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Effects of adding bulking agents on biostabilization and drying of municipal solid waste

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ABSTRACT

The influence of adding a bulking agent on the bio-stabilization and drying of municipal solid waste (MSW) was investigated. Three treatments were considered: the addition of either cornstalks or wood peat to MSW as a bulking agent before bio-drying and a control treatment that contained no bulking agent. Addition of bulking agents to MSW produced less leachate, higher moisture-removal rates, and consumed less volatile solids. Bulking with cornstalks achieved the highest water-removal rate (0.58–0.65 kg kg^{-1}). The extent of organic degradation was related to temperature integration during bio-drying. Lipids and cellulose were the main components of organic losses in all treatments and adding a bulking agent changed the sequence and extent of degradation of biochemical components. The bio-drying index values were 1.75, 3.18, and 2.64 for MSW alone, MSW with cornstalks, and MSW with wood peat, respectively. Evaporation heat was the main component of heat consumption, accounting for 58.1–60.7% of the total energy consumption.

1. Introduction

In recent years, the generation of municipal solid waste (MSW) has increased considerably with accelerating urbanization in China. Regulations and policies are important tools for MSW management. In China, national policies have addressed waste reduction, recycling, and recovery; for example, the specific policies to "actively promote incineration, sanitary landfill, and other comprehensive utilization (biological treatment and cement kiln coordination technology) of MSW", and to "establish waste separation and collection systems and continuously improve renewable resource recycling systems" (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2010). The National Twelfth Five-Year Plan established a target proportion of safe MSW disposal of 80%, which was to be reached by 2015, and all Chinese counties possess the capacity for this level of safe MSW disposal (The State Council, 2011).

Recent MSW management strategies advocate materials recycling, energy recovery, reduction, and stabilization of MSW before landfill disposal (Adani et al., 2002; Stan et al., 2014; Ionescu et al., 2015; Coventry et al., 2016). Combustion is an effective MSW treatment option that stabilizes waste and maximizes the reduction of waste volume, as well as contributing to sanitation and energy recovery (Liu and Liu, 2005). However, MSW in many developing countries (such as China) is typically characterized by high water content (as high as 75%) because of the relatively high proportion of food waste (>60%) (He et al., 2005; Norbu et al., 2005; Münnich et al., 2006). This high water content lowers the recovery of recoverable material and increases the operating cost of combustion. Landfills are the main MSW disposal method in China; they occupy large amounts of land and produce high levels of secondary pollutants, including leachate, greenhouse gases, and odors (Li et al., 2004). Use of thermal drying enables a product with high solid content to be rapidly obtained; however, in most cases, this technique is neither cost-effective nor environmentally friendly because a nonrenewable energy resource is consumed.

To comply with legislation and manage waste as a resource, a strategic hierarchy is proposed that includes prevention, reuse or recycling, recovery in the form of energy, and disposal by landfilling. The number of incinerators almost doubled from 2006 (71) to 2014 (138) in China (China Statistical Yearbook). In most cases, MSW is incinerated in incinerators without pre-treatment in China because the calorific value of MSW is not suitable for a direct combustion because of its high humidity. A large amount of petroleum and coal are typically added to support combustion. Bio-drying is composting process that has a good potential as a pre-treatment of MSW especially with high concentration of organic waste. The

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bio-drying process was proposed for the first time as a pretreatment before landfilling in the 1990s. Presently this process is gaining traction in Europe, spreading from Germany and Italy and extending its presence in Great Britain and Spain and getting attention in the recent EU countries like Greece. Its success is largely because the process of bio-drying is considered to be a good solution for MSW management, allowing the production of refuse-derived fuel.

Over recent years, the biological pretreatment of MSW is becoming an increasingly applied process, either before landfilling or prior to combustion (Norbu et al., 2005; Nguyen et al., 2007; Rada et al., 2007, 2009a; Ragazzi et al., 2007; Białowiec et al., 2008; Mahar et al., 2009; Dziedzic et al., 2015). Composting and other bio-stabilization processes result in complete degradation of easily degradable volatile solids. Microbial metabolism in the bio-drying process is similar to that for composting; however, the former is aimed towards water removal, while the latter focuses on the bio-stabilization and maturity of composted materials (Sugni et al., 2005; Bezama et al., 2007; Rada et al., 2007). Bio-drying technology, aimed towards removing water by microbial activity, is regarded as a good solution for reducing the water content of wet organic wastes (Choi et al., 2001; Zhang et al., 2009a; He et al., 2010; Rada et al., 2012; Cioranu and Badea, 2013; Rada and Ragazzi, 2015; Tom et al., 2016). Besides having a high water-removal rate, this approach is expected to constrain organic degradation, thereby preserving energy for subsequent utilization, e.g., as residue-derived fuels (Adani et al., 2002).

It is always necessary to add a bulking agent to modify the properties of MSW during composting or bio-drying because of its high moisture content and low C/N ratio.

Cornstalks are common and economical waste materials in most areas of China and have been demonstrated to be a good composting bulking agent in many studies (Yang et al., 2013; Zhang et al., 2013). Wood peat is rich in carbon, mainly in the form of lignins, and has a high density and low moisture content. In contrast, cornstalks contain large amounts of cellulose and hemicellulose. Few studies have focused on the effects of wood peat as an additive in composting or bio-drying.

Bio-drying research has, to date, focused mainly on sewage sludge (Xu et al., 2011; Zhao et al., 2011; Cai et al., 2013). Most studies of MSW bio-drying have been reported by Zhang et al. (2008, 2011). They found that inoculation of products from bio-drying accelerated biodegradation and lowered the final water content (Zhang et al., 2009b). In an earlier study, they indicated that when a hydrolytic stage was supplemented prior to aerobic degradation, more water could be released in the form of leachate, along with hydrolysis or disintegration of volatile solids (Zhang et al., 2008). Production of leachate is, however, prone to causing secondary environmental pollution and it is very expensive to use physical and chemical processes to treat leachate (Rasool et al., 2016; Wang et al., 2016). This differs from combined hydrolytic–aerobic processes in that adding bulking agent can improve the size and number of inter-particle voids in a pile of bio-drying waste, increase air permeability, and decrease (or avoid completely) the amount of leachate produced (Yang et al., 2013; Yuan et al., 2015). Furthermore, adding an organic bulking agent that is rich in carbon to MSW bio-drying could provide a carbon resource and improve the calorific value of the final bio-drying product (Rada et al., 2009b).

To date, most studies of MSW bio-drying have focused on water removal, organic degradation, and calorific value (Adani et al., 2002; Sugni et al., 2005; Rada et al., 2006, 2012; Tambone et al., 2011; Viganò et al., 2011; Bilgin and Tulun, 2015). However, few studies have focused on the water-removal capacity, organic degradation by biochemical components, the bio-drying index, or heat utilization of bio-drying systems. It remains unclear whether addition of a bulking agent can really improve bio-drying performance for MSW with a high initial water content. This study investigated the bio-drying performance of two different bulking agents (relative to a control with no bulking agent) and assessed their impacts on water losses and organic degradation in MSW. In addition, the contributions of degradation of biochemical components to total organic losses and heat generation and utilization during bio-drying were calculated.

2. Materials and methods

2.1. Materials and experimental setup

The MSW feedstock was collected from a sorting collection system at the Majialou MSW transfer station in Beijing, China. The MSW consisted of, by wet mass, 63.46% kitchen waste, 23.93% paper, 5.03% plastics, and 7.58% other materials. Cornstalks were obtained from a research station at the China Agricultural University. They were passed through a cutting mill to produce pieces with sizes of 1–5 cm. Wood peat was obtained from Indonesia and was provided by Sino-View International Co. Ltd. (Beijing, China). The properties of the raw materials are shown in Table 1.

The trials were performed in laboratory column reactors (60 L in volume, 0.6 m high, 0.36 m inner diameter), made of stainless steel (Fig. 1). Each vessel was insulated with two layers of stainless steel to minimize heat loss. A stainless steel cap was fitted on the top of each reactor to facilitate its filling and emptying. A 3-mm stainless steel grid was installed at the bottom of each reactor to support the composting bed and to ensure that the added gases were uniformly distributed. Two holes in the bottom of each reactor allowed the reactor to be aerated (the aeration gas was added using a controllable aquarium pump) and the leachate to drain away. There were three sampling locations with plugs, each 5 cm in diameter, at different heights (0.2, 0.4, and 0.6 m) from the bottom. Two holes in the lid of each vessel allowed a temperature sensor to be inserted and the gas within the vessel to be sampled. An exhaust port (50 mm inner diameter) in the lid of each vessel was connected to a condenser using plastic piping. A jar at the bottom of the condenser enabled collection of condensed water. This experimental setup has been used in previous studies (Guo et al., 2012; Shen et al., 2011).

Three bio-drying trials were conducted. The control treatment, labeled MSW in this paper, comprised 100% MSW without addition of any bulking agent and the other two treatments contained 10% (by wet mass) of one of the bulking agents (cornstalks (CS) or wood peat (WP) and 90% MSW.

Each bio-drying trial operated for 21 days and a forced-draft aeration system was used. All of the systems were continuously aerated at a rate of 0.3 L kg^{-1} min^{-1} (the mass of material being determined on a dry basis). The wastes fed to all of the trials were manually turned every 3 days. The temperature in each vessel was recorded using the *C-LGX* program (Scan-2000x, Hongyuanpengao, China).

2.2. Sample collection and analytical methods

The O_2 and CO_2 contents were monitored daily using a portable biogas analyzer (BIOGAS-5000, Geotech, UK). Leachate and condensate water were collected and weighed every day, recording the mass of the vessels at the same time. A sample (of about 200 g) of the solid material was taken from each vessel at the beginning and end of the composting process, and after each turning procedure had been performed. Each sample was divided into two parts. One part was stored at 4 °C and the other was