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Study on dynamics model of Biodegration of organic matter in aerobic mesophilic composting reactor for sanitary disposal of human feces

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Abstract. Aerobic composting is a method for sanitary disposal of human feces as has been used in bio-toilet systems. As the composting method can be used at family in city to save water and to control water pollution, it would be favorable if the composting process could be controlled for easily orperating and saving energy as far as possible. In this study, batch experiments were conducted using a closed aerobic composting reactor with sawdust as the bulky matrix to simulate the condition of a bio-toilet for sanitary disposal of human feces. Attention was paid to the Biodegration property of organic matter. Under a controlled condition of temperature at 35℃(near composting condition at home without heating), moisture content at 60%, and continuous air supply, more than 63% fecal organic removal was obtained in a two-week composting period. Based on assumptions that the organic matter of feces was invided into two parts included degradation and undegradation, the organic matter's biochemical degradation of similar level 1 dynamics model can build. Using the experimental data of composting reaction under mesophilic composting conditions, calculated out respectively reaction kinetics constants 0.2684. Without an automatically controlled heating system, mesophilic composting could be considered to also keep more than 63% fecal organic removal, while proloogting maturity period of compost.

Keywords: composting reactor, human feces, aerobic mesophilic composting.

1. Introduction

Aerobic composting has been recognized as an applicable method for sanitary disposal of human feces in a bio-toilet system [1]. It draws attention especially from regions and areas where provision of sufficient water for toilet flushing is difficult due to water shortage [2]. In order to maintain a hygienic condition for using the bio-toilet, special measures are often taken for its operation such as (a) to preload bulky matrix, e.g. sawdust particles, acting as shelters for microorganism growth and providing void space within their porous structure for ventilation, (b) to fully mix the feces with bulky matrix for maintaining a homogeneous reaction condition, and (c) to provide, as far as possible, a thermophilic condition under which extra liquid entered the composting reactor can quickly evaporate and more importantly pathogenic microorganisms such as fecal coliforms, viruses and ascarid eggs can be effectively inactivated. The operational temperature for the commercial bio-toilet has thus been recommended as 50-60 ^{o}C through an automatically controlled heating system [3].[1]

Many studies have so far been conducted on the characteristics of aerobic composting for sanitary disposal of human feces. Attentions are mainly given to the process of biodegradation in which organics and fecal nitrogen are decomposed or transformed under the action of microorganisms, and the effect of pathogen inactivation which is the most important issue from the sanitary viewpoint under thermophilic condition. A thermophilic condition ranging from 50^{o}C up to 65^{o}C have been recognized to be optimum both for obtaining the best biodegradation effect [4] and effective removal of E. coli and other pathogens [5-7]. Some studies have indicated that addition of mixtures, as bulky matrices or composting additives, is important for maintaining an aerobic condition and greatly influences the organic decomposition and nitrification process [8, 9]. The mixtures with high lignocellulose contents, such as sawdust which in most cases is less biodegradable than other additives, can decrease nitrogen loss in the composting process [10, 11]. As the composting products can be utilized as fertilizers, it would be favorable if the composting condition could be well controlled for holding fecal nitrogen as far as possible in the composts. In different studies using sawdust as bulky matrices for feces composting, nitrogen losses are reported in a wide range from less than 50% to as high as 94% [7, 12, 13] depending on the composting conditions. Fecal nitrogen may be categorized into three parts as initially inert one, slowly biodegradable one, and inert one reproduced by endogenous respiration of heterotrophic microorganism, and those remained in the composts are the sum of the first and the third parts [14]. However, the process of biodegradation of fecal organic matters during aerobic composting is still a topic needing detailed investigation [10, 13-16].

Our previous work on a prototype bio-toilet for sanitary disposal of human feces shows that high percent fecal organic matters could be well biodegraded in the composts under thermophilic condition [7, 17]. In order to gain understanding on the process of biodegradation of organic matters of fecal in the composting process and the characteristics of their biodegradation under an aerobic mesophilic condition, an experimental study was conducted using a specially designed device. Attention was mainly paid to the process of biodegradation of organic matters of fecal in the composting process and the characteristics of their biodegradation.

2. Materials and methods

2.1. Experimental device and raw materials

The experimental device used in this study is a closed composting reactor as shown in Fig. 1. The reactor chamber is a polymethyl methacrylate cylinder with inner diameter as 10 cm and height as 55 cm. An outer jacket space is provided as a water bath where hot water is circulated through a pump connecting to the thermo controlled water heater. A hand-driven shaft with agitation blades is mounted horizontally in the reactor for intermittent mixing. An air diffuser is set at the bottom of the reactor for introducing a constant air flow through the air supply unit. An exhaust pipe on top of the reactor is connected to a water cooled condensing unit where vapor is condensed and gas is led to an ammonia absorber containing sulfuric acid solution for absorbing the exhausted ammonia gas from the reactor. The bulky matrix used in this study was sawdust from a local timber processing plant. The main components of the sawdust were cellulose (about 44%), hemicellulose (about 18%) and lignin (about 35%). It was found in previous study that these lignocellulose substances were non-biodegradable and could keep a stable state after using for several months in a composting reactor [18, 19]. The human feces used in this study were collected from the university campus under the assistance of students. In order to keep the initial quality of the feces identical in different experimental runs, the collected substances were well mixed, divided into equal quantity stocks, and preserved at -20^{o}C for later use. The physicochemical properties of the sawdust and feces are shown in Table 1 regarding their moisture content, organic solid content (S_{org}), total organic carbon (TOC), chemical oxygen demand (COD), total nitrogen content (N_{tot}) and its organic and inorganic parts (N_{org} and N_{ino}). These contents were calculated on dry solid weight basis as g/kg for either sawdust or feces.

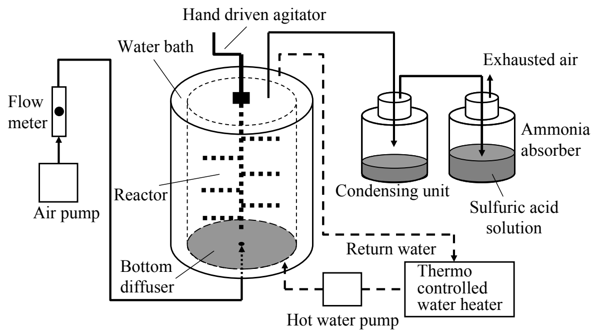

Fig.1 Diagram of the experimental composting reactor

Table 1 Physicochemical properties of the sawdust and feces used in the experiment

item	moisture content %	S_{org} g/kg	TOC g/kg	COD g/kg	N_{tot} g/kg	N_{org} g/kg	N_{ino} g/kg
sawdust	11.1	956.9	378.1	1270.3	2.10	2.10	0
feces	81.8	901.0	497.9	1671.3	68.23	55.94	12.29

For each experimental run, human feces was mixed with sawdust particles to a dry weight ratio of feces/sawdust as 1:4 following our previous experience of using sawdust as the solid matrix in the bio-toilet system [7, 11, 17]. The total wet weight of the mixture was 1 kg. As the sawdust particles were almost inert in the composting reaction, their main function was to provide void space within their porous structure for ventilation, and the dry weight ratio of 1:4 was found to be the limit condition above which the aerobic composting condition might become difficult to maintain.

2.2. Operation conditions

The feces and sawdust with dry weight ratio of 1:4 was adjusted to 60% using deionized water. During the composting operation, the condensed water collected in the condensing unit (Fig. 1) was sent back to the reactor daily for maintaining the moisture content. From the thermo controlled water heater, hot water with a constant temperature of 35^{o}C was circulated between the heater and the water both (Fig. 1) so that a constant temperature was kept in the reactor. The composting period for each experimental run in this study was set as 14 days[12]. In order to maintain a completely aerobic condition in the reactor, air flow was controlled as 0.4 $m^3min^{-1}kg^{-1}$ for feces composting in this study. Intermittent mixing of the composting mixture was provided throughout the composting process by operating the hand mixer mounted in the reactor (Fig. 1) for about 2 min in every 8 hours for keeping the mixture in a homogeneous condition following the practice of normal composting operation[8].

2.3. Sampling and Analytical methods

The composting mixture was sampled everyday during the composting process after completely mixing the mixture in the reactor. The wet weight of each sample was 10 g which took 1% of the total substance in the reactor. The daily loss of mixture by sampling was accounted in material balance calculation in this study. Each sample was immediately stored at -20^{o}C for analysis later. Each sample of the composting mixture was dried at 105^{o}C following the standard method [20]. The organic solid content (S_{org}) was analyzed by drying the sample at 600^{o}C [20]. Organic matter analysis was conducted regarding COD and TOC. The COD was analyzed by a modified fast digestion-spectrophotometric method [12, 21] and calculated on dry solid basis. The TOC was measured directly using Shimadzu SSM-5000 with TOC-Vcph analyzer. The measured organic contents contributed by the sawdust were exempted from the final calculation of fecal COD and TOC contents on dry weight basis as g/kg.

3. Results and discussion

3.1. General performance of the composting reactor for fecal organic matters decrease

As shown in Fig. 2, the composting reactor performed organic degradation well in the experimental period under the aerobic mesophilic condition. Total solid matters(S_{tot}) of feces included organic matters(S_{org}, about 82% of S_{tot}) and inorganic matters(S_{ino}, about 28% of S_{tot}). Feces organic matters was quckly degraded and decreaed under aerobic condition in first 12 days. Removal of organic matters reached 51% of S_{tot} and 64% of S_{org}, the organic matter of feces was invided into two parts included degradation and undegradation. As shown in Fig. 3, the composting reactor performed organic degradation well in the experimental period under the aerobic mesophilic condition. Taking COD content as an indicator of the fecal organic matter, it was almost halved in the first two days and the final removal of 73.5% was achieved after 12 days composting. The final TOC removal was also about 71.7%. The COD or TOC removal was apparently accompanied by a decrease of S_{org} which was finally reduced by about 68%. Removal of organic matters reached 71% of COD、67% of TOC and 64% of S_{org}, It indicated again that the organic matter of feces was invided into two parts included degradation and undegradation.

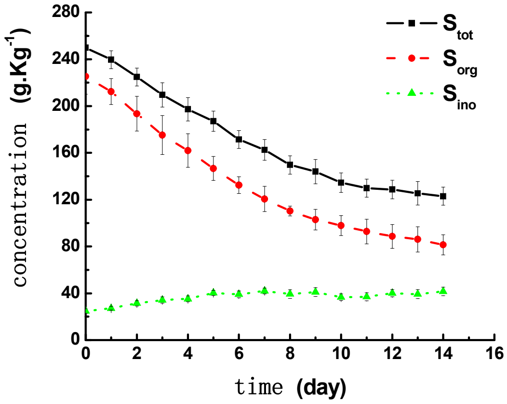

Fig. 2 Variation of fecal solid contents

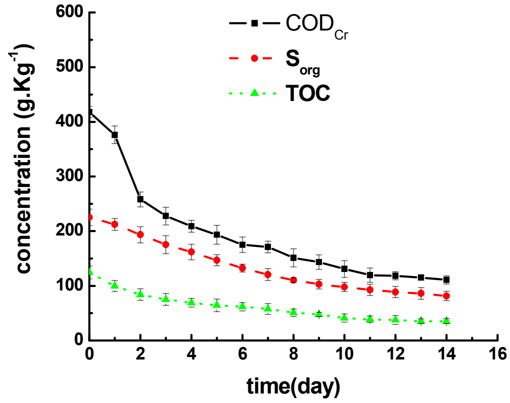

Fig. 3 Variation of fecal organic contents

3.2. biochemical degradation of similar level 1 dynamics model

Based on assumptions that the organic matter of feces was invided into two parts included degradation and undegradation, the organic matter's biochemical degradation of similar level 1 dynamics model can build.

$$C_0 = C_{0a} + C_{0b} \tag{1}$$

C_{0a}: initial biodegradated organic matters, C_{0b}: initial unbiodegradated organic matters.

The only biodegradable organic matter taked part in reaction in the composting process, the process of the biodegradation of organic matter was level 1 dynamics model,

$$\frac{d(C - C_{0b})}{dt} = -k(C - C_{0b}) \tag{2}$$

Initial conditions: $t=0$, $C=C_0=C_{0a}+C_{0b}$, on the integration of (2):

$$C - C_{0b} = (C_0 - C_{0b})e^{-k(C-C_{0b})} \tag{3}$$

Simplified: $$C = Ae^{-kC} + C_{0b} \tag{4}$$

In above Equation: $$A = (C_0 - C_{0b})e^{kC_{0b}} \tag{5}$$

Using the experimental data(COD) of composting reaction under mesophilic composting conditions, calculated out respectively reaction kinetics constants 0.2684 and $r^2=0.9850$.

$$C = 310.48374 ? EXP(\ 0.2684c) + 106.85345 \tag{6}$$

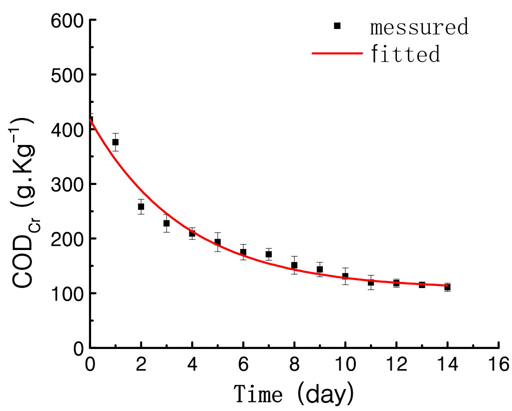

Fig.4 Variation of fecal COD in the composting process

4. Conclusions

This study investigated biodegration property of organic matter in an aerobic mesophilic composting reactor using sawdust as bulky matrix. Under a controlled condition of temperature at 35^{o}C, moisture content at 60%, and continuous air supply, more than 68% fecal organic biodegradation was obtained. By subdividing the fecal organic matters into biodegraded content and unbiodegraded content, the organic matter's biochemical degradation of similar level 1 dynamics model can build, Using the experimental data(COD) of composting reaction under mesophilic composting conditions, calculated out respectively reaction kinetics constants 0.2684 and r^2=0.9850. it was found that the similar level 1 dynamics model well reflect the amount of organic matters reduced in the same period.

5. Acknowledgement

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