Improving municipal organic waste treatment through thermal hydrolysis to enhance anaerobic digestion performance

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Abstract: Municipal solid waste (MSW) generation is steadily increasing, while current treatment strategies underutilize the bioenergy potential of its organic fraction. This study evaluates BIOMAK® thermal hydrolysis (TH), as a pretreatment to enhance anaerobic digestion (AD) of mechanically separated organic fraction of MSW (MS-OFMSW). Thermal hydrolysis markedly improved substrate solubilization, increasing the availability of biodegradable compounds. During AD, thermally treated substrates (thermally hydrolyzed organic fraction (THOF) and biopulp (diluted THOF)), achieved higher methane yields (332 (1) and 346 (2) mL STP CH_4 g/VS_{added}, respectively) compared to raw MS-OFMSW (275 (2) mL STP CH_4 g/VS_{added}). Conversely, THOF plus condensate and process water from BIOMAK® (BO-Mix) showed reduced performance, attributed to inhibitory aromatic compounds generated during TH. Operational parameters (pH, alkalinity, and ammonia) remained within non-inhibitory ranges, ensuring stable digestion conditions. Overall, BIOMAK® thermal hydrolysis significantly enhances MS-OFMSW biodegradability and energy recovery, supporting circular-economy objectives, while highlighting the need to mitigate effluent-derived inhibitors for optimal process integration.

Keywords: Biochemical methane potential; Biowaste valorization; Pretreatment

Introduction

Municipal solid waste (MSW) generation is increasing globally, while separation rates remain limited, and landfilling persists despite European Union circular-economy targets. Mechanical biological treatments (MBT) play a central role in managing unsorted MSW by enabling metal and energy recovery, and stabilization of organic residues. The mechanically separated organic fraction of MSW (MS-OFMSW) is a valuable resource for anaerobic digestion (AD), yet its low substrate biodegradability limits performance. Thermal hydrolysis (TH) is widely applied to sewage sludge to improve AD efficiency but remains underdeveloped for MSW (Barber, 2016; Parisa et al., 2025). Econward's BIOMAK® technology applies industrial TH conditions to homogenize, degrade, and sanitize solid organic waste (Econward, 2025). This study assesses BIOMAK®-treated substrates for enhancing the anaerobic digestion of MS-OFMSW.

Material and Methods

Anaerobic digestate obtained from a mesophilic reactor at a municipal wastewater treatment plant (Madrid, Spain) was used as inoculum. MS-OFMSW obtained via MBT from MSW and sourced from a treatment plant near Madrid was used as the substrate. Thermal hydrolysis (1.3 t of feedstock (53% moisture)) was performed in the BIOMAK® system at 152 °C and 4 bar for 20 min. The thermally hydrolyzed organic fraction (THOF) was screened through a 40 mm sieve and subsequently cleaned using a pulper–hydrocyclone–rejector system to produce a diluted biopulp. The BIOMAK® outflow mix (BO-Mix) was prepared by combining THOF with the

condensate and the process water (PW) generated during the process, according to their TH mass balance ratio (96:16:1, respectively).

Biochemical methane potential (BMP) tests were performed to determine the ultimate methane potential of each substrate. Assays were conducted at 36 °C for 29 days using an inoculum-to-substrate ratio of 2 on a volatile solids (VS) basis (De la Rubia et al., 2018). Seven reactors were sacrificed per substrate periodically for 29 days, and biogas generation and composition were assessed in parallel (three more reactors) on seven measurement events. For both the inoculum and the sacrificed samples, the following parameters were quantified: soluble and total chemical oxygen demand (SCOD and TCOD), total solids (TS), VS, alkalinity, pH, total ammonia nitrogen (TAN), total Kjeldahl nitrogen (TKN), and volatile fatty acids (VFA). Methane yield was determined by subtracting the methane produced in blank runs and normalizing the results to the amount of VS added.

Results and Discussion

Table 1 collects the initial characteristics of the inoculum and substrates. Thermal hydrolysis significantly modified MS-OFMSW properties, reducing pH and improving C:N and VS/TS ratios, which indicate higher biodegradability. Biopulp exhibited additional acidification compared to THOF, suggesting early VFA formation during pretreatment. These changes anticipate improved biogas yield in treated substrates, compared to raw MS-OFMSW.

Table 1 Inoculum and substrates characteristics.

	pH	TS (g/kg)	VS (g/kg)	TCOD (g O_2/kg)	TKN (g N/kg)	C (wt. %)	N (wt. %)
Inoculum	7.2 (0.2)	30.7 (0.1)	19.2 (0.1)	29.6 (0.5)	3.0 (0.3)	31.4 (0.6)	5.3 (0.1)
MS-OFMSW	7.5 (0.1)	474.2 (10.4)	290.8 (10.2)	576.6 (31.0)	12.0 (3.6)	29.2 (2.3)	2.4 (0.4)
THOF	6.2 (0.1)	418.6 (5.9)	281.4 (4.1)	511.1 (0.7)	8.2 (0.3)	38.5 (2.0)	1.9 (0.2)
Biopulp	4.5 (0.1)	149.2 (4.2)	104.4 (4.9)	167.9 (2.1)	1.9 (0.3)	39.9 (0.7)	1.8 (0.1)
BO-Mix	6.2 (0.1)	353.8 (15.6)	249.8 (22.1)	437.2 (0.8)	7.2 (0.3)	39.4 (0.2)	1.8 (0.1)
Condensate	4.6 (0.1)	0.2 (0.1)	0.2 (0.1)	16.6 (0.1)	0.2 (0.004)	0.3 (0.1)	0.1 (0.0)
PW	5.0 (0.1)	37.0 (0.4)	25.8 (0.3)	63.5 (0.8)	1.4 (0.01)	1.5 (0.0)	0.2 (0.01)

The pH remained within the optimal range (7.1-7.9), supported by enough alkalinity and non-inhibitory TAN concentrations, ensuring stable AD performance. The removal of VS averaged 29% for MS-OFMSW, THOF and biopulp, while BO-Mix showed slightly lower removal (25%). The reduction of TCOD was lowest for untreated MS-OFMSW (33%) and highest for THOF (43%), confirming the positive effect of thermal hydrolysis on organic matter degradation (Figure 1a).

Figure 1b depicts the evolution of SCOD and VFA, expressed as g COD/L. TH-treated substrates exhibited rapid accumulation of soluble compounds and VFA

during the first four days, followed by their consumption as methanogenesis progressed. In contrast, MS-OFMSW showed minimal accumulation and slower conversion, with residual SCOD and VFA concentrations persisting at the end of the assay. Pretreated substrates reached stability after day 7, indicating faster hydrolysis and acidogenesis compared with the raw fraction.

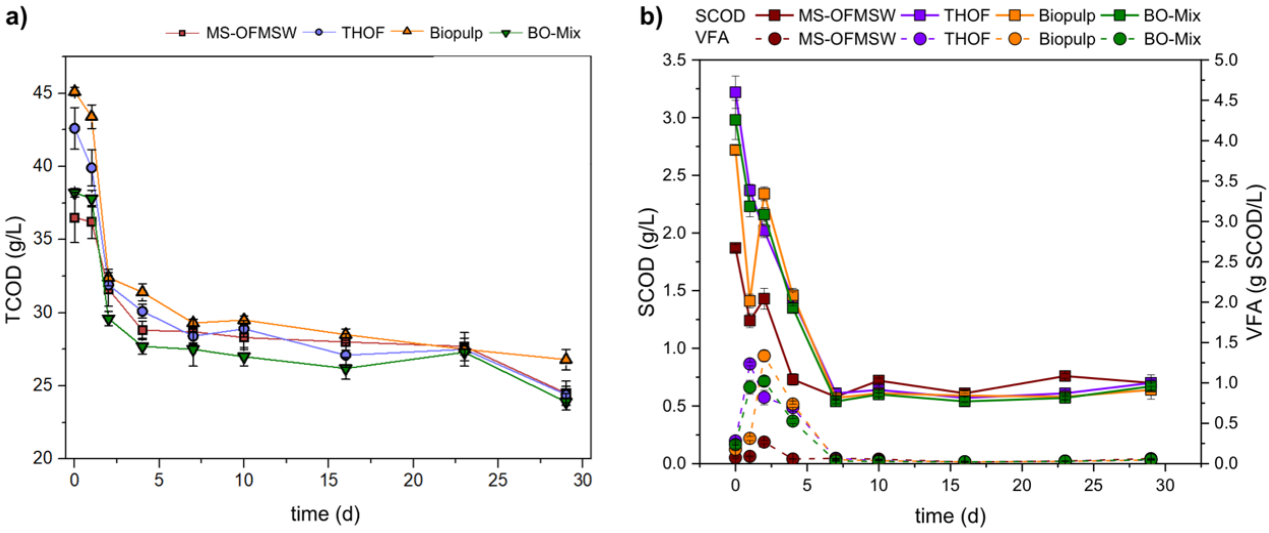

Figure 1 TCOD (a) evolution; SCOD and VFA (b) evolution.

Figure 2 shows the cumulative specific methane yields. TH markedly improved performance: biopulp and THOF achieved 346 (2) and 332 (1) mL STP CH_4 g/VS_{added}, respectively, compared to 275 (2) mL STP CH_4 g/VS_{added} for MS-OFMSW. BO-Mix exhibited similar yield to MS-OFMSW, likely due to inhibitory aromatic compounds present in the condensate that hindered methanogenesis.

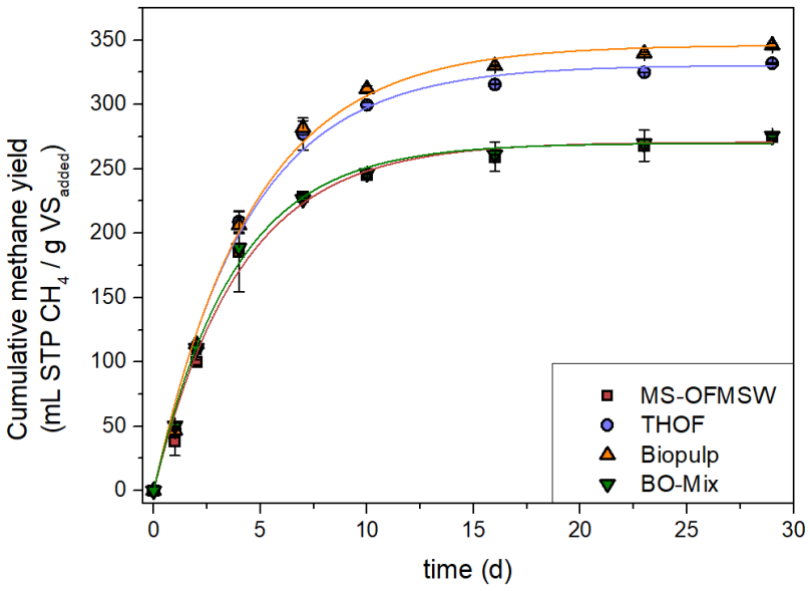

Figure 2 Cumulative methane potential per g VS_{added}.

Conclusions

BIOMAK® thermal hydrolysis markedly enhanced the biodegradability and methane production of MS-OFMSW, reinforcing its role in biowaste valorization and circular economy frameworks. Although effluent-derived aromatic compounds introduced inhibitory effects, TH represents a promising pretreatment strategy for optimizing AD performance.

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