Short communication

Enhanced sludge degradation process using a microbial electrolysis cell in an up-flow anaerobic sludge blanket reactor with ultrasound treatment

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HIGHLIGHTS

- This study proposed a sludge disintegration and degradation system.
- Ultrasound was used to disintegrate sludge.
- UASB was used to degrade the disintegrated sludge.
- MEC was used to further degrade the disintegrated sludge.
- TCOD removal and VSS/SS ratio reached 71.4% and 24.7% after AD for 7 days.

ARTICLE INFO

ABSTRACT

This study proposes a process with the following steps: (i) use of ultrasound treatment (UT) to disintegrate sludge; (ii) application of an up-flow anaerobic sludge blanket (UASB) reactor to degrade the disintegrated sludge; and (iii) utilization of a microbial electrolysis cell (MEC) composed of graphite fiber brush and titanium in replacement of a three-phase UASB separator. The soluble chemical oxygen demand (SCOD) and protein concentration in the MEC effluent reached 569.5 and 373.1 mg/L, respectively, after 7 days of anaerobic degradation. The concentration of volatile suspended solid (VSS) in the MEC effluent was maintained at 320–380 mg/L (*ca.* 0.08% of raw sludge concentration), thereby revealing successful separation by MEC during sludge degradation. The total chemical oxygen demand (TCOD) concentration, TCOD removal, and VSS/SS ratio in the UT reactor reached 1885.8 mg/L, 71.4%, and 24.7%, respectively. The proposed sludge degradation system can potentially minimize the energy consumption during ultrasound disintegration while simultaneously accelerating the anaerobic sludge degradation process. This study provides the basis for a further development of sludge mineralization processes.

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1. Introduction

Excessive amounts of sludge are generated from municipal and industrial wastewater by means of the activated sludge method. Sludge contains significant amounts of microorganisms as well as polysaccharides, proteins, nucleic acids, lipids, and humic acids [1]. The management of this sludge is thus a critical problem in view of its serious environmental risks. Simultaneous anaerobic digestion (AD) technology is typically applied for the treatment of high-strength organic wastewater and the generation of bioenergy resources [2]. Since the membrane of the microorganism cells restricts sludge digestibility, sludge pre-treatment before AD is a promising technology for sludge degradation and energy recovery [3]. Therefore, researchers have focused on sludge pretreatment and degradation processes leading to reduced sludge production.

Microbial electrolysis cells (MEC) are bio-electrochemical systems developed from microbial fuel cells. Mohammadi et al. [5] found that large amounts of organic matter are released from the solid sludge into the liquid phase thereby rapidly deteriorating the quality of the sludge filtrate after every sludge treatment run. Additionally, Jiang et al. [1] demonstrated that a microbial fuel cell treatment increases the rate and extent of organic matter degradation in the sludge, particularly when ultrasound is applied during sludge pretreatment. Accordingly, MEC have been applied to accelerate the decomposition of organic pollutants [2,4].

Lu et al. [7] reported that MEC can degrade organic matter while producing hydrogen at high yields using an effluent from an ethanol-type reactor (i.e., reducing sugars, ethanol, acetic acid, propionic acid, butyric acid, and valeric acid) as the substrate. Additionally, a pair of ferric or zero valent iron electrodes were inserted into an up-flow anaerobic blanket (UASB) reactor to improve the treatment of azo dye- and other organic wastewaters [2,6]. Hence, AD and MEC anodic oxidation may be effectively combined with the electric field installed in the UASB reactor for improving the sludge degradation process.

This study proposes and investigates the following processes for a highly efficient sludge disintegration and degradation methodology (Fig. 1): (i) use of ultrasound treatment (UT) to disintegrate sludge; (ii) application of a UASB reactor to degrade the disintegrated sludge; (iii) replacement of the three-phase UASB separator with an MEC comprising graphite fiber brush and titanium; and (iv) the combined performance of the UT-UASB-MEC degradation system.

2. Materials and methods

2.1. Sludge

Raw sludge was collected from the Shenshuiwan wastewater treatment plant in Shenyang, China. Anaerobic granular sludge was artificially cultivated in the laboratory. Table 1 summarizes the characteristics of both the raw and the anaerobic granular sludges used herein.

2.2. Sludge degradation system configuration

Sludge disintegration was performed using an ultrasonic cell disruption system with a frequency of 20 kHz and a probe of 20 mm in diameter (GM1200D, Shunmatech LTD, China). The UT reactor (10 L volume, diameter: 20 cm, height: 40 cm) was fabricated in polymethyl methacrylate based on the propagation direction of complex cavitation processes in the proximity of powerful ultrasonic sources [8]. The ultrasonic probe (maximum power: 1200 W) was immersed 10 mm in depth into the sludge.

The UASB reactor was made of polymethyl methacrylate (35 L volume, diameter: 14 cm, height: 160 cm). A single-chamber and membrane-less MEC was applied in the UASB reactor. This strategy potentially reduces the energy recovery efficiency, although it decreases the costs of the system for engineering application [7,9]. Both the MEC anode and the cathode electrodes were comprised of graphite fiber brush (diameter: 15 cm, height: 20 cm) and titanium wire [1]. The electrodes were located at 1/2 reactor depth (i.e., the distance between the two brushes was 5–10 cm). The electricity was supplied to the electrode by a regulated DC power source through an electric wire (Fig. 2).

2.3. Sludge degradation system operation

2.3.1. Start-up

10 L of raw sludge was placed in the UT reactor, while 5 L of anaerobic granular sludge and 30 L of raw sludge were added to the UASB–MEC reactor. The ultrasonic cell disruption system in the UT reactor was operated 10 min/day. A magnetic stirrer was

Table 1
Characteristics of the raw and anaerobic granular sludges.

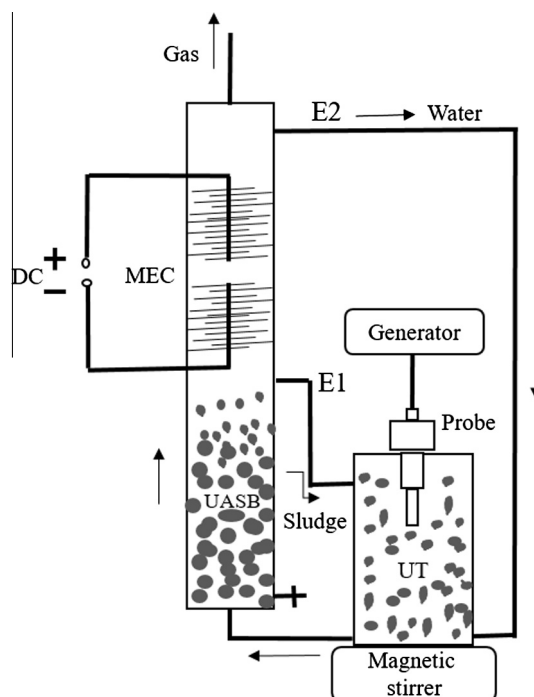| Parameters	Raw sludge	Anaerobic sludge
Suspended solid (SS, mg/L)	5320 ± 50	17,420 ± 50
Volatile suspended solid (VSS, mg/L)	4210 ± 50	5450 ± 50
Total chemical oxygen demand (TCOD, mg/L)	6275.3 ± 127.5	7825.8 ± 127.5
Soluble chemical oxygen demand (SCOD, mg/L)	127.5 ± 27.5	3275.6 ± 27.5
Protein (mg/L)	29.3 ± 5	185.7 ± 5

Fig. 2. Schematic of the UT-UASB-MEC integrated reactor degradation system.

used to continuously stir (100 rpm) the sludge. Sludge (20 vol%) was replaced by fresh raw sludge every day. In the UASB reactor, 80% of the sludge flowed reversely through "E1," while the flow rate of "E2" was fixed at 5 L/day (Fig. 2). The MEC was supplied at 0.5 V as the potential required for the bacterial oxidation of the organic matter is in the 0.2–0.8 V range. The sludge degradation system was maintained at a temperature of 35 °C, while a constant pH value (7.5–8.0) was kept by an automatic control system (MIK-PH160, Meacon, China). Concentrations of SCOD, Protein and VSS in the effluent through "E2" gradually stabilized after 30 days. The MEC achieved 0.5 V and 45 mA (resistance = 11.2 Ω) and the operation was then finished.

2.3.2. Experimental process

All the sludge samples (10 L) were replaced by fresh raw sludge in the UT reactor. AD was performed for 7 days (i.e., system response time: 7 days) by sequencing batch reactors. The effect
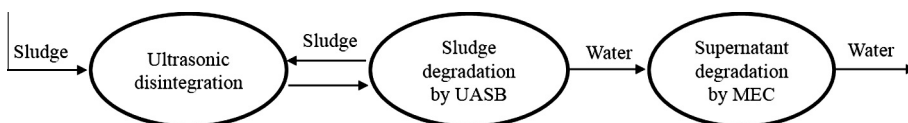

Fig. 1. Schematic of the highly efficient sludge degradation technology herein proposed.