Pilot scale experience of anaerobic co-digestion of pig slurry with fruit wastes – on site operation in a pig farm with a mobile plant

Ferreira, L.M.[1], Duarte, E. A[1], Figueiredo, D.[1]
[1]Dpt. Agricultural and Environmental Chemistry, Superior Institute of Agronomy, Technical University of Lisbon, Tapada da Ajuda, 1349-017 Lisboa, Portugal.
Email:lferreira@isa.utl.pt

Introduction

Pig production units (particularly farrow-to-finish systems) in Portugal are characterized by generating very dilute slurries, 1,5-2,5 % total solids (TS) with a total volatile solid (VS) content of 67%, and this represents a barrier to establish economically feasible Anaerobic Digestion (AD) processes. On the other hand there are several full scale farm biogas plants where could be interesting to introduce other substrates to co-digest with pig manure (PM), in order to raise biogas production. Most of these digesters are very old and operate in very inefficient conditions due to operators lack of technical skills, inadequate design of the plants or because reinvestments were not done in due time.

Fruit wastes (FW) are produced in large quantities in centralised fruit producers storage and distribution facilities, during the selection and rejection processes before fruit enter into the market. The waste stream targeted by this project was originated from a group of apple and pear producers.

One of the most promising alternatives for managing these organic wet wastes is anaerobic digestion (AD). A major limitation of anaerobic digestion of FW is a rapid acidification of these wastes decreasing the pH in the reactor, and a larger volatile fatty acids production (VFA), which can stress or inhibit the methanogenic biomass activity (Bouallagui *et al*, 2005).

A previous research work concluded that a bioconversion process of fruit wastes before feeding a co-digestion process was considered advantageous, once the result of this bioconversion is a stable product (Bioconverted Fruit Wastes - BFW) in anoxic conditions, more convenient to be stored, handled and improves the stability of the AD process (Ferreira *et al*, 2007). The same authors studied the co-digestion of a mixture of BFW:PM, 30:70 (v/v) with an average organic loading rate (OLR) of 4 kg COD/$m^3.d^{-1}$, operating at a hydraulic retention time (HRT) of 16 days.

A mobile AD pilot plant was developed to demonstrate on site the capabilities and potential of farm scale co-digestion as a technological key tool for decentralized biogas production and biowaste management. One of the advantages of the mobility characteristic of this plant is the possibility to test and demonstrate on site, the co-digestion process of different substrates according to the biowaste set from the different local economies.

Objective

Among other goals, the main objective of this investigation was to evaluate in real operation conditions the interest of the utilization of fruit wastes (FW) produced in the region (apples and pears), for biogas production. Furthermore, to compare the lab scale trials results from previous research work and to anticipate problems for future full scale application.

Methods

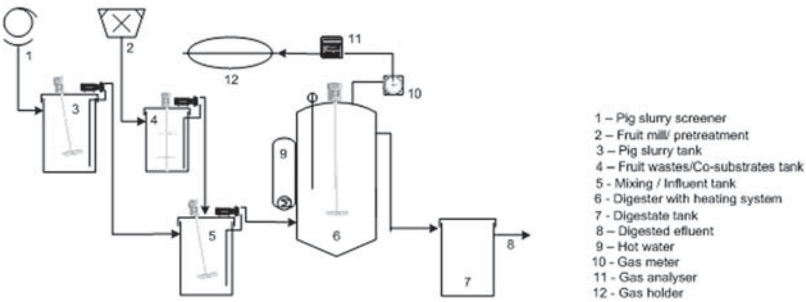
Strategy. Before starting operating the mobile pilot plant, it was developed and studied at lab scale the anaerobic co-digestion process of fruit wastes with pig manure. It was concluded that a bioconversion process of fruit wastes before feeding a co-digestion process would be advantageous and a mixture (% v/v) of 30% of it with 70% pig manure would be advisable.

Origin of materials. The substrates used were screened pig manure (PM) from a farrow-to-finish pig farm and fruit wastes (FW) characterised by a mixture of refused flows of apples and pears. To perform the lab trials, samples of pig slurry were collected according to a procedure in order to get weekly composed samples. Fruit waste was pulped with a semi-industrial fruit mill with a 5 mm screen. Batchs of fruit pulp (aprox.500 litres) were stored in a 1 m^3 closed vessel with mechanical mixer at environmental temperature, in order to develop a spontaneous fermentation process. During this process, internal pressure was alleviated releasing the CO_2 produced, although due practical reasons it was not possible to measure it. After aprox. 10 days of fermentation, the pulp of bioconverted fruit wastes (BFW) was considered ready to be used as a co-substrate.

Inoculum was obtained from a mesophilic (35ºC) sewage sludge digester. Characteristics of BFW and PM are presented in Table 1.

Continuous trials. Continuous lab trials, used a heated stainless steel digester (CSTR) with V = 11 litre. Pilot scale trials were performed on site, in a farrow-to-finish pig farm The mobile AD plant, was carried in a standard container loading truck, and it consists of a semi-automatic device, equipped with a heated stainless steel digester (V = 2 m^3) with a mechanical mixer, a mixing tank and tanks for slurry , pumpable feedstocks and digestate, all equipped with the respective pumping and mixing systems (Figure 1). This plant could operate the continuous process autonomously, fully automatic, during an average period of 10 days.

Figure 1. Diagram of the mobile pilot plant setup



Considering the goals proposed, dynamic mesophilic (35º - 37º C) continuous lab and pilot-scale trials were performed. Pig manure AD lab trials operated with a OLR = 1,4 -1,5 Kg CQO/$m^3.d^{-1}$ and a HRT=11 d, nevertheless it was possible to reach OLR = 1,6-2,3 Kg CQO/$m^3.d^{-1}$ with a HRT=16 d, on pilot plant trials. With regards to co-digestion trials with a mixture of FW:PM, a volumetric composition (%v/v) of 30:70 was used. Lab trials were operated at OLR = 3,8-4,2 Kg CQO/$m^3.d^{-}1$, although it was possible to reach na OLR = 4,8–5,10 Kg CQO/$m^3.d^{-}1$ with a HRT=16 d, on pilot plant trials.

The main process operational parameters (methane, carbon dioxide, H_2S and COD fractions of the digestate, nitrogen and phosphorous) has also been investigated. Results were obtained considering a steady-state achieved after three reactor volumes.

Analytical methods. pH, chemical oxygen demand (COD), total solids (TS), volatile solids (VS), total kjeldahl nitrogen (TK-N), ammonical nitrogen (NH_4^+-N), total phosphorous (TP), total volatile fatty acids (T-VFA), Bicarbonate alkalinity were determined according to standards methods (APHA, 1995). Glucose, fructose, ethanol and organic acids were determined by isocratic high performance liquid chromatography (HPLC) with IR or UV detection.

Results and Discussion

Characterization of waste materials

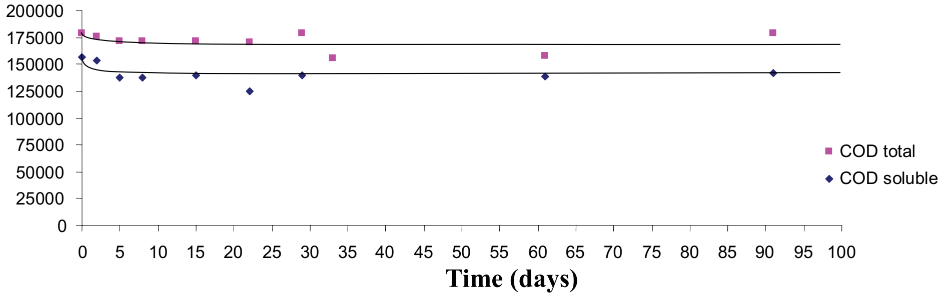
Table 1. Initial characteristics of waste materials

		Lab trial		Pilot trial	
		PM	BFW	PM	BFW
pH		7,13 – 7,70	3,53 - 3,69	7,06 - 8,79	2,71 - 3,24
Conductivity	$mS.cm^{-1}$	10 -15	3 - 4	16 - 20	3 - 4
TS	g/l	15 - 21	56 - 59 [a]	20 - 29	49 - 56[a]
VS	g/l	10 - 14	49 - 57 [b]	13 - 22	46 - 51[b]
COD	g/l	17 - 36	168 - 206	25 - 36	161 - 181
CODsoluble	g/l	9 - 23	132 - 164	13 - 15	119 - 141
T-P	mg/l	342 - 668	106 - 109	525 - 552	107 - 120
TK-N	g/l	1,8 - 1,9	0,64 - 0,71	2,07 - 2,34	0,62 - 0,69
NH_4^+ - N	g/l	1,04 - 1,34	0,12 - 0,14	1,52 - 1,71	0,11 - 0,13
T-VFA	g acetic acid/l	n.d	5,5	n.d	6,0
Glucose	g/l	n.d	0	n.d	0
Frutose	g/l	n.d	0	n.d	0
Ethanol	g/l	n.d	45,0	n.d	44,0

a) – Non volatile fraction at 104ºC; b) – Volatile fraction at 550ºC of the non volatile fraction at 104ºC;
n.d - not determined

Table 1, show the characteristics of the substrate flows used and differences can be observed on TS content of the pig manure used on the lab trials when compared with pig manure obtained on site during pilot scale trials. Composed sampling procedures and lab manipulation could be the reason for such differences. In comparison, fruit waste pulp had almost ten times more COD and 80 % of it is soluble. Buffiere *et al.* (2005) reported very similar characteristics for apple wastes.

Figure 2. Chemical oxygen demand (COD) mg/l. Evolution during the bioconversion process and storage



It can be foreseen that a better C/N ratio was achieved in the substrate mixture 30%BFW:70%PM when compared with 100% PM digestion. On the other hand figure 2, shows the fruit wastes COD evolution during the bioconversion process and after a long storage period. A lost of 5% of the initial total COD was obtained which is a good indicator of the energy conservation during this process.

It can be discussed from table 2 in one hand the operating and process performances obtained between lab and pilot plant trials and on the other the results from the co-digestion of BFW with PM. The performance results obtained in the pilot plant were considerable better than those produced in lab scale. Some operational reasons could be argued, but the main reason is deeply related with the lower OLR achieved for the lab trials, conditioned by the PM quality. On site operation, enabled the use of pig manure on real conditions, avoiding sampling and lab manipulation interferences.

Process stability was monitored measuring the pH and T-VFA/BA ratio (Figures 4a-b, 5a-b). A comparison between the results from lab trials and from pilot plant operation, indicates a higher T-VFA/BA ratio was reached at lab scale, which would suggest a more stressed process. It was reported that without enough buffer capacity, values higher than 0,5 indicate stability problems in anaerobic digestion processes and this ratio should not be higher than 1 (Gerardi, 2003 ; Scharer, 2007). Both indicators, pH and T-VFA/BA ratio, suggests that the co-digestion process developed in the pilot plant is more robust than the one developed in the lab scale.

Table 2. Operating and process performance obtained from lab and pilot plant trials

Mixture BFW:PM (% v/v)	HRT days	OLR kg COD/m^3.d^{-1}	m^3 biogas/ m^3 digester.d^{-1}	Biogas quality % CH_4	Biogas quality ppm H_2S	COD removal %	m^3 biogas/ m^3 biomass
0:100 (a)	11	1,4 -1,5	0,47	73	> 1500	70	5,14
0:100 (b)	16	1,6-2,3	0,56	75	> 1500	70	9,6
30:70 (a)	16	3,8-4,2	1,57	67	605	75	24,31
30:70 (b)	16	4,8-5,1	1,84	69	950	80	31,2

(a) – Lab trial; (b) – Pilot plant trial

Process performance results, show that biogas productivity when BFW is codigested with pig manure can be considerably raised. An increase of 300% can be foreseen (Figure 3), nevertheless the biogas quality resulting from digestion of 30%BFW:70%PM mixture, became slightly poor in methane. The biogas quality regarding the H_2S content improved significantly, although the reduction achieved from the digestion of the mixture 30%BFW:70%PM, results mainly from the low S content of the BFW (results not shown).

Figure 3. Biogas production rates performed during the pilot plant operation with the mixture of BFW:PM and PM

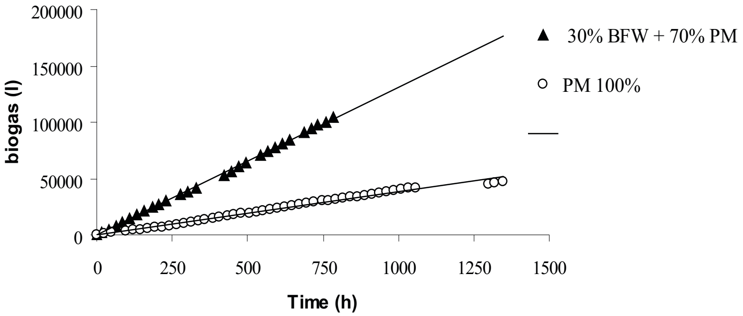


Figure 4a. TVA/BA evolution during the lab trial

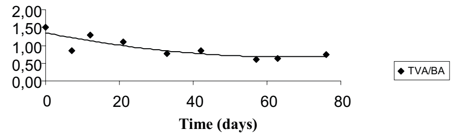


Figure 4b. pH evolution during the lab trial

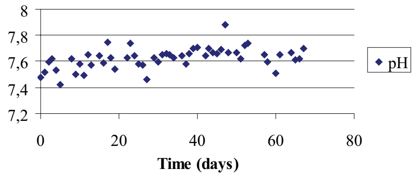


Figure 5a. TVA/BA evolution during the pilot-scale trial

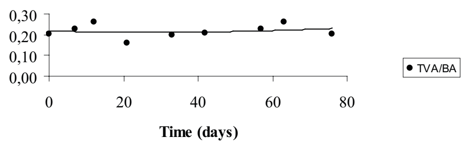
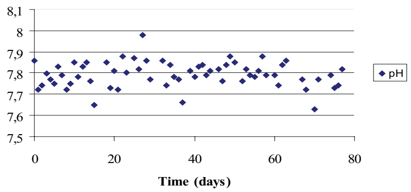


Figure 5b. pH evolution during the pilot-scale trial



Conclusions

It was demonstrated the potential to increase the biogas productivity up to 300% through the use of bioconverted fruit wastes (BFW) as a co-substrate in anaerobic co-digestion processes with pig manure.

Bioconversion of fruit wastes (apples and pears) was shown to be a feasible way of conserving methane potential and it is likely to offer a cost efficient solution for biogas production in farm scale biogas plants.

The possibility to develop on site co-digestion processes, using versatile mobile pilot plant, enabled to obtain more realistic performance results than those obtained from lab scale trials. Particularly important were the results regarding process stability indicators measured, therefore the pilot plant operation was very useful to demonstrate the following:
1 - Conclusions concerning the process stability supported on the results from the lab scale co-digestion trials of a similar feedstock mixture of 30%BFW:70%PM, were not definitive.
2 - The process was not unstable and it's robust enough to allow raising the OLR.

Lab manipulation, slurry conservation and storage period required to feed a continuous lab process, digester design and slurry sampling procedures, are some of the reasons identified that could justify the differences obtained.

References

APHA, (1995). Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington, DC.

Buffiere, P., Loisel, D., Bernet, N., Delgenes, J-P. (2005). Towards new indicators for the prediction of solid waste anaerobic digestion properties. In proceedings of 4 th International Symposium on Anaerobic Digestion of Solid Waste, September 2005, Copenhagen, Denmark.

Bouallagui, H.,Touhami,Y., Cheikh, R.B., Hamdi, M.(2005). Bioreactor performance in anaerobic digestion of fruit and vegetables. Process Biochemistry 40: 989-995.

Gerardi, Michael H. (2003).The microbiology of anaerobic digesters.Hoboken, NJ: John Wiley & Sons, Inc.

Ferreira, L., Duarte, E. A., Silva, Carla., Malfeito-Ferreira, M. (2007). Fruit wastes bioconversion for anaerobic co-digestion with pig manure. Process development for the recycling in decentralised farm scale plants. In proceedings of the International Conference Progress in Biogas, pp 135-140, September 2007, Stuttgard, Germany.

Scharer, Paul. (2007). Operating analytics of biogas plants to improve efficiency and to ensure process stability. In proceedings of the International Conference Progress in Biogas, pp 135-140, September 2007, Stuttgard, Germany.