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# Anaerobic co-digestion of grease sludge and sewage sludge: The effect of organic loading and grease sludge content

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## HIGHLIGHTS

- Grease sludge is a suitable co-substrate for sewage sludge anaerobic digestion.
- Co-digestion of GS and SS increases biogas yield up to 55%.
- Biogas yield of co-digestion systems depends on both GS content and OLR.
- The limit GS organic loading which provides for stable operation is 2.4 g $VS_{GS}$/L/d.
- Anaerobic co-digestion of GS and SS may increase the energy recovery of an WWTP.

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## ABSTRACT

The objective of this study was to assess the feasibility of co-digesting grease sludge (GS) originating from domestic wastewater along with sewage sludge (SS) and to assess the effect of organic loading rate (OLR) and GS content on process performance. Three lab-scale semi-continuous fed mesophilic anaerobic digesters were operated under various OLRs and SS–GS mixtures. According to the results, addition of GS up to 60% of the total VS load of feed resulted in a 55% increase of biogas yield (700 vs. 452 $m^3$/$tVS_{added}$) for an OLR of 3.5 kg VS/$m^3$/d. A stable and satisfactory operation of anaerobic co-digestion units can be achieved for a GS-OLR up to 2.4 kg $VS_{GS}$/$m^3$/d. For such values biogas yield is linearly proportional to the applied GS-OLR, whereas biogas yield is minimal for GS-OLR higher than this limit and acidification of the anaerobic digestion units is taking place.



## 1. Introduction

Lipids (fats, oils, grease) constitute a major part of domestic wastewater organic matter which accounts for the 25–40% of the total COD of the raw wastewater (Quemeneur and Marty, 1994; Chipasa and Medrzycka, 2006). The main sources of lipids in domestic wastewater are originated from food activities (kitchen waters) and human feces, which account for the 14–36% and 4–23% of the total lipids content respectively (Quemeneur and Marty, 1994). The major fraction of lipids found in wastewater are triglycerides and a smaller portion is present as free long chain fatty acids (LCFA). The transfer of significant lipids quantities through biological treatment units is very often associated with various operational problems like biological bulking and foaming, floc flotation, oxygen mass-transfer difficulties, odors, or even increase of effluent concentration of organic matter (Noutsopoulos et al., 2007).

Lipids (especially those in a suspended form) can readily be removed from wastewater by physical methods. Several methods (i.e. trapping, interception, use of skimmers, air flotation) have been employed in order to prevent lipids passing through the biological treatment units, achieving significant lipids removal (to the order of 50–90%). The remaining fraction of lipids is readily removed in the biological treatment units. The common management practices adopted for the disposal of the accumulated lipids in the form of grease sludge (GS) are landfilling and incineration. Alternatively due to its high free fatty acids content GS is a suitable source for biodiesel production through the reaction of free fatty acids with an alcohol (usually methanol) to form an alkyl ester (Jolis et al., 2010; Montefrio et al., 2010). However appropriate pretreatment of GS is required enabling an acid catalyzed process

*Abbreviations:* GS, grease sludge; SS, sewage sludge; OLR, organic loading rate; PS, primary sludge; WAS, waste activated sludge.

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followed by an alkaline catalyzed transesterification process (Long et al., 2012). Another GS alternative management option might be composting in order to decrease methane production trough landfilling (Lemus et al., 2004; Long et al., 2012). Given that landfilling is prohibited by the continuously stricter environmental legislation regarding the management of such biodegradable wastes (31/1991/EU), treatment of GS seems to be an unavoidable practice.

Although effective for achieving high removal efficiency (Chipasa and Medrzycka, 2006), the aerobic treatment of lipids does not seem to be a cost efficient method primarily due to the high oxygen demand and the corresponding high energy consumption. However, due to their significant methane yield (1 $m^3$ $CH_4$/kgVS) when compared to carbohydrates and proteins, lipids are considered to be a promising substrate for anaerobic treatment and a potential energy source (Hanaki et al., 1981; Kim et al., 2004; Alves et al., 2009). Several biochemical pathways are related to lipids degradation under anaerobic conditions. Triglycerides are firstly hydrolysed into free LCFA and glycerol; a process which is catalyzed by extracellular enzymes called lipases. After hydrolysis the majority of lipids methane potential (more than 90%) is conserved in LCFA. Degradation of free LCFAs and glycerol is taking place intracellularly. Glycerol is further degraded mainly to acetate by acidogenic bacteria, whereas LCFA are transformed to acetate (or propionate), hydrogen and $CO_2$ via β-oxidation biochemical pathway (syntrophic acetogenesis). The last step during anaerobic digestion is methanogenesis (hydrogenotrophic and acetotrophic).

Besides their high methane potential, lipids and lipids-rich wastes are not commonly used as a sole substrate in anaerobic digesters due to their inhibition effect to anaerobic biocenosis, along with the development of other operational problems like clogging, foaming and biomass flotation (Pereira et al., 2004). The inhibitory problems of lipids are mainly related to LCFA. The main mechanisms of LCFA toxicity is through their adsorption onto the cell wall of microorganisms thus inhibiting transport phenomena (Hwu et al., 1998; Alves et al., 2001; Cirne et al., 2007) and the acute toxicity on microbial activity of both aceticlastic and hydrogenotrophic methanogens (Angelidaki and Ahring, 1992; Rinzema et al., 1994). Recently it was suggested that inhibition is a reversible phenomenon provided that specific recovery practices will be applied (Cavaleiro et al., 2008; Palatsi et al., 2009).

Anaerobic digestion (AD) of sewage sludge (SS) is a well known technology resulting in energy generation through biogas production and sludge stabilization and sanitization. Several strategies have been proposed to improve biogas yield in SS-AD units. Among these, co-digestion of SS along with other organic substrates which present high methane potential have also be proposed as an interesting option, due to the improvement of nutrient balance and the positive synergisms established in the digesters, allowing, beyond others, the dilution of any inhibitory substances contained in SS. Besides these merits of co-digestion, a number of issues have been raised regarding potential operational problems of applying such an option, like process inhibition due to increase content of LCFA (Hanaki et al., 1981; Rinzema et al., 1994; Shin et al., 2003), substrate transport limitations (Pereira et al., 2004) and digester foaming (Kabouris et al., 2008), with the latter not being fully evidenced (Ganidi et al., 2009).

Since the anaerobic digestion with lipids as a sole substrate is not a feasible practice due to the aforementioned inhibition phenomena, the in situ digestion of SS (thickened primary and surplus biological sludge) produced in a WWTP along with GS collected in the same WWTP, seems an interesting approach.

There are several studies suggesting that an increased methane yield can be achieved through co-digestion of SS with lipid-based material (especially grease trap sludge). More specifically Luostarinen et al. (2009) reported a methane yield increase to the order of 60% when grease from a meat processing plant was co-digested with SS. According to Luostarinen et al. (2009) the co-digestion was feasible for a maximum grease content equal to 46% on a VS basis, whereas Wan et al. (2011) found an increase in methane yield equal to 137% for a grease content equal to 64% on a VS basis. Kabouris et al. (2009b) reported that co-digestion of SS along with grease trap sludge from restaurants (at a 48% GS content on a VS basis) produced 2.95 times higher methane yield. Davidsson et al. (2008) reported high grease trap sludge methane yield in single substrate anaerobic digestion batch tests (845–928 $Nm^3$ $CH_4$/$tVS_{added}$), but could not reach stable methane production in semi-continuous flow anaerobic digestion systems. Furthermore the authors ascertained an increase on methane yield of 9–27% when 10–30% of grease trap sludge (on a VS basis) was digested along with sewage sludge. Finally Silvestre et al. (2011) found an increase in methane yield to the order of 138% when a GS content of 23% on a VS basis was added to SS.

Based on these findings it seems reasonable to expect that more data are required in order to assess the optimal operating conditions for the co-digestion process.

In view of the above the aim of the present study was to assess the feasibility of co-digesting lipids originated from domestic wastewater (in the form of GS) along with SS and to evaluate the effect of the organic loading and GS content on the performance of anaerobic co-digestion.

## 2. Methods

### *2.1. Inoculum and substrates*

All experimental systems were inoculated with mesophilic digested sludge from Psyttalia Wastewater Treatment Plant (PWTP). PWTP is located in the greater Athens region and has a treatment capacity of 3,500,000 population equivalent. The average wastewater flow entering PWTP was equal to 750.000 $m^3$/d. Wastewater treatment train consists of pretreatment, primary treatment and biological treatment. Primary sludge (PS) and waste activated sludge (WAS) after separate thickening (gravity thickening for PS and mechanical thickening for WAS) are pumped to mesophilic anaerobic digestion tanks at a feed ratio of 74% PS and 26% WAS on a VS basis. Average flowrates pumped to the anaerobic reactors of PWTP were equal to 3000 and 1200 $m^3$/d for PS and WAS respectively. Average totals solids concentrations of thickened PS and WAS were equal to 54.5 and 51.5 g TS/L respectively whereas the average VS/TS ratios for PS and WAS were equal to 75% and 80% respectively. The aforementioned mixture of PS and WAS thickened sludge from PWTP was used as sewage sludge (SS) substrate in the present study. Grease sludge (GS) originating from PWTP was also used as a co-substrate in the experimental units. GS was collected from the primary settling tanks of PWTP through surface skimming. The average quantity of GS collected at PWTP was equal to 60 g VS/$m^3$ wastewater, whereas the quantities of PS and WAS produced were equal to 170 g VS/$m^3$ wastewater and 70 g VS/$m^3$ wastewater respectively. Based on laboratory analyses GS exhibits a high organic content (VS/TS ratio equal to 90 ± 2%) and adverse rheological characteristics. Total and volatile solids content of GS was equal to 0.71 ± 0.06 kg TS/kg wet GS and 0.64 ± 0.05 kg VS/kg wet GS respectively. SS and GS were shipped to the laboratory once a week and upon delivery they were stored at 4 °C after being analyzed for total and volatile solids concentrations.

### *2.2. Semi-continuous anaerobic digestion systems*

Three lab-scale single stage mesophilic anaerobic digesters were operated under a constant hydraulic retention time (15 d)