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Effect of inoculation time on the bio-drying performance of combined hydrolytic–aerobic process

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ABSTRACT

The study aimed at investigating the effects of inoculation time on the bio-drying performance of combined hydrolytic–aerobic process. Results showed that the addition of inoculating material at different time exhibited various effects not only on the degradation rate of total organics, but also on the performance of water removal and water content reduction. The beginning of aerobic stage (day 5) was suggested to be the optimal time for inoculation. Under this operational condition, 815 g/kg-W_0 (W_0 = initial water content) was removed and the water content reduced from the initial 72.0% to 48.5%. Adding inoculating material at the start of hydrolytic stage (day 0) reduced water removal and water content reduction rates. The addition of inoculating material at day 7 or 9 could not improve the bio-drying performance significantly. Additionally, the inoculation at days 0, 5, 7 and 9 enhanced lignocelluloses degradation rate by 3.8%, 11.6%, 7.9% and 7.7%, respectively.

1. Introduction

The high water content of municipal solid waste (MSW) will reduce the efficiency of its energy recovery and the feasibility of mechanical separation for beneficial utilization. The bio-drying technology is regarded as a good solution to reduce water content of MSW (Adani et al., 2002; Choi et al., 2001; Rada et al., 2005; Sugni et al., 2005). The microbial metabolism for the bio-drying process was similar to that for the composting process. However, the former aimed at the water removal, while the latter focused on the bio-stabilization and maturity of composted materials. Therefore, the strategy of controlling air-flow rate at a relatively fixed value was usually taken for the former, while feedback control based on O_2 content or temperature was used commonly for the latter. Nowadays, a combined hydrolytic–aerobic bio-drying process has become of great interest (Bezama et al., 2007; Zhang et al., 2008). The combined process is characterized by supplementing a hydrolytic stage prior to the aerobic degradation, so that the cell wall or membrane can be destructed with less organics consumption. By this way, the ratio of water content to biodegradable organics is expected to be lowered and thus be favorable for water evaporation during the aerobic stage.

Inocula are usually added at the initial degradation stage and can intensify the aerobic degradation of substrates (Bolta et al., 2003; Vargas-García et al., 2007; Wei et al., 2007; Xi et al., 2005). For the combined bio-drying process, two stages (the hydrolytic and aerobic stages) are involved and the shift between these two stages may lead to the replacement of the dominant microorganisms. Besides, with the evolution of bio-drying, not only the quantity of specific microorganisms and their abilities to degrade substrates, but also the availability of substrates and environmental conditions for microbial growth are different. Therefore, the inoculation time would affect the degradation rate of total organics. Consequently, the performance of water removal and water content reduction may also depend on the inoculation time. Until now, it is unknown how the inoculation time influences the performance of water removal or water content reduction for combined hydrolytic–aerobic process.

This study investigated the effects of inoculation time on the performance of water removal and water content reduction, in order to optimize the inoculation operation of the combined hydrolytic–aerobic process. The activities of extracellular enzymes and the quantity of microorganisms during bio-drying were monitored to explain the bio-drying performance from the viewpoints of enzymolysis and microbiology.

2. Methods

2.1. Characteristics of the MSW feedstock

The MSW was sampled from a residential area in Shanghai, China. It comprised 60% (w/w, in wet weight, the same below) of kitchen waste, 23% (w/w) of paper, 11% (w/w) of plastics and 6% (w/w) of other components. The initial water content was 72%

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Table 1
Biochemical composition and microorganism numbers of sampled wastes and inoculating material

Parameters	Unit	feedstock	Inoculating material
Amylums	g/g-TS	0.42 ± 0.028	0.12 ± 0.008
Proteins	g/g-TS	0.12 ± 0.013	0.05 ± 0.001
Lipids	g/g-TS	0.12 ± 0.009	0.02 ± 0.001
Celluloses	g/g-TS	0.15 ± 0.009	0.34 ± 0.014
Hemicelluloses	g/g-TS	0.01 ± 0.001	0.01 ± 0.001
Lignins	g/g-TS	0.05 ± 0.007	0.08 ± 0.008
Ash	g/g-TS	0.13 ± 0.008	0.38 ± 0.026
Bacteria	CFU[a]/g-DM	1.91×10^9	1.43×10^9
Fungi	CFU/g-DM	1.62×10^7	2.30×10^6
Actinomycetes	CFU/g-DM	1.78×10^7	8.64×10^6
Celluloses degraders	CFU/g-DM	2.18×10^6	3.07×10^7

[a] CFU: colony forming units.

(w/w). The biochemical composition and microorganism numbers of the feedstock with plastics, glasses and metals removed are given in Table 1.

2.2. Characteristics of the inoculating material

The inoculating material (Table 1) was collected from the products of the bio-drying process, with all plastics, glasses and metals removed. The initial water content was 39% (w/w).

2.3. Experimental equipment

The trials were performed in laboratory column reactors, as previously reported (Zhang et al., 2008). Each column was 1200 mm high and 400 mm internal diameter. The outer wall of the column was wrapped with 100-mm-thick hollow cotton for thermal insulation. A 100 mm high layer, filled with crockery balls (diameter about 5 mm), was placed at the bottom of each column for leachate drainage and air distribution. Above the balls, there was a perforated baffle (2-mm mesh) to support the waste and to facilitate aeration. Straw and cotton layers covered above the waste to avoid heat loss and vapor condensation. A whirlpool pump (XGB-8, Penghu Co., Shanghai, China) and a gas-flow meter (LZB-10, Shanghai Instrument Co., Shanghai, China) were used for aeration.

2.4. Experimental setup and operation

Five trials were setup during bio-drying. The whole bio-drying process lasted for 16 days and was separated into two stages, i.e. the hydrolytic and aerobic stages. During the hydrolytic stage (0–4 days), ventilation interval was 10 min run/230 min stop. During the aerobic stage (5–16 days), the ventilation intervals of all trials were enhanced to 7 min run/23 min stop and the wastes were manually turned every 2 days. The air-inflow rate was fixed at 0.056 m^3 per kg wet wastes per hour during the whole experiment. The inoculating material was added into the column at a ratio of 1:9 (w/w, in wet weight). However, the inoculation time varied for different trials. These trials were: (1) trial A (TA), inoculated at day 0; (2) trial B (TB), inoculated at day 5; (3) trial C (TC), inoculated at day 7; (4) trial D (TD), inoculated at day 9; and (5) control (CK), without inoculation. The detailed operational conditions of the five trials are listed in Table 2.

2.5. Experimental monitoring

The processes were monitored daily for temperature, oxygen (O_2) concentration in gas and leachate quantity. Temperature was monitored by a thermometer (WMY-01C, Huachen Co., Shanghai, China) with sensors located at the top, middle and bottom points along the longitudinal axis of the column, and the average value was reported. A probe (CYS-1, Xuelian Co., Shanghai, China) was placed at the same points as the middle one of thermometer to measure O_2 concentration before ventilation. The leachate produced from the column was collected and weighed.

2.6. Sampling and analytical methods

Every 2 days, samples of about 300 g were collected from different depths of the column (top, middle and bottom) and mixed for analysis when the fed materials were turned. Thus, considering the overall weight of waste, only about 5% was sampled during the whole bio-drying. Water contents, volatile solids (VS), biochemical compositions (amylums, proteins, lipids and lignocelluloses) and extracellular enzyme activities (amylase, protease, lipase, FPase, i.e. filter paper cellulase, and CMCase, i.e. carboxymethyl cellulase), as well as the numbers of microbial populations (including bacteria, fungi, actinomyces and celluloses degraders) were analyzed in triplicate for all samples with standard deviations less than 10%. Moreover, the calibration curves were established each time when the extracellular enzyme activities were determined.

2.6.1. Physico-chemical analysis

The pH and total organic carbon (TOC) of the collected leachate were determined by using a pH meter and a TC/TN analyzer (multi N/C 3000, Analytikjena, German).

The water content of the wastes was determined by air-drying at 70 °C for 48 h. VS was analyzed by loss on ignition at 550 °C to the constant weight. The determination of celluloses, hemicelluloses and lignins was based on the measurement of neutral detergent fiber, acid detergent fiber and ash contents of the samples (Faithfull, 2002). For the measurement of amylums, the air-dried solid sample was firstly digested by the aether, ethanol and boiled HCl solution (6 mol/L) in sequence, and then titrated with alkaline copper tartrate (Faithfull, 2002). The lipids concentration was determined gravimetrically after Soxlett extraction with petro-

Table 2
Control conditions of the bio-drying trials

Conditions	Unit	TA	TB	TC	TD	CK
Inoculum addition time	–	day 0	day 5	day 7	day 9	–
Initial weight	kg	32	32	32	32	32
Initial density	kg/m^3	212	212	212	212	212
Ventilation flow rate[a]	$m^3/(kg\ h)$	0.056	0.056	0.056	0.056	0.056
Time in hydrolytic stage	days	4	4	4	4	4
Ventilation interval in hydrolytic stage	min run/min stop	10/230	10/230	10/230	10/230	10/230
Ventilation interval in aerobic stage	min run/min stop	7/23	7/23	7/23	7/23	7/23
Turning frequency in aerobic stage	–	1 time per 2 days	1 time per 2 days	1 time per 2 days	1 time per 2 days	1 time per 2 days
Inocula to wastes ratio	w/w	1:9	1:9	1:9	1:9	1:9

TA: inoculated at day 0; TB: inoculated at day 5; TC: inoculated at day 7; TD: inoculated at day 9; CK: without inoculation.
[a] $m^3/(kg\ h)$: supplied air quantity (m^3) per kg wet waste per hour.