

Effect of process water recirculation on gasification behavior of hydrochar from organic fraction of municipal solid waste

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Waste generation is a critical global issue, presenting significant environmental and social challenges. The management of the organic fraction of municipal solid waste (OFMSW) is particularly complex due to its high heterogeneity and moisture content. However, within a circular economy framework, OFMSW can be transformed from an environmental burden into a valuable resource (European Environment Agency, 2020).

Chemical recycling offers a promising pathway to convert biowaste into value-added products for energy and fuel applications. Among the available methods, gasification stands out as an effective thermochemical conversion process for addressing waste management challenges, producing syngas, a crucial building block for the synthesis of various chemicals and fuels. However, the direct utilization of biomass in gasification processes is hindered by limitations such as low energy density, high moisture content, and tar formation, which negatively impact the process efficiency and the syngas application. Therefore, biowaste must undergo upgrading to enhance its performance. One promising upgrading technique is hydrothermal carbonization (HTC).

HTC has gained increasing attention as an effective method for converting wet biowaste into carbon-rich, energy-dense solid fuels with reduced oxygen content. Operating under mild conditions in an aqueous environment (below 250 °C, autogenous pressure), HTC eliminates the need for feedstock drying, resulting particularly suitable for integrating into biorefinery plant for wet biowaste treatment. The process yields a carbon-enriched solid (hydrochar), a liquid phase containing valuable organic compounds, and minimal gas emissions. Hydrochar has versatile applications as a biofuel, in energy storage, and in environmental remediation, including water pollution control, soil amendment, and nutrient recovery (Picone et al., 2024). Despite these advantages, HTC generates large volumes of wastewater (process water, PW), which presents challenges related to treatment and disposal. The high total organic carbon (TOC) and chemical oxygen demand (COD) of PW can significantly increase process costs and limit industrial-scale applicability, making the development of a sustainable and cost-effective PW management strategy a bottleneck in HTC implementation (Becker et al., 2014). Recirculating PW represents a potential approach to reduce freshwater consumption, improve the overall efficiency of the process and contribute to a sustainable biowaste conversion (Dominik et al., 2021).

This study evaluates the gasification performance of OFMSW hydrochars produced through “standard” HTC using a pilot-scale plant (HC-PP) and “recirculating Hydrothermal Carbonization” conducted in a lab-scale reactor (HC-R), comparing the results with raw OFMSW. The pilot-scale HTC experimental test was conducted at 195 °C for 3 hours under a saturated steam pressure of 13.3 bar with a water/biomass ratio of 4/1. After the reaction, the sample was left to cool within the reactor overnight. The cooled products were then recovered, with the liquid phase collected from the bottom of the reactor and the wet hydrochar manually retrieved and mechanically dried. The R-HTC tests were carried out in a 3 L batch reactor at 200°C, with a residence time of 2 hours and a water/biomass ratio of 4/1. A total of 10 batches were processed. At the end of each batch, hydrochar and PW were recovered, with the PW being reused in subsequent batches. Freshwater was introduced only in the first batch. Table 1 reports the results of ultimate and proximate analyses and HHV of the materials.

Table 1. Results of raw and pretreated materials characterization.

		OFMSW	HC-R	HC-PP
Elemental analysis	C (wt.%dry basis)	44.15	50.17	49.74
	H (wt.%dry basis)	5.72	5.91	6.09
	O (wt.%dry basis)	32.71	19.98	26.13
	N (wt.%dry basis)	2.56	2.68	2.74
	S (wt.%dry basis)	0.26	0.25	0.20
Proximate analysis	Ash (wt.%dry basis)	14.61	21.02	15.11
	Volatile matter (wt.%dry basis)	73.38	63.93	69.43
	Fixed Carbon (wt.%dry basis)	12.01	15.05	15.46
	Moisture (wt.%)	14.10	3.98	5.94
	LHV	16.7	18.1	20.2

Gasification tests were performed using both raw and pretreated materials at 850 °C with a steam-to-feedstock ratio of 0.5. The main results of gasification tests are reported in Table 2, while Figure 1 shows the syngas composition obtained.

Table 2. Summary of the main results of gasification tests

	OFMSW	HC-R	HC-PP
Gas yield (Nm ³ /kg)	1.19	1.41	1.41
Residual char (%)	3.67	5.21	6.55
LHV gas (MJ/Nm ³)	10.42	11.74	11.25
CGE	0.76	0.92	0.79
Tar content (g/Nm ³)	25.00	11.50	11.25

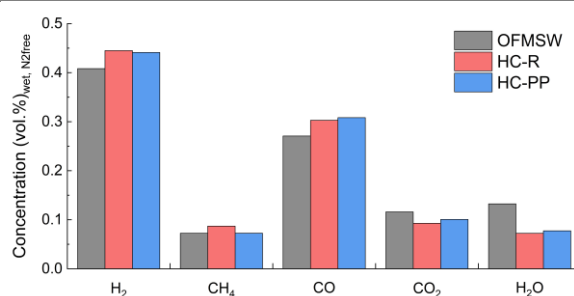


Figure 1. Comparison of the syngas composition

The elemental analysis shows that HTC process effectively increases the carbon content of the feedstock while significantly reducing its oxygen content in both hydrochars. In particular, HC-R exhibits a lower oxygen content, possibly due to the PW recirculation, which may facilitate deoxygenation reactions through the presence of alkaline earth metals (He et al., 2022). The proximate analysis indicates an increase in ash content in HC-R, likely due to the concentration of inorganic components during process water (PW) recirculation. Despite the higher ash content and lower volatile matter, the gas yield achieved with HC-R is comparable to that of HC-PP and higher than with raw material. These results suggest that the ash content did not negatively affect gasification performance. Instead, the presence of alkaline substances in the ash may have played a catalytic role, promoting tar cracking and enhancing carbon conversion, as evidenced by the lower residual char obtained with HC-R compared to HC-PP.

The syngas composition highlights the benefits of HTC pretreatment, showing a clear improvement in syngas quality. The increased CO and H₂ content and reduced CO₂ levels are correlated with the decreased oxygen content in the pretreated feedstock, leading to more efficient gasification reactions and a higher calorific value of the syngas. HTC pretreatment significantly reduced tar content in the syngas, from 25 g/Nm³ with raw OFMSW to approximately 11 g/Nm³ with both hydrochars. This reduction not only enhances syngas quality but also contributes to process stability and efficiency. Overall, the study demonstrates that HTC significantly improves the performance of the OFMSW as a feedstock for gasification. Interestingly, the PW recirculation approach did not negatively affect gasification performance despite the higher ash content. The similar performance of HC-R and HC-PP in gasification tests, despite differences in ash content, suggests that the recirculation strategy may provide a cost-effective and efficient pathway for biowaste upgrading. Further research should focus on optimizing process water management and exploring the catalytic potential of ash components to maximize gasification performance and minimize environmental impact.

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