Anaerobic co-digestion of cheese whey and liquid dairy manure: Batch tests

Rico Carlos[1*], Rico José Luis[2], Muñoz Noelia[2], Fernández Josefa[2]
(1) UNIVERSITY OF CANTABRIA, Dept. Water and Environmental Science and Technologies, Los Castros s/n, 39005 Santander, ES
(2) UNIVERSITY OF CANTABRIA, Dept. Chemical Engineering and Inorganic Chemistry, Los Castros s/n, 39005 Santander, ES.
*Corresponding author: ricoc@unican.es

Abstract
Anaerobic co-digestion of cheese whey and screened liquid fraction of dairy manure has been investigated under batch mode operation. Six cheese whey proportions were tested, from 10 to 60%. Co-digestion of both substrates permitted to digest a difficult substrate such as the whey without alkalinity addition. However, above 20% cheese whey proportion, methane yield was lower than expected from methane potentials of both substrates. The best results in terms of methane conversion were obtained at 20% whey proportion. Under this condition methane yield of the mixture was 46.4% higher than that of the liquid manure, and cheese whey was completely degraded with an estimate methane yield of 18.4 L CH_4 kg^{-1} whey. On the contrary, with 60% cheese whey proportion, the methane yield was 82.7% higher than that of the liquid manure but the estimate methane yield of the whey was reduced to 13.2 L CH_4 kg^{-1}.

Introduction
The increase in production and concentration of intensive livestock operations have resulted in greater awareness and concern for the proper storage, treatment and utilization of livestock manure. Much larger dairy farms have become more common since 1990. To collect and store manure at these large farms, farmers often use liquid manure management systems that use water to flush or clean alleyways or pits where the manure is excreted.

Cheese whey is the major by-product of dairy industries and presents rather high pollutant characteristics. It is produced in high amounts which are constantly increasing [1]. Typically, cheese whey has 5-8% of dry matter of which around 10–20% are proteins, 60–80% are lactose and the rest are minerals, vitamins, fat, lactic acid and trace elements [2]. Cheese whey presents high organic load (up to 80 g COD L-1), very low alkalinity content and high biodegradability [3]. Because of its high organic load, cheese whey disposal constitutes a serious environmental problem. Although this high biodegradable organic load is a chance for both green energy generation and pollution control through anaerobic digestion, cheese whey is a quite problematic substrate for being treated by anaerobic process due to the lack of alkalinity, the high COD concentration and the tendency to acidify very rapidly [4].

The characteristics of dairy manure and cheese whey are completely opposite. Dairy manure presents many suspended solids and fibrous material and only a small part of the organic matter content is in soluble form. Manure has enough alkalinity and nutrients to develop the anaerobic process and its anaerobic biodegradability is about 45%. Hydrolysis is the rate-limiting step in the anaerobic digestion of manure whereas for the whey it is the methanogenesis. Manure and cheese whey are totally antagonistic but complementary and therefore have to be a good match for a co-digestion process. To date very few attempts have been carried out for co-digestion of cow manure and cheese whey [5, 6].

In this work the anaerobic co-digestion of cheese whey and the screened liquid fraction of dairy manure have been studied in batch tests at mesophilic conditions. The tests were conducted under six different cheese whey proportions, from 10 to 60% in order to evaluate the influence of cheese whey proportion in methane production and stability of the process.

Material and Methods

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 enhance the contact between microorganisms and substrate.

Anaerobically digested solid fraction of dairy manure was used as inoculum for this test. It had 52.2 g VS L^{-1} and a VS/TS ratio of 0.66.

Batch laboratory anaerobic co-digestion tests

250-mL serum bottles capped with rubber septum sleeve stoppers were used as reactors. Gas production was determined by pressure measurement. Biogas samples were also taken through the septum by a needle connected to a syringe. After set-up of the reactors biogas was flushed to remove the air in the headspace of the bottles. Thereafter, all the reactors were placed in an incubator at 35ºC. Gas produced in each reactor was determined daily for 30 days.

In order to compare the different proportions of CW in the anaerobic co-digestion test, mixtures of CW and SLF were prepared with the following mass proportions of whey: 10% (M10), 20% (M20), 30% (M30), 40% (M40), 50% (M50) and 60% (M60). Additionally the SLF and the CW were tested separately to determine their ultimate methane yield (B_0) which resulted to be 5.5 L CH_4 kg^{-1} SLF and 17.9 L CH_4 kg^{-1} CW.

For each mixture of CW and SLF, reactor was supplied with approximately 43 g of inoculum and 84 g of substrate mixture. The resulting $VS_{inoculum}/VS_{substrate}$ ratios ranged from 1.07 for M10 to 0.75 for M60. Since experiments were performed in batch, only methane production was used as indicator of the co-digestion process.

Analytical techniques

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 (TS, VS, COD, Total Kjeldahl Nitrogen (TKN-N), Ammonia Nitrogen (NH_4^+-N), and Total Phosphorous (P_T) were performed according to Standard Methods [7].

Results

Characteristics of substrates

Characteristics of the CW and SLF are shown in Table 1. CW presents higher organic content than SLF but a lower nutrient and alkalinity content. CW presented VS and TS content of 46.4 and 55.7 g L^{-1} and very low bicarbonate alkalinity content. With regards to SLF, it presented lower organic content than other screened liquid fraction used by the authors [8], but enough alkalinity to enable the anaerobic process. This low VS content will limit methane production per kg of substrate.

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.

Parameter	TS	VS	COD	TKN-N	NH_4^+- N	P_T	Alkalinity	pH
SLF	36.1	23.2	30.4	2.3	1.6	0.57	12,500	6.9
CW	55.7	46.4	58.0	0.65	0.15	0.18	0	5.3

Batch co-digestion tests

In Fig. 1 the daily specific methane production rates for all the co-digestion samples are presented. They have been separated in two groups, M10, M20 and M30 in Fig. 1a and M40, M50 and M60 in Fig 1b. Daily specific methane yields showed a similar trend for samples M10, M20 and M30. This trend was characterized by a peak at day 1 and then by a progressive methane yield decrease which dropped to negligible values after 12 days from the start of the test. Moreover the higher the CW content, the higher the peak observed in methane yield.

For the co-digestion samples M40, M50, M60 as CW proportion increased, the peak in methane production decreased. After these peaks, there was a progressive methane yield decrease which dropped to negligible values after the 15 days of test. For the sample M60 three peaks were observed. All these peaks in methane production can be caused by the sudden degradation of accumulated volatile fatty acids. This can be explained by the fact that batch co-digestion tests were performed on a fixed mass ratio of inoculum to substrate, resulting in lower ratios $VS_{inoculum}/VS_{substrate}$ for the samples with higher CW proportion. It can be a sign indicating the first effects of inhibition at CW proportions higher than 30%.

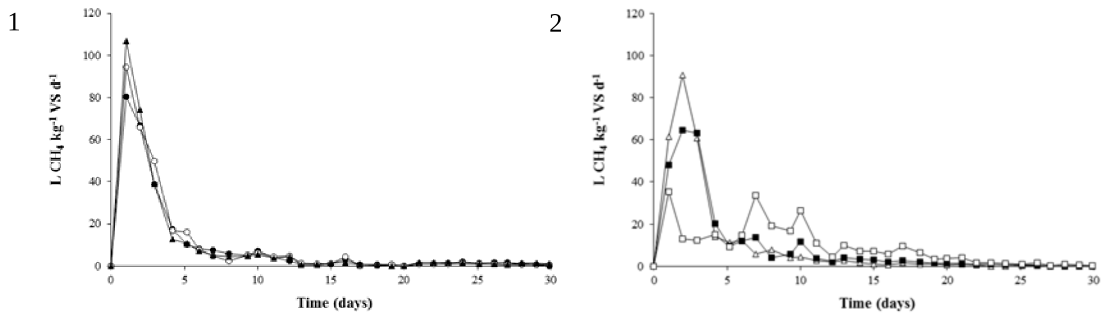

Figure 1. Daily specific methane yields for co-digestion samples at 35ºC. 1- ●: M10, ○: M20, ▲: M30. 2- △: M40, ■: M50, □: M60

Cumulative methane yields per mass of sample for all the co-digestion are presented in Fig. 2. After the 30 days test methane production of the different samples were: 5.5, 6.8, 8.1, 8.9, 9.3, 9.8 and 10.1 L CH_4 kg^{-1} sample for M10 to M60 respectively.

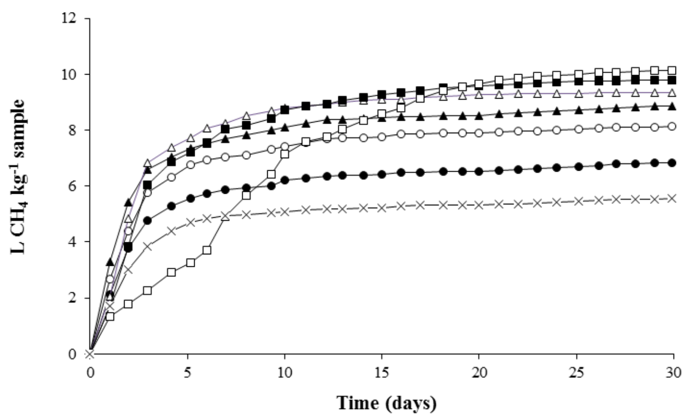

Figure 2. Cumulative methane yields for co-digestion samples and SLF at 35ºC (●: M10, ○: M20, ▲: M30, △: M40, ■: M50, □: M60, ×: SLF)

As can be observed, the increase in CW proportion resulted in higher methane yields. However as CW proportion increased, the increase in methane yield was smaller. Methane production of CW can be determined for each co-digestion sample if we use out the B_0 of SLF as a blank. This way of calculation resulted in the following methane yields: 18.2, 18.4, 16.6, 15.0, 14.0, 13.2 L CH_4 kg^{-1} CW for M10 to M60 respectively. As expected from the previous data, samples with 10% and 20% of CW gave similar methane yield per kg of CW which would result in higher methane production per mass of mixture as CW proportion increases within this range. When CW content was equal or higher than 30%, the methane yield per kg of CW suffered a decrease. The higher the CW content the lower the methane yield from CW. Alkalinity from SLF was enough to maintain the expected methane production up to 20% CW proportion. At higher CW proportions the mixture was degraded to methane but a loss of efficiency was detected. Indeed, at a CW proportion of 60% a slower rate of methane production was observed and the ultimate methane yield of the co-digested sample M60 was similar to that of M50. The best results in terms of methane conversion were obtained at 20% cheese whey proportion. Under this conditions methane yield of the mixture was 46.4% higher than that of the liquid manure, and cheese whey was completely degraded with an estimate methane yield of 18.4 L CH_4 kg^{-1} whey. On the contrary, with 60% cheese whey proportion the methane yield of the mixture was 82.7% higher than that of the liquid manure but the estimate methane yield of the whey was reduced to 13.2 L CH_4 kg^{-1} whey. It must be taken into account that the inoculum used in this work was digested manure which also provided alkalinity to the process. For the co-digestion samples, over 20% CW proportion, the higher CW proportion the lower methane yield obtained with respect to the expected yield. There was not a severe inhibition but methane yields lower than expected were probably due to some inhibition caused by lack of alkalinity in the substrate mixture.

Conclusion and perspectives

This study shows that the screened liquid fraction of dairy manure enhances the anaerobic co-digestion with cheese whey due to its alkalinity content, allowing to digest a difficult substrate such as the whey without external alkalinity addition. However, cheese whey proportions higher than 20% resulted in lower methane yields than expected from methane potentials of both substrates separately, which indicates some inhibition. So, caution must be taken when co-digesting this kind of substrate without chemicals addition for pH control.

Acknowledgements

The authors would like to thank the Ministry of Science and Innovation for financially supporting this research under contract CTM2011-28042. Co-funded with FEDER funds.

References

[1] Peters D, 1999. Raw materials. Advances in Biochemical Engineering/Biotechnology 105, 1–30.

[2] Koutinas A, Papapostolou H, Dimitrellou D, Kopsahelis N, Katechaki E, Bekatorou A, Bosnea L., 2009. Whey valorisation: a complete and novel technology development for dairy industry starter culture production. Bioresource Technology 100, 3734–3739.

[3] Mawson AJ, 1994. Bioconversions for whey utilization and waste abatement. Bioresource Technology 47, 195-203.

[4] Malaspina F, Stante L, Cellamare CM, Tilche A., 1995. Cheese whey and cheese factory wastewater treatment with a biological anaerobic-aerobic process. Water Science & Technology 32, 59-72.

[5] Comino E, Riggio V, Rosso M., 2012. Biogas production by anaerobic co-digestion of cattle slurry and cheese whey. Bioresource Technology 114, 46-53.

[6] Hublin A, Zelic B., 2012. Modelling of the whey and cow manure co-digestion process. Waste Management and Research doi:10.1177/0734242X12455088.

[7] APHA, 1998. Standard methods for the examination of water and wastewater, 20th ed., American Public Health Association, Washington, DC.

[8] Rico C, Rico JL, Muñoz N, Gómez B, Tejero I., 2011. Effect of mixing on biogas production during mesophilic anaerobic digestion of screened dairy manure in a pilot plant. Engineering in Life Sciences 11, 476–81.