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Usage of pumice as bulking agent in sewage sludge composting

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HIGHLIGHTS

- Water absorption characteristics of pumice were studied.
- Pumice can hold water during composting.
- Reused pumice promoted degradation of organic matter and reduced nitrogen loss.
- Sucrose-decorated pumice was used to reduce nitrogen loss.

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ABSTRACT

In this study, the impacts of reused and sucrose-decorated pumice as bulking agents on the composting of sewage sludge were evaluated in the lab-scale reactor. The variations of temperature, pH, NH_3 and CO_2 emission rate, moisture content (MC), volatile solid, dissolved organic carbon, C/N and the water absorption characteristics of pumice were detected during the 25 days composting. The MC of pumice achieved 65.23% of the 24 h water absorptivity within the first 2 h at the mass ratio of 0.6:1 (pumice:sewage sludge). Reused pumice increased 23.68% of CO_2 production and reduced 21.25% of NH_3 emission. The sucrose-decorated pumice reduced 43.37% of nitrogen loss. These results suggested that adding pumice and sucrose-decorated pumice in sludge composting matrix could not only adjust the MC of materials, but also improve the degradation of organic matters and reduce nitrogen loss.

1. Introduction

With the upgrading and expansion of wastewater treatment plants in China, increasing amounts of sewage sludge are produced. Indirect severe risk to human health exists due to the possibility of pollutants migration to soil and groundwater. Composting is one of the most popular biological technologies to treat organic solid wastes including animal matures, agricultural residues, sewage sludge, food waste etc. (Doublet et al., 2010; Li et al., 2011; Jiang et al., 2014). Nutrients such as humics, nitrogen and phosphorous in sewage sludge can be recycled for plant growth and soil fertility improvement (Cheng et al., 2007; Wang et al., 2014). During composting process, aeration is one of the most important factors in affecting aerobic biodegradation efficiency and product quality. However, the high moisture content (MC) of dewatered sewage sludge (about 80%) caused poor air permeability (Eftoda and McCartney, 2004). Accordingly, bulking agent (BA) is needed in the feedstock to adjust the MC and porosity of materials before composting.

BA could be divided into active and inert materials according to whether the BA is involved in the biological reactions in the composting process (Zhou et al., 2014). Active BA, such as wheat straw, rice straw, rice husk, woodchips and sawdust, have been widely applied in composting plant (Gea et al., 2007; Adhikari et al., 2009; Shao et al., 2014). However, the active BAs were degradable and compacted in the incubation process (Jolanun and Towprayoon, 2010), leading to the high cost and poor mass transfer in the composting matrix during the later stage. Additionally, the application of the organic BAs was also limited because of the difficulties in the collection, transportation and secure storage (Zhou et al., 2014). On the other hand, the inert BAs (e.g. zeolite, coal fly ash and peat) had the better performance on heavy metal passivation, improving the physical structure and the MC of composting materials (Zorpas and Loizidou, 2008). However, the inert BAs cannot increase C/N ratio of the mixture

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materials to achieve desired nutrient condition for microorganism growth.

It has been confirmed that sucrose could contribute to reduction of nitrogen loss during sewage sludge composting (Li et al., 2013). However, adding sucrose in the feedstock could increase osmotic pressure and viscosity of materials, which would not only impact the microbial activity and oxygen transfer efficiency in composting matrix, but also increased operating cost of sludge treatment. Therefore, an applicable way of sucrose addition which could ensure indirect contact to sludge and slow consumption was needed.

A series of research experiences evaluating the recyclable BAs and their influence on the composting process has been reported in recent years. Nagao et al. (2008) compared synthetic polyethylene terephthalate (PET) flake with woodchip as the bulking agent. Due to the high abrasion resistance and non-biodegradability, PET showed the greater viability than the woodchip. Zhou et al. (2014) used a recyclable plastic bulking agent (RPBA) to reduce costs. The improvement of temperature, oxygen transfer, and water removal was demonstrated by adding RPBA. Adding some natural minerals (clinoptilolite and pumice) could significantly increase organic degradation rate, material porosity, NH_3 adsorption and water holding capacity according to Hulya (2012). However, a large amount of matured compost retained on the surface of BAs was involved in the composting when the recyclable BAs were reused. Few studies have investigated the influence of matured compost on this process.

Pumice, a lightweight porous volcanic rock (Wang et al., 2013), which could be screened and reused, was expected to carry more matured compost due to the rough surface and porous structure. But the impact of recycling on the composting process and the water absorption characteristics of pumice were still unclear. As an inert BA, pumice hardly contains any organic matters to improve the C/N ratio of composting materials. Therefore, decorating pumice by sucrose would be an efficient and convenient method which could ensure sucrose's indirect contact to sludge simultaneously.

The purpose of this study is to investigate the effect of reused pumice on the composting process in terms of nitrogen loss and organic degradation rate. Sucrose-decorated pumice was introduced as the bulking agent to reduce nitrogen loss during composting. Laboratory scale comparative experiments were conducted under controlled conditions. Moreover, the water absorption characteristics of pumice were evaluated.

2. Methods

2.1. Feedstock composition and composting process

Dewatered sewage sludge was obtained from a wastewater treatment plant in Harbin, China. Fresh pumice was used as an inorganic bulking agent, and the sucrose was introduced as carbon source. Reused pumice was collected from previous composting experiment. Sucrose-decorated pumice was treated with sucrose solution. 20 g of sucrose was dissolved into 200 ml distilled water, and then the sucrose solution was sprayed onto 2 kg of pumice evenly. The pumice was dried in an oven at 45 °C for 4 h and then pumice was mixed with 2 kg sewage sludge as the feedstock of composting. The characteristics of the raw materials are presented in Table 1.

The composting process was conducted in closed batch reactor with an inner diameter of 300 mm and height of 600 mm. Forced ventilation was supplied by the air pump, and the aeration rate was controlled by a flow meter and maintained at 0.4 L h^{-1}. Fresh air was pumped into the reactor from the bottom through a perforation plate. The reactor is completely closed and the exhaust gas passed through the absorption glass jars in which CO_2 and NH_3 generated by aerobic fermentation were trapped by 4 mol l^{-1} sodium hydroxide and 0.5 mol l^{-1} of boric acid, respectively.

Table 1
Characteristics of the raw materials.

Parameters	MC (%)	Volatile solid (%)	pH	C/N
Sewage sludge	78.86 ± 0.84	55.53 ± 0.91	7.13 ± 0.02	6.42
Pumice	0.57 ± 0.12	–	7.24 ± 0.05	–
Reused pumice	15.65 ± 0.92	0.53 ± 0.28	7.68 ± 0.04	–
Sucrose-decorated pumice	0.42 ± 0.22	1.96 ± 0.55	6.96 ± 0.03	–

2.2. Experiment design and procedure

To investigate the hydroscopicity of the pumice, two water sorption experiments were detailed below. In the water sorption experiment 1, the mass ratios were 1.2:1, 1:1, 0.8:1, 0.6:1, and 0.4:1 (pumice:sludge), respectively. The MC of the pumice after 2 h and 24 h and the MC of mixture after 2 h were measured. In the water sorption experiment 2, the pumice was mixed with the sewage sludge at the mass ratio of 0.6:1 (pumice:sludge), the MC of the pumice was detected every two hours.

To evaluate the effects of reused pumice and sucrose-decorated pumice on composting progress, three composting experiments were conducted. In the composting experiment 1, the sewage sludge and the pumice were mixed at the mass ratio of 1:0.6 (pumice:sludge). The MC variation of the sewage sludge, pumice and mixture were detected. In the composting experiment 2, fresh pumice (R1) and reused pumice (R2) were used as the bulking agents, respectively. The amount of the reused pumice was same with the fresh one on volume. In the composting experiment 3, fresh pumice (P1) and sucrose-decorated pumice (P2) were mixed with sewage sludge at the mass ratio of 0.6:1 (pumice:sludge).

2.3. Physical and chemical analysis

The amounts of CO_2 and NH_3 emission were measured by titration according to Alkanani et al. (1992) every 24 h. The difference in the weight between before and after drying at 105 °C for 24 h was concerned as the MC of sample. The pH of samples were detected by a pH meter after 5 g sample was dissolved with 50 ml distilled water (Rihani et al., 2010). The dried sample was further heated at 550 °C for 4 h, the weight difference was determined as the VS content (Wang et al., 2011). The dried sewage sludge samples were pestle completely and screened through a mesh size of 200. 5–10 mg residue was wrapped with aluminum foil and accurately weighed to the nearest 0.001 mg. Then the contents of carbon and nitrogen in the sludge were determined by using elemental analyzer (Vario EL, Germany). For scanning electron microscopy (SEM), samples was dehydrated according to the method described by Dresbøll and Magid (2006), coated with gold in a sputter coater (IB-5), examined in the scanning electron microscope (HITACHI S-20).

The MC of pumice was calculated by formulas below. MC_P means the MC of pumice, and M_{PB} means the weight of pumice in mixture before drying. M_{PD} means the weight of pumice in mixture after drying (pumice was easy to be separated from sewage sludge after drying). M_0 means the weight of mixture before drying. M_{SD} means the weight of mixture before drying. MC_S means the MC of sewage sludge.