Volatile fatty acids production from organic fraction of municipal solid waste: Effect of hydraulic retention time, feeding regime and temperature

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Abstract: Anaerobic bioprocesses based on mixed microbial cultures (MMC) can handle a wide variety of organic wastes to transform them into value-added bioproducts (Strazzera et al., 2018). Volatile fatty acids (VFAs) can be obtained by MMC acidogenic fermentation through different metabolic routes depending on the composition of the substrates and the operating conditions, while restricting methanogens proliferation (Vázquez-Fernández et al., 2022; Vidal-Antich et al., 2022). The production of biobased VFAs is getting attention due to its market increasing demand as chemical products, as well as precursors of chemicals (esters, ketones, aldehydes, alcohols and alkanes), biopolymers (such as polyhydroxyalkanoates) and bioenergy (biomethane, biodiesel, biohydrogen, electricity via microbial fuel cells), among others (Nosek et al., 2023; Pereira et al., 2022; Valentino et al., 2021, p. 21). Biobased VFAs is an alternative to petroleum-based ones, which currently supply most of the market demand. Therefore, biobased VFAs are key building blocks in waste processing biorefineries that could contribute to the transition from a linear to a circular economy while increasing the sustainability of their supply chain (Dai et al., 2017; Feng et al., 2022).

In this study, the acidogenic fermentation of organic fraction of municipal solid waste (OFMSW) in semi-continuous lab-scale fermenters was studied under different conditions of feeding regime, hydraulic retention time (HRT) and temperature. The OFMSW was collected from a mechanical-biological treatment plant of the Barcelona Metropolitan Area, sieved at 5 mm mesh size and preserved at 4 ºC until its use. Table 1 shows the main characteristics of the OFMSW samples (4 different collection periods) which were characterised by a VS content in the range of 49-54 g/L, a circumneutral pH (6.5-7.1), a high alkalinity (17-19 g $CaCO_3$/L) and a relatively high VFAs content (24-33 g COD/L) due to unintended fermentation during the OFMSW pre-treatment at the treatment plant (Fernández-Domínguez et al., 2020).

Table 1. Main characteristics of the collected OFMSW samples.

Parameter	Units	OFMSWa	OFMSWb	OFMSWc	OFMSWd
VS	(g/L)	51.76 ± 0.21	54.09 ± 4.40	48.87 ± 0.50	54.22 ± 0.40
VFAs	(g COD/L)	24.09 ± 3.54	25.83 ± 0.92	33.48 ± 2.26	27.16 ± 0.25
TAN	(g NH_4^+-N/L)	3.26 ± 0.05	3.57 ± 0.07	3.67 ± 0.15	4.35 ± 0.01
pH	-	6.94 ± 0.01	6.88 ± 0.01	6.54 ± 0.01	7.15 ± 0.01
Alkalinity	(g $CaCO_3$/L)	17.10 ± 0.78	15.43 ± 0.85	16.29 ± 1.50	19.49 ± 1.09
	Days of operation	0-25	26-58	70-116	126-154

The continuous acidogenic fermentation of OFMSW was carried out in two lab-scale fermenters (1.75 L effective volume) equipped with a pH probe, a mechanical stirrer and a temperature control system to establish mesophilic (35 ºC) and thermophilic (55 ºC) conditions. The process was started up using the indigenous microorganisms present in the OFMSW (no external inoculum). Two lab-scale fermenters (A and B) were used to assess the long-term VFAs yield and distribution under different conditions. In Fermenter A, the feeding regime, the HRT and temperature were modified according to Table 1, while Fermenter B acted as a control reactor and it was always operated at 35 ºC, HRT of 4 days and fed once a day (0.45 L/day). At the beginning of each new period (1, 2 and 3), Fermenters A and B were started-up again to avoid that previous periods could affect the results of the subsequent ones. Moreover, to analyse the maximum VFAs production potential, batch fermentation tests were performed for each collected OFMSW sample (sieved and non-sieved). The duration of each batch assays was 14 days, when no changes in VFAs production were recorded.

Figure 1 shows the results of one representative batch fermentation test performed on non-sieved (Figure 1a) and sieved (Figure 1b) OFMSW (sample OFMSWb). During the batch assay, the VFAs concentration increased from 23 to 44 g COD/L (non-sieved sample) and 42 g COD/L (sieved sample). In both cases, VFA distribution was dominated by acetic, propionic and butyric acids, representing the 28-32, 31-32 and 28-29% (COD basis) of the total VFAs, respectively. Total ammonium nitrogen (TAN) concentrations increased from 3.6 g N/L to 5.4-5.8 g N/L and pH decreased from 6.90 down to 5.97-5.99. These results demonstrate that a 5 mm sieving pre-treatment had no significant impact on the VFA production.

Table 2. Operating conditions tested in Fermenter A.

Period	Sub-Period	Days of operation	Temperature (ºC)	HRT (days)	Feeding regime
1	1.1	0-14	35	4.0	0.45 L (per day)
	1.2	14-42	35	4.0	0.90 L (every 2 days)
	1.3	42-58	35	4.0	1.2 L (every 3 days)
2	2.1	60-75	35	4.0	0.45 L (per day)
	2.2	75-88	35	3.0	0.60 L (per day)
	2.3	88-98	35	2.0	0.90 L (per day)
	2.4	98-106	35	1.3	1.2 L (per day)
3	3.1	106-138	55	4.0	0.45 L (per day)

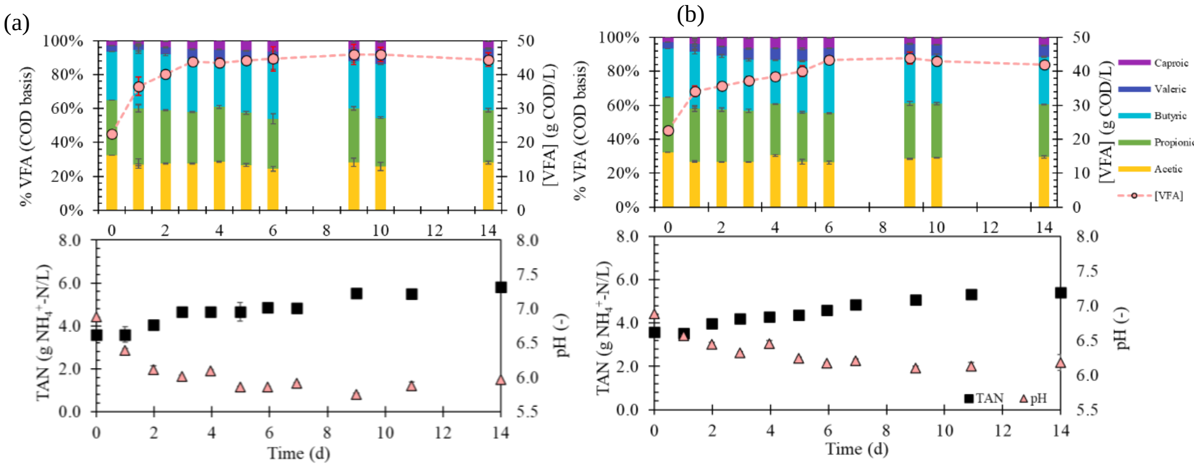

Figure 1 – Evolution of VFA concentration, pH and VFA distribution of (a) non-sieved OFMSW and (b) sieved OFMSW representative batch fermentation test.

Figure 2 depicts the VFA concentration, fermentation yield (inside the fermenter, subtracting the initial VFA concentration of the substrate) and the overall yield (considering the total VFA concentration of the effluent), VFA/soluble COD (sCOD) ratio, TAN and pH of the long-term fermentation operation under different conditions as defined in Table 2. During the long-term treatment of the OFMSW, VFA concentrations reached similar values as in batch tests, increasing from 18-25 g COD/L up to 32-44 g COD/L with no significative differences between the Fermenter B (control) and the conditions tested in Fermenter A. When stable operation was reached, VFA content represented the 52-82% of the total soluble COD (sCOD). VFA distribution in both fermenters was dominated by acetic, propionic and butyric acids, which is in accordance with other continuous treatment of OFMSW results reported (Cheah et al., 2019; Micolucci et al., 2020; Valentino et al., 2019). Treated effluents presented TAN concentrations in the range of 3.3-5.7g N/L and neutral pH values (6.0-8.0), being strongly related to the influent properties. The average fermenter's VFA yield was ≈ 0.3 g COD_{VFA}/g VS in both fermenters, representing an overall yield (considering the VFA initially present in the OFMSW) of ≈ 0.7 g COD_{VFA}/g VS, which is in the upper range of those reported in literature (Fernández-Domínguez et al., 2020; Strazzera et al., 2021), due to the high biodegradability of the substrate and its high alkalinity thanks to the recirculation of the supernatant from anaerobic digestion. The analysis of the microbial community of the fermentation assays is ongoing to elucidate the microorganisms responsible of this stable long-term VFA production despite the conditions subjected.

This study demonstrates that a stable VFA production (32-44 g COD/L), composition (roughly 30% in COD basis for acetic, propionic and butyric acids) and VFA/sCOD ratio (52-82%) could be achieved under long-term acidogenic fermentation of OFMSW at 35 ºC, HRT of 4 days and once per day semi-continuous feeding. When the feeding frequency was reduced (until feeding 1.2 L once every three days) at the same HRT of 4 days, no significant changes in the VFA production, distribution and VFA/soluble COD ratio were recorded. However, when the HRT was reduced from 4 to 1.3 days, only a small reduction in the obtained VFA concentration was recorded (<4 g COD/L). Finally, the increase of temperature from 35 to 55 ºC did not represent a significant improvement of the VFA production and distribution despite the improved hydrolysis due to higher temperature, which leaded to a lower VFA/sCOD ratio. Stability is a key parameter in long-term acidogenic fermentation since OFMSW composition could importantly vary depending on the season and could modify significantly the VFA production, composition and yield (Qin et al., 2024).

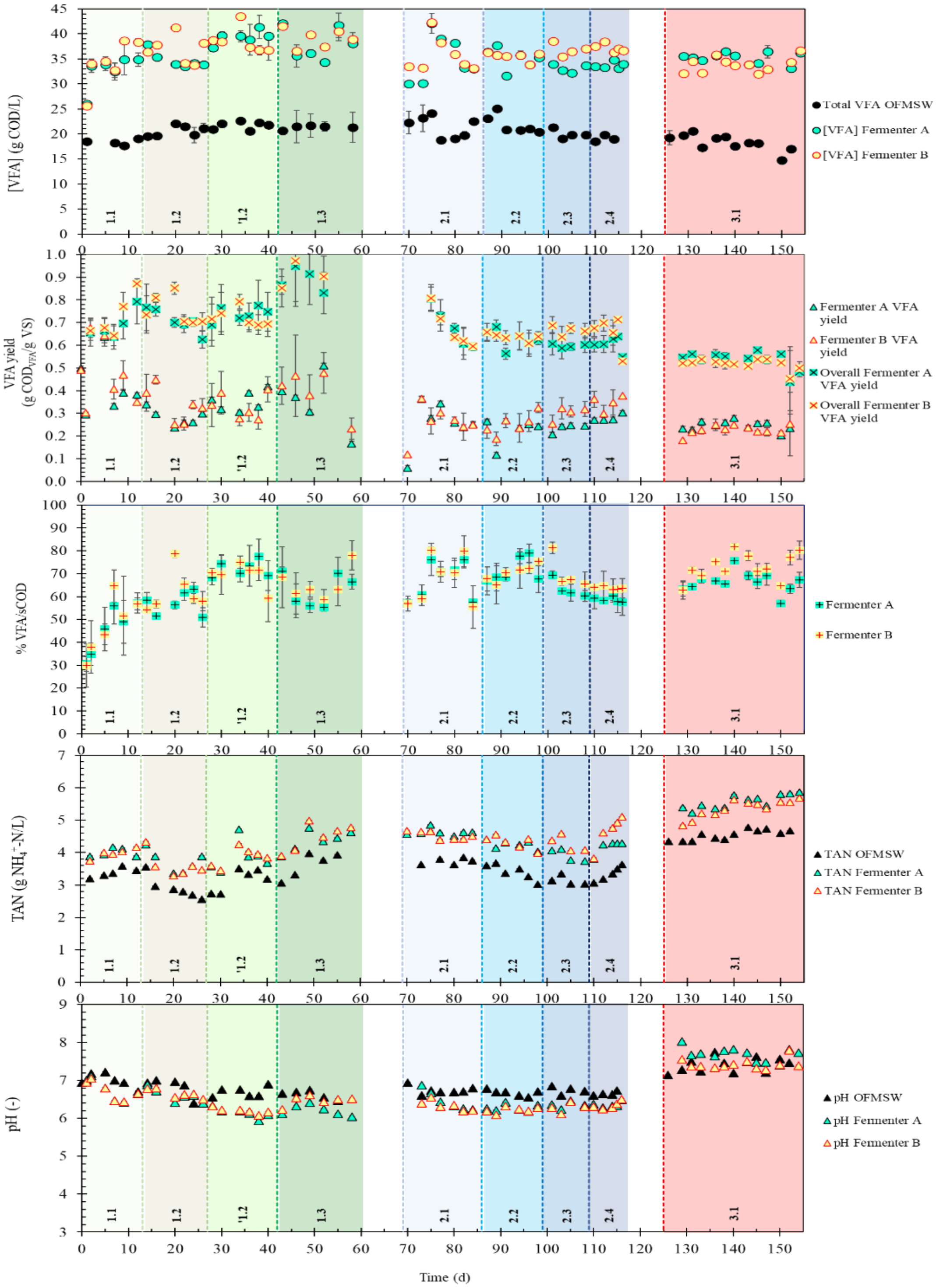

Figure 2 – Evolution of VFA concentration, fermenter's and overall VFA yield, solubilization yield, TAN and pH along the whole continuous operation.

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