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Assessing the Effect of Temperature and Biomass Composition for Hydrogen Production through Gasification

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Abstract Sustainable forest biomass management is essential for ecological balance, rural economies, and climate change mitigation. Biomass residues—branches, thinnings, and wood waste—can enhance forest health and reduce fire hazards, promoting regeneration, and enabling renewable energy production.
Gasification, a thermochemical process that converts organic material into syngas, offers an efficient and cleaner alternative to traditional combustion, supporting low-carbon heat, electricity, and biofuel generation. This study examines the gasification of biomass waste—including miscanthus, peach stones, Pinus pinaster, and wood chips—for syngas production, with H_2 as the target fuel. Plasma gasification was also explored for peach stones.

Keywords: biomass management, gasification, syngas, H_2

1. Introduction

The sustainable management and conservation of forests are essential strategies to mitigate climate change, regulate ecosystems, and safeguard biodiversity, simultaneously sequestering carbon and providing renewable resources (Ribeiro, Bertani et al. 2024). Within this framework, an effective approach involves utilizing biomass waste for bioenergy production, through thermal processes such as gasification. Thus, biomass waste can be transformed into a renewable energy source, a cleaner and more sustainable alternative to fossil fuels (World Bank Group 2017). Recent advancements in biomass gasification have significantly improved energy efficiency and reduced emissions (Helf, Cloete et al. 2022), and enhanced reaction rates through the use of novel catalysts (Yang, Hu et al. 2023). Literature shows that temperature is one of the leading parameters in gasification, impacting aspects such as syngas composition and conversion efficiency (Ramos, Monteiro et al. 2018). In this work, a preliminary assessment of the impact of temperature will be conducted, as a starting point to define the ideal set of parameters that enables the optimization of H_2 production.

2. Methodology

2.1. Characterization of biomass samples

The samples are characterized in Table 1.

Table 1. Feedstock characterization (Ramos and Rouboa 2020, Oliveira, Ramos et al. 2023, Lazaro, Oliveira et al. 2024).

Properties	Miscanthus	Peach stone	*Pinus pinaster*	Wood chips
C	44.5	41.0	53.0	48.12
H	5.2	5.70	6.04	6.12
N	5.3	4.90	0.17	0.08
O	45.0	48.40	39.31	45.74
Volatile	64.4	63.00	69.45	63
Fixed C	22.1	29.00	15.73	14.5
Ash	2.1	1.00	1.15	3.5
Moisture	11.4	7.00	13.67	7.5
Calorific content	18.6 MJ/kg	18.8 MJ/kg	---	3.36 MJ/Nm^3

2.2 Numerical method

The numerical model was developed in Aspen Plus, following the minimum energy principle of Gibbs (Jarungthammachote and Dutta 2008). Figure 1 shows the gasification model and the conditions applied, in an atmospheric pressurized fluidized bed, the torch being activated for plasma studies to test higher temperatures.

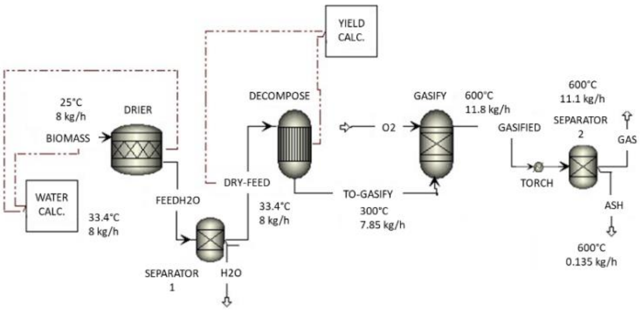

Figure 1. Representation of the Aspen Plus gasification model.

3. Results and Discussion

Temperature varied in the range 400 °C – 1200 °C, except for peach stone which was also tested for the 1200 ºC - 3000 ºC range with the plasma torch. Figure 2 shows the effect in syngas composition. As observed, CO and H_2 levels seem to increase with raising temperatures for all feedstocks, CO depicting superior yields after T = 800 °C. This trend is justified by the evolution of reactions such as Boudouard, water-gas and water-gas shift (Ramos, Monteiro et al. 2018). On the other hand, CO_2 and CH_4 show the opposite trend, dropping for higher temperatures. Overall, temperatures around 800 °C seem to set the base for a good share of H_2, wood chips presenting the highest fractions, almost 40% share being achieved from after T = 1000 °C. This supports this type of wastes as a promising candidate for the production of H_2-based commodities, namely synthetic fuels and chemicals (Ramos and Rouboa 2020). Miscanthus presents the lowest H_2 yields (maximum 27.5%), while *Pinus pinaster* 33% H_2. For peach stone, 29% H_2 is observed for the gasification regime, while for plasma gasification this value is approximately 33% at 3000 ºC. However, in the plasma regime, CO levels start to drop from 1200 ºC, achieving around 49% share at 3000 ºC (similar to the levels seen for regular gasification at 800 ºC). Yet, other operational parameters (eg. equivalence ratio, steam-to-biomass ratio and oxidizing agent) must be explored to optimize hydrogen production, without compromising the operation of the gasification system, nor the efficiency of the conversion.

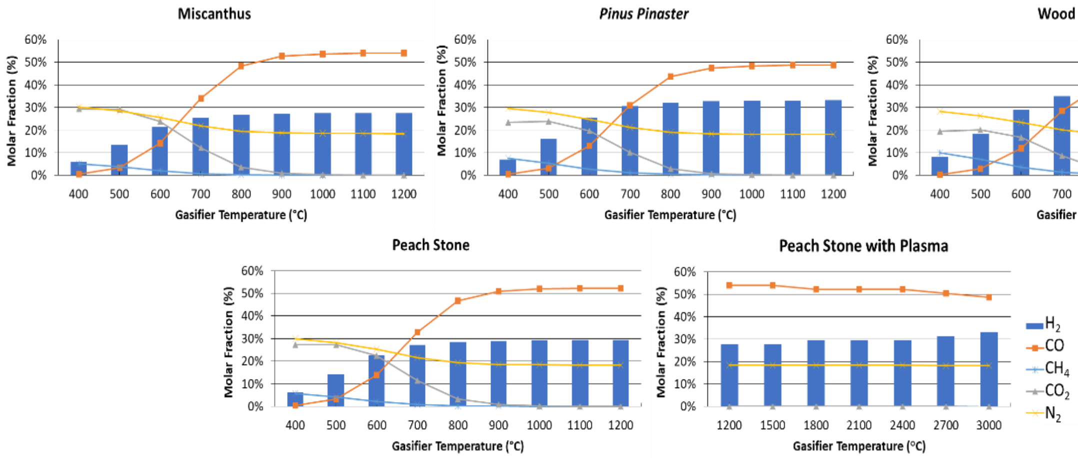

Figure 2. Syngas composition with varying temperature.

4. Conclusions

This approach offers preliminary insights on a possible solution for some forest wastes, while contributing to the production of high added-value assets such as the ones based on H_2. Taking into account the herein tested conditions, the feedstocks assessed show the following trend in terms of hydrogen yield: miscanthus < peach stone < *pinus pinaster* < wood chips. Plasma gasification seems to improve H_2 yields by 4% at higher temperatures, the other syngas fractions remaining unaltered. However, literature shows that the effect of other experimental parameters plays a significant role when combined with temperature, therefore testing these may afford distinct outcomes. Also, testing plasma for the other feedstocks might provide diverse findings.

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