Bioresource Technology 140 (2013) 131–137

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Comparison of sludge digestion under aerobic and anaerobic conditions with a focus on the degradation of proteins at mesophilic temperature

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HIGHLIGHTS

- Protein degradation mainly limited by hydrolysis under aerobic condition.
- Protein degradation limited by hydrolysis and metabolism under anaerobic condition.
- Humification degree of aerobic digested sludge was greater than anaerobic one.

ARTICLE INFO

Article history:
Received 25 March 2013
Received in revised form 19 April 2013
Accepted 20 April 2013
Available online 28 April 2013

Keywords:
Waste activated sludge
Aerobic digestion
Anaerobic digestion
Protein
Humification

ABSTRACT

Aerobic and anaerobic digestion are popular methods for the treatment of waste activated sludge. However, the differences in degradation of sludge during aerobic and anaerobic digestion remain unclear. In this study, the sludge degradation during aerobic and anaerobic digestion was investigated at mesophilic temperature, focused on protein based on the degradation efficiency and degree of humification. The duration of aerobic and anaerobic digestion was about 90 days. The final degradation efficiency of volatile solid was 66.1 ± 1.6% and 66.4 ± 2.4% under aerobic and anaerobic conditions, respectively. The final degradation efficiency of protein was 67.5 ± 1.4% and 65.1 ± 2.6% under aerobic and anaerobic conditions, respectively. The degradation models of volatile solids were consistent with those of protein under both aerobic and anaerobic conditions. The solubility of protein under aerobic digestion was greater than that under anaerobic digestion. Moreover, the humification index of dissolved organic matter of aerobic digestion was greater than that during anaerobic digestion.

1. Introduction

Waste activated sludge (WAS) is an inevitable by-product of the biological, physical and chemical processes in wastewater treatment plants (Appels et al., 2008). The treatment and disposal of WAS is a problem of growing importance, representing up to 50% of the current operating costs of wastewater treatment plants (Appels et al., 2011; Higgins and Novak, 1997). WAS is comprised of a microbial consortium and organic and inorganic matter held together in a matrix formed by exocellular biopolymers and cations (Murthy and Novak, 1999). Owing to the high water content and presence of putrescible organic matter, WAS must undergo treatment to guarantee its stability and reduce its corresponding volumes before final disposal.

Aerobic and anaerobic digestion are popular methods of WAS treatment (Hall, 1995). However, studies of these techniques conducted to date have focused on their ability to improve the dewatering characteristics and reduction efficiency of WAS (Devlin et al., 2011; Yang et al., 2011, 2010; Rasheda et al., 2010; Li et al., 2008). No matter aerobic or anaerobic digestion, the degradation of organic matter is the basic process influencing the digestion efficiency. Novak et al. (2003) found that the concentration of dissolved protein and polysaccharides was greater under anaerobic digestion than anaerobic digestion. Moreover, Tomei et al. (2011a) found that dissolved proteins and polysaccharides showed obvious accumulation under anaerobic digestion, but were notably reduced under aerobic digestion. Tomei et al. (2011b) observed that the concentration of protein and polysaccharides increased in the anaerobic phase, but decreased in the subsequent aerobic phase. By using the excitation–emission matrices (EEM) spectra method, Ramesh et al. (2006) showed that protein and humic substances

Abbreviations: WAS, waste activated sludge; EEM, excitation–emission matrices; DOM, dissolved organic matter; TS, total solids; VS, volatile solids; HIX, humification index; HA, humic acid; FA, fulvic acid; HyI, hydrophilic.

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http://dx.doi.org/10.1016/j.biortech.2013.04.081

declined in relative intensities after digestion, and that aerobic digestion was more effective than anaerobic digestion. However, these studies lack a comparison of the degradation properties of the organic matter during different stages of WAS aerobic and anaerobic digestion, which is necessary to provide a fundamental basis for improving digestion efficiency by combined digestion.

WAS digestion primarily occurs via the degradation of macromolecular organic matter. Protein, polysaccharides and humic substances are the major components of macromolecular organic matter in WAS (Wilen et al., 2003), among which protein is the dominant component, accounting for 50% of the total WAS organic matter (Jimenez et al., 2013). The first-order rate coefficient for protein is usually smaller than that of carbohydrate (Christ et al., 2000).

Owing to deficiencies in parallel comparison studies of the degradation of WAS organic matter, it is difficult to gain a deep comprehension of the difference between aerobic and anaerobic degradation of WAS organic matter. In this study, a parallel experiment method was used to measure the protein solubility and fluorescence EEM properties of dissolved organic matter (DOM). The overall objectives of this study were: (1) to investigate the aerobic and anaerobic digestion degradation of WAS protein at mesophilic temperature; (2) to present humification characteristics of sewage sludge during aerobic and anaerobic digestion at mesophilic temperature.

2. Methods

2.1. Materials

The same WAS was used for both digestion modes. WAS was obtained from the aeration tank of a local domestic wastewater treatment plant in Shanghai, China. The capacity of the plant was 75,000 $m^3\ d^{-1}$ and it employed an anaerobic–anoxic–oxic process. After being collected and passed through a 1.2 mm screen, WAS was centrifuged at 2000×*g* for 10 min. The sediments were then suspended in the supernatant of sludge to adjust to the required concentration. Mesophilic seeding sludge with a total solids (TS) of 14.6% and volatile solid (VS) was 88.8% of the TS was collected from an anaerobic internal circulation reactor of a local paper mill, and crushed before seeding.

2.2. Aerobic and anaerobic digestion incubation

All batch operations were carried out in vessels with each effective volume of 12 L (No. 2600-0012, Nalgene, USA). Table 1 shows the characteristics of the mixture sludge in the vessels.

During aerobic digestion, continuous aeration was conducted using an aeration pump, a gas-flow meter and two micro porous diffusers (placed at the bottom of the reactor). A gas flow meter was connected before the diffusers to control the ventilation rate at approximately 1.2 $m^3\ h^{-1}\ kg^{-1}$ (dry basis), which was selected to ensure aerobic conditions. The moisture loss was then replenished by adding distilled water to the reactor daily to maintain the original volume (subtracting the volume of sample). The reactors were then incubated at 35 ± 1 °C for about 90 days and a peristaltic pump (120 rpm) was used to provide internal circulation for mixing.

For anaerobic digestion, after being inoculated with mesophilic seeding sludge at 10% (w/w) VS of the WAS, and diluted with water at a ratio of 1:2 to ensure good mechanical mixing condition, the reactors were sealed and flushed with nitrogen gas for 1 min to induce anaerobic conditions. The reactors were then incubated at 35 ± 1 °C for about 90 days, during which time they were mixed with an airtight stirrer (240 rpm).

All tests were conducted in duplicate, and the data shown in this paper were the averages based on two parallel experiments.

2.3. Analytical methods

Sludge samples were collected from the reactors using a peristaltic pump at different intervals. In addition, the filtrate (0.45 μm, microfiber filter) of the supernatant (2000×*g*, 10 min) of sludge samples was collected as liquid samples.

Determination of the TS content of sludge samples was conducted by drying the samples at 105 °C for 24 h, while the VS content of the sludge samples was determined by heating the samples at 600 °C for 2 h. Total organic carbon (TOC), inorganic carbon (IC) and total nitrogen (TN) of liquid samples were analyzed using a TC/TN analyzer (TOC-V CPN, TNM-1, SHIMADZU, Japan). Kjeldahl nitrogen (KN) and ammonia nitrogen (AN) were analyzed using an auto Kjeldahl determination system (8400, FOSS, Sweden) for sludge samples and liquid samples. Protein was calculated by multiplying the concentration of organic nitrogen (ON) (KN–AN) by 6.25. Polysaccharides was measured by the Anthrone method using glucose as a standard (Gaudy, 1962).

2.4. Protocol for the extraction of sludge protein

Protein solubility determined by a thermochemical method was used to characterize the degradability of protein of sludge during aerobic and anaerobic digestion. The effect of thermochemical pretreatment on WAS is to promote hydrolysis and to split complex organic polymers into simpler constituent molecules (Stuckey and McCarty, 1978; Whiteley et al., 2002). Thermophilic enzymatic hydrolysis of sludge can further disrupt sludge extracellular polymer matrix, which resulted in enhanced solubilization of the sludge, including protein (Whiteley et al., 2002).

Briefly, sludge samples were centrifuged at 2000×*g* for 10 min, after which the sediments were diluted 15 times (m/m) using distilled water. The diluted sediment was then mixed by vortexing for 1 min (XW-80A, Shanghai, China), after which it was incubated at 60 ± 1 °C in a thermostatic water bath for 5 h. Protein extraction efficiency was defined as the protein concentration of the liquid sample divided by the protein concentration of the diluted sediment before incubation.

2.5. Fluorescence measurement

Fluorescence EEM was measured on a fluorescence spectrophotometer (Cary Eclipse, Varian, USA) in scan mode. EEM spectra were gathered from scanning emission spectra from 250 to 500 nm at 2 nm increments by varying the excitation wavelength from 200 to 450 nm at 10 nm increments.

In this study, the fluorescence regional integration (FRI) technique was employed to analyze the five excitation–emission re-

Table 1
Characteristics of the initial material in the vessels (mg/L, except pH).

	pH	VS	TS	AN	KN	Protein
Aerobic	6.38 ± 0.00	17,260 ± 10	22.870 ± 10	197.7 ± 9.3	1523 ± 17	8283 ± 49
Anaerobic	6.97 ± 0.03	8890 ± 420	12.620 ± 420	121.1 ± 2.8	961.1 ± 27.3	5250 ± 153