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Recovery strategies of inhibition for mesophilic anaerobic sludge treating the de-oiled grease trap waste

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ABSTRACT

De-oiled grease trap waste (GTW) could be a feasible substrate for anaerobic digestion. However, due to high concentration of lipid, the long-chain fatty acid (LCFA), as an intermediate in the anaerobic lipid degradation, easily inhibits the anaerobic digestion, resulting in long recovery period. Four recovery strategies: bentonite addition, water dilution, mixing with low LCFA substrate and mixing with inocula, with control test as comparison, were employed in order to accelerate the recovery process of mesophilic anaerobic sludge. Adding bentonite, water dilution with 80% mixing ratio and mixing with active inocula achieved shortening of the recovery process. The whole recovery time took approximately 3.5 months for the control test, as calculated from the beginning to the end of the lag time after de-oiled GTW was re-added as F/I ratio of 0.4. At least 10 g l^{-1} of bentonite addition was necessary for the fast recovery of the inhibited sludge, with the whole recovery time one month shorter than the control test. 1.5 months could be saved for the whole recovery process when the strategy of water dilution with 80% mixing ratio was considered. The more inocula were mixed with the inhibited sludge, the more the recovery period was lessened. For the strategy of mixing with inocula with the mixing ratio 80%, only 20 days were needed for the whole recovery process.

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1. Introduction

Grease trap waste (GTW) from a grease trap commonly installed inside the food service establishments (Wang et al., 2013; Aguilar-Garnica et al., 2014), has become a major stream of organic waste in urban areas. Landfill of this waste is no longer permitted in many jurisdictions (Razaviarani et al., 2013). The direct drainage into the collection system is also illegal in most municipalities, because it can accumulate on pipe walls, and potentially form hardened deposits through a chemical reaction or a physical aggregation process (He et al., 2011). It was responsible for up to 47% of the reported blockages and 50–75% of sanitary sewer overflows as it tends to solidify, reduce conveyance capacity, and eventually block flow (Wang et al., 2013; Iasmin et al., 2014). Millions of dollars each year have to be spent in cleaning, repairing, and maintenance of the pipes. Therefore, it is urgent to seek an efficient method to dispose the GTW.

GTW is often high in biodegradable volatile solids (VS) ranging from 17% to 93% (w/w) and chemical oxygen demand (COD) up to 1,211 kg m^{-3} (Wang et al., 2013). Conversion of oily content in GTW to biodiesel is widely studied because of concerns relating to the quality of the feedstock, specifically the presence of high moisture content and free fatty acids (Felizardo et al., 2006; Montefrio et al., 2010; Toba et al., 2011). The de-oiled GTW was proved an appropriate substrate for anaerobic digestion (Kobayashi et al., 2014). In addition, due to high lipid content in the de-oiled GTW, more methane can be produced owing to theoretically higher methane production potential of lipid than other organic matters (Angelidaki and Sanders, 2004). Theoretically, 1 g of glycerol trioleate ($C_{57}H_{104}O_6$), a common lipid in nature, is equivalent to 1.08 l of methane at standard temperature and pressure (STP), while 1 g of glucose ($C_6H_{12}O_6$) is equivalent to only 0.37 l (Kim and Shin, 2010).

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In the anaerobic digestion, lipids are initially hydrolysed to long-chain fatty acids (LCFA) and glycerol. Glycerol is fermented to propionate (Li et al., 2005), and LCFA is further fermented by β-oxidation to hydrogen and acetate, and finally to methane by methanogenic archaea (Weng and Jeris, 1976; Palatsi et al., 2012). The conversion (hydrolysis) of lipids to LCFA is not the rate limiting step for anaerobic digestion (Heukelekian and Mueller, 1958; Hanaki et al., 1981; Beccari et al., 1998). However, LCFA is well-known inhibitors for various microorganisms even at millimolar concentrations, and consequently causes some serious problems in anaerobic treatment systems, such as the scum layer formation and the biomass flotation (Rinzema, 1988; Hwu et al., 1998; Shin et al., 2003).

It has been summarized that adsorption onto the surface of the bacterial cells, precipitation with divalent ions, and entrapment in the flocculant structure of the sludge are the mechanisms responsible for the LCFA inhibition (Pereira et al., 2005). Among them, adsorption is considered as the main reason to cause inhibition due to the physical disturbance to the cell wall of microorganisms, affecting the transport of substrate and nutrients (Petruy and Lettinga, 1997; Hwu et al., 1998; Nadais et al., 2003; Pereira et al., 2004). Some prevention measures have been developed to reduce the toxicity of LCFA towards anaerobic digestion at the beginning of the operation by reducing the bioavailability of LCFA adsorbed on the surface of the biomass, such as precipitation with soluble calcium (Hanaki et al., 1981; Roy et al., 1985; Koster, 1987; Angelidaki et al., 1990) or bentonite (Angelidaki et al., 1990; Beccari et al., 2001; Mouneimne et al., 2004), and adsorption with iron-containing clay (Ivanov et al., 2002) or zeolite (Nordell et al., 2013). Moreover, the feasibility by limiting the LCFA loadings in a certain range and co-digestion with other substrate were also demonstrated by the increased methane production (Li et al., 2002; Salminen and Rintala, 2002; Cirne et al., 2007; Silvestre et al., 2011). Hwu, 2001 summarized the enhanced strategies, including acclimation of sludge to LCFA and recirculation of washed out biomass, to promote the degradation performance of lipid-containing waste. The recovery under the condition that the inhibition from the LCFA has existed, though, was scarcely concerned in the previous studies.

It has been proved that it is a reversible process even though the inhibition caused by LCFA has existed, due to either the dramatically increasing methane production rate, or the final high methane production within a certain time after biomass is inhibited by LCFA (Roy et al., 1985; Pereira et al., 2005; Cavaleiro et al., 2008; Palatsi et al., 2009; Kim and Shin, 2010). Thus, it becomes possible for biomass recovery from the inhibited state caused by LCFA. However, once the anaerobic biomass is inhibited by LCFA, a long time is needed before a high-efficiency biogas production is achieved, which is not applicable in engineering practice. Therefore, it is necessary to find some ways to accelerate the recovery process. Some strategies with a definite set value for the recovery of thermophilic anaerobic sludge inhibited by LCFA have been put forward in the previous study (Palatsi et al., 2009), but studies about the recovery of mesophilic anaerobic digestion are hardly found. In particular, recovery from the inhibited stage caused by GTW was studied less. In this study, some recovery strategies of inhibition for mesophilic anaerobic digestion treating the de-oiled GTW were investigated, in order to evaluate the feasibility of the strategies in accelerating the recovery process and obtain the optimal recovery method.

2. Materials and methods

2.1. Substrate, inhibited sludge and inocula

The GTW was collected from 7 different types of restaurants in Japan, mainly supplying meat products and serving for the banquet. Subsequently, the mixture of different restaurant sources was heated to 60 °C for at least 6 h, which caused layer separation. The upper oil layer was pumped away for biodiesel recovery, while the residual de-oiled GTW was used as the substrate of the anaerobic experiment in this study. Raw food waste (FW) was obtained from a dining hall at the National Institute of Environmental Studies, Tsukuba, Japan. It was mixed with tap water as 1:1.4 (raw FW: tap water) before it was shredded with a shear pump to the particle size less than 5 mm. The inhibited sludge was from a laboratory-scale mesophilic continuously stirred tank reactor, in which there was little biogas produced for at least two months since the de-oiled GTW was added into the reactor. Inocula were from a mesophilic reactor having been treating FW for longtime. The characteristics of substrate, inhibited sludge and inocula used in this study are shown in Table 1.

2.2. Recovery and re-adding experiment

A batch experiment was conducted to investigate the recovery strategies of inhibition for mesophilic anaerobic digestion of de-oiled GTW by using glass serum vials. The same anaerobic sludge, inhibited by LCFA, was utilized for each test. Four recovery strategies for enhancing the recovery process were investigated, while a test without any strategy utilized was set as the control. All of the tests in this study were prepared in duplicate.

2.2.1. Strategy 1—Bentonite addition

Bentonite (WAKO, Japan), consisting mainly of the clay mineral montmorillonite, is often used in plant oil refineries for cleaning and decolouring vegetable oils, due to its strong adsorption ability to oil (Angelidaki et al., 1990). It was added to 50 ml of inhibited sludge individually at six different concentrations 5 g l^{-1}, 10 g l^{-1}, 15 g l^{-1}, 20 g l^{-1}, 35 g l^{-1}, and 100 g l^{-1}.

2.2.2. Strategy 2—Water dilution

The inhibited sludge was diluted at four different mixing ratios, 20%, 40%, 60%, and 80%. For example, mixing ratio 20% means that the volume of water added accounts for 20% in that of the water-sludge mixture.

2.2.3. Strategy 3—Mixing with low LCFA substrate

FW was chosen as the low LCFA substrate. The mixing ratios of FW and the inhibited sludge were set as 20%, 40%, 60%, and 80%. For example, the mixing ratio 20% means that in the mixture the percentages of FW and the inhibited sludge are 20% and 80%, respectively. A comparative test with inocula substituted for the inhibited sludge was also carried out (FW @).

2.2.4. Strategy 4—Mixing with inocula

Similar to the description above, the mixing ratios of inocula and the inhibited sludge were also set as four different mixing gradient, 20%, 40%, 60%, and 80%.

The final volumes of all tests prepared as above were adjusted to 50 ml. The vials were flushed with nitrogen gas for at least 30 s to provide anaerobic conditions. Subsequently, the vials were sealed with rubber stopper and aluminum cap. Finally, the vials were put onto an agitator in the 35 °C of incubator to culture. During the culture period, gas production and gas composition in each of the vials were analyzed every two or three days until the gas production stopped. Once gas production stopped, according to the gas production performance in the recovery experiment, part of the tests with shorter recovery time than control test and the control test were selected to re-added de-oiled GTW into the tests to start the re-adding experiment, as F/I (Food/Inocula) 0.4 referring to the

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