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Bioleached sludge composting drastically reducing ammonia volatilization as well as decreasing bulking agent dosage and improving compost quality: A case study

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ABSTRACT

Sludge bioleaching technology with *Acidithiobacillus* species has been commercially adopted for improving advanced dewatering of sludge in China since 2010. However, up to now, little information on bioleached dewatered sludge (BS) composting is available. Here, we report the changes of physicochemical and biological properties in BS composting and evaluate compost product quality compared to conventional dewatered sludge (CS) composting in an engineering scale composting facility. The results showed that the amount of bulking agents required in BS composting was only about 10% of CS composting to obtain optimum moisture content, reducing about 700 kg bulking agents per ton fresh sludge. pH of BS composting mixture was slightly lower consistently by about 0.2–0.3 pH units than that in CS mixture in the first 30 days. Organic matter biodegradation in BS system mainly occurred in the first 9 days of composting. In spite of higher content of NH_4^+-N was found in BS mixture in related to CS mixture; unexpectedly the cumulative ammonia volatilization in the former was only 51% of the latter, indicating that BS composting drastically reduced nitrogen loss. Compared to CS composting system, the relative lower pH, the higher intensity of microbial assimilation, and the presence of water soluble Fe in BS system might jointly reduce ammonia volatilization. Consequently, BS compost product exhibited higher fertilizer values ($N + P_2O_5 + K_2O = 8.38\%$) as well as lower heavy metal levels due to the solubilization of sludge-borne heavy metals during bioleaching process. Therefore, composting of BS possesses more advantages over the CS composting process.

1. Introduction

Sewage sludge is becoming available in increasing quantities with the wastewater treatment capacity exceeding 157 million m^3/d by 2014 in China, and then an estimated 100,000 tons of conventional dewatered sludge (CS) with 80% of moisture content will be produced per day (MOHURD, 2014). The way to dispose and utilize sludge needs considerable attention because of its high level of unstable organic matters as well as heavy metals. Composting of sludge seems to be the most attractive and feasible technology, since it converts biodegradable organic matters into a humus-like product, eliminates the risk of spreading of pathogens, reduces the volume of sludge, and satisfies the needs of fertilizer (Bernal et al., 2009). However, CS cake, usually with moisture content in the range of 78–85%, cannot be composted alone. Studies showed that generally 2–3 times volume of bulking agents or dried organic amendments were used to adjust the moisture content to an optimum level (50–60%) and increase air void (Viessman et al., 2008), which lead to large operation areas required, high expense of bulking agents, difficult control of offensive odor, and low nutrient content in compost products (Hoitink and Keener, 1993).

Sludge bioleaching with *Acidithiobacillus* species mainly including *Acidithiobacillus ferrooxidans* has been proved to be an effective process in removing toxic metals and improving advanced dewatering of sludge (Zhou et al., 2006; Zheng and Zhou, 2011; Liu et al., 2012). The first sludge bioleaching plant around the world treating equivalently 50 t/d of CS was operated since 2010 in Wuxi Taihu Xincheng Sewage Treatment Plant, Jiangsu Province, China (Zhou, 2012). Up to now, 11 sludge bioleaching plants are in operation, equivalently with total treatment capacity of 2200 t/d of CS. Liquid bioleached sludge could be directly dewatered mechanically into semi-dried khaki-colored sludge cake with the moisture content of 60% or below without adding any flocculation agents. Moreover, the dewatered bioleached sludge cake (BS) maintained high contents of organic matter, total N and P, calorific

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value, and with low levels of heavy metal content, which is helpful in consequent reutilization of BS (Zhou, 2012). Obviously, composting of semi-dried BS only requires a few of bulking agents to adjust moisture content compare to CS composting, consequently which drastically decreases the pile volume of windrow composting (Hu et al., 2014).

During sludge composting, nitrogen in materials is easily lost through ammonia volatilization due to the decomposition of nitrogenous substances, reducing the fertilizer value of compost product and causing offensive odors (Ogunwande et al., 2008). The emission of ammonia has been reported to be from 21% to 77% of the initial total nitrogen during composting of different bio-wastes (Martins and Dewes, 1992; Eghball et al., 1997). Ammonia volatilization is mainly affected by raw material properties and other factors including pH, carbon/nitrogen ratio (C/N), carbon sources, moisture content, aeration rate and temperature (Li et al., 2013; Jiang et al., 2015). Several researchers have tried to increase C/N ratio, control composting temperature or lower pH value to reduce ammonia emission, because when initial C/N is low, the excess amount of nitrogen will easily volatilize as ammonia at pH > 7.5 and high temperature (Pagans et al., 2006; Zhu, 2007). Other researchers have focused on adding amendments to sequester or neutralize the released ammonia (Darees Boucher et al., 1999; Wang et al., 2013; Yang et al., 2015). Although these approaches are considered effective to achieve nitrogen conservation during composting in lab study, mostly they are difficult to be used in the large-scale engineering projects due to low efficiency and difficulty in inhibiting ammonia emission for opening circumstances. Therefore, it is of great significance to obtain desired sludge compost product with low operation cost and ammonia emission. The way of accomplishing this goal in windrow composting is to reduce the addition of bulking agents and acidify composting materials at the same time. Fortunately, BS are characterized by slightly low pH (pH < 5.5), much lower moisture content (<60%) and high Fe content due to the addition of $FeSO_4$ as energy substance in bioleaching treatment (Huo et al., 2014). It was thus speculated that composting of BS will reduce the required amount of bulking agents and have *in situ* inhibitory effect on ammonia volatilization because of these properties of BS. However, BS composting has hardly been documented in published literatures because a series of engineering application of sludge bioleaching technology with commercial scales started only from 2010 in the world as mentioned above.

Therefore, the objectives of this study were to understand the changes in physicochemical and biological properties of BS composting with windrow system and evaluate its compost product quality with compared to CS composting operated in an engineering scale composting facility.

2. Materials and methods

2.1. Dewatered sludge and bulking agent

CS and BS of same origin were simultaneously collected from Wuxi Xincheng Wastewater Treatment Plant (WXWTP), China, which treats 10×10^4 m^3/d of municipal wastewater. Two types of sludge dewatering systems have been synchronously working in WXWTP since 2010. One was a belt filter press system by which the liquid slurry of thickened sludge was mixed with polyacrylamide and then dewatered to produce CS. The other one was the variable-volume diaphragm filter press system by which the thickened sludge from the same sludge thickener was conditioned by bioleaching and then directly dewatered by using diaphragm press to obtain semi-dryness odorless khaki-colored BS. Bulking agent for composting was a mixture consisting of mushroom residue and rice hull at the volume ratio of 1:1, equal to the fresh weight ratio of 2.5:1. The preliminary properties of these two kinds of dewatered sludge and bulking agent are listed in Table 1.

2.2. Windrow Composting of bioleached sludge and conventional dewatered sludge

Bioleached sludge composting plant (BSCP) with the windrow system in the greenhouse was employed in the study. BSCP, about 10 km away from WXWTP, was built and operated by Wuxi Xinli Bio-tech Co. Ltd. in 2012. To our knowledge, it is the first plant in the world for bioleached sludge composting with a commercial scale of treating 80 t/d of BS. The details of the plant have been described in our previous study (Hu et al., 2014).

In the present study, CS collected from WXWTP was mixed with bulking agents at the volume ratio of 1:2, equal to the fresh weight ratio of 1.2:1, in the receiving area at BSCP to obtain the composting mixture with the moisture content below 60%. The mixture of the composting materials was fed through belt conveyor into crusher to produce a homogeneous mixture. Likely, the composting of BS of the same origin was also performed at the same time at BSCP according to the description mentioned above with an exception of the ratio of sludge to bulking agents. BS was simply mixed with bulking agents at the volume ratio of 1:4, equal to the fresh weight ratio of 11:1, to obtain similar moisture content below 60% for CS composting. Both mixed compost material was arranged in long parallel rows with trapezoidal in cross-sectional shape. The height of each windrow was 1.2–1.3 m, and its bottom width was 2.8 m. The windrows were agitated by periodic turning once every two days in the first two weeks and once every week in the latter stage by using self-propelled windrow-straddling composting machine. To observe the changes of the properties of the compost materials, the composting process were maintained deliberately as long as 39 days until the interior temperature of the piles was approximately equal to the ambient temperature and did not increase after turning. In the period of sludge composting, temperature was *in situ* monitored daily at a depth of 40 cm from the top of the composting piles using multi-probe thermoscope automatograph (ZDR-31, China). The temperature measurements were taken at 09:00 am with 6 points in each pile when the ambient temperature was fairly stable. 15 compost samples were periodically collected from the depth of approximately 20 cm below the surface of composting mass after turning and then mixed to homogeneous triplicate samples. Each fresh sample was divided into two parts. One was stored at 4 °C and determined for pH, conductivity, moisture, water soluble organic carbon (WSOC), water soluble ferrous iron concentration, the concentrations of NO_3^--N and NH_4^+-N, and germination index as soon as possible. Theother one was air-dried and ground to pass through a 1-mm sieve for analyzing organic matter and its components, ash content, total N and total P, etc.

2.3. Analytical method

The aqueous compost suspension was obtained by mechanically shaking the samples with distilled water for 1 h at a fresh sample/water ratio of 1:10 (w/v). The suspensions were centrifuged and filtered through 0.45 μm membrane filters. pH and conductivity were determined using a pH meter (Orion 902 ISE, Thermo, US) and conductivity meter (DJS-1C, China), respectively. WSOC was measured by using a TOC analyzer (TOC-5000A, Shimadzu, Japan). The concentration of water soluble ferrous iron concentration was determined by using 1,10-phenanthroline method (APHA, 2005).

The moisture content was measured by weight loss of the compost sample after drying at 105 °C for 24 h while the ash content was determined by burning at 550 °C for 4 h (Page et al., 1982).