Anaerobic co-digestion of poultry manure and used cooking oil for enhanced biogas production

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Abstract

Aim of this study was to evaluate the anaerobic co-digestion of diluted poultry manure (DPM) and used cooking oil (UCO). Mixtures of DPM with different UCO dosages (1 to 6% v/v) were prepared using a high-shear emulsifier and digested in batch anaerobic reactors. Increasing the UCO dosage resulted in a respective increase of the emulsion COD (from initially 64 to 182 g/L) however the stability of the emulsion was adversely affected. The optimum UCO dosage (1.5-2.0% v/v) was further digested in a semi-continuous mesophilic anaerobic reactor, to assess the feasibility of the process at OLR up to 8 g/Ld. The anaerobic reactor was stable, giving a biogas yield of 0.45 L/gCOD, with low supernatant COD (6 g/L), negligible VFA accumulation and without foaming.

Keywords: anaerobic digestion; pre-treatment; fat oil and grease; poultry manure, biogas

1. Introduction

Used cooking oil (UCO) is a residue of major importance mainly due to its high organic content. It can be used as a cosubstrate in anaerobic digesters to increase biogas yield and methane recovery (Labatut et al., 2011).

Poultry manure was traditionally applied on land, as organic and nitrogen-rich fertilizer (Thangarajan et al., 2013). Anaerobic digestion of poultry manure results in waste stabilization, volume reduction and odor control, combined with the production of methane gas that can be used as a source of energy (Rodriguez-Verde et al., 2018). This substrate, however, is often consider problematic for mono-digestion due to its high protein and ammonia nitrogen content (Elasri and Elamin, 2016). As such, anaerobic co-digestion with lipid-rich eastes can increase the carbon to nitrogen ratio and improve the overall anaerobic digestion process.

Aim of this study was to evaluate the anaerobic co-digestion of diluted poultry manure (DPM) and used cooking oil (UCO). For this purpose the substrates were pre-treated using a high-shear emulsifier aiming to disintegrate and promote solubilization of the UCO (Harris and McCabe, 2015; Carrere et al. 2016). Mixtures of DPM with different UCO dosages were accordingly digested in batch anaerobic reactors, while the optimum mixture was further treated in a semi-continuous anaerobic reactor, to assess the feasibility of the process (biogas production rate, methane yield, effluent quality, VFA accumulation and degree of foaming).

Table 1. Physicochemical properties of diluted poultry manure (DPM).

Parameter	Value
pH	6.68
EC (mS/cm)	22.0
COD total (g/L)	64.0
COD soluble (g/L)	31.4
TSS (g/L)	36.3
VSS (g/L)	25.4
TKN (g/L)	4.64
NH_4-N (g/L)	1.74

2. Materials and Methods

2.1. Substrates origin and characteristics

The poultry manure (without bedding material) originated from an egg producing facility (Ioannina, Greece). The used cooking oil was obtained from a local restaurant.

2.2. Poultry manure and UCO pre-treatment

Poultry manure was mixed with hot water at ratio 1:3 (w/w), followed by screening (1 mm mesh) to remove large solids. The liquid fraction, so called diluted poultry manure (DPM), was used for the study (Table 1). The emulsification of DPM with UCO was performed at different UCO dosages from 1 up to 6% (v/v), using a high-shear emulsifier (IKA) at 3000 rpm. The corresponding mixtures were characterized for emulsion stability (percentage of floating material in graduated cylinders) after five (5) subsequent freeze-thaw cycles.

2.3. Batch anaerobic digestion studies

Mixtures of DPM with different UCO dosages were digested in batch anaerobic reactors (2 L working volume) at an initial COD concentration of 3 g/L. The experiments were conducted in triplicate. All batch reactors were equipped with magnetic stirrer, thermal bath with hot water recirculation in double glass jacket and pH measurement. The biogas production from each batch reactor was measured using an inverse water column, with acidified water to avoid dissolution of the biogas CO_2.

2.4. Continuous anaerobic digestion studies

An anaerobic digester (CSTR) with 42 L working volume was used for the study. The digester temperature was maintained at 38 ± 1 °C, using a thermal bath (LAUDA) with hot water recirculation through the reactor double jacket. Mixing was performed with a paddle mixer operated at 40 rpm. The substrate mixture was prepared daily and it was fed into the digester in batch-fed mode (once per day). The hydraulic retention time was gradually decreased from 40 to 10 d, corresponding to an organic loading rate increase from 2 to 8 g L^{-1} d^{-1}. The substrate was supplemented with trace elements according to Eftaxias et al., (2018).

3. Results and Discussion

3.1. DPM and UCO emulsion stability

The DPM was characterized by a total COD concentration of 64 g/L, consisting of 14% lipids and 35% of proteins (see Table 1). Emulsification with UCO resulted in an increase of COD by a factor of 1.9 – 2.8, i.e. from initially 64 to 120 g/L (at a UCO dosage 2% v/v), and to 182 g/L (at a UCO dosage 6% v/v). However, with increasing the UCO dosage, the stability of the mixture was adversely affected, since the lipids tended to aggregate and float. As shown in Figure 1, the percentage of floating material after 5 subsequent freeze/ thaw cycles increased from 3 to 20% with increasing UCO dosage from 1 to 6% (v/v). Moreover, the COD of the emulsion remained close to theoretical values when the UCO dosage was < 2.3% v/v. With increasing the UCO dosage from 2.3 to 6.0% (v/v) a significant fraction of COD (from 10 up to 25%) remained as large floating aggregates.

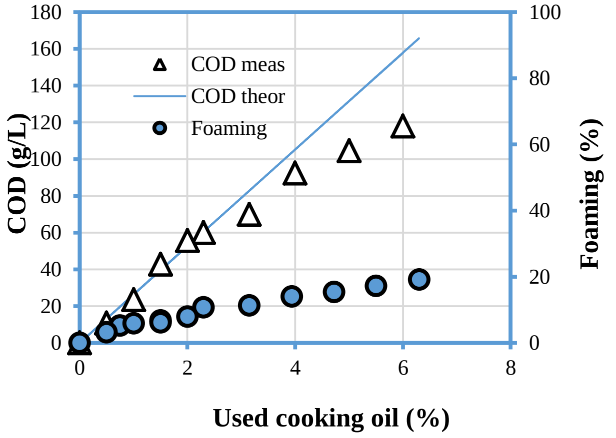

Figure 1. Effect of UCO dosage on emulsion stability (percentage of floating material) and the corresponding used cooking oil COD concentration (theoretical and measured).

3.2. Anaerobic co-digestion in batch reactor

The anaerobic digestion of UCO alone displayed low biogas production rate (0.022 L g^{-1} COD d^{-1}) combined with a 4-5 days lag phase period (Figure 2). On the contrary, the DPM alone was digested without any lag phase at significantly higher biogas production rate (0.13 L g^{-1} COD d^{-1}). The mixture of DPM with a UCO dosage of 1.5, 1.75 and 2% (v/v) displayed high biogas production rates similar to the DPM alone ($p = 0.84$, 0.88 and 0.98 respectively). This was not the case, however, for the 6% (v/v) mixture where a lag phase of 2-3 days was recorded. Based on these findings the UCO dosage between 1.5-2.0% (v/v) was selected for further study in a continuous (batch-fed) anaerobic digester.

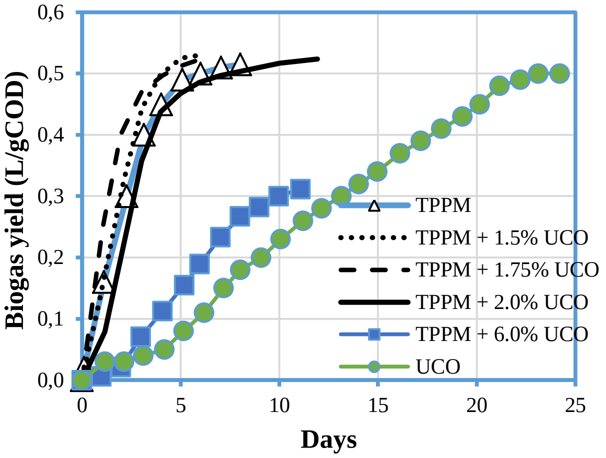

Figure 2. Cumulative biogas production from batch anaerobic digestion of UCO alone, DPM alone and DPM-UCO mixtures.

3.3. Anaerobic co-digestion in continuous reactor

The CSTR received daily the DPM-UCO mixture (between 1.5-2.0% v/v). No digester foaming or sludge floatation was recorded during the study despite that the anaerobic reactor received around 50% of the incoming COD as lipids. The biogas production rate displayed an increase up to 2.0-2.5 L L^{-1} d^{-1} with increasing the OLR, however, the biogas yield declined from 0.45±0.05 to 0.34±0.07 L g^{-1} COD when the OLR increased > 5 g L^{-1} d^{-1} (Figure 3). The biogas methane content remained equal to at 74.2 (±2.9) %. Supernatant COD (SCOD) was also constant at 5.3±0.8 g/L, throughout the study, corresponding to a SCOD removal efficiency of 85%. The digester was stable with negligible VFA accumulation (<0.5 g/L).

4. Conclusions

Anaerobic digestion of UCO alone displayed low biodegradability, which was attributed to low solubility and bioavailability. When the UCO was mixed with diluted poultry manure (DPM), up to 2% (v/v), the batch anaerobic digestion process was stable without inhibition. Further increasing the UCO dosage from 2 to 6% (v/v), affected adversely the stability and the digestibility of the mixtures. Under optimum conditions, the DPM-UCO mixture was digested at OLR up to 8 g L^{-1} d^{-1}, with negligible VFA accumulation nor sludge floatation. DPM is a suitable substrate for UCO co-digestion. The results of this study are important for full-scale anaerobic digestion facilities since supplementing 2% (v/v) UCO it is possible to double both the organic content and the corresponding biogas yield.

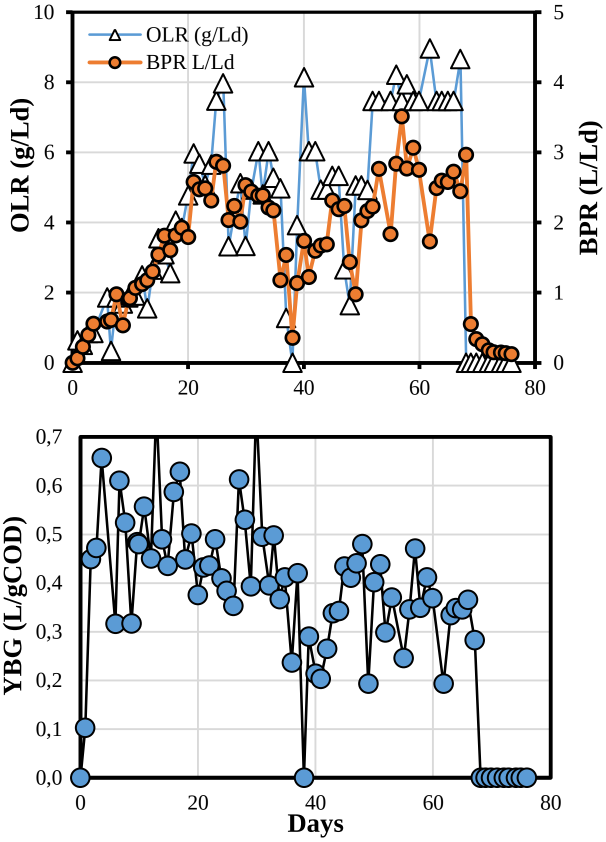

Figure 3. Performance of the continuous (batch-fed) anaerobic digester treating DPM and UCO.

Acknowledgements: The research was supported by the General Secretariat for Research and Technology (GSRT) and the Hellenic Foundation for Research and Innovation (HFRI).

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