Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 82 (2015) 811 – 818

Energy Procedia

ATI 2015 - 70th Conference of the ATI Engineering Association

Biogas production from poultry manure and cheese whey wastewater under mesophilic conditions in batch reactor

Carlini M.[a], Castellucci S.[b,*],Moneti M.[a]

[a]DAFNE, University of Tuscia, Via San Camillo de Lellis snc, 01100 Viterbo, Italy
[b]CIRDER, University of Tuscia, Via San Camillo de Lellis snc, 01100Viterbo, Italy

Abstract

Co-digestion of organic waste is a technology always more frequently applied for simultaneous treatments of several solid and liquid organic wastes. In a co-digestion process the content of nutrients, as well as the negative effects of toxic compounds, can be balanced, increasing the gas yield.
Moreover, co-digestion may contribute to a more efficient use of anaerobic digestion (AD) reactors and cost-sharing by processing multiple waste streams in a single facility.
The aim of this study is to investigate the biogas production from mixture of Poultry Manure (PM) and Cheese Whey Wastewater (CWW). Batch experiments were performed under mesophilic conditions (37ºC) at a pH from 6,5 to 7,5. The methanogenic reactor was operated at hydraulic retention time (HRT) 35 d.
The trend of volatile solids (VS) have been verified.

Peer-review under responsibility of the Scientific Committee of ATI 2015

Keywords: *anaerobic co-digestion, cheese wastewater, poultry manure*

* Corresponding author. Sonia Castellucci Tel.: +39 0761 357416.
E-mail address: sonia.castellucci@unitus.it

1876-6102
Peer-review under responsibility of the Scientific Committee of ATI 2015
doi:10.1016/j.egypro.2015.11.817

Introduction

Nomenclature

CWW	Cheese Whey Wastewater
PM	Poultry Manure
BMP	Biochemical Methane Potential
HRT	Hydraulic Retention Time
COD	Chemical Oxygen Demand
TS	Total Solid
VS	Volatile Solid

This study is part of Rural Development Plan (RDP) project (Reg. 1698/2005 of Lazio 2007/2013), Measure 124: "Cooperation for development of new products, processes and technologies in agriculture, food and forestry: energetic use of agro-industry wastes". The project promotes the innovation of the company through the realization of the activities that envelope new ways for the waste biomass.

Cheese factories and poultry farms are agro-industries that represent a considerable share of the European economy with particular interest focused in the Mediterranean region. These industries generate a large amount of liquid and solid wastes, which in many cases are totally unexploited and furthermore dangerous for the environment [1].

Cheese Whey Wastewater (CWW) is a greenish-yellow liquid, that remains in the boiler after the separation of the curds and it can be ovine, buffalo or cow whey as a function of the origin of the milk. Into the whey there are all the soluble elements of the milk that have not participate at the coagulation, and they are in particular lactose, proteins, soluble salts and fats as a function of the curds processing. The whey composition is a function of different factors such as animal species, feeding, the season of the milk production, the kind of cheese and the processing to produce it. Cheese manufacturing industry generate large amounts of CWW, with associated high biological (BOD_5) and chemical oxygen demand (COD) and a BOD_5/COD ratio commonly higher than 0.5 [2]. CWW contains a significant amount of carbohydrates (4-5%), mainly lactose (45-50 g/l), proteins (6-8 g/l), lipids (4-5 g/l), and mineral salts (8-10% of dried extract). CWW also contains significant quantities of lactic (0,5 g/l) and citric acid, non-protein nitrogen compounds and B-group vitamins [3].

Whey obtained by manufacture of hard, semi-hard or soft cheese, is known as sweet whey and has a pH of 5.9-6.6, while the manufacture of mineral-acid precipitated casein, is known as acid whey, and has a pH of 4.3-4.6 [4].

The CWWs have not dangerous substances (pathogens, heavy metal, virus, etc.) but they have high organic matter content. From the agricultural and environmental point of view some parameters can be incompatible with the diffusion of these wastes on the soil. These parameters are pH, salinity, and some elements concentration, that are under the law limits, but can be used only after some treatments [5]. In particular CWW has an acid pH that after few hours reaches values of about 4. In the dairy industry the CWW is one of the main waste. These substances are generally not reused, and they represent a pollution source for the watercourses. The possibility to recycle these materials in other with a higher economic value could be a solution to the environmental problems and at the same time a profit or savings for the dairy industry. For these reasons the CWW should be recycled, transformed and valued [6].

Anaerobic digestion of cheese whey is an excellent method for wastewater treatment, although raw whey is known to be quite problematic to be treated anaerobically due to low bicarbonate alkalinity, high COD concentration and tendency to get acidified very quickly. Supplemental alkalinity is required so as to avoid acidification and subsequently anaerobic process failure [7].

Poultry manure (PM) is rich in nitrogen and phosphorus, therefore, the traditional utilization is to enrich soil and fertilize crops. In some areas, the number of poultry farms is many high, therefore, a treatment process of the PM is necessary. Since the good biological degradability of PM, anaerobic digestion is considered to be a good choice to minimize these kinds of wastes and recover bioenergy [8].

However, high content of organic nitrogen, low C/N ratio, undigested protein and uric acid cause the production of the ammonia that inhibits anaerobic process, particularly when digestion is under thermophilic condition.

A common method to avoid ammonia inhibition is the dilution of the substrate usually with fresh water. Fresh PM has high concentration of total solid (TS), ranging from 20% to 62,4% [9]; before adding it to a digestor, PM must be diluted so that concentration of TS is amount to 0.5-3%, in this way ammonia accumulation is avoided [10]. This on one hand, decreases the biogas production per unit of digestor volume, on the other hand, it increases the consumption of water and the processing cost for manure discharge.

Another method to avoid ammonia inhibition is co-digestion of PM with other substrates. Many biogas plant operators are more willing to use co-digestion, because this can receive high biogas output with high nutrient content in digestate [11] .

The above considerations highlight the difficulty of energetic use of the individual waste, and for this reason co-digestion is the best process for the production of electrical and thermal energy from cheese waste and poultry manure.

This study analyses availability, characteristics and yields of the waste biomass of two agricultural companies, that are partners into the project, to rise their product values, the competitiveness and the profit, reducing at the same time the environmental impact. The agricultural companies Pacifici and Delrio are part of agricultural and farm chains, in Lazio Region. Delrio company is between Bagnoregio and Bolsena, in the Viterbo Province, where it carries out the whole process of milk and cheese production. The company consists of 60 ha of grazing land for the 370 sheep and the milk is used for the cheese production and the direct sale. The agricultural company Pacifici is in Grotte Santo Stefano, Viterbo municipality, and it consists of 60 ha and a rearing of 34000 laying hens. The wastes biomass of the companies are:

- CWW for a total of about 85 m^3 year;
- PM about 1172.5 m^3 year;

The samples were analysed and evidence of biogas production were performed in order to verify the feed composition which allowed the maximum yield of biogas.

Materials and methods

2.1 Substrates and inoculum

The CWW and PM were analysed and fed in a batch reactor. Development of composition in volatile solids and COD of biomass have been checked. Inoculum used in this study has been taken from a plant fed with agricultural wastes in Nepi, Viterbo. The inoculum was earlier acclimated and degassed at 37ºC for 4 days to minimize the background methane production and then fed into the plant [12].

The following analysis have been carried out [13]:

- Ultimate analysis (C, H, N contents);
- Moisture content;
- Ash content;
- Volatile Solid (VS);
- Chemical Oxygen Demand (COD).

The characteristics of substrates and inoculum are shown in Table 1.

Table 1. Characterization of substrates and inoculum

Parameter	CWW	PW	Inoculum
C [%]	32.5±0.9	36.8±0.9	34.3±0.7
H [%]	4.4±0.4	5.7±0.4	4.9±0.3
N [%]	5.6±0.8	3.4±0.3	3.8±0.6
C/N ratio	5.8±1.3	10.82±2.9	9.02±1.8
Total Solid [%]	5.88±2.1	78.82±2.3	5.48±1.9
Ashes [% dry matter]	1.54±1.1	38.45±0.9	0.98±0.8
Volatile Solids[%]	5.79±1.08	48.51±0.8	5.15±0.7
COD [g/l]	65±3.1	-	53±2.9
pH	6±0.2	8.7±0.3	7.8±0.12

2.2 Biochemical methane potential (BMP) assay

BMP assays of substrates were carried out using a batch reactor working in mesophilic conditions (37ºC) [14].

A reactor was cylindrical in shape, made entirely of stainless steel (INOX136), having a working volume of 5 L and was operated at constant temperature of 37ºC± 0.2 °C, via thermocouple controller. Agitation was performed at 75 rpm by a geared motor drive. Gas production was measured in a water column and analysed with gas chromatograph AGILENT TECHNOLOGY.

The trend of temperature, pH and pressure was continuous measured during the test by means of probes inserted into the reactor and connected to a PLC.

BMP tests have been carried out for all the feedings to verify possible problems for the anaerobic digestion process.

All experiments were run as triplicate and the mean values of net biogas production and methane content were calculated.

The high content of lactic, citric acid and non-protein nitrogen compounds (urea and uric acid) in CWW have produced a quick decrease of pH into the digestor. After 24-48 hours by the beginning of the tests, the average pH value was about 4.5. It shows the necessity to use CWW in a co-digestion process with other biomass to reduce the acidification into the reactor due to the ammonia produced in the feeding.

Bio-methane tests conducted on PM have confirmed the literature [10,11]; there was no production of biogas due to the process inhibition for the presence of the ammonia. For this reason there is the necessity to use PW in a co-digestion process.

In order to determine the anaerobic biodegradability of different mixtures, three feed with mixing ratio (CWW/PM: 3:1, 1:1, 1:3) have been studied. In the feed of reactor the content of TS was not to be greater than 10% in weight.

The batch reactor was fed with an appropriate amount of substrate mixture and inoculum keeping a TS ratio (TS substrate to TS inoculum) at 1:1 in all setups.

A BMP test (control) was conducted on the inoculum, to estimate the volume of methane resulting from anaerobic digestion. The BMP was about 65 mL/gVS. Based on the initial TS contents of CWW, PM and inoculum, a sufficient amount of deionized water was added for reach hemi-solid state anaerobic digestion (HSS-AD) condition [15].The average Hydraulic Retention Time (HRT) of tests was 35 days.

All experiments were run as triplicate and the mean values of net biogas production and methane content were calculated.

3. Results and discussion

The composition analysis of each waste used in this study, i.e. CWW and PM is presented in Table 1. Significant differences in the composition were detected, in particular PM presented the highest total solid content (78% in weight) compared to CWW (5.88 % in weight) e consequently a remarkable difference in terms of volatile solids (VS). A mix of CWW and PM has ensured sufficient levels of both nitrogen and alkalinity in the feeding, decreasing high COD concentration and tendency to get acidified very rapidly of the CWW, and high content of organic nitrogen and low C/N ratio of the PM. Table 2 shows the properties of the mixture fed into the plant.

Table 2. Properties of the mixtures used.

Parameter	CWW:PM=3:1	CWW:PM=1:1	CWW:PM=1:3
TS (%FM*)	7,6	8,9	10,2
VS (%TS)	65,89	71,8	75,5
C/N	25,78	22,67	18,84
pH	7,93	7,14	7,26

*FM=Fresh mass

Batch experiments were carried out using different mixtures in order to evaluate optimum mixing ratio (CWW/PM) to reach the maximum biogas yield.

During the test the trend of pH, production and composition of biogas were monitored, as showed in Fig. 1, 2 and 3.

The trend of pH has been greatly affected by the composition of the starting mixture (Fig.1). As regards the feeding with mixing ratio CWW: PM = 3: 1, the pH value, after 5 days of the test, reached values of 5.5. For so low pH values the anaerobic digestion process stops and the test was interrupted.

The tendency to acidification of CWW was not reduced by mixing it with PM, this caused a sudden drop in pH and a test block.

For mixing ratio CWW:PM=1:1 and CWW:PM=1:3 the daily biogas production has had the same trend (Fig.2). The biogas production started immediately, increasing until reaching the peak at around day

5, and then quickly decreased. After about 18 days, almost 90% of the experimental biogas yield was obtained. The average content of methane was 65% for ratio 1: 1 and 55% for ratio 1:3 (Fig.3).

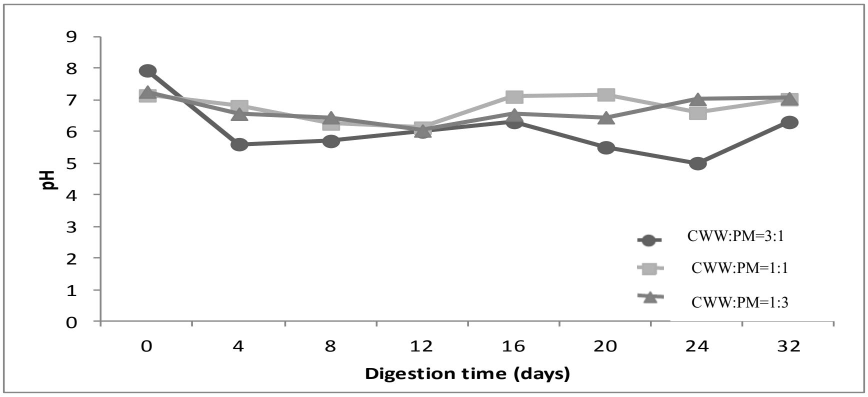


Fig. 1. Trend of pH

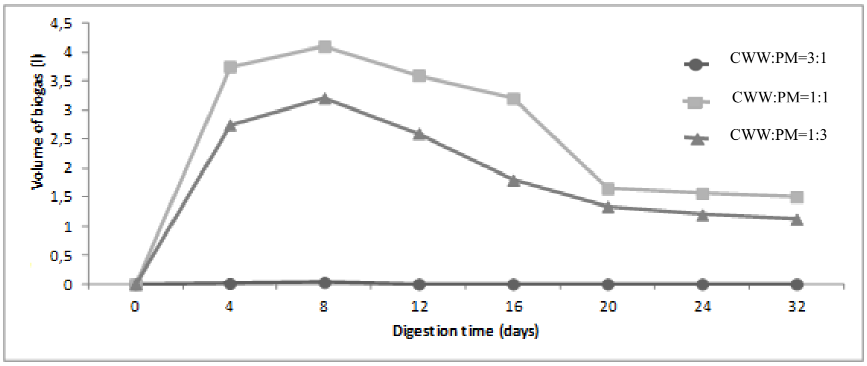


Fig. 2. Daily biogas yeld (l)

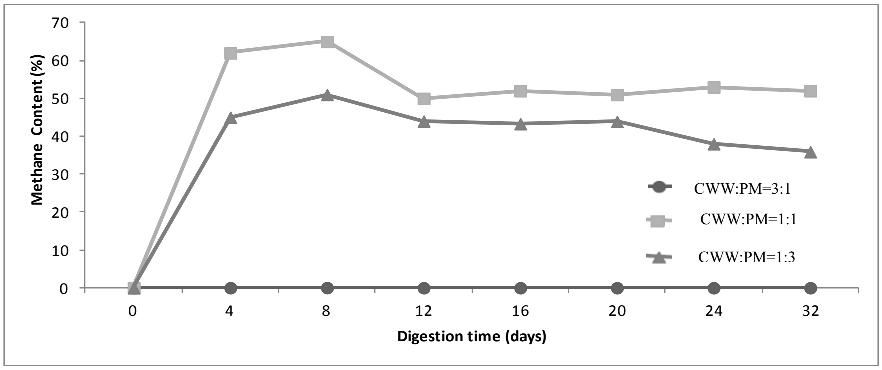


Fig. 3. Methane content of biogas

In Fig. 4 the trend of VS into the mixtures is showed. The time trend of the VS shows behaviour consistent with that expected: the reduction of the VS increases with test time.

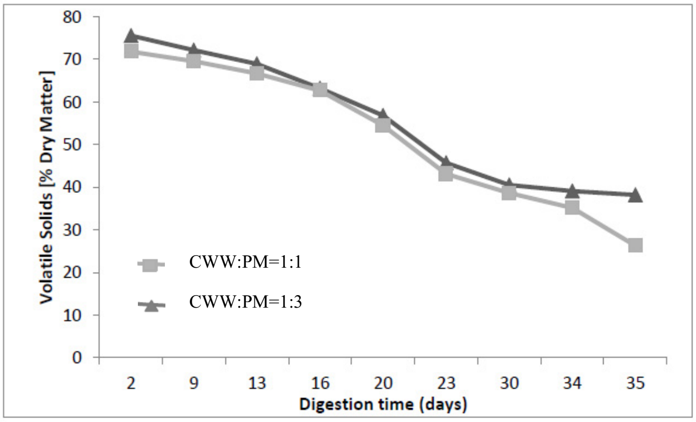


Figure 4. VS on wet basis and trend line

In Table 3 the BMP and methane average percentage of the two tests have been reported. The co-digestion test of mixture ratio 1:1 has produced better results, indeed, a TS content of 8.9% of fresh mass and a C / N ratio of 22,67 are suitable conditions for the production of biogas.

Table 3. BMP and methane average percentage in biogas of the two tests

Test	BMP [mL/gVS]	Methane average percentage in biogas [%]
CWW:PM=1:1	223	65%
CWW:PM=1:3	135	55%

3.1 Conclusions

CWW and PM represent a significant environmental problem in Mediterranean area where they are produced in huge quantity and seasonally, therefore in short periods of time. One of the most promising processes to exploit this waste for energy production is anaerobic digestion.

Anaerobic co-digestion technology is increasingly used to simultaneously treat several solid and liquid organic wastes in order to balance the nutrients content, to reduce negative effects of toxic compounds on the process, and, therefore, to increase the biogas yield. Moreover, co-digestion technology contributes to a more efficient use of anaerobic digestion, because multiple streams of wastes can be processed together in a single plant at the same time.

The use of CWW and PM represents economically a very attractive possibility for farms where they are produced.

From the obtained results, the test with CWW:PM ratio of 1:1 permits to produce a greater quantity of methane and at the same time to reduce the acidification trend of CWW, to improve C/N ratio and to reduce the TS fed into the plant.

Considering a BMP equal to 223 mL /gVS and the amount of wastes identified into the agricultural companies, a 65 kW anaerobic digestion plant is possible to realise, with an annual production of about 520.000 kWh of electricity.

References

[1] Dareioti MA, Vavouraki AI, Kornaros M. Effect of pH on the anaerobic acidogenesis of agroindustrial wastewaters for maximization of bio-hydrogen production: A lab-scale evaluation using batch tests. Bioresour Technol 2014;162:218–27. doi:10.1016/j.biortech.2014.03.149.

[2] Prazeres AR, Carvalho F, Rivas J. Cheese whey management: A review. J Environ Manage 2012;110:48–68. doi:10.1016/j.jenvman.2012.05.018.

[3] Venetsaneas N, Antonopoulou G, Stamatelatou K, Kornaros M, Lyberatos G. Using cheese whey for hydrogen and methane generation in a two-stage continuous process with alternative pH controlling approaches. Bioresour Technol 2009;100:3713–7. doi:10.1016/j.biortech.2009.01.025.

[4] Bylund G. Dairy Processing handbook. Tetra Pak Processing Systems.Sweden 1995.

[5] Marwaha SS, Kennedy JF. Whey—pollution problem and potential utilization. Int J Food Sci Technol 1988;23:323–36. doi:10.1111/j.1365-2621.1988.tb00586.x.

[6] Zafar S, Owais M, Saleemuddin M, Husain S. Batch kinetics and modelling of ethanolic fermentation of whey. Int J Food Sci Technol 2005;40:597–604. doi:10.1111/j.1365-2621.2005.00957.x.

[7] Lo KV, Liao PH. Digestion of cheese whey with anaerobic rotating biological contact reactors. Biomass 1986;10:243–52. doi:10.1016/0144-4565(86)90001-6.

[8] Nie H, Jacobi HF, Strach K, Xu C, Zhou H, Liebetrau J. Mono-fermentation of chicken manure: Ammonia inhibition and recirculation of the digestate. Bioresour Technol 2015;178:238–46. doi:10.1016/j.biortech.2014.09.029.

[9] Bruni E, Ward AJ, Køcks M, Feilberg A, Adamsen APS, Jensen AP, et al. Comprehensive monitoring of a biogas process during pulse loads with ammonia. Biomass Bioenergy 2013;56:211–20. doi:10.1016/j.biombioe.2013.05.002.

[10] Bujoczek G, Oleszkiewicz J, Sparling R, Cenkowski S. High Solid Anaerobic Digestion of Chicken Manure. J Agric Eng Res 2000;76:51–60. doi:10.1006/jaer.2000.0529.

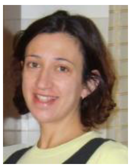
[11] Abouelenien F, Fujiwara W, Namba Y, Kosseva M, Nishio N, Nakashimada Y. Improved methane fermentation of chicken manure via ammonia removal by biogas recycle. Bioresour Technol 2010;101:6368–73. doi:10.1016/j.biortech.2010.03.071.

[12] Li Y, Feng L, Zhang R, He Y, Liu X, Xiao X, et al. Influence of Inoculum Source and Pre-incubation on Bio-Methane Potential of Chicken Manure and Corn Stover. Appl Biochem Biotechnol 2013;171:117–27. doi:10.1007/s12010-013-0335-7.

[13]Castellucci S.; Cocchi S., Celma C.B.(2014). Energy characterization of residual biomass in mediterranean area for small biomass gasifiers in according to the European standards, APPLIED MATHEMATICAL SCIENCES, Volume 8, Issue 129-132, 2014, Pages 6621-6633, ISSN:1312-88

[14] Carlini M, Castellucci S, Moneti M. (2014) Anaerobic co-digestion of olive-mill solid waste with cattle manure and cattle slurry: analysis of bio-methane potential, Proceeding ATI 2014

[15] Li Y, Zhang R, Liu X, Chen C, Xiao X, Feng L, et al. Evaluating Methane Production from Anaerobic Mono- and Co-digestion of Kitchen Waste, Corn Stover, and Chicken Manure. Energy Fuels 2013;27:2085–91. doi:10.1021/ef400117f.



Biography

Sonia Castellucci Born in Viterbo, Italy, in 1976. She received degree in Chemical Engineering from the University of Rome, Sapienza, in 2003. Since 2010, research fellow at CIRDER-University of Tuscia in Viterbo. Research focus: Process simulation of renewable energy systems in TRNSYS, COMSOL; Biomass energy characterization at CIRDER; Designing biofuel