

Gasification of Waste Mattresses for Syngas Production: Impact of Different Gasifying Agents (CO₂, Air, and Steam-Oxygen)

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Introduction

In the context of the European Union's strategy for achieving a circular economy by 2050, the valorization of bulky and complex waste streams has gained increasing attention (Communication, 2021). Discarded mattresses represent a significant environmental challenge due to their large volume and heterogeneous composition, primarily consisting of steel springs, textiles, and polyurethane foams (PUF). While mechanical recycling is effective for recovering the metallic fraction, the organic and polymeric components are typically landfilled or incinerated, leading to secondary pollution and resource loss (Garrido et al., 2016). Thermochemical conversion, specifically gasification, emerges as a robust alternative. It not only achieves massive volume reduction but also allows for the recovery of high-value chemical building blocks and energy. Furthermore, the use of alternative gasifying agents such as CO₂ or steam can drastically alter the syngas profile, offering a pathway for Carbon Capture and Utilization (CCU) (Valin et al., 2016). This study comparatively evaluates the gasification of mattress waste using air, CO₂, and a mixture of O₂ and steam to optimize syngas quality and assess the overall energy balance of the process.

Experimental Methodology

The experimental campaign was conducted in a pilot-scale fluidized bed reactor, chosen for its excellent heat and mass transfer properties, which are crucial when handling heterogeneous feedstocks like shredded mattresses. The system was operated using three distinct gasifying agents: conventional air, pure CO₂, and a steam/O₂ mixture. Operating parameters, including temperature and the Equivalence Ratio (ER), were systematically varied. The performance of each configuration was assessed based on the resulting syngas composition, mass conversion efficiency, the Lower Heating Value (LHV), and the overall Cold Gas Efficiency (CGE) of the system.

Results and Discussion

The choice of gasifying agent had a profound impact on the thermochemical degradation of the polyurethane-rich waste and the final gas quality. The product distribution and syngas quality parameters obtained for each GA are summarized in Table 1. Gas yields were exceptionally high when CO₂ was used (up to 87 wt.%), indicating an effective conversion of the solid waste into the gaseous phase via the Boudouard reaction (Müller et al., 2024). Regarding syngas composition, conventional air gasification provided a stable operational baseline but yielded a nitrogen-diluted gas. Conversely, the implementation of steam-enhanced gasification promoted the water-gas shift and steam reforming reactions (Karatat & Akgun, 2018), yielding a high-quality syngas with an H₂/CO molar ratio of up to 1.6. The LHV of the generated syngas ranged from 9.2 to 14.3 MJ/m³(STP) depending on the agent, with CGE values peaking between 54% and 73%. Beyond syngas quality, the energetic viability of the process was evaluated through an overall energy balance. These results were compared with the gasification of textile waste (TW) (Gracia-Monforte et al., 2025), as depicted in Figure 1. Gasification using air is characterized by a fully autothermal behavior at a stoichiometric ratio of 0.2, requiring no additional external energy ($\Delta E > 0$). In contrast, utilizing CO₂ or steam/O₂ as reactive gasifying agents is inherently endothermic and requires an external heat input. However, the superior LHV of the syngas produced under these conditions completely compensates for the energy penalty of the reactor. This results in a highly positive net energy surplus (ΔE), demonstrating that the energy content of the generated syngas far exceeds the internal thermal requirements of the endothermic gasification reactions.

Conclusions

The comparative analysis confirms that gasification is a highly flexible and efficient technology for the valorization of waste mattresses. By adjusting the gasifying agent, the process can be tailored to produce a high-energy gas. While air gasification allows for fully autothermal operation, the use of CO₂ and steam/O₂ significantly

improves the syngas heating value and H₂ concentration. Despite the initial external heat required for the latter agents, the overall energy balance reveals a substantial energy surplus, demonstrating the high energetic efficiency of this thermochemical route as a realistic solution for bulky waste management.

Table 1. Experimental results: product distribution, syngas composition and syngas quality and energy.

	Air	CO ₂	O ₂ +steam
Product distribution (g/(g_{MW} + g_{GA}))			
Liquid (wt.%)	17.0 ± 0.1	8.6 ± 0.1	17.8 ± 1.2
Char (wt.%)	6.2 ± 0.7	2.1 ± 0.2	5.0 ± 1.3
Gas (wt.%)	80.9 ± 2.2	87.2 ± 4.6	58.7 ± 7.2
Total (wt. %)	104.2 ± 1.5	97.9 ± 4.7	88.2 ± 8.1
Liquid yield (wt. %, g _{liquid} /g _{MW})	23.8 ± 0.3	27.7 ± 0.2	34.7 ± 11.3
Solid yield (wt. %, g _{char} /g _{MW})	8.7 ± 0.9	6.6 ± 0.5	12.0 ± 2.8
Waste Reduction (wt.%)	67.6 ± 0.6	65.7 ± 0.3	54.0 ± 5.1
Tar concentration			
g _{TAR} /m ³ (STP) _{syngas}	1.2 ± 0.1	1.4 ± 0.1	2.2 ± 0.3
(g _{TAR} /kg _{MW})	2.7	3.2	3.3
Gas Composition (vol.%, dry basis)			
H ₂	15.2 ± 0.1	14.0 ± 0.6	32.7 ± 1.2
N ₂	47.6 ± 0.4	0.0 ± 0.0	14.3 ± 0.8
CH ₄	7.2 ± 0.1	8.5 ± 0.8	11.0 ± 0.7
CO	18.0 ± 0.9	35.6 ± 2.2	20.3 ± 1.4
CO ₂	11.8 ± 0.5	41.6 ± 3.4	21.5 ± 1.2
C ₂ H _X	0.2 ± 0.1	0.3 ± 0.1	0.2 ± 0.1

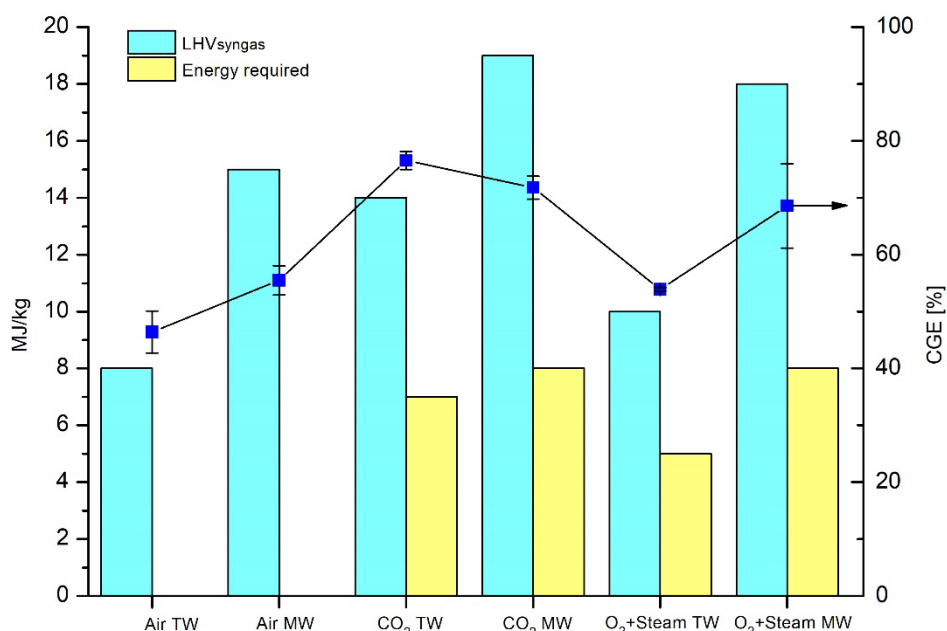


Figure 1. Heat required for the gasification process for MW and TW (Gracia-Monforte et al., 2025b) (Q, MJ/kg_{TW} or MJ/kg_{MW}, syngas LHV (MJ/kg_{TW} or MJ/kg_{MW}), and CGE.

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