Radiation Physics and Chemistry 121 (2016) 110–114

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

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

Gamma irradiation induced disintegration of waste activated sludge for biological hydrogen production

Yanan Yin [a], Jianlong Wang [a,b,*]

[a] Collaborative Innovation Center for Advanced Nuclear Energy Technology, INET, Tsinghua University, Beijing 100084, PR China
[b] Beijing Key Laboratory of Radioactive Wastes Treatment, Tsinghua University, Beijing 100084, PR China

HIGHLIGHTS

- The waste activated sludge could be disintegrated by gamma irradiation.
- The disintegrated sludge could be used for biohydrogen production.
- The hydrogen yield was 10.5 ± 0.7 mL/g $SCOD_{consumed}$.

ARTICLE INFO

Article history:
Received 9 November 2015
Received in revised form
15 December 2015
Accepted 8 January 2016
Available online 9 January 2016

Keywords:
Gamma irradiation
Waste activated sludge
Bio-hydrogen production

ABSTRACT

In this paper, gamma irradiation was applied for the disintegration and dissolution of waste activated sludge produced during the biological wastewater treatment, and the solubilized sludge was used as substrate for bio-hydrogen production. The experimental results showed that the solubilization of waste activated sludge was 53.7% at 20 kGy and pH=12, and the SCOD, polysaccharides, protein, TN and TP contents in the irradiated sludge solutions was 3789.6 mg/L, 268.3 mg/L, 1881.5 mg/L, 132.3 mg/L and 80.4 mg/L, respectively. The irradiated sludge was used for fermentative hydrogen production, and the hydrogen yield was 10.5 ± 0.7 mL/g $SCOD_{consumed}$. It can be concluded that the irradiated waste activated sludge could be used as a low-cost substrate for fermentative hydrogen production.

1. Introduction

Large amount of waste activated sludge are produced during the biological wastewater treatment process. As the public demand for the sustainable management of wastes is increasing, the disposal of waste activated sludge has become a great concern (Chu et al., 2011). Waste activated sludge from wastewater treatment process is rich in various contaminants and pathogens, which requires proper treatment before being discharged. Ionizing radiation has been used in treating waste activated sludge since 1970s. However, the application of ionizing radiation was limited to sludge disinfection (Wen et al., 1997; Borrely et al., 1998; Engohang-Ndong et al., 2015). With the development of radiation technology, more effects of ionizing radiation on sludge were explored, such as sludge dissolution (Zheng et al., 2001), hazardous materials elimination (Al-Bachir et al., 2003; Peng et al., 2012; Chu et al., 2015), minimizing excess sludge production (Song et al., 2003) and enhancing anaerobic treatability of sludge (Park et al., 2009).

Waste activated sludge is mainly composed of microorganisms, in which quite a few biodegradable organic matters are encapsulated (Muller et al., 1998). To make waste profitable, it is necessary to disrupt the microbial cells to release the useful organic compounds into solution. Ionizing radiation can destroy cellular structure by the active radicals produced during water radiolysis, thus improving the biodegradability of waste activated sludge (Wang and Wang, 2007; Wang and Xu, 2012). Ionizing radiation was applied to recover carbon source from waste activated sludge for different purposes, for instance, as supplementary organic source for biological denitrification (Kim et al., 2009), as substrate of anaerobic fermentation for biogas generation (Lafitte-Trouqué and Forster, 2002; Park et al., 2009; Yin and Wang, 2015). However, to reduce the cost of ionizing radiation and improve the treatment effect, ionizing radiation is usually combined with some traditional treatment methods in treating waste activated sludge (Lafitte-Trouqué and Forster, 2002; Kim et al., 2009; Yin and Wang, 2015).

Hydrogen is a promising clean energy carrier when it is generated from renewable resources. Sustainable hydrogen generation can be achieved through dark fermentation, especially when

* Correspondence to: Neng Ke Lou, Tsinghua University, Beijing 100084, PR China.
E-mail address: wangjl@tsinghua.edu.cn (J. Wang).

http://dx.doi.org/10.1016/j.radphyschem.2016.01.009

organic wastes are used as substrate (Wang and Wan, 2009a).

In this study, gamma irradiation was used to disintegrate and dissolve waste activated sludge, and the organic substituents released from the sludge were used as substrate for hydrogen production.

2. Materials and methods

2.1. Sludge

Waste activated sludge was collected from the secondary sedimentation tank of a local sewage treatment plant in Beijing. The physicochemical characteristics of the sludge are as follows: pH 6.80, suspended solids (SS) 12430 mg/L, volatile suspended solids (VSS) 8250 g/L, total chemical oxygen demand (TCOD) 7244 mg/L, and soluble chemical oxygen demand (SCOD) 102 mg/L. The sludge was preserved at 4 °C until being used.

2.2. Sludge pretreatment

The sludge hydrolysis was carried out in a 1 L glass bottle. First of all, the pH of sludge was adjusted to 12.0 with 10 mol/L NaOH and HCl, and then the sludge was treated by 20 kGy dose gamma irradiation at ambient temperature (around 25 °C). Gamma irradiation was carried out using a ^{60}Co-source located in the Institute of Nuclear and New Energy Technology, Tsinghua University. The absorbed dose was measured by a standard Fricke dosimeter. After gamma radiolysis, the sludge was adjusted to neutral pH and stored at 4 °C until being used.

2.3. Inoculum

The seeding sludge was obtained from an anaerobic digester of a sewage treatment plant located in Beijing, the volatile suspended solids (VSS) of the sludge was 2.42 g/L. To inhibit the hydrogen consumers, 5 kGy gamma irradiation was applied to the seeding sludge (Yin et al., 2014b). After the irradiation pretreatment, seeding sludge was pre-cultured at 36 °C for 48 h. The composition of pre-culture medium contains: glucose 20 g/L; yeast extract 0.5 g/L; peptone 10 g/L and nutrient solution 10 mL/100 mL. Each liter of nutrient solution contains $NaHCO_3$ 40 g, NH_4Cl 5 g, $NaH_2PO_4 \cdot 2H_2O$ 5 g, $K_2HPO_4 \cdot 3H_2O$ 5 g, $FeSO_4 \cdot 7H_2O$ 0.25 g, $MgCl_2 \cdot 6H_2O$ 0.085 g, $NiCl_2 \cdot 6H_2O$ 0.004 g.

2.4. Bio-hydrogen production

To examine hydrogen production from gamma irradiated sludge, batch experiments were conducted in 150 mL Erlenmeyer flasks with working volume of 100 mL. To make a comparison, 0.1 g glucose, 80 mL treated sludge, mixture of 0.1 g glucose and 80 mL treated sludge were used as substrate, respectively. Each bottle was inoculated with 10 mL seeding sludge. Furthermore, the effect of nutrient solution on hydrogen production from sludge was explored.

Before the incubation process, the initial pH value of media was adjusted to 7.0 with 5 mol/L HCl and 5 mol/L NaOH. Argon gas was passed through the medium for 3 min to drive away the residual oxygen. During the fermentation process, bottles were incubated in a reciprocal shaker at constant temperature of 36 °C and agitation speed of 100 rpm. Each batch test was conducted in three replicates.

2.5. Analytical methods

Biogas produced during the fermentation process was passed through NaOH solution to absorb CO_2, and then the volume of residual biogas was determined by the water displacement method at room temperature (25 °C). The fraction of H_2 in the biogas was measured by a gas chromatograph (model 112A, Shanghai, China). The gas chromatograph was equipped with a thermal conductivity detector (TCD) and a packed column (model TDX-01, long 3 m, diameter 3 mm). The temperature of the column, detector and injector were 160 °C, 110 °C and 180 °C, respectively. Argon was used as the carrier gas and the pre-column pressure was 0.2 MPa.

The liquid samples were collected and filtered through a 0.45 μm filter membrane to obtain a filtrate for analyses. The physicochemical characteristics of sludge were measured by standard methods (APHA, 1995), including suspended solid (SS), volatile suspended solid (VSS), total chemical oxygen demand (TCOD), soluble chemical oxygen demand (SCOD), total phosphorus (TP) and total nitrogen (TN) contents. The protein content was measured by the modified Lowry method using bovine serum albumin as standard. Polysaccharide was measured by phenol sulfuric acid method using glucose as the standard. The pH value was measured by a pH meter (Model 526, Germany). The volatile fatty acids (VFA) were analyzed using an ion chromatograph (Dionex model ICS 2100) equipped with a dual-piston pump, a Dionex IonPac AS11-HC analytical column (4 × 250 mm), an IonPac AG11-HC guard column (4 × 50 mm), and a DS6 conductivity detector.

3. Results and discussion

3.1. Sludge dissolution by gamma irradiation

In our previous study, sludge disintegration by various doses of gamma irradiation at different pH conditions were explored, in which the best SCOD dissolution effect was obtained by 20 kGy gamma irradiation treated sludge at pH = 12 (Yin and Wang, 2015). Thus, in this study, the combination of gamma irradiation (20 kGy) and alkaline (pH = 12) treatment was adopted to disintegrate the sludge for fermentative hydrogen production.

TCOD reduced slightly from 7244 mg/L to 7062 mg/L, which may be due to the oxidation effects caused by gamma irradiation. Similar phenomenon was also observed by Park et al. (2009). Fig. 1 shows that the SCOD, polysaccharides, protein, TN and TP concentrations of raw sludge were 102.2 mg/L, 9.8 mg/L, 49.9 mg/L, 21.8 mg/L and 67.3 mg/L, respectively. It can be seen that before the treatment, organic matter content in the solution of raw

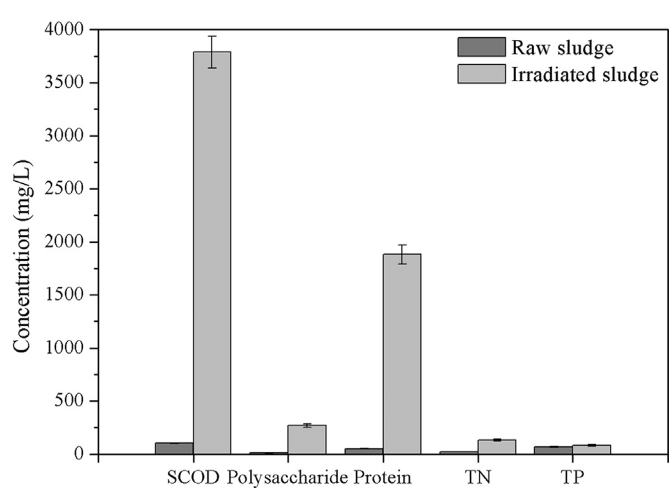

Fig. 1. Sludge dissolution by gamma irradiation.