproducibility and representativeness of the sample.

Results and discussion

Evolution of internal pressure

Figure 2a shows the temporary evolution of internal pressure inside the bioreactor for different experiments. In general, one first level was observed at the beginning of composting process for a period of 2 h and one second level toward the end of the experiment. The first stage corresponded to the compost activation period with a slight pressure increase of 0.18, 0.14, 0.22 0.16 bar which corresponded, respectively, to the first, second, fourth and fifth experiment. However, it is noted for the third experiment a significant increase of about 0.8 bar which is due to good activity of microorganisms. Indeed, presence of air oxygen in the bioreactor allows organic matter degradation by

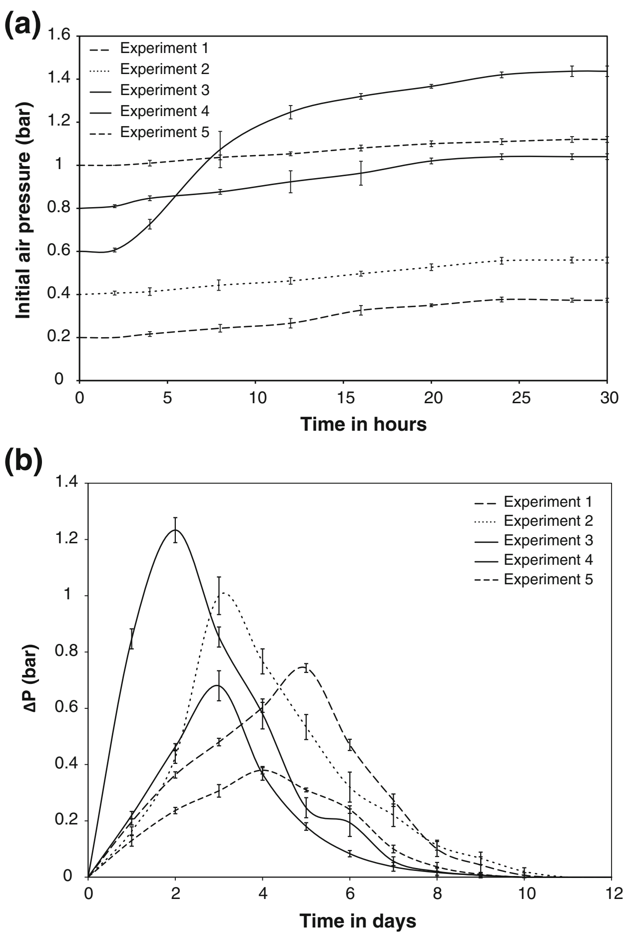

Fig. 2 Evolution of internal air pressure for different experiments

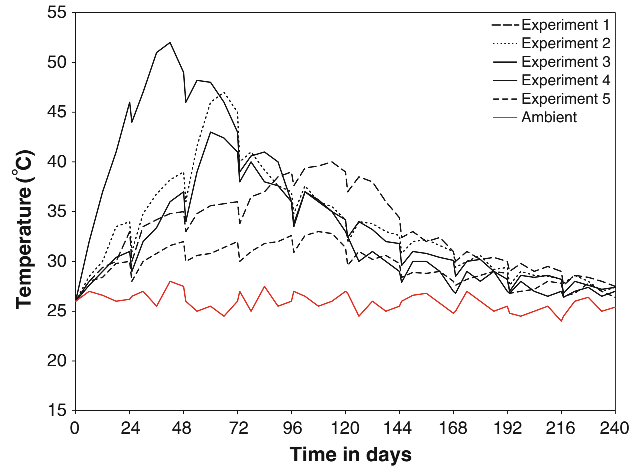

Fig. 3 Change of temperature during composting process for different experiments

microorganisms and formation of gases that are responsible of internal pressure increase. The second level reflects decrease in activity following the depletion of oxygen. Thus, a daily intake of air, under the same pressure, to the bioreactor is necessary to provide oxygen to microorganisms and follow degradation process under aerobic conditions.

The composting process took about 8–10 days, and the required indicator values of the process were measured. Figure 2b shows the evolution of pressure change, ΔP, inside the bioreactor for the five experiments. In the first experiment, the pressure change, ΔP, reached its maximum value toward the fifth day of composting with a ΔP of 0.72 bar. The pressure variations in the second and fourth experiment reached their maximum values at the third day of composting process with a ΔP of 0.9 and 0.6 bar, respectively. The greatest ΔP value is given by the third experiment at the second day of composting with a variation of 1 bar, and then, the fifth experiment has the lowest value of ΔP and that is at the fourth day of composting with 0.38 bar.

Temperature profile

The temperature has been widely recognized as one of the most important parameters in the composting process, and the variation of temperature has been reported to correlate with microbial activities (Tiquia and Tam 2002). Figure 3 shows the average temperature profile at different initial air pressures during the composting process. It reaches the maximum value of 43, 47, 52, 40 and 33 °C in first, second, third, fourth and fifth experiment, respectively, after 5, 3, 2, 3 and 5 days. However, temperature regime was nearly similar to ambient level among all composting experiments after 9 days, and we can consider that the compost is stabilized. Compared to all experiments, third experiment is most successful because temperature has reached maximum value and this is consistent with the higher activity of microorganisms.

Evolution of moisture and Δm

Figure 4 shows the evolution of moisture and mass transformed into gas, Δm, for different initial air pressure in the bioreactor. We note that the variation of moisture is in the opposite direction of Δm. This phenomenon can be explained by temperature change that reflects the activity of microorganisms. Indeed, the higher the temperature, the higher the microbial activity and therefore the degradation of organic matter is greatest. The aerobic microbial activity leads to water release (product of aerobic respiration of microorganisms), but the elevation of temperature and aeration during the hot fermentation stage lead to waste drying which can be important. It is, therefore, necessary to periodically check the moisture of the waste being processed and, if necessary, make additions of water to maintain moisture content at the level considered optimal

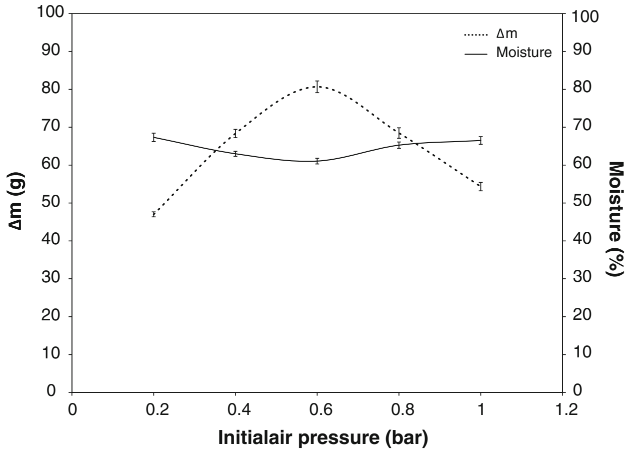

Fig. 4 Changes of Δm and moisture during composting process for different experiments

Table 3 Final mean values of pH, EC, TN, TOC, NH_4^+-N, and C/N ratio for different experiments

Experiment	pH	EC (mS/cm)	TN (%)	TOC (%)	NH_4^+-N (mg/kg)	C/N ratio
Experiment 1	6.4	5.11	2.04	43.26	414.33	21.61
Experiment 2	6.52	3.09	2.78	40.53	306.66	14.15
Experiment 3	6.79	2.55	2.88	39.63	242.33	13.42
Experiment 4	6.24	3.34	2.18	41.70	277.66	18.63
Experiment 5	6.61	4.37	1.97	44.20	424.33	21.62

(Petrica et al. 2009). The aeration method used in this study is non-continuous, and the system is closed what might be interesting in moisture waste control. A significant amount of evaporated water during the biodegradation remains in the bioreactor, which does not require any additional water. Therefore, waste drying is very low, and optimal content of oxygen and moisture are recovering in the bioreactor (Richard et al. 2002) especially for experiment 3; moisture content was optimal (61 %) under 0.6 bar. In addition, optimal initial pressure evaluated at 0.6 bar enables transformation of the greater amount of waste into gas (80 g kg_{OM}^{-1}). Thus, the third experiment allows the best environment for composting process.

Evolution of pH and EC

Measurements of pH and EC were performed before and after each experiment. Table 3 shows that pH varies very slightly ($6.18 \leq pH \leq 6.66$), indicating a good quality compost and within the suggested range of 6–8.5 as has been reported by several studies (Fogarty and Tuovinen 1991). Moreover, ECs of final composts were evaluated at 5.13, 3.07, 2.57, 3.54 and 4.41 mS cm^{-1}, respectively, for first, second, third, fourth and fifth experiment. In general, there was a decrease from the initial conductivity of 7.2 mS cm^{-1}. Avnimelech et al. (1996) found that the EC was initially 7.5 mS cm^{-1} and dropped after composting to a stable level of about 4 mS cm^{-1}. For organic waste, Corti et al. (1998) and Erhart and Burian (1997) reported that the EC of composts ranged between 0.14 and 12.2 mS cm^{-1}. In the experiment 3, the EC of composting product did not exceed the limit content of 3 mS cm^{-1}, which indicated that EC would not adversely affect the plant growth (Soumaré et al. 2002).

Evolution of TOC and TKN

In Table 3, the TOC and TKN values of five final composts are presented. As labile fractions of OM were mineralized into stable compounds by microbial activities, the OM content decreased in all experiments during composting. This decrease was more pronounced in the second and third experiment. However, TOC was subjected to an overall reduction of 6, 12, 15, 10 and 5 % in the first, second, third, fourth and fifth composting process, while the remaining carbon at the end of the process was 43.7, 40.6, 39.4, 41.9 and 44 %, respectively. In contrast, TKN was subject to an increase of 0.2, 1.05, 1.12, 0.42 and 0.16 % in the first, second, third, fourth and fifth experiment, while the TKN at the end of the process was 2.03, 2.87, 2.94, 2.24 and 1.98 %, respectively.

Evolution of NH_4^+-N and C/N ratio

The NH_4^+-N content in starting material was 511 mg kg^{-1}. Results in Table 3 show that the NH_4^+-N content in final composts from the 5 experiments decreased to 413, 308, 245, 280 and 427 mg kg^{-1}, respectively, in first, second, third, fourth and fifth experiment, due to the assimilation process carried out by the microorganisms, volatilization and nitrification (Gao et al. 2010). Riffaldi et al. (1986) reported that the decrease in NH_4^+-N was an indicator of both good composting and maturation processes. Moreover, Zucconi and de Bertoldi (1987) recommended an NH_4^+-N content of 400 mg kg^{-1} as the maximum content in mature compost. Thus, the second, third and fourth compost met the demand for agricultural applications.

Due to mineralization of organic matter, C/N ratio in the five experiments decreased during composting process (Table 3). The C/N ratio for experiment 1, 2, 3, 4 and 5 decreased from initial value of about 26, respectively, to 21.53, 14.15, 13.40, 18.71 and 21.67. However, when the initial C/N ratio is between 25 and 30, the final C/N ratio equals to or <20 is the standard for mature compost (Hirai et al. 1983). Therefore, the second, third and fourth compost has reached maturity according to this C/N criterion.

Conclusion

Obtained results show that initial pressure inside the bioreactor has effectively an influence on composting process. However, a pressure of about 0.6 bar offers a suitable environment for microorganisms' growth and allows rapid and efficient degradation of organic matter. Compost produced from the third experiment had good physicochemical properties for use as a soil conditioner. In addition, composts obtained from second and fourth experiment showed good maturity levels and may also be used for agricultural applications.

In general, the composting process proposed in this study is effective since it accelerates degradation and requires less space for its installation. In this study, gases produced from the process are evacuated but can be easily recovered, recycled and used for other applications.

Therefore, pilot-scale and full-scale experiments, using the same initial air pressure, need to be performed in order to confirm this finding. Future work will focus on method optimizing, comparison with other composting methods (with continuous aeration) and its application to industrial scale.

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