VOLATILE FATTY ACIDS PRODUCTION BY ANAEROBIC FERMENTATION OF URBAN ORGANIC WASTES

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KEYWORDS

Volatile fatty acids, methyl ethyl esters, organic fraction of the municipal solid waste

ABSTRACT

During six months of experimentation, a plug-flow system without recirculation was employed to study the volatile fatty acids (VFA) production by means of anaerobic fermentation of urban organic wastes. Results showed an important VFA production at mesophilic range of temperature (37°C). Particulary, VFA concentration in the outlet sludge went from 11.8 g/L at 2 days of retention time up to 23.1 g/L at 6 days of retention time.

INTRODUCTION

One of the biotechnologies developed in the last years to utilize municipal solid wastes (MSW) for useful energy and materials recovery is the anaerobic digestion. Particulary, the anaerobic fermentation of the organic fraction of the municipal solid wastes (OFMSW) mainly to acetic, propionic, butyric and valeric acids has been studied. The volatile fatty acids obtained can be recovered and used to produce methyl or ethyl esters which, considering their elevate octane number (between 103-118), could be advantageously used as additive for gasoline (D'Addario et al., 1992). An alternative possibility would be the production of biogas in a second step of the anaerobic digestion. The resulting sludge from the fermentation could be converted in an optimal soil amendment after a composting step. All these possibilities makes the alternative particulary interesting.

The main studies described in the literature about the steps for the production of esters from MSW are the ones made by Antonopoulos in the U.S.A and D'Addario and co-workers in Italy (Antonopoulos and Wene, 1989; D'Addario et al., 1992). However, further research is necessary in order to study the feasibility of the process.

This work shows and discusses the results obtained using the OFMSW to produce volatile fatty acids in a tubular pilot-scale reactor at mesophilic temperature. The influence of operational parameters, such as hydraulic and solid retention time and organic loading rate, on the hydrolytic-acidogenic phase of the anaerobic digestion has also been investigated.

MATERIALS AND METHODS

Experimental device

The research was carried out with a pilot-plant, located in the experimental facilities of the University of Venice in Treviso (Italy). The plant can be divided in two sections. In the first section, the substrate is introduced into a 80 litters tubular reactor from the feed tank by an archimedean screw. The retention time of the sludge in the reactor can be controlled changing the turn of the screw. In the second section, the sludge coming out from the reactor goes to a separation area where part of the liquid phase is separated from the outlet sludge. VFA will be extracted from the liquid phase. The concentrated sludge can be partially recycled to the feed tank by a recycling archimedean screw and partially discharged.

Substrate

The substrate used for the experimentation was a mixture of the OFMSW coming from the mechanical selection plant of San Giorgio di Nogaro (Udine, Italy), and source sorted OFMSW coming from the food market of the city of Treviso (Italy). Tables 1 and 2 show the most important characteristics of both types of refuses. Initially, the substrates were mixed in a way to obtain a feed substrate with a total solids (TS) content around 20 % and a total volatile solids (TVS) content around 60 %TS, adding water for diluting purposes when necessary. The feeding mixture was prepared three times a week and kept in the feeding tank. The archimedean screw carried the substrate daily inside the digester at the desired loading rate, by controlling the time and rate of running of the screw, which determined the hydraulic retention time.

Analytical methods

The digestion process was monitored following the analytical procedure according to the Standard Methods for the examination of water and wastewater (1985). Total volatile fatty acids (TVFA) were carefully monitored in the feed, in the outlet sludge and in each valve of the reactor, when possible. TVFA were determined by a gas-chromatographic method (Chromatograph Vega serie 6000 Carlo Erba). Conditions of this analysis were: Capillary column type Nukol, length 15 m, internal diameter 0.53 mm; Injector temperature, 200°C; Detector -flame ionization- temperature, 220°C; Air pressure 120 kPa, H_2 pressure 70 kPa; Temperature program (isotherm): 106°C; Duration, 6 minutes; Carrier pressure 30 kPa.

RESULTS AND DISCUSSION

During six months of continuous operation, the acidogenic process was studied at different working conditions in the mesophilic (37±2°C) range of temperature. Table 3 shows the operational parameters and results obtained in the 4 different mesophilic periods experimented.

The start-up of the digester was performed at mesophilic temperature for almost one month. During the first period (period 1), solid recirculation was operated, in a way to work with a solid retention time (SRT) > hydraulic retention time (HRT). But, due to different technical problems mainly at the separation and recirculation stage, the complete control of the solids retention time was not possible, although it can be considered close to 8 days. Taking into account the difficulties found during the first period of operation it was decided to eliminate solid recirculation system in the next periods experimented. Hydraulic and solid retention times studied were 2, 4 and 6 days (periods 2, 3 and 4, respectively). The screw of the reactor operated discontinuously. This particularity and the obliqual disposal of the digester caused separation of the liquid phase back to the feed box and desiccation of the sludge inside de digester. Thus, in order to avoid these problems, the reactor position was changed and placed horizontally during period 4 and for the rest of the periods studied. The influence of reactor design on the results during this period were sufficiently important to present them separately (period 4.1: obliqual reactor; period 4.2: horizontal reactor, see Table 3).

Figure 1 shows the VFA production with retention time of periods 1-4. The TVFA concentration in the outlet sludge obtained when working at SRT>HRT= 2 days, that is, with solid recirculation (period 1) was 19.5 g/L. This concentration is quite superior compared with the one obtained in period 2 (mean value 11.8 g/L, see Table 3), when working at SRT=HRT= 2 days without solid recirculation. The solid recirculation implied the presence of acidogenic inoculum in the feeding mixture which increased bacterial activity and substrate degradation in the reactor. Another result that supports this conclusion is the higher ammonia concentration in the outlet sludge of period 1, compared with period 2 (360.3 mg/L and 101.3 mg/L, respectively). This indicates a major protein mass degradation in the working conditions of the first period. The TVFA concentration obtained in period 3 (HRT=SRT= 4 days) increased respect period 2 (18.3 g/L and 11.8 g/L, respectively), which could indicate that retention time of 2 days (period 2) was not enough for an optimal degree of substrate degradation. This hypothesis is confirmed by the acid concentration reached in period 4.2 (HRT=SRT= 6 days), when correction in digester disposal was already done. There were obtained 23.1 g/L of volatile fatty acids in the outlet sludge, which determine the increasing profile of VFA production with retention times (see Figure 1). The optimal bacterial activity in period 4.2 was also reflected in the ammonia concentration, which was higher when acid concentration was maximum (486.7 mg/L in the digester sludge of period 4.2).

Figure 2 shows the yields obtained in the different mesophilic periods studied. Important yields were obtained when solid recycling was applied (period 1): yield expressed in percentage of TVFA produced per TS of the feeding mixture reached 9.3 % and in percentage of TVS reached almost 15 %, which can be considered an optimal result, taking into account the high organic loading rate operated (66.9 $kgTVS/m^3d$) and the kind of substrate utilized for the digestion. When there was no solid recycle (periods 2, 3 and 4.2) yields increased with increasing retention time (see Figure 2). Maximum values were obtained at 6 days of retention time and those were 7.8% TS, 13.9% TVS and 12.1% TCOD.

TVFA concentration obtained in the sludge samples from the first valve of the tubular reactor where quite high for the four mesophilic periods: the concentration increased with retention time from 9 g/L in period 2 up to 13.4 g/L in period 4.2. This is because acidogenic bacteria are fast-growing bacteria, with minimum doubling times around 30 minutes (Mosey, 1983) and are capable of fermenting the soluble fraction of the organic refuse to produce a mixture of VFA in a short interval of time. Maximal VFA concentration in the first valve was obtained in period 1, when solid recycling was operated (17.8 g/L), that is, with acidogenic inoculum in the feeding mixture.

The stability parameters -pH and alkalinity- were always within the optimal ranges: pH in the reactor varied between 4.77 (period 2) and 5.97 (period 4.1) but mean value never reached values that could inhibit the acidogenic process, that is, pH values below 4.5 (Zoetemeyer et al., 1982). ΔTA in the outlet sludge kept always quite high and between 11.6 and 19.5 $gCaCO_3/l$, as well as ammonia concentration (between 81.2 mg/L and 486.7 mg/L, see Table 3), so the system was always optimally selfbuffered.

CONCLUSIONS

This work shows that the acidogenic fermentation of the organic fraction of the municipal solid waste in a tubular reactor and at pilot scale level, is an optimal process for the obtention of volatile fatty acids. These fatty acids are the row material of valuable products, like methyl-ethyl esters or alkane.

In mesophilic conditions, the production of VFA increased with the retention time up to a production of 23.1 g/L for 6 days of retention time. No inoculation of the substrate was necessary as VFA concentration was already important at short retention time (first valve of the tubular reactor). The yields obtained can be considered as optimal (15% expressed as TVFA, % TVS fed), considering the high values of loading rates employed (66.9 $KgSV/m^3d$) and the mixture of urban wastes utilized as substrate for the digestion. The acidogenic process, in the working conditions studied, is stable, considering the parameters pH, alkalinity and ammonia. Furthermore, the ammonia concentration in the reactor sludge has revelled as a good indicator of the bacterial activity.

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Table 1: Main characteristics of the OFMSW coming from the mechanical selecting plant of San Giorgio di Nogaro (Italy).

PARAMETERS	AVER.	MAX.	MIN.	STD	SAMPL.
TS, g/Kg	647.2	832.4	472.2	89.3	45
TVS, g/Kg	300.8	487.5	212.4	65.1	33
TVS, % ST	45.4	62.4	35.8	6.9	33
TCOD, % ST	51	76	23	15	22
TKN, % ST	1.36	1.79	1.06	0.22	22
P, % ST	1.41	1.82	1.02	0.30	10
TC, % ST	22.05	26.80	18.94	2.78	6

Table 2: Main characteristics of the source-sorted OFMSW coming from the market of the city of Treviso (Italy).

PARAMETERS	AVER.	MAX.	MIN.	STD	SAMPL.
TS, g/Kg	163.9	353.3	69.42	58.5	115
TVS, g/Kg	153.6	568.3	54.7	82.5	88
TVS, % ST	90.0	95.3	52.8	16.8	87
TCOD, % ST	112	133	84	64	44
TKN, % ST	2.07	3.07	1.21	6.39	45
P, % ST	2.57	5.45	0.82	6.26	43
TC, % ST	43.21	48.80	34.25	15.16	19

Table 3: Working conditions and averaged results obtained at steady state conditions in the 5 periods studied at mesophilic conditions.

PERIOD	1	2	3	4.1	4.2
HRT, d	1.8	1.9	3.8	4.9	4.6
SRT, d	-	2.0	4.0	6.0	6.0
OLR, KgSV/m³d	66.9	85.2	42.3	33.9	38.5
Feed:					
TS, g/Kg	198.5	248.3	244.9	285.9	285.5
TVS, g/Kg	122.2	159.0	159.2	155.7	160.4
STS, g/Kg	32.7	38.6	35.2	34.2	34.6
SVS, g/Kg	27.2	32.9	27.9	27.8	28.7
TCOD, gO_2/Kg	188.0	199.5	192.7	179.5	196.7
SCOD, gO_2/Kg	33.7	41.7	37.9	30.9	32.1
pH	5.92	6.11	6.19	6.39	6.06
ΔTA, $gCaCO_3$/l	2.9	4.0	2.9	3.4	3.6
TVFA, mg/L	2902	2645	7651	4722	4361
Sample valve 1:					
STS, g/Kg	27.7	61.2	64.3	38.9	55.3
SVS, g/Kg	20.2	42.7	47.3	27.8	36.6
pH	5.33	4.77	5.68	5.21	5.69
ΔTA, $gCaCO_3$/L	10.7	12.3	9.0	9.0	13.0
NH_4-N, mg/L	223.4	40.6	177.6	49.0	100.7
TVFA, mg/L	17822	9061	12782	7375	13372
Sample exit reactor:					
TS, g/Kg	230.4	255.2	304.0	419.5	303.6
TVS, g/Kg	125.5	153.9	188.2	214.5	152.7
STS, g/Kg	24.1	58.4	71.4	45.3	36.5
SVS, g/Kg	17.0	40.6	48.5	29.3	25.0
TCOD, gO_2/Kg	161.2	212.6	237.9	247.8	214.8
SCOD, gO_2/Kg	22.1	39.8	52.6	28.6	38.8
pH	5.57	5.08	4.98	5.97	5.72
ΔTA, $gCaCO_3$/L	11.6	14.7	17.2	16.2	19.5
NH_4-N, mg/L	360.3	101.3	81.2	255.4	486.7
TVFA, mg/L	19524	11780	18265	13000	23110

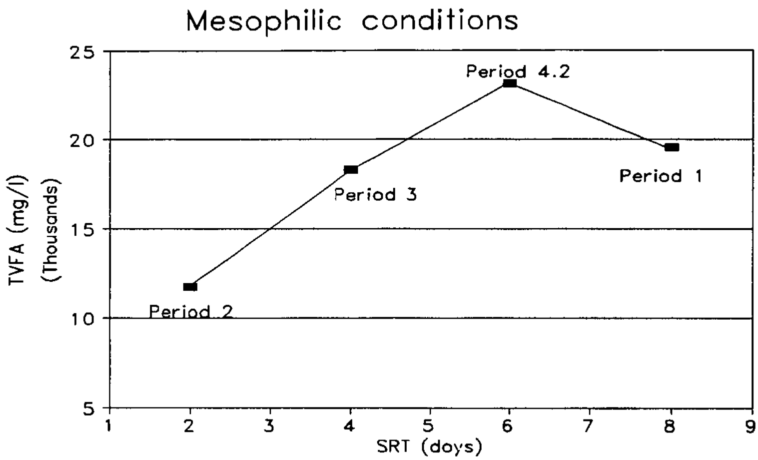

Figure 1: Variation of TVFA production in the outlet sludge with solid retention time in mesophilic conditions.

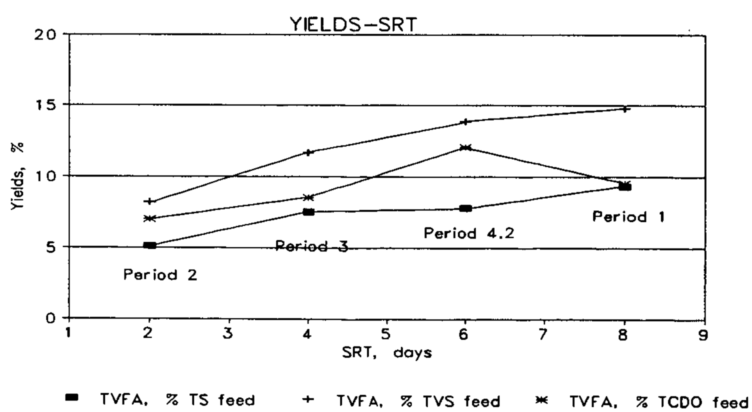

Figure 2: Yields obtained in the four mesophilic periods studied.