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Dual-fuel production from restaurant grease trap waste: Bio-fuel oil extraction and anaerobic methane production from the post-extracted residue

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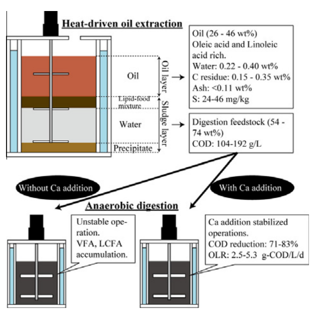
HIGHLIGHTS

- Oil content was extracted from grease trap waste (GTW) by heat-treatment.
- A high purity oil equivalent to an A-grade fuel oil with 81–93 wt% of efficiency.
- Anaerobic digestion of post-extracted residue was inhibited by long-chain fatty acid.
- Ca-added digester achieved stable semi-continuous operation over one year.

GRAPHICAL ABSTRACT



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ABSTRACT

An effective way for restaurant grease trap waste (GTW) treatment to generate fuel oil and methane by the combination of physiological and biological processes was investigated. The heat-driven extraction could provide a high purity oil equivalent to an A-grade fuel oil of Japanese industrial standard with 81–93 wt% of extraction efficiency. A post-extracted residue was treated as an anaerobic digestion feedstock, and however, an inhibitory effect of long chain fatty acid (LCFA) was still a barrier for high-rate digestion. From the semi-continuous experiment fed with the residual sludge as a single substrate, it can be concluded that the continuous addition of calcium into the reactor contributed to reducing LCFA inhibition, resulting in the long-term stable operation over one year. Furthermore, the anaerobic reactor performed well with 70–80% of COD reduction and methane productivity under an organic loading rate up to 5.3 g-COD/L/d.

1. Introduction

A grease trap is standard equipment in restaurant kitchens and food-processing factories to separate greasy waste from wastewater by letting it float to the top of the basin. Wastewater from cooking and dishwashing contains high concentration of fat, oil grease (FOG), and the FOG going into the sewage system is easy to accumulate and create deposits inside the sewer pipes (Williams et al., 2012; He et al., 2013). The deposits potentially cause various problems such as pipes clogging, odor and other human health hazard, and therefore it is important that the grease traps are used effectively in removing FOG from wastewater before it enters the sewer system. Restaurants and food processing factories are required to

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install grease traps. However, to our knowledge, there are a few cases that the grease traps are appropriately managed because grease trap maintenance is usually performed by commercial cleaning service, and so it is a cost that restaurant or facility managers want to reduce. As such, excessive accumulation of grease trap waste (GTW) in the basin allows FOG pass to the sewer systems and makes problems as stated above. Therefore, it should be facilitated that GTW is periodically removed and properly treated.

GTW has high concentrations of FOG and food solids, and therefore GTW is recently considered a source for biological methane production (Long et al., 2012). Anaerobic digestion of lipid-rich materials has high methane production yields, but on the one hand high concentration of long-chain fatty acids (LCFA) as intermediate products severely inhibit methanogenic activity. Beta-oxidation of LCFA frequently becomes a limiting step of lipid digestion, which resulted in the accumulation in a reactor. Inhibitory effects of accumulated oleic acid or palmitic acid on anaerobic digestion were reported by other researchers dealing with oily substrate (Pereira et al., 2002; Jeganathan et al., 2006). That applies to GTW digestion: there has been a report that the reactor treating GTW as a single substrate has failed to achieve stable continuous operation while the co-digestion with municipal wastewater sludge, which reduced lipid concentration in the substrate, enabled to perform a successful operation (Davidsson et al., 2008). For this reason, co-digestion of GTW and sludge has been investigated as a promising method for energy conversion of FOG by many researchers. This is a good way to increase methane production yield of a sludge digester, which has low methane productivity, but there are still some limitations. Successful continuous operations have been reported under the mixing ratio of around 80–90% wastewater sludge and 10–20% GTW as volatile solids (VS) (Davidsson et al., 2008; Girault et al., 2012; Razaviarani et al., 2013), but increasing GTW addition triggered off serious operational problems induced by LCFA inhibition. Therefore, the anaerobic digester must be operated by properly controlling a loading balance between wastewater sludge and GTW. This is a difficult task because the chemical characteristics of GTW vary greatly depending on the restaurant type and seasons (De los Reyes and He, 2009; Nitayapat and Chitprasert, 2014). Moreover, FOG-rich GTW is hard to deal with in an anaerobic digestion plant since most of the FOG is solid at normal temperature. We found that the FOG made a deposit inside the substrate acceptance storage tank and feeding pipes. The deposit leads to reduction in actual FOG feeding and methane conversion, and moreover cleaning and maintenance are required to operate the plant effectively.

This study provides an alternative way for GTW treatment as a sole substrate to generate dual fuels: fuel oil and bio methane. Physical properties of GTW greatly vary according to the cases: in some cases orange-colored oil is quite clearly separated and in other cases oil-sludge emulsion with a large amount of non-lipid contamination is formed (Nitayapat and Chitprasert, 2014). In our previous work (Nishimura et al., 2011), however, we measured the solid–liquid equilibria in different systems of fatty acid and fatty acid triglyceride, some of which are similar to FOG in GTW. The results indicated heating GTW up to 60 °C easily separate any type of GTW into oil and sludge. Furthermore, we confirmed that this simple heat-driven separation technique was useful for recovering a high-quality oil from GTW. As a result, the oil can be used for a bio-fuel feedstock and the sludge can be fed into an anaerobic digester. Accordingly, the oil-reduced sludge is expected to lighten the problems of LCFA-inhibition and lipid-solidification in an anaerobic digestion plant even if the GTW is used as a single substrate. Moreover, the oil-sludge separation provides a benefit to a bio-fuel production process. It has been known that GTW can be converted into not only bio methane but also bio-fuel, especially bio-diesel fuel (BDF). Utilization of GTW as a biodiesel feedstock has been investigated elsewhere (Canakci, 2007; Hasuntree et al., 2011; Thompson et al., 2012). Since the problem of processing such a feedstock is high concentration of moisture, free fatty acids and insoluble impurities (Canakci, 2007), the extraction would contribute to reducing the barrier to bio-fuel use of GTW. The current study aimed to: (1) investigate characteristics of the heat-driven fuel oil extraction from mixed fresh GTW collected from several restaurants in a bench scale apparatus; (2) evaluate and upgrade anaerobic digestion of the post-extracted residue as a single substrate. In anaerobic digestion experiments, an inhibitory effect of the substrate and its reduction by addition of inhibition reducer were investigated to achieve a stable and high-rate digestion.

2. Methods

2.1. Feedstocks and pre-treatment

Mixed GTW was collected from at least 7 different types of restaurant's grease traps by the staffs of commercial cleaning service every sampling time. Usually, GTW forms strata in the grease trap basin and lipid-rich materials accumulate in the upper stratum. In Japan, there are two methods for grease trap cleaning; the first one is pumping up by a vacuum truck, the other drawing up by the cleaning staff. Especially, the latter is used for cleaning the trap basin in social buildings, and the staffs normally collect the oily upper stratum and the other separately during the trap cleaning. The GTW of the upper stratum was investigated in this study. After brought back to the laboratory, the GTW was transferred into the acrylic tank reactor (120 L) with a water jacket and heated to 60 °C with circulating hot water for at least six hours. During the heating, oil melted and floated up and finally the GTW in the reactor was clearly stratified. Subsequently, the upper oil layer was pumped away and collected for analysis while the residual sludge was used for anaerobic digestion. The entire process of the oil extraction has been automated, so that it is replicable: Motor-driven slider equipped with in parallel a pumping port and a turbidity sensor, which was able to distinguish the oil layer from a sludge layer, was inserted from the top of the heated reactor. The slider lowered from an upper stand-by position and fixed when the turbidity sensor recognized an interface between oil layer and sludge layer, and the oil above the sensor was pumped out and collected. The oil extraction efficiency (E_{Oil}) was calculated as follows.

$$E_{\mathrm{Oil}} = 100\frac{W_{\mathrm{O}}}{W_{\mathrm{O}} + W_{\mathrm{R}}} \quad (1)$$

where W_{O} is oil weight extracted and W_{R} is oil weight in post-extracted residue.

2.2. Batch biochemical methane potential tests

The GTW collected after oil extraction as stated above was single substrate for the anaerobic digestion experiment. Inoculum sludge was effluent from a mesophilic anaerobic digester (35 °C) treating kitchen food wastes, which mainly consist of rice and vegetable wastes, and therefore the sludge did not seem to be acclimated to FOG. SS and VSS concentrations of the inoculum sludge were 8.4 g/L and 6.8 g/L, and VFA concentration was below 300 mg/L. Experiments were carried out using closed glass vials with a working volume of approximately 60 ml in shaking incubators at 35 °C with a shaking speed of 120 rpm. The feeds, inocula and supplementary materials ($CaCl_2$, bentonite) were added to the vials, subsequently the vials were flushed by nitrogen gas and sealed with butyl rubber stoppers and sealing caps. The amount of gas production was measured using a glass syringe with