Compost Physical Properties Study on Degradation of Poultry Manure Composting in Closed-Aerated Composter

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Abstract. A variety of parameters including physical, chemical, and biological properties of different input materials contribute to different composting performance. This study aimed to investigate the compost physical properties (bulk density, porosity, specific surface area and water holding capacity) on the composting process at different initial moisture content (MC). The degradation of total organic carbon (TOC) for the compost inoculated with Bacillus coagulans (BC) and effective microorganism (EM) was determined. The composting materials consisted of 50 % sawdust, 12 % chicken dung and 38 % rice husk with a fixed initial C/N ratio of 30. A closed-aerated composter was fabricated with an optimum air flow rate of 0.3 L/min.kg compost to avoid O₂ limitation for 7 d of composting. The compost temperature was recorded to exhibit the active reaction between microorganisms and compost materials will generate a considerable amount of heat. The effect of the initial MC of the compost bed has been intensively investigated with regards to compaction analysis and compost particle for the composting inoculated with BC or EM in an aerated closed-system composter. The results showed that composting using the single strain of BC provides comparable results to that degraded by the commercial mixed culture EM.

1. Introduction
Defining a key-controlled parameter at an optimal degradation environment is a great challenge since the system has a spatial variation and boundary limitation. The initial moisture content (MC) is highlight to be a key-controlled parameter on the composting process as reflected to the previous study by several researchers. The initial MC affects the bulk density [1], porosity [2], specific surface area [3], and water holding capacity [4] of the composting system. Optimum MC leads to an optimum degradation of organic materials (OM) because it can provide an adequate amount of liquid film where active metabolic reaction occurs. The compost moisture should be ranging between 50 and 60 % [5]. A large quantity of liquid water will be evaporated during composting due to the bio-drying process, which is associated with the self-heating process by the microbial activity [6]. Evaporation of water controls the compost bed temperature and as the water content reduces, the rate of degradation also decreases [7].

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The characterisation of the compost bed properties is important to justify that the defined states of the initial MC is important in order to reduce the variability of the uncertainties during composting. A comprehensive study on the composting degradation should be determined to decipher the stability period. The duration of composting to achieve stability is a critical factor because it is affected by the amount of degraded TOC. Physical properties including bulk density, porosity, water-holding capacity, and specific surface area distribution have a potential to generate anaerobic conditions. These factors are possible to be manipulated while changing in MC to inhibit the diffusivity of O₂.

The volume occupied by air (gas phase) within the compost bed indicates the void fraction, i.e. pore space and free air space is dependent on the physical properties (bulk density and porosity) of solid substrates and MC. Active reaction between microorganisms and substrates induced the degradation of organic matter, which occurs within the liquid film (liquid phase) on the surface of compost particle (solid phase) at the specified water holding capacity. The lack of MC has resulted in a very thin liquid film that will consequently inhibit the bacterial growth and composting activity. Too much moisture decreases the void fraction occupied by air and limits the O₂ concentration that leads to anaerobic condition.

2. Materials and Methods
Characterisation of compost raw materials was firstly conducted. The microbial inoculants, namely *Bacillus coagulans* (BC) and effective microorganisms (EM) were prepared in their respective liquid medium. One kg dry compost materials in the 15 L aerated compost reactor was prepared at different initial moisture content (36, 45, and 62 %) by manipulating the initial liquid medium (500, 800, and 1000 mL) of the microbial inoculants. Each composting run was conducted for 7 d with continuous air supplied (compressed air) using an air flow meter (a valve with a diameter of 1.5 cm, Krohne, USA) from the bottom of the compost reactor at 0.3 L/min.kg dried compost. BC was purchased from Arachem (M) Sdn. Bhd. A media culture for BC was prepared from glucose and yeast extract medium. The glucose is 99 % purity (346351, Merck, Germany) and yeast extract was purchased from Sigma, USA with purchased code of Y1625. The commercial inoculant, EM solution (EM-1) and molasses were purchased from EMRO (M) Sdn. Bhd in Skudai, Johor. The raw materials, sawdust (SD), rice husks (RH), and chicken dung (CD) were bought from Sarjani (M) Sdn. Bhd in Batu Pahat, Johor.

2.1 Chemical Characterisation of Compost Raw Materials
GC was used to analyse the chemical characteristics (total organic C, total N, total C, and total P) for the compost raw material by following the method proposed by Hwang et al. (2006). The chemicals present in each compost raw material was characterised using GC (Clarus 680, Perkin-Elmer, USA) followed by the method suggested by [8]. The compositions of raw materials were identified using data processing Scalable Total Chromatography Data Systems (CDS).

2.2 Cultivation of Microbial Inoculant
The initial single strain of BC from the preliminary cell bank in a form of ‘kwik-stik’ was acquired from the ATCC supplier (ATCC 7050, Arachem, Malaysia). BC was grown at 37 °C in 250 mL glucose-yeast extract. Its growth was analysed using the UV-VIS spectrophotometer at the optical density of 600 nm. All cultures were harvested in the middle to late exponential phase. EM activated solution (EMAS) was prepared using molasses as a carbon source with an appropriate ratio (1:1:18) of EM-1 solution, molasses, and distilled water as recommended by EMRO (M) Sdn. Bhd. (Johor, Malaysia). EMAS was gently mixed until homogenous and allowed to ferment in anaerobic condition for 7 d and when the pH of EMAS declined to below 4.0, the EMAS was ready to be inoculated into the compost for further composting. The quality of EMAS decreases over time due to lack of glucose source. EMAS was used within two weeks after one week of preparation.
2.3 Preparation of Composting Bed

1 kg of compost raw materials (C/N ratio of 30:1) was dried to remove the moisture in the oven at 40 °C for 48 h. All compost raw materials were sieved to the sizes of less than 20 mm prior to the composting stage [9]. The dried compost raw materials were sterilised in an autoclave (150 L, Selecta, Barcelona) for 15 min at 121 °C to remove all indigenous microorganisms so that the composting process were accomplished only by BC and EM. All compost materials (SD, RH, CD) were mixed to achieve the initial C/N ratio of 30:1. Each treatment consists of 1 kg of the mixed compost materials on the wet weight basis (w.b). The initial water content was fixed using 500 mL, 800 mL, and 1000 mL of the inoculum solution to achieve the respective initial MC (36, 45, and 62 %) of the compost bed. The preparation of composting experiments is shown in Table 1 and presents the dry cell mass (DCM) for BC was greater than EM during their active phase, DCM of BC as 0.007 g/mL, and by EM as 0.003 g/mL.

| Initial MC (%) | DCM (g/mL) |
|----------------|------------|
| 36 BC          | 0.007      |
| 45 EM          | 0.003      |
| 62 Distilled water (control) | 0          |

3. Results and Discussion

3.1 Evolution of the Compost Temperature

The temperature regimes at different initial liquid medium and microbial inoculant (MI) (BC and EM) are shown in Figure 1. The reaction temperatures reached in the range of 40 to 55 °C as soon as the compost bed is formed and remained above thermophilic phase for consecutive 24 h for all the composting experiments. For 1 kg of compost bed, the maximum temperature recorded by BC800 was only 54 °C during active phase. This result was comparable with [10] who found a considerable energy generated in a compost bed and it did not reach a temperature of 60 °C for a small compost pile. The temperature for the control composting was recorded to be constantly near the ambient temperature, which indicated the absence of microbial activity presented in the control.

Figure 1 (a) shows the regime of $T_{\text{max}}$ of compost inoculated with BC was recorded higher than the $T_{\text{max}}$ of compost inoculated with EM for all different initial MC. It shows that BC produced more metabolic heat and accelerate the decomposition of organic compound due to the characteristic of thermophilic bacteria that able to tolerate at high temperature during the active phase [11]. It was also supported by the initial concentration DCM for BC was greater than EM in Table 1. This could be a reasonable experimental strategy as a higher microbial population of inoculants positively affected higher compost bed temperature.

According to [12], as the supply of high-energy compounds become exhausted, the compost temperature started to decrease. For this study, glucose is pronounced to be the most important carbon source for metabolic activity of microorganisms, and it is contained in the liquid medium of both MIs (glucose yeast extract for BC and molasses for EM). Since both BC and EM utilised glucose for energy, the concentration of glucose consistently decreased along the composting period. The temperature gradient shows in Figure 1 (a) is well corresponding to the reduction of glucose in Figure 1 (b). After 7 d of composting, the end compost was no longer actively decomposed and was biologically stable.
The temperature declined from the thermophilic to mesophilic phase was influenced by the compost volume [13]. If the volume is not sufficiently large (less than 200 L) for the heat accumulation, heat is excessively removed by the ventilation during the active phase and the mesophilic can quickly take place. This result explained the fast declined of the temperature profile after day 2, due to the small bulk volume of the compost bed (1 kg) the accumulation of metabolic heat may not be sufficient to sustain the desired high temperature [14]. For the instance, prior to the continuous supply of forced air into the closed compost reactor, higher/prolong thermophilic temperature of compost bed is difficult to achieve, due to the cooling effect of the inlet air forced on the system [15].

3.2 Effect of Initial Moisture Content on Compost Particle
Water is held in the pores within the solid particles and in the thin films surrounding the particle [16]. This provides the capability of the solid compost particle to hold water and specific surface area that is associated to the greater number of microorganisms able to attach on the compost solid particle [17]. Compost dries up when the compost bed does not retain the water content and this process could be worsen by the continuous supply of air into the system. Table 2 presents the data of the initial and the final specific surface area, water-holding capacity and MC of the compost bed.

**Table 2.** Initial and final data for physical properties at different initial MC

| MI   | Initial Volume (mL) | SSA (m²/g) | WHC per 100 of compost (%) | MC (%) |
|------|---------------------|------------|-----------------------------|--------|
|      | Initial | Final   | Initial | Final   | Initial | Final   |
| EM   | 1000    | 11.6 ± 0.5 | 9.2 ± 0.2 | 50.1 ± 2.2 | 88.3 ± 4.1 | 61.3 ± 0.6 | 51.3 ± 0.4 |
|      | 800     | 15.1 ± 0.4 | 11.0 ± 0.3 | 82.2 ± 8.2 | 110.9 ± 12.9 | 45.6 ± 0.8 | 36.6 ± 1.2 |
|      | 500     | 5.4 ± 0.4  | 5.5 ± 0.6  | 74.5 ± 2.1 | 129.2 ± 1.1 | 36.4 ± 0.7 | 31.5 ± 0.7 |
|      | 1000    | 12.7 ± 0.5 | 10.8 ± 0.8 | 44.6 ± 0.6 | 84.7 ± 3.8 | 61.7 ± 0.3 | 51.6 ± 1.6 |
| BC   | 800     | 16.5 ± 0.5 | 12.9 ± 0.6 | 66.4 ± 5.1 | 81.4 ± 5.1 | 45.5 ± 0.7 | 38.6 ± 0.6 |
|      | 500     | 8.1 ± 0.7  | 4.8 ± 0.5  | 84.6 ± 2.0 | 131.0 ± 4.2 | 36.6 ± 0.6 | 31.6 ± 0.4 |

MI = microbial inoculant, SSA = specific surface area and WHC= water holding capacity
Compost with high initial MC resulted in high specific surface area, which associated to the increase in water film at surrounds solid surface. The high specific surface area supports an effective space for
adsorption of the microorganisms. In such a condition of having a larger specific surface area, the liquid water greatly flows in the water-filled space along the larger water films on the solid surface [18]. Also, a larger surface area increases the degradation rate of OM in compost [19]. At the end of the composting, the specific surface area for all the composting experiments decreased as the BC800 and EM800 composting showed the highest final specific surface area.

The decrease in water capacity corresponds to the increased in free air space within the compost solid particle. The increase in free air space is able to replace the water produced by metabolic decomposition during the degradation of TOC [15]. This result was in accordance with the data shown in Table 2, where water-holding capacity of the compost bed increased at the end of composting process. The number of free air space (porosity) increase linearly with water-holding capacity as the compost MC was declined during the composting process. The finding in Figure 2 (b) supported the results in Table 2, where higher porosity for the composting of BC500 and EM500 is able to retain more water compared to BC1000, EM1000.

3.3 Effect of Initial Moisture Content on Compaction Study
Study on the effect of compost bed compaction is closely related to the bulk density and porosity. The relationship between bulk density and porosity with respective MCs are shown in Figure 2. The figure exhibits both MC and bulk density that were inversely proportional to the compost porosity. The trend was similar for all set of the composting experiments.

The composts of BC1000 and EM1000 present the densest bed among all other composting experiments (BC800, EM800, BC500, and EM5000) as shown in Figure 2. This indicates that BC1000 and EM1000 possessed the highest bulk density and the lowest porosity and for distinctive manner, low initial MC resulted in low bulk density and high porosity. This result was supported by [20] who observed that the decrease in bulk density would alter the pore size and the number of pores would increase, which resulted in the increase of compost porosity [21].

The level of MC controls the physical characteristic of the compost bed. When the free air space between the compost solid particles was occupied by more liquid medium, the compost bed will be more compact and heavier; thus, resulted in low porosity. The reduction of compost bed porosity is due to the compaction effect by the increase in bulk density [22], affected by the increase in water content within the solid particle [23]. As expected, the compost with higher initial MC having less free air space and possesses lower porosity of compost bed. This result is in-line with [24], where the MC strongly affects bulk density and porosity. Higher MC indicates higher amount of water occupied within the intracellular space between the solid particles and caused the compost bed to be denser.

3.4 Effect of Initial Moisture Content on TOC Degradation
The same compost materials inoculated with BC and EM has almost gradually along the 7 d of composting. Overall, the increasing slope of the curve in Figure 3 (b) after day 1 and day 3 indicate a vigorous compost degradation process occurred at the thermophilic phase and the second mesophilic phase. Thermophilic phase enhanced the degradation of TOC due to the highest similar initial TOC (about 40 %) as described in Figure 3(a).
Figure 2 Effect of initial MC on bulk density and porosity of compost bed.
The TOC of the compost decreased microbial activity at this phase (Chang and Yang, 2009), reflected by the highest glucose content at initial composting process. This finding also conformed to the finding obtained by [25] who reported that the second mesophilic phase can rapidly decomposed organic matter (80 %) at the optimum working temperature ranging from 25 to 40 ºC.

Figure 3 (b) illustrates the trends of TOC degradation were similar to each other. Composting with low initial MC showed high degradation of TOC compared to high initial MC. Although the optimum initial MC to proceed the composting in a range of 45 to 65 % [26], but in this study, the 36 % initial moisture content was observed to give the highest degradation of TOC. The results indicated that setting a correct initial MC would affect the composting performance because the degradation of TOC by microbial activity occurs at the water film on the solid compost particles [25]. A stagnant water film at the solid compost particle provides a medium for the transport process of substrates and dissolved nutrients for microbial activities [27]. The degradation of TOC is due to the biological degradation processes and the transport process is driven by the change of water content [28]. If the MC is too low, there is inadequate water film for the microorganisms to survive; if the MC is too high, the interfacial free air space within the compost particles are filled with water [26], and thus lower the degradation of TOC. It is due to the thick water film within the solid compost particle inhibit the bacterial growth on the compost particle and microbial activity.

4. Conclusion
The composting system facilitated the reproducible results for the correlation of initial MC to other parameters for composting. The effect of the initial MC of the compost bed has been intensively investigated with regards to all parameters for the composting inoculated with BC or EM in an aerated closed-system composter. Low initial MC of the compost bed could decrease the bulk density. For water-holding capacity, all composting experiments showed a higher water-holding capacity at the end of composting. The increase in water-holding capacity was correspondent to the reduction of MC
during composting. A lower initial MC resulted in a higher water-holding capacity, as it specifies a high number of free air space. For all composting experiments, the specific surface area decreased at the end of composting. Compost with high initial MC resulted in a high specific surface area at the end of compost process. Initial MC would affect the degradation of TOC during composting. If the initial MC is too low, there will be inadequate water film for the microorganisms to survive. Meanwhile, if the MC is too high, the interfacial free air spaces within the compost particles are filled with water; hence, resulting in a low degradation rate of TOC.

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