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Scum sludge as a potential feedstock for biodiesel production from wastewater treatment plants

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ABSTRACT

The main goal of this study was to compare the component and yield of biodiesel obtained by different methods from different sludge in a wastewater treatment plant. Biodiesel was produced by ex-situ and in-situ transesterification of scum, primary and secondary sludge respectively. Results showed that scum sludge had a higher calorific value and neutral lipid than that of primary and secondary sludge. The lipid yield accounted for one-third of the dried scum sludge and the maximum yield attained 22.7% under in-situ transesterification. Furthermore the gas chromatography analysis of fatty acid methyl esters (FAMEs) revealed that all sludge contained a significant amount of palmitic acid (C16:0) and oleic acid (C18:1) regardless of extraction solvents and sludge types used. However, the difference lay in that oleic acid methyl ester was the dominant component in FAMEs produced from scum sludge while palmitic acid methyl ester was the dominant component in FAMEs from primary and secondary sludge. In addition, the percentage of unsaturated fatty acid ester in FAMEs from scum sludge accounted for 57.5–64.1% of the total esters, which was higher than the equivalent derived from primary and secondary sludge. In brief, scum sludge is a potential feedstock for the production of biodiesel and more work is needed in the future.

1. Introduction

Scum is a floatable material skimmed from the surface of primary and secondary settling tanks, especially from the surface of grit chamber in wastewater treatment plants. The origin of scum is mainly from fats, oil, and grease, which are washed into the plumbing system through kitchen sinks and floor drains and are eventually conveyed to wastewater treatment plants downstream. Animal oil, vegetable oil, and grease from restaurants and fast-food outlets that do not implement adequate grease control measures are the main contributors to the fats, oil, and grease of wastewater treatment plants. According to a survey conducted by the National Renewable Energy Laboratory (NREL) in 30 US metropolitan areas, fats, oil, and grease are generated at a rate of approximately 1.9 gallons/person/year (Wiltsee, 1998). Fats, oil, and grease are difficult to recover once it has been mixed with raw sewage and the NREL study likely overestimates the recoverable quantity (Long et al., 2012). Another type of nonpolar oils and greases that is not readily biodegradable is that generated from petroleum products or other industries (Jarde et al., 2005; Durand et al., 2004). This type of grease also pours into wastewater treatment plants by storm runoff or pipes.

Scum has some detrimental impacts on the operation of wastewater treatment plants. It can clog wastewater treatment systems and result in the flotation of sludge in thickening units. Significant amounts of fats, oil, grease or lipid in sludge can affect both aerobic and anaerobic processes (Chipasa and Medrzycka, 2006), inhibit methanogenesis during anaerobic digestion (Luostarinen et al., 2009; Carucci et al., 2005), and clog sludge dewatering equipment when scum is pumped to the waste sludge treatment system along with the sludge. Thus, scum must be skimmed off the surface of the wastewater at the beginning of the wastewater treatment process using the grit chambers.

However, the treatment and disposal of scum are invariably overlooked compared with that of primary and secondary sludge in the wastewater treatment plants, which spend 20–60% of total wastewater treatment plants' operating costs (Chipasa and Medrzycka, 2008). Some scum sludge is recycled to the inlets of wastewater treatment plants in consideration of its slow microbial degradation (Andreoli et al., 2007), which often leads to a higher concentration of lipid in the effluent. Some scum sludge is

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discarded into garbage cans as municipal trash and directly disposed in landfills. The disposal scum landfills not only increases the cost of treatment facilities, but also causes many environmental problems. For instance, the Metropolitan Wastewater Treatment Plant at St. Paul. MN (Metro Plant) spends $100,000 a year just for land filling the scum (Bi et al., 2015). Furthermore, the landfill could rise to underground water pollution because of the landfill leachate. Therefore, the alternative approach is needed to improve the disposal situation of scum, which is also consummated the management of sewage sludge in wastewater treatment plants.

Actually, the treatment and disposal of sewage sludge are significant environmental challenges these years since the amount of this sludge is expected to increase in the future as a result of increasing urbanization and industrialization, especially in China. The use of sludge as fertilizer is restricted in many countries given its bad odor and the presence of heavy metals, toxic substances, and pharmaceutical chemicals. Moreover, sludge incineration generates emissions that contain heavy metals and dioxins (Angerbauer et al., 2008; Kargbo, 2010; Woon and Lo, 2014; Samolada and Zabaniotou, 2014). Thus, the feasible approach to treat and dispose sewage sludge must be established and a new disposal method is proposed to utilize sewage sludge as a biodiesel feedstock because of the rapid increase in fuel demand worldwide, reduced fossil fuel reserve, and the high cost of feedstock for present biodiesel production over the past decade (Haas et al., 2007; Meng et al., 2009; Devereaux and Lee, 2009; Tao and Aden, 2009; Marufuzzaman et al., 2014). Previous studies have demonstrated the potential of primary and secondary sludge from municipal wastewater treatment plants as biodiesel feedstock. For instance, Dufreche et al. (2007), Mondala et al. (2009), Revellame et al. (2010) and Olkiewicz et al. (2015) reported that the biodiesel generated from wastewater treatment plants sludge mainly contains methyl esters of palmatic acid (C16:0), palmitoleic acid (C16:1), stearic acid (C18:0), oleic acid (C18:1), and linoleic acid (C18:2). This biodiesel composition is similar to that of some vegetable oil biodiesel such as olive, corn and rapeseed (Ramos et al., 2009), which had the better properties because of the greater monounsaturated content.

In theory, scum sludge is mainly composed of fats, oil, and grease, which is a waste product rich in free fatty acids (Marufuzzaman et al., 2014) and has high lipid content (Bi et al., 2015; Sangaletti-Gerhard et al., 2015). Thus, it is more beneficial to biodiesel production than primary and secondary sludge. Unfortunately, little research has been conducted on the application of scum sludge to biodiesel production to date, although fats, oil, and grease have recently been recovered for use as a biodiesel feedstock (Sangaletti-Gerhard et al., 2015; Pastore et al., 2014).

The main objective of this paper is to introduce scum sludge to biodiesel production and to compare the biodiesel yield of scum sludge with that of primary and secondary sludge through ex-situ and in-situ production systematically. The research is important to the management of scum sludge in wastewater treatment plants and to the scope widening of the potential feedstock for production of second-generation biofuels.

2. Materials and methods

2.1. Sludge collection and preparation

Scum, primary, and secondary sludge were collected from the grit chamber, primary clarifier, and secondary clarifier of a municipal wastewater treatment plants in Xi'an, China. The raw sludge was first sieved (<2 mm) through a screen mesh and then concentrated overnight by gravity-settling. The supernatant was discarded, and the settled solids were centrifuged using a 5804R centrifuge (Eppendorf, Germany) operated at 3000 rpm for 20 min. The concentrated sludge was then stored in a freezer until further use.

2.2. Sludge drying and thermal analysis

Two methods were employed to obtain dried sludge to measure calorific values. The first method was oven-drying, in which concentrated sludge was placed in an oven at 103 °C for approximately 24 h until the moisture content of the sludge dropped below 5%. The other method was freeze-drying, where concentrated sludge was initially spread on a series of 100 mm × 8 mm strays and then freeze-dried using a freeze dryer (FD-1A-50, Boyikang, Beijing, China) for roughly 15 h per 15 g sample until the solid content of the dried sample reached 95% as per the weight method. The dried sludge was then pulverized using a mortar and pestle, homogenized, and divided into 5 g samples for further use. A microcomputer automatic calorimeter (TQHW-5A, Tianqi, Hebi, China) was used in the thermal analysis of sludge.

2.3. Biodiesel production

2.3.1. Ex-situ production of biodiesel from sludge

In ex-situ production, lipids were extracted from sludge by boiling and then converted into fatty acid methyl esters (FAMEs, biodiesel). By contrast, the lipids in sludge were converted directly into FAMEs during in-situ production.

2.3.1.1. Lipid extraction. Prior to extraction by boiling, the sludge samples were freeze-dried, pulverized using a mortar and pestle, and then homogenized. Sludge powder (5 g) was placed in an Erlenmeyer flask that was equipped with a magnetic stirrer and a condenser. Extraction solvent (200 mL) was added to the flask and refluxed at 50 °C for 4 h. Sequential extractions were thrice performed using the mixture. The resultant slurry after extraction was immediately filtered using a Buchner funnel, Whatman filter paper (No. 1), and a water aspirator. The filtrates were concentrated using a rotary evaporator and then dried to constant mass in vacuum desiccators (Jarde et al., 2005). The extraction solvent used in this experiment was a mixture of methanol, hexane, and acetone at ratios of 20:60:20, 40:40:20, 60:20:20, and 80:20:0 (actually without acetone).

2.3.1.2. Biodiesel production from extracted lipids. The extracted lipids were converted to FAMEs through acid catalysis in accordance with a modified version of Dufreche's method (Dufreche et al., 2007). These lipids were dissolved in 25 mL of hexane and added to a vial containing 125 mL of 5% sulfuric acid in methanol. The vial was then capped and heated at 55 °C for 24 h. Then, 5 mL of saturated sodium chloride was added, and the FAMEs were extracted with hexane (3 × 50 mL). The mixture was stirred vigorously for 3 min by a flash vortex and then centrifuged using a 5804R centrifuge operated at 3000 rpm for 3 min. The extraction procedure was repeated thrice to recover any biodiesel remaining in the sludge. The solid was discarded, and the supernatant was transferred to a separatory funnel. Subsequently, 10 mL of 2% $NaHCO_3$ was added to this funnel as a washing solution. After washing, the aqueous layer was discarded from the separatory funnel, and the hexane phase was dried by passing it through a Whatman filter paper (110 mm in diameter) that contained anhydrous sodium sulfate. It was then collected in a measuring flask. A 1.5 mL aliquot of the hexane phase was pipetted into a 2.0 mL Supelco PTFE-lined capped vial (Supelco, Bellefonte, PA) for FAME analysis. The remaining hexane phase was transferred to a conical flask, and the solvent was removed under vacuum using a rotary