Anaerobic co-digestion of cheese whey and liquid dairy manure in a CSTR digester

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Abstract
Anaerobic co-digestion of cheese whey and screened liquid fraction of dairy manure has been investigated in a lab-scaled CSTR digester operating at 35ºC. The reactor was operated at a constant HRT of 14 days with increasing volume proportions of whey from 5% to 30%. Digester performance was evaluated in terms of methane yield and organic removal percentages. Due to the higher biodegradability of cheese whey, removal percentage of COD increased from 43.1% with 5% cheese whey proportion in the influent to 55.8% with 30% cheese whey content in the influent. In addition, volumetric methane production rate increased from 0.46 L CH_4 L^{-1} d^{-1} at 5% cheese whey proportion to 0.73 L CH_4 L^{-1} d^{-1} at 30% cheese whey content of the substrate mixture. Anaerobic co-digestion of these two substrates resulted advantageous than processing each one separately because liquid manure provides alkalinity and stability whereas cheese whey increases the methane yield of liquid manure.

Introduction
The overall pollution prevention targets require increasingly sustainable solutions for the management of animal manures and organic wastes. The directives from the European Union require member states to increase renewable energy consumption and to reduce uncontrolled methane emissions. In the ecologically sustainable society of the future, anaerobic digestion should play an important role due to the environmental benefits such as renewable energy production, environmental protection and nutrients recovery [1]. Anaerobic co-digestion is also a very attractive solution from a socio-economic point of view since biogas production and energy sales are increased, the fertiliser value of the digestate is improved and organic waste treatment costs can be reduced resulting in an additional source of income for farmers and food industry.

Cheese whey is a by-product of the cheese industry rich in proteins and lactose. Cheese whey presents rather high pollutant characteristics and is the major by-product of dairy industries. It is produced in high amounts which are constantly increasing. It is highly biodegradable (~ 99%), has a high organic load (up to 80 g COD/l) and a very low alkalinity. However, cheese whey is a quite problematic substrate for being treated by anaerobic process due to the lack of alkalinity and the high COD concentration [2]. These characteristics of the cheese whey are responsible of the tendency to rapidly acidify and produce an excess of viscous exopolymeric materials that difficult the granulation process and reduce sludge settleability which can be a cause of biomass washout in UASB reactors [3]. Dairy manure is a waste with high organic content composed mainly by particulate material and low biodegradability compared to whey (~ 45%), but high alkalinity [4]. Whereas for the anaerobic treatment of the whey the rate limiting step is the last one, involving the formation of methane, for dairy manure the slowest stage is the first, the hydrolytic one, in which particulate material get solubilized.

In this work the anaerobic co-digestion of cheese whey and the screened liquid fraction of dairy manure has been studied in a lab-scaled CSTR at mesophilic conditions (35ºC). The aim of the experiment was to evaluate the performance of the digester with different proportions of cheese whey in the substrate mixture, from 5% to 30%.

Material and Methods

CSTR digester

The CSTR reactor was constructed of PVC with a total volume of 25 litres, 20 litres useful. The operating temperature was set at 35°C and was obtained by circulating hot water through a coil tube inside the reactor. Mixing was performed using a mechanical paddle stirrer that operated at intervals of 15 minutes. The biogas produced was measured in a volumetric gas measurement device which worked on the principle of liquid displacement. The methane yields are expressed in normal conditions of pressure and temperature (0ºC and 1 atm).

The digester was fed in semi-continuous mode. Daily amount of feed was introduced manually by a tube that ended submerged into the reactor. At the same time effluent was withdrawn out of the reactor by other pipe located at the bottom of the digester.

Substrates and inoculum

Cheese whey (CW) was received from a dairy company, Queserías la Fuente, located in Heras (Cantabria, Spain). CW was collected and immediately delivered to the laboratory, where it was stored at 4ºC prior to use.

Dairy manure was collected from an intensive dairy farm located in Loredo (Cantabria, Spain) equipped with a 0.8 mm mesh size screw press separator (Cri-Man, Italy). It holds 140 lactating cows, 40 dry cows, 80 heifers and 30 calves. The screened liquid fraction of dairy manure (SLF) was used in this test to facilitate operation and to avoid clogging into the digester.

Analytical techniques

The following parameters were determined: Total Solids (TS), (Volatile solids (VS), Volatile fatty acids (VFA), Total COD (COD_T), Supernatant COD (COD_{sup}), Alkalinity, pH, Ammonia Nitrogen (NH_4^+-N), Kjeldahl Nitrogen (TKN-N) and Total Phosphorous (P_T). VFA were determined using a HP6890 GC instrument fitted with a 2m x 1/8 in. glass column, liquid phase 10% AT 1000, packed with the solid support Chromosorb W-AW 80/100 mesh. Nitrogen was the carrier gas and a FID detector was installed. Biogas composition was measured on a 2m Poropak T column in a HP 6890 GC System with helium as the carrier gas and a TCD detector. Biogas composition was measured on a 2m Poropak T column in a HP 6890 GC System with helium as the carrier gas and a TCD detector. Methane volumes are expressed at 0ºC and 1 atm. All other analyses were performed following the Standard Methods for the Analysis of Waters and Wastewaters [5].

Results

Characteristics of substrates

The mean values for the performance of the CSTR reactor at 14 days HRT are shown in Table 1.

Table 1. Characteristics of CW and SLF used in the test (all concentrations expressed in g L^{-1}, except alkalinity (mg $CaCO_3$ L^{-1}) and pH.

% Whey (v/v)	5	10	15	20	25	30
OLR (g COD/(l·d))	3.48	3.58	3.65	3.73	3.80	3.90
% COD rem	43.1	45.4	46.1	49.6	51.8	55.8
% VS rem	34.2	35.5	39.3	42.8	45.6	48.6
L CH_4/g COD	0.135	0.140	0.150	0.166	0.172	0.185
L CH_4/g VS	0.164	0.170	0.197	0.209	0.238	0.315
L CH_4/(L·d)	0.462	0.485	0.532	0.617	0.651	0.727
% CH_4	65.6	68.7	62.4	63.4	62.6	65.3

The COD concentration values for SLF and CW were similar. However biodegradability of CW was much higher (~ 99%) than that for SLF (about 45%). For this reason, the value of OLR remained practically constant with the increasing percentage of CW in the influent, while the percentage of COD removed increased as the percentage of CW in the influent increased as well. Likewise, the production of methane per gram of COD influent also increased up to a maximum value of 0.185 L CH_4 g^{-1} COD for a 30% volume proportion of CW. The volumetric production of methane reached a maximum value of 0.727 LCH_4 $(L \cdot d)^{-1}$ for a 30% CW influent. Figures 1 and 2 represent OLR applied vs OLR removed and OLR applied vs volumetric methane production. Both relationships exhibited good linear correlations.

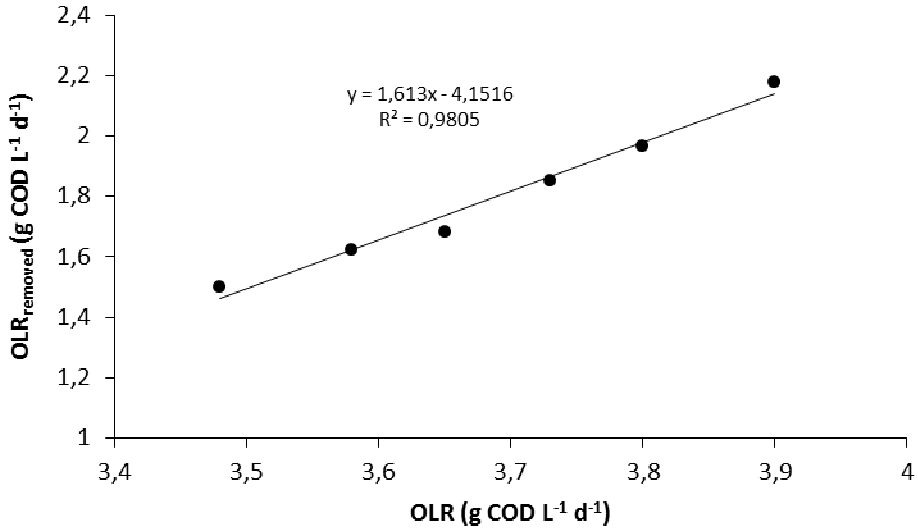

Figure 1. Organic removal rate vs organic loading rate

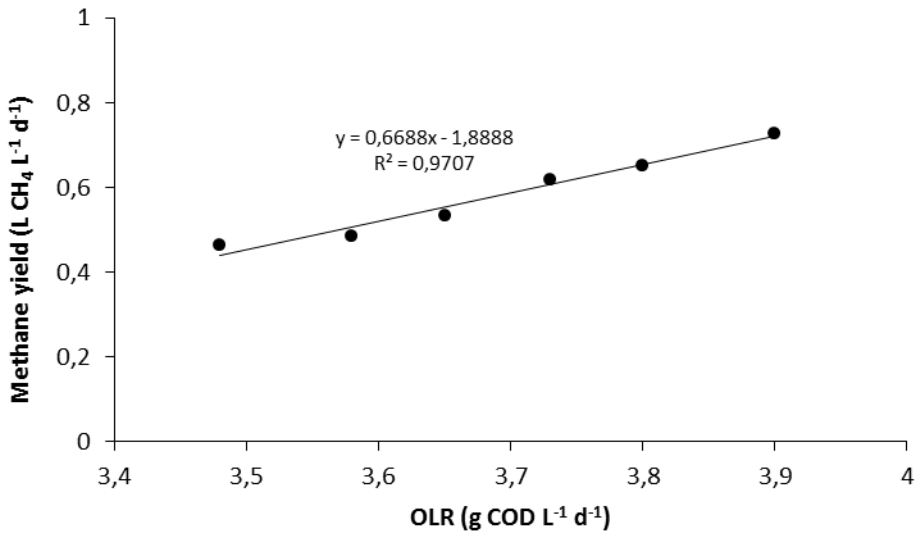

Figure 2. Volumetric methane production rate vs organic loading rate

Conclusion and perspectives

The results indicate that cheese whey as a co-substrate enhanced the anaerobic co-digestion of the screened liquid fraction of dairy manure within the experimented range. The higher proportions of cheese whey resulted in higher organic matter removal and biogas and methane yields due to the higher biodegradability of the whey. Screened liquid manure provided alkalinity and nutrients that were enough to achieve a stable operation for all the experimental conditions performed, from 5% to 30% cheese whey content in the feed mixture. Co-digestion of liquid manure and cheese whey improves the performance of anaerobic process for both substrates separately increasing volumetric methane production and solving the problem of acidification of the reactor due to lack of alkalinity when cheese whey is digested alone.

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