



Water state changes during the composting of kitchen waste



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ARTICLE INFO

Article history:

Received 21 August 2014

Accepted 12 January 2015

Available online 7 February 2015

Keywords:

Kitchen waste

Composting

Water state

Principal component analysis

ABSTRACT

Changes in water states during the composting of kitchen waste were determined. Three experiments, R_{55} , R_{60} , and R_{65} , with different initial moisture contents, 55%, 60%, and 65%, respectively, were performed. Three water states, entrapped water (EW), capillary water (CW), and multiple-molecular-layer water (MMLW), were monitored during the experiments. Changes only occurred with the EW and CW during the composting process. The percentage of EW increased, and the percentage of CW decreased as the composting process progressed. The R_{60} experiment performed better than the other experiments according to changes in the temperature and carbon-to-nitrogen ratio (C/N). The percentage of EW correlated well ($P < 0.05$) with the dissolved organic carbon content (DOC), electrical conductivity (EC), pH, and C/N, and was affected by the hemicellulose and cellulose contents.

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1. Introduction

Kitchen waste is a special solid organic waste that has high moisture content and high organic substrate (Adhikari et al., 2008). In terms of resource utilization and environmental-friendly disposal of kitchen waste, composting has been mostly recommended (Kumar et al., 2010; Nair et al., 2006). Composting is a useful way of turning organic waste into stable and valuable product that can be widely used as soil amendment and fertilizer (Evanylo et al., 2008), and the efficiency of composting will be affected by the stability and maturity of the product. It has been found that the optimum moisture content in waste material during composting is different for different waste compositions, but the optimum moisture content should generally be 50–65% (Kumar et al., 2010).

The moisture content is an important parameter in the composting process, because water provides a medium for the dissolution and transport of nutrients that are required for microbial activity (Liang et al., 2003). Generally, the moisture content in waste material during the composting process is controlled by the microbial activity, the degree of aeration, and the temperature. Microbial activity can cause the moisture content to increase because of water released during the decomposition of organic matter, while higher degrees of aeration and higher temperatures

can increase the evaporation rate, potentially leading to the loss of large quantities of water (Bernal et al., 2009). A low moisture content will generally arrest biological processes and cause the composting product to be unstable and immature (Liang et al., 2003), whereas a high moisture content can cause the waste material to become compacted, which will affect the mass transfer of air and produce anaerobic conditions that inhibit the composting process. It is therefore important to control the moisture content balance during the composting process.

The moisture content in waste material comprises different water states. Studies of water states in food and sludge (Chen et al., 2010; Devine et al., 2014; Liao et al., 2000) have shown that the water state balance is affected by the characteristics of the material, such as the moisture content, its chemical composition, and its physical structure, and the different water states are removed in turn as the total moisture content decreases (Robinson and Knocke, 1992; Tsang and Vesilind, 1990). As the composting process progresses, the characteristics of the waste material change clearly (Abdullah and Chin, 2010; Kumar et al., 2010; Nair et al., 2006), so the water states of the waste material may change accordingly.

In a mixed organic matter system, the water states can generally be divided into two fractions, free water and bound water (DeMan, 1999; Fennema, 1996). The free water fraction consists of entrapped water (EW) and capillary water (CW), and the bound water fraction consists of multiple-molecular-layer water (MMLW) and monolayer water. EW is entrapped by membranes and

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macromolecular gel networks, and CW is held in the capillaries by capillary force. MMLW refers to the bound water that forms several layers of molecules around hydrophilic groups through solute–water and water–water hydrogen bonds, and monolayer water is the first layer of water on non-aqueous components, and is associated with polar groups (such as carboxyl, amino, and hydroxyl groups) by ion–water and dipole–water hydrogen bonds (Sikorski, 2007). The free water (EW and CW) and MMLW can be removed by heating the material (Wang and Lv, 2009), but monolayer water hardly evaporates even at 105 °C. Removing monolayer water requires heating the material at a decreased pressure, and the percentage of monolayer water is kept around 0.5% (Chen, 2011), so that the EW, CW, and MMLW can be studied in the composting of kitchen waste.

The aim of the work presented here was to study changes in the water states during the composting of kitchen waste, and to determine the relationships between the water states and the general characteristics of the kitchen waste during the composting of kitchen waste.

2. Materials and methods

2.1. Materials

2.1.1. Kitchen waste and air-dried garbage

Fresh kitchen waste and air-dried garbage were used in the experiments described here. The air-dried garbage contained a great deal of vegetable waste, a small quantity of meat waste and little starchy waste, the garbage had been generated in food pretreatment processes, and the air-dried garbage was used as a bulking agent for the composting process.

Fresh kitchen waste and garbage were collected from the Zhejiang Gongshang University canteen, Hangzhou, Zhejiang Province, China. All of the fresh kitchen waste and garbage was cut into pieces with diameters of 5.0 ± 0.5 cm, and then the cut garbage was allowed to dry naturally before it was used. The characteristics of the fresh kitchen waste and air-dried garbage were shown in Table 1.

2.1.2. Inoculums for composting

The high-performance mixed flora containing microorganisms that could decompose starch, glucose, and protein had been isolated in a previous study (Yang et al., 2013) and preserved at below -80 °C in glycerol. The high-performance mixed flora was activated in Luria–Bertani culture medium (Miller, 1992) before the composting systems were inoculated with them. The concentration of the high-performance mixed flora seed that was used was $>1 \times 10^{15}$ colony forming unit (CFU) mL^{-1} .

2.2. Experimental set-up and operation

A specially designed laboratory-scale reactor with an effective volume of 16 L was developed for the composting experiments (Fig. 1). The reactor consisted of an insulated cylindrical plastic vessel, an air pump, a gas rotameter, and a thermometer probe attached to a temperature recorder. The vessel was surrounded by a layer of rubber insulation board (20 mm thick) and covered with an insulating layer of straw (50 ± 5 mm thick). The

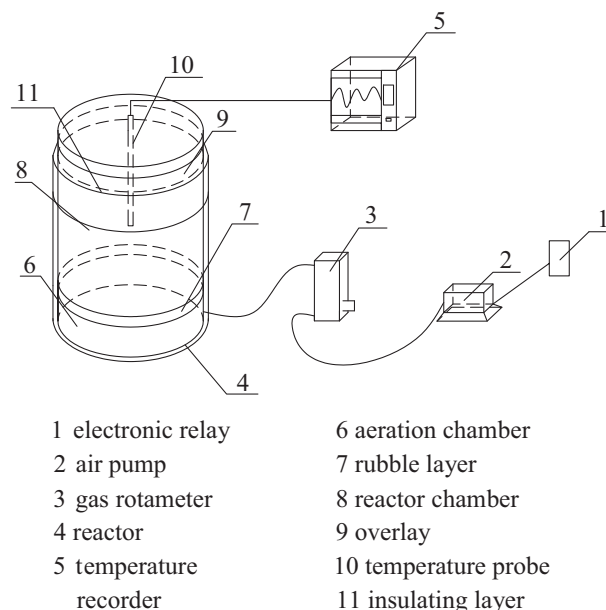


Fig. 1. Simple laboratory-scale reactor system.

thermometer probe was mounted in the center of the composting pile, and the temperature was recorded by the temperature recorder once every 20 s. An aeration chamber was installed at the bottom of each reactor, to maintain aerobic conditions, and the flow rate of the air was continuously controlled using a gas rotameter. The reactor was completely auto-thermal without any external heating source.

Three groups of experiments were performed, with initial moisture content of 55% (R_{55}), 60% (R_{60}), and 65% (R_{65}). Each reactor contained 5.0 kg of fresh kitchen waste, air-dried garbage, and distilled water, with a fresh kitchen waste to air-dried garbage ratio of 2:1 in wet mass, and the distilled water was added to adjust the moisture content to the target value. The high-performance mixed flora inoculum was added to the waste material at a rate of 1 mL kg^{-1} . All three groups of experiments were performed in a greenhouse at 29 ± 1 °C, the aeration rate in each experiment was 0.8 L min^{-1} , and each group of experiments had three replications at the same time.

2.3. Analyses

During the composting process, about 80 g waste material was collected from each reactor every 2 d. To collect about 80 g sample, the cross-section of the vessel was marked into quarters, and a sample of about 20 g was taken from the top to the bottom of the waste at the center of each quartered section. The four samples taken from a reactor were mixed together to form an 80 g sample. The material in each sample was immediately cut into pieces with diameters of <5 mm using a multifunctional food mixer (MJ-25BM05C; Midea, Foshan, China), then the sample was either immediately analyzed or temporarily stored at 4 °C.

The water states were analyzed using a gradient evaporation technique described in Supplementary material (Table S1 and Fig. S1), 30, 40, 50, 60, 70, 80, 90, 100, and 105 °C were set with

Table 1
Characteristics of fresh kitchen waste and air-dried garbage.

| Parameter | Moisture content (%) | TC (g kg^{-1} dw) | TN (g kg^{-1} dw) | C/N | pH | EC (mS cm^{-1}) |
|---------------------|----------------------|-----------------------------|-----------------------------|-------|-----------------|----------------------------|
| Fresh kitchen waste | 73.90 ± 0.69 | 553.22 ± 3.74 | 19.11 ± 2.07 | 28.95 | 4.53 ± 0.05 | 1.01 ± 0.03 |
| Air-dried garbage | 12.85 ± 0.22 | 523.27 ± 0.34 | 21.56 ± 2.41 | 24.27 | 5.46 ± 0.02 | 4.40 ± 0.06 |

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