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Fate of LCFA in the co-digestion of cow manure, food waste and discontinuous addition of oil

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ABSTRACT

Different concentrations of oily waste were added in a discontinuous mode and recurrently to anaerobic continuous stirred tank reactors fed with cow manure and food waste. Four continuous stirred tank reactors were run in parallel. A control reactor (R1) received no additional oil and R2, R3 and R4 received increasing concentrations of oil in two different experimental approaches. First, the lipids composition was forced to change suddenly, in three moments, without changing the total chemical oxygen demand (COD) fed to the reactors. The only long chain fatty acid (LCFA) detected onto the R1 solid matrix was palmitic acid (C16:0). Nevertheless in the solid matrix of R2, R3 and R4 C16:0 and stearic acid were detected. For occasional increase in the oil concentration up to 7.7 $gCOD_{oil}/L_{reactor}$ (55% $Oil_{COD}/Total_{COD}$) no statistical differences were detected between the reactors, in terms of methane production, effluent soluble COD, effluent volatile fatty acids and total and volatile solids removal. Therefore this experiment allowed to conclude that cow manure–food waste co-digestion presents sufficient buffer capacity to endure solid-associated LCFA concentration up to 20–25 gCOD-LCFA/kgTS.

In a second experiment higher concentrations of oil were added, raising occasionally the concentration in the reactors to 9, 12, 15 and 18 $gCOD_{oil}/L_{reactor}$. All pulses had a positive effect in methane production, with the exception of the highest oil pulse concentration, that persistently impaired the reactor performance. This experiment demonstrates that threshold values for LCFA and C16:0 accumulation onto the solid matrix, of about 180–220 gCOD-LCFA/kgTS and 120–150 gCOD-C16:0/kgTS, should not be surpassed in order to prevent persistent reactor failure, as occurs in some full scale co-digestion plants.

1. Introduction

Several organic wastes are treated today in co-digestion processes together with manure (Weiland, 2004). The biogas yield from raw manure alone is only 20–30 m^3/ton and the operation of the plant is only economically feasible when the biogas yield is higher than 30 m^3/ton (Lindboe et al., 1995). Co-digestion of manure with biodegradable waste appears as a robust process technology that can increased by 80–400% the biogas production in anaerobic biogas plants (Braun et al., 2003; Weiland, 2004), like food waste. Although co-digestion is an established and applied process, it is important to understand how the changes in the composition will affect the overall process. Food waste, composed by carbohydrates, cellulose, proteins, and lipids, can be highly variable depending on their sources and are not homogeneous in their day-by-day composition. Among the food components, lipids degradation still requires a deeper understanding. It is

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realistic to consider possible transient, occasional, accidental or even on purpose increase in the lipid content of a food waste stream in a real context.

Lipids as substrate or co-substrate for anaerobic digestion processes constitutes an important issue due to the higher theoretical methane yield (0.99 LCH_4/g) as compared to carbohydrates (0.42 LCH_4/g) and proteins (0.63 LCH_4/g), at standard temperature and pressure conditions (Alves et al., 2009). In this context, lipid-rich wastes can be regarded to have a large potential as a renewable energy source (Hansen et al., 1999). Nevertheless, in practice, the anaerobic digestion of lipids is often hampered as the theoretical methane production is not easily achieved. Frequently, the most reported problem is the failure of the system due to the presence/accumulation of the long chain fatty acids (LCFA), ensuing the lipids hydrolysis. LCFA have been reported as inhibitory/toxic to microorganisms even at low concentrations (Hanaki et al., 1981; Angelidaki and Ahring, 1992; Rinzema et al., 1994). More recently it was reported that LCFA inhibition was reversible. The observed transient inhibition was partially assigned to transport limitation, due to LCFA adsorption, instead of exclusively to metabolic phenomena (Pereira et al., 2004, 2005). Adsorption of LCFA is a wide reported phenomenon in the anaerobic digestion processes and is frequently the reason appointed to process failure (Miranda et al., 2006; Hwu et al., 1998; Cirne et al., 2007). Nonetheless, there are examples of successful anaerobic digestion of lipids in the literature. Li et al. (2002) reported that food wastes containing high lipids content, ranging from 8% to 40% by adding salad oil and lard of pork, were effectively degraded by high solids co-digestion process and over 85% of the lipids content was degraded. Ahring (2003) reported that the addition of 5% fish oil to a manure digester increased twofold the methane production per volume of feed. Recently, Nielsen and Ahring (2006) also showed that the addition of oleate pulses to thermophilic reactors treating mixtures of cattle and pig manure had a stimulating effect on the overall process.

In a previous work (Neves et al., 2009a), pulses of oily waste from a canned fish processing industry were added to mesophilic (37 °C) continuous stirred tank reactors with hydraulic retention time of 15 days fed daily with cow manure and food waste. Concentrations up to 15 $gCOD_{oil}/L_{reactor}$ had a positive effect in methane production, whereas after a sudden addition of oil at 18 $gCOD_{oil}/L_{reactor}$ a decay in methane production was observed, which persisted for a long time, suggesting an irreversible inhibition in the time scale of the experiment. This is extremely important as far as the co-digestion of lipids is concerned. Prevention of inhibition by LCFA rather than recovery after inhibition should be the right operational strategy to manage the full potential of methane production from lipids in full scale continuous anaerobic digestion plants.

So far, the exact behaviour of LCFA in co-digestion processes is not well understood. Inhibitory LCFA concentrations, ratio between solid phase-associated LCFA and methane production or/and fate of individual LCFA in co-digestion processes with lipids, are issues that demand additional research efforts. The present study focus on assessing the individual profiles of LCFA associated to the solid phase of four reactors fed with cow manure and food waste, in two different approaches: First, the lipids composition was forced to change suddenly in three moments without changing the total chemical oxygen demand (COD) fed to the reactors. Secondly, pulses of lipids were added, raising the concentration in the reactors up to 9, 12, 15 and 18 $gCOD_{oil}/L_{reactor}$. Lipid concentration was manipulated by adding oily waste from a canned fish industry. One of the reactors was used as control and was devoid from the oily waste during both experiments. The ultimate goal was to determine the specific amount of LCFA that can be adsorbed into the solid phase (expressed as mg COD-LCFA/gTS) without compromising the process stability of a co-digestion anaerobic plant based on cow manure and food waste.

2. Materials and methods

2.1. Substrates

Three substrates were used in the anaerobic co-digestion process. (i) Cow manure, collected in a dairy farm in the suburbs of Braga (Portugal) and stored in a refrigerator (4 °C) until use to minimize the decomposition of substrate; (ii) Food waste, which was a composite sample (one week based) from the waste produced in the canteen of the University of Minho, located in ‘‘Campus de Gualtar’’, Braga, Portugal. It was crushed to 1–3 mm particle size and stored at 4 °C during 5 days, until the end of the collecting process. Then it was mixed and stored at −18 °C; (iii) Oily waste collected in a canned fish processing industry was used to simulate the variation of lipids content. The characteristics of each substrate are presented in Table 1.

2.2. Reactor start-up

Four 5-L mesophilic continuous stirred tank reactors with hydraulic retention time of 15 days were fed with cow manure and food waste. The digesters were inoculated with the effluent from a stable laboratory mesophilic anaerobic digester fed with cow manure and food waste. The biogas flow rate generated was measured by a Ritter Milligascounter (Dr. Ing. Ritter Apparatebau GmbH, Bochum, Germany). After a stable operation of the four reactors, for 48 days, the experiments with occasional feeding of fat were initiated.

2.3. Experimental plan

Two sets of experiments with addition of different lipid concentrations were performed. In both experiments, the feed to the four reactors had a ratio of cow manure and food waste of approximately 1:1, either in COD or TS basis. The organic loading rate of the four reactors was 4.6 ± 0.1 $gCOD/(L_{reactor} \cdot day)$. The lipid content was changed by adding pulses of oily waste to three of the four reactors fed with the mixture cow manure/food waste as depicted in Table 2.

One of the reactors (R1) was used as control and was devoid from the oily waste during the both experiments. The feed composition was changed on specific days as follows. In the first experiment, the oil composition was forced to change suddenly in three moments of the reactors operation. The