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Simultaneous effect of initial moisture content and airflow rate on biodrying of sewage sludge

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ABSTRACT

The simultaneous effect of initial moisture content (initial Mc) and air-flow rate (AFR) on biodrying performance was evaluated. For the study, a 3^2 factorial design, whose factors were AFR (1, 2 and 3 L/min kg_{TS}) and initial Mc (59, 68 and 78% w.b.), was used. Using energy and water mass balance the main routes of water removal, energy use and efficiencies were determined. The results show that initial Mc has a stronger effect on the biodrying than the AFR, affecting the air outlet temperature and improving the water removal, with higher maximum temperatures obtained around 68% and the lowest maximum matrix temperature obtained at initial Mc = 78%.Through the water mass balance it was found that the main mechanism for water removal was the aeration, with higher water removal at intermediate initial Mc (68%) and high AFR (3 L/min kg_{TS}). The energy balance indicated that bioreaction is the main energy source for water evaporation, with higher energy produced at intermediate initial Mc (68%). Finally, it was found that low values of initial Mc (59%) improve biodrying efficiency.

1. Introduction

Biological drying or simply "biodrying", an alternative pretreatment method intended for combustion, has been developed in recent years. Biodrying, which is based on a process similar to composting, aims at removing water from biowastes with high water content using the heat generated during the aerobic degradation of organic substances, in addition to forced aeration (Frei et al., 2004; Navaee-Ardeh et al., 2011; Velis et al., 2009; Zhao et al., 2010).

Among the parameters that affect the biodrying process, initial moisture content (initial Mc) and air-flow rate (AFR) have proven to be the most important ones. Although both have been studied independently, the simultaneous effect of initial Mc and AFR in the process has not been addressed in the studies. A study of the simultaneous effect of these parameters may shed light on which of them has more influence on biodrying performance, information that so far has not been published in the literature. According to the literature, AFR is the main operational variable used for process control in biodrying, both in laboratory (Adani et al., 2002; Navaee-Ardeh et al., 2006; Sugni et al., 2005) and commercial applications. The inlet airflow rate can be manipulated to control matrix temperature, in turn, affecting the air dew point and biodegradation kinetics (Velis et al., 2009). The effect of AFR on biodrying has been studied recently by several researchers. Zhao et al. (2010) studied the effect of air-flow rate and turning frequency on bio-drying of dewatered sludge, showing that the higher air-flow rate, heat consumed by sensible heat of inlet air and heat utilization efficiency for evaporation was higher than the lower one. Cai et al. (2013) showed that forced aeration controlled the pile

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temperature and improved evaporation, making it the key factor influencing water loss during the process of sewage sludge biodrying. Colomer-Mendoza et al. (2013) studied the effect of AFR on the biodrying of gardening wastes, showing that high airflow affects the biodrying process, because the thermophilic phase is avoided, so that the waste is dried only by physical phenomena and not by biodrying. Finally, Sharara et al. (2012) showed that high aeration level was superior in terms of both drying energy and time requirements than the other considered rates. None of these studies worked with different levels of initial Mc, therefore, the effect of both parameters on the biodrying performance should be evaluated.

Moisture is a critical parameter involved in biodrying technology that influences the complex biochemical reactions associated with microbial growth and the biodegradation of organic matter that occurs during the process (Cai et al., 2012; Ryckeboer et al., 2003). The initial Mc is important because an excessively high initial Mc limits oxygen transport and microbial activity is hindered, invalidating the biodrying (Navaee-Ardeh et al., 2011). On the contrary, if initial Mc is too low, microbial activity will be slowed by lack of moisture, which results in reduced drying performance. Recently, Yang et al. (2014) studied the effect of initial Mc in the biodrying process. They showed that 50–70 wt% was the optimal initial Mc range for the sludge biodrying process, with VS reduction between 12.3 and 21.2%; however, they worked at only one constant air flow rate. Other studies in composting process (Komilis et al., 2011; Liang et al., 2003; Petric et al., 2009; Tremier et al., 2009) also showed the critical importance of initial Mc in the biodegradation process.

One of the variables that should be taken into account in biodrying is the outlet air temperature. The increased outlet air temperature (as a consequence of the microbial activity) allowed the air to hold greater quantities of moisture, thus increasing the drying rate (Frei et al., 2004; Navaee-Ardeh et al., 2006). Several researchers have developed mass and energy balance by supposing that the outlet air temperature is equal to that of the matrix temperature (He et al., 2013; Yang et al., 2014; Zhao et al., 2010); however, the outlet air temperature is not necessarily equal to the matrix temperatures, depending mainly on the AFR value (Navaee-Ardeh et al., 2011). To date, only Frei et al. (2004) present values of outlet air temperatures, working with these values using only one AFR. Therefore, the effect of AFR and initial Mc on the outlet air temperature is one of the goals of this work.

In light of the above, the study of the simultaneous effect of both initial Mc and AFR, on the biodrying performance has not been presented so far. Thus, this work focuses on investigating the interactive influence of these two parameters on outlet air temperature, water removal and energy utilization of dewatered sludge as a biomass resource. As a result of the mass and heat balance calculation, the water holding capacities of air-flow and heat uses were clarified.

2. Materials and methods

2.1. *Characteristics of the raw material*

Dewatered secondary sludge was obtained from a slaughterhouse wastewater treatment plant in Puente Alto, Santiago, Chile. Sludge was dewatered by screw filter with the addition of organic flocculating agents. Wood shavings of 2.5 mm in average diameter were used as bulking agent. The characteristics of the raw materials are presented in Table 1.

2.2. *Experimental equipment and process operation*

The biodrying experiments were performed in three 64 L cubic reactors (40 cm in height, 40 cm in width, and 40 cm in length) made of acrylic plastic connected to data acquisition system OPTO22. Heat losses were reduced by wall insulation provided by a 5 cm layer of polyurethane foam. A perforated baffle with a 2 mm mesh was fixed above the bottom to support the material and facilitate aeration. Temperature measuring ports were set in the middle of the reactor. The temperature and relative humidity of the inlet and outlet air were measured each 15 min using a series HMP110 humidity and temperature transmitter (Vaisala, Vantaa, Finland) with ±0.1 °C and ±1.5% accuracy, respectively. A constant and uninterrupted air-flow rate was used in all the assays using a mini-compressor (150 L/min, ACO-012, China) connected to the bottom of the column, while a rotameter (1–10 lpm, Veto, Santiago, Chile; 4–40 lpm, Veto, Santiago, Chile) was used to measure the air flow rate. In the reactors, matrix temperatures were measured each 15 min through a heat-resistant temperature electrode (Pt100, Veto, Chile), placed in the middle of substrate and in the inlet of bioreactor. All the sensors were connected through the acquisition module SNAP PAC OPTO22 (California, USA) on a PC. The schematic representation of the laboratory bioreactor is shown in Fig. 1.

The biodrying process was studied through a 3^2 factorial design, whose factors were air flow rate AFR (1, 2 or 3 L/min kg_{TS}) and initial Mc (59, 68 and 78% w.b.). The AFR levels were chosen based on the work of Huilinir and Villegas (2014), while the initial Mc values were chosen according to values reported by Yang et al. (2014) and Petric et al. (2009). Table 2 shows the experimental matrix.

When the matrix temperature was close to the environmental temperature, the reactors were weighed. The matrix was removed from the reactors and loaded again after mixing for 30–60 min, as recommended by Zhao et al. (2010). Weight loss, which is directly related to the loss of moisture and VS from the sample, was measured using a portable scale.

Before the material was loaded again into the bioreactor, three 10 g samples of mixed waste were collected to measure moisture content and volatile solids (VS) of the matrix.

2.3. *Analytical and statistical methods*

The dry matter content was determined by drying the sample at 105 °C for 24 h in an OV-180 Blue M (Stabil-Therm, USA) oven. The difference between the initial and final weights was the water content or the moisture content of the solids. The volatile solids content (VS) was analyzed by heating the sample at 550 °C for 5 h in a muffle furnace.

Nitrogen content was determined by the total Kjeldahl nitrogen method, using the modified.

Nessler method (method 8075), with 0.25 g of homogenized material. Digestion was first done using digester Digesdahl Hach (HACH, USA), based on a single total digestion of organic