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Variable oil properties and biomethane production of grease trap waste derived from different resources

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ABSTRACT

Restaurant grease trap waste (GTW) is a potentially feasible energy source that can be used as an alternative to liquid fossil fuels and natural gas. However, GTW must be collected from many different resources for energy production because restaurants in Japan only produce an average of 486 kg GTW per year. This study investigated the variation in oil properties and methane generation potential of 44 GTW samples from 13 types of restaurants during different seasons. The GTW samples had high variation in oil content and oil properties. Biofuel oil was extracted from most GTW samples at a high efficiency (more than 80 wt%). In contrast, the methane yield varied little among de-oiled GTW samples. All types of GTWs are potential sources of biomethane generation. GTW samples are classified into five major oil property clusters according to solid chemical stability. Oil properties depend little on the season and heavily on the restaurant type.

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1. Introduction

Fat, oil, and grease (FOG) produced by restaurants and food-processing industries pose a major problem to urban sewer systems as urbanization advances globally. The direct discharge of these compounds into sewer collection systems is not permitted in most municipalities because it accumulates on pipe walls and forms sticky deposits in the pipe. These FOG deposits can lead to clogging, odor, and pathogenic problems (Williams et al., 2012; He et al., 2011). Grease traps and interceptor equipment are commonly used to remove FOG from wastewater before it enters the public sewer lines. However, grease traps require routine maintenance and floating scum, or grease trap waste (GTW), which accumulates over time must be removed to sustain sufficient performance levels (Ragauskas et al., 2013). Despite public education, a significant amount of FOG is discharged into the sewer lines from poorly maintained grease traps due to the high cost of equipment maintenance. GTW in Japan is generally collected manually or pumped from grease traps and then discarded in landfills or incinerated. The EU does not permit GTW disposal in landfills due to the presence of pathogens and toxic substances (Luostarinen et al., 2009; Nitayapat and Chitprasert, 2014). Generation of fuel from GTW has been studied recently because it is a more promising alternative than the disposal methods mentioned. Researchers have mainly investigated biodiesel conversion and biomethane production by anaerobic digestion (Canakci, 2007; Davidsson et al., 2008; Montefrio et al., 2010; Hasuntree et al., 2011; Toba et al., 2011; Wang et al., 2013). The direct use of the FOG fraction of GTW as fuel in a gas turbine generator has been reported (Al-Shudeifat and Donaldson, 2010). Anaerobic digestion is a better option due to the high moisture content of GTW. However, anaerobic digestion of GTW alone is not considered feasible (Davidsson et al., 2008). Microorganisms were inhibited by intermediate long-chain fatty acids (LCFA) during the anaerobic degradation of lipids at a low (below 2.3 kg-VS/m^3/d) organic loading rate (OLR). Only small amounts of methane were generated as a result (Davidsson et al., 2008). High OLR operation also destabilizes the anaerobic digestion process, even though co-digestion with other organic wastes such as sewage sludge reduces the potential toxicity to microorganisms (Noutsopoulos et al., 2013). Moreover, since the GTW lipid content varies daily, it is difficult to determine a constant OLR. Therefore, a dual-fuel production process that extracts oil for liquid fuel and anaerobically digests the de-oiled GTW residue has been proposed (Kobayashi et al., 2014; Wu et al., 2015).

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Our previous study (Kuramochi et al., 2013) determined that the average annual production of GTW by Japanese restaurants is 486 kg. Another study demonstrated that heat-driven extraction from mixed GTW from different types of restaurants during various seasons provides a highly pure oil (biofuel oil) equivalent to A-grade fuel oil in the Japanese industrial standard (JIS), with more than 81 wt% extraction efficiency and 249 L/kg-COD_{fed} methane generated from the residue (Kobayashi et al., 2014). However, the analytical results from the four samples had a high amount of variation. GTW is either an oil or sludge-like grease that includes food scraps and water. These two forms clearly differ in appearance and seem to be related by physicochemical characteristics. For example, the extracted biofuel oil accounts for 26%–46% of GTW total weight, and the pour points vary from 2.5 °C to 22.5 °C. The aspects of fluidity (viscosity, pour, and melting point) vary and sometimes exceed those of the JIS while the contents of impurities such as carbon, ash and sulfur were very low. This is likely because restaurants use many different types of cooking oil and methods that probably change seasonally. Whether the GTW is liquid or solid at ambient temperature affects collection, transport, and separation. Solid GTW requires more heat to extract biofuel oil than GTW that is completely liquid at ambient temperature and requires little or no heat pretreatment. High viscosity biofuel oil should be preheated to reduce viscosity prior to injection into a generator (Al-Shudeifat and Donaldson, 2010).

The goal of this study is to clarify the variation among the crucial characteristics of GTW potentially used for dual-fuel generation. We focused on identifying GTW variation among seasons and types of restaurants. Despite many studies on the properties of used cooking oil (Linstromberg and Henry, 1970; Goering et al., 1982; Canakci, 2007), there is limited information available regarding the properties of GTW. Furthermore, we know very little about the specific biomethane potential of a wide variety of de-oiled GTW types. This information is beneficial for the design of a practical bioenergy generation system that includes collection, treatment, and energy utilization using GTW as feedstock. This study investigated the oil properties and methane generation potential of GTW samples obtained from various types of restaurants. Several samples were collected separately from each site during different seasons to identify any seasonally dependent variation. Results were analyzed and classified statistically.

2. Experimental

2.1. Materials

GTW was collected from 13 types of restaurants in Tokyo, Japan in the spring, summer, and winter seasons from 2014 to 2016. Cleaning service workers collected floating GTW manually from grease trap basins in restaurant kitchens on scheduled maintenance days and transferred them to 10 L plastic bottles. The method details are provided in Kobayashi et al., 2014. The restaurant types sampled included: Japanese-style bar (JSB1, JSB2); Japanese-style curry (JSCR); Japanese-style Chinese noodles and soup referred to as "ramen" (JSCN); Japanese-style cafeteria (JSCF); Japanese-style grilled meat (JSGM); Chinese-style restaurant (CSR1, CSR2); Portuguese-style restaurant (PSR); Italian-style bar (ISB); Belgian-style bar (BSB); French-style bakery (FSB); and French-style restaurant (FSR). A brief explanation of the types of food served and oil or fat used in the less common restaurant cuisines follows. Japanese-style bars serve a wide variety of dishes including various vegetable salads, sliced raw fish, grilled fish, fried chicken, rice, and noodles. Therefore, many types of oil and fat are used in Japanese-style bars. Japanese-style curry contains rice, curry, and a variety of vegetables and meats. Palm oil, lard, and tallow are used to make Japanese curry dishes. Ramen (JSCN) consists of Chinese-style wheat noodles in a pork or soy sauce-based broth and can be topped with sliced eggs, pork, seaweed, or green onions. The broth often contains lard. Japanese-style cafeteria investigated in this study serves many Japanese traditional style foods such as cooked rice, salads, and stewed dishes. Soy sauce and soybean paste are used instead of oil or fat. Japanese-style grilled meat refers to bite-sized meat (beef and offal) and vegetables cooked on gridirons over a flame.

When the 10 L plastic bottles of GTW were brought to the laboratory, they were immediately heated to 60 °C in a hot water bath. This sample temperature was maintained for more than 3 h to separate the oil and water that included food scraps. The 10 L bottle was then stirred by a laboratory mixer Model BLG-3D (AS ONE). Approximately 1 kg of GTW was transferred to a 1 L clear tube to identify the oil-water interface and the tube was placed in the hot water bath (60 °C) again. The upper layer subsequently created was pipetted and transferred to a new bottle to be analyzed as a biofuel oil. The de-oiled GTW residue was stored for further experiments. The two sample portions (oil and residue) were weighed. The separated oil and residue weights were determined by subtracting the empty bottle weight.

2.2. Methane potential tests using de-oiled GTW

The de-oiled GTW samples were used as a substrate for batch experiments of methane potential. Anaerobic digested sludge taken from a semi-continuous flow reactor (35 °C) treating mixed de-oiled GTW was utilized as inoculum. Volatile solids (VS) in the inoculum sludge were 6.9 g/L in the first experiment and 6.2 g/L in the second experiment. The de-oiled GTW and 50 mL of inoculum sludge were mixed to meet a 0.25 feed to inoculum ratio for all batch experiments. Experiments were performed using 120 mL closed glass vials in shaking incubators at 35 °C with a shaking speed of 120 rpm. Blank tests were performed using only 50 mL inoculum sludge to determine the inoculum methane production. When the substrates and inoculum were added to the vials, the vials were flushed by nitrogen gas and sealed with butyl rubber stoppers and sealing caps. All the tests in this study were performed in triplicate.

The Modified Gompertz equation [Eq. (1)] was used for kinetic analysis (Periyasamy et al., 2014) of the cumulative methane production data during approximately 30 days of cultivation.

$$P(t) = P_{max} \times exp\left[-exp\left\{\frac{R_m}{P_{max}} \times e \times (\lambda - t)\right\} + 1\right], \quad (1)$$

where P(t) is the cumulative methane production (mL) at time t (h), P_{max} is the maximum methane production (mL), R_m is the maximum hydrogen production rate (mL/h), λ is the lag phase time (h), and t is the cultivation time (h). Delta Graph version 7 was used to produce the graphs.

2.3. Analytical methods

Differential scanning calorimetry (DSC) experiments were performed using a NETZSCH DSC-200-F3 with an internal cooling system and thermal analysis system software. The sample was heated from −10 °C to 100 °C at a rate of 3 °C/min. The liquidus temperature (T_L), above which the sample is a homogeneous liquid, of each sample was defined as that of the highest endothermic peak in the DSC thermograms of each GTW sample. The overall heat of fusion (ΔH_f) was defined as the sum total of each specific heat of fusion based on endothermic peak areas above 0 °C in DSC analysis. An 848 Titrino plus automatic titrator (Metrohm, Switzerland) was

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