High-rate anaerobic co-digestion of agro-industrial wastes combined with ammonia recovery and biogas purification

Eftaxias A.*, Georgiou D., Diamantis V., Koumara A., Koskinari M.D., Aivasidis A.

Department of Environmental Engineering, Democritus University of Thrace, Vas. Sofias 12, GR67100, Xanthi, Greece

*corresponding author: e-mail: alexeftaxias@gmail.com

Abstract
Screened dairy manure, pressure-sterilized animal by-products, and cheese whey were co-digested in a Plug Flow Reactor (PFR) over a period of 150 days. The PFR process was stable even under a hydraulic retention time of 3 days, corresponding to an organic loading rate (OLR) of 22 g/Ld. Effluent COD remained low (5.6±1.4 g/L) while VFA concentrations were negligible (< 0.5 g/L as COD). The biogas production rate from the PFR ranged from 2.6 up to 7.3 L/Ld. The anaerobic digestate was characterized by high ammonia content (1.7±0.5 g/L); therefore air-stripping was chosen for the effective removal of ammonia. Hydrated lime as a slurry was utilized for the necessary pre-treatment step (pH-raising), due to its fast reaction and low cost. A temperature of ≥ 45 °C was also needed for efficient ammonia removal. The final effluent was neutralized by CO_2 absorption through biogas injection in a scrubber. Concurrently, the biogas was upgraded since its methane content increased substantially, while H_2S was completely removed.
Keywords: anaerobic digestion; biogas; biomethane; dairy manure; ammonia stripping.

1. Introduction

Anaerobic digestion of dairy manure often results in low biogas yield, which subsequently affects the economic feasibility of the anaerobic digestion facility (e.g. conventional CSTR digester). Co – digestion of manure with lipid-rich wastes can increase the biogas yield (Salama et al., 2019), however special care should be given to avoid lipids and LCFA accumulation and process inhibition (Eftaxias et al., 2018).
Plug flow reactors (PFR) provide optimum residence time distribution, minimize flow short – circuit and has been successfully applied for organic waste processing under different operating conditions (Yue et al., 2011; Namsree et al., 2012). The objectives of the study were to examine the efficiency of this type of reactor (PFR) for the anaerobic digestion of a complex substrate, consisting of a mixture of screened dairy manure, pressure sterilized animal – by – products and cheese whey.

2. Materials and Methods

2.1. Substrates origin and characteristics

Dairy manure, cheese way and pressure-sterilized animal by-products were obtained from agro-industrial facilities in the region of Xanthi, Greece. Mixture (Table 1) was performed twice per week with the following composition (v/v): 51% of screened dairy manure, 11.4% pressure sterilized animal by products, 21% of cheese way and 16.6% water to maintain the COD total around 70g/L.

Table 1. Physicochemical properties of feed mixture

Parameter	Units	Value
pH	-	5.9 ± 0.5
EC	mS/cm	11.6 ± 0.8
COD total	g/L	70 ± 8
COD soluble	g/L	26 ± 6
TSS	g/L	20 ± 5
VSS	g/L	18 ± 6
TS	g/L	33 ± 5
VS	g/L	26 ± 2
NH_4-N	g/L	1.5±0.3

2.3. Continuous anaerobic digestion studies

The PFR (Figure 1) was constructed from plexiglass with 20 L working volume. The operational temperature was maintained at 36±1 °C. Mixing was performed intermittently at 8 rpm for 4 min every hour. Anaerobic sludge was recirculated from the end of PFR at a rate of 20% of the influent flow. The substrate was fed equally at the beginning and at the middle of the PFR. Bioreactor monitoring and trace element supplementation was performed according to Eftaxias et al. (2018). Process efficiency was evaluated on the basis of COD removal efficiency, biogas production rate, methane yield and VFA accumulation.

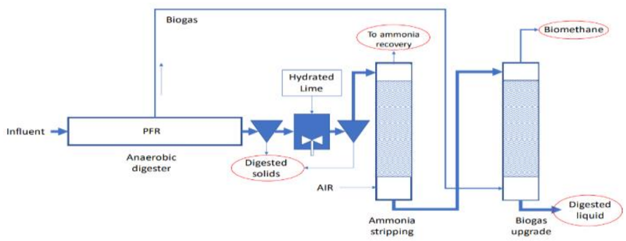


Figure 1. Schematic representation of the laboratory-scale anaerobic digestion facility combined with ammonia stripping and biogas upgrade.

2.4. Ammonia recovery and biogas purification

Ammonia air-stripping took place in a packed-tower installation consisted of a water-jacketed glass column of a height of 1.5 m and aninternal diameter of 8 cm (see Figure 1). Glass-made cylinders of the “Raschig ring”type, of a size of 1 cm and a thickness of 2 mm were utilized as the packing material; the packing bed had a total height of 0.95 m. Temperature was maintained constant by means of a water-bath and an external water-coil. More details about the experimental setup of the ammonia recovery and biogas purification facility can be found at Georgiou et al., (2019).

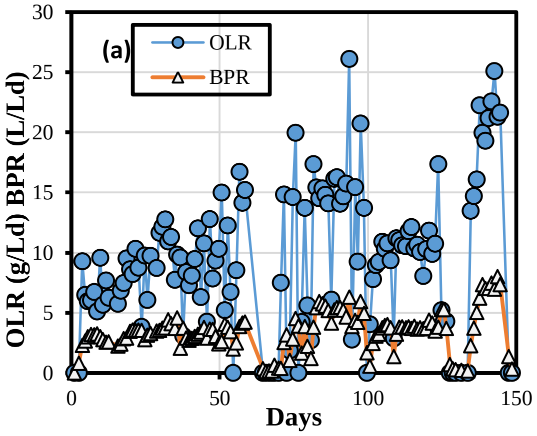
3. Results and Discussion

3.1. Performance of the anaerobic PFR

The PFR was in operation for around 150 days with an OLR from 7 up to 22 g/Ld, giving a biogas production rate from 2.6 up to 7.3 L/Ld (see Figure 2). The biogas yield was 0.36 L/gCOD fed, for OLR > 9 g/Ld (Figure 3), with a biogas methane content of 73±3%. The anaerobic effluent was characterized by a SCOD concentration of 5.6±1.4 g/L (see Figure 2b) and an ammonia nitrogen 1.7±0.5 g/L. The PFR displayed high process stability during the study with negligible VFA accumulation (< 0.5 g/L as COD), both at the middle and the end of the reactor. SCOD removal efficiency remained constant during the study at 80±4 %.

3.2. Ammonia recovery and biogas purification

The anaerobic effluent was treated with lime-slurry (50% solids), at a pH of 12.0. The effect of temperature and G/L ratio on ammonia removal efficiency was studied (Georgiou et al., 2019). Ammonia was almost completely removed at 50 °C and G/L = 2000, while at the same temperature, ammonia removal efficiency was high even at half the above G/L ratio (G/L = 1000). The ammonia stripper effluent was further treated in a chemical absorption tower at different L/Q_{biogas}. Biogas was indeed upgraded since methane percentage at the exit of the scrubber reached 84%, at all L/Q_{biogas} ratios.



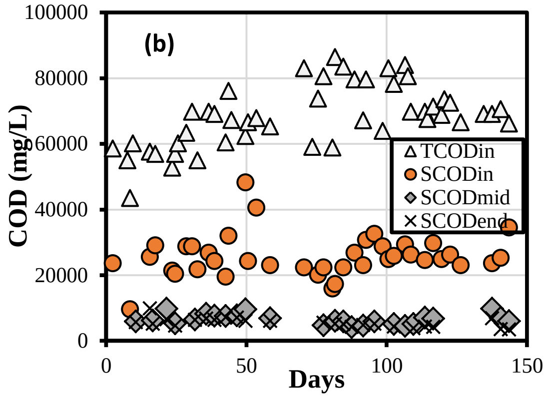


Figure 2. Evolution of (a) the organic loading rate (OLR) and the biogas production rate (BPR), and (b) the influent and the effluent COD (total and supernatant) during continuous operation of the anaerobic PFR treating dairy manure, animal by-products and cheese whey.

4. Conclusions

Co-digestion of screened dairy manure, pressure sterilized animal by-products and cheese whey was successful at high OLR using a mesophilic PFR. Chemical absorption of CO_2 in a scrubber, utilizing the biogas as the scrubbing agent, proved to be a very effective technique for neutralizing the air-stripper's effluent and for biogas upgrading. The proposed technology is of interest for the anaerobic digestion of complex wastewaters and more studies are currently conducted at industrial prototype level.

Acknowledgements

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