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Proceedings of Engineering & Technology -PET Vol 96, pp.176-182 **Advances in Energy Transition and Environmental Impacts**

Optimization of Steam Gasification Process for Fischer Tropsch Synthesis and Methanation.

Ibtihel SOUISSI[#1], Najla GRIOUI[#1] Amal ELLEUCH[#1]

[# 1]*Laboratory of Systems Integration and Emerging Energies (LR21ES14), National Engineering School of Sfax (ENIS),*

University of Sfax, IPEIS Road Menzel Chaker km 0.5, P.O. 1172, Sfax 3018, Tunisia

#[2] Smart Bio-Energy Systems, Digital Research Center of Sfax, Technopole of Sfax, Sakiet Ezzit, Sfax 3021, Tunisia

[1]amal.elleuch@ipeis.usf.tn

***Abstract*: This work presents a validated numerical study of steam biomass gasification to assess syngas production and its suitability for fuel synthesis. Different biomass feedstocks were compared, showing that their composition significantly affects syngas quality, particularly the H_2/CO molar ratio. The study also analysed temperature effects for methanation ($H_2/CO \approx 3$) and Fischer–Tropsch synthesis ($H_2/CO \approx 2.15$). Results indicate that increasing temperature enhances the syngas-to-biomass ratio due to the endothermic nature of gasification, with a stronger impact for methanation because of its higher hydrogen requirement. The findings help optimize gasification conditions to tailor syngas for specific downstream fuel production pathways.**

***Keywords*: Steam gasification, Aspen Plus, Modelling, Biomass feedstock, Fischer Tropsch, Methane synthesis**

I. INTRODUCTION

Biomass is a renewable and carbon-neutral energy resource that offers a sustainable alternative to fossil fuels[1]. Among thermochemical conversion routes, gasification has gained significant attention due to its ability to convert solid biomass into synthesis gas (syngas), mainly composed of CO, H_2, CO_2, and CH_4. This syngas can be used for power generation, hydrogen production, and the synthesis of value-added fuels and chemicals such as methanol and Fischer–Tropsch (FT) hydrocarbons. [2]. The Fischer–Tropsch process enables the production of clean liquid fuels with very low sulfur and aromatic contents, contributing to reduced pollutant emissions in combustion applications[3]. Another important valorization pathway is methanation, which converts syngas into methane and provides a renewable substitute for natural gas suitable for energy storage, heating, and electricity generation [4].

Biomass gasification involves several stages including drying, pyrolysis, oxidation, and reduction reactions, leading to syngas formation with minor impurities such as tar and sulfur compounds[5]. The composition of syngas strongly depends on the gasifying agent. Air or oxygen promotes partial oxidation, whereas steam gasification enhances hydrogen production through endothermic reactions but requires external heat input[6] . Among these options, steam gasification is particularly attractive due to its ability to increase hydrogen yield, improve syngas quality, and reduce tar formation[7].

II. GASIFICATION MODELLING:

This study develops a thermodynamic model of steam gasification for selected Tunisian biomass feedstocks using Aspen Plus. The model integrates the main gasification reactions, including steam reforming and water–gas shift (WGS), to predict syngas composition and assess its suitability for downstream applications.

Four biomass types were investigated: wood residues (WR), olive wood (OW), almond shells (AS), and exhausted olive pomace (EOP). Their proximate and elemental analyses are summarized in Table I and serve as input data for the simulation. The elemental and proximate analyses of the biomass feedstocks used are summarized in Table I.

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Table I: Elemental analysis of biomass.

	Proximate analysis %				Elemental analysis %					
	Moisture %	VM	FC	ASH	C	H	N	O	S	Cl
WR [8]	5.01	81.81	17.83	0.36	50.08	6.7	0.16	42.51	0.2	0
OW [9]	4.4	63.6	24.97	7.03	45.08	6.21	0.4	45.39	0.29	0
AS [10]	7	78.23	19.06	2.71	45.64	6.19	<0.5	45.43	<0.05	0
EOP [11]	7.31	56.5	25.28	10.91	39.45	5.58	2.68	41.2	0.8	0

A. *Model Description of The Steam Gasification of Biomass:*

The process was simulated in Aspen Plus under steady-state conditions at atmospheric pressure with a biomass feed rate of 1000 kg/h and steam supplied at 1 bar and 150 °C. Complete carbon conversion was assumed, with negligible tar formation and no heat or pressure losses.

The model simulates biomass decomposition, char separation, gasification reactions, steam reforming, and the WGS reaction to generate a clean syngas stream suitable for fuel synthesis applications.

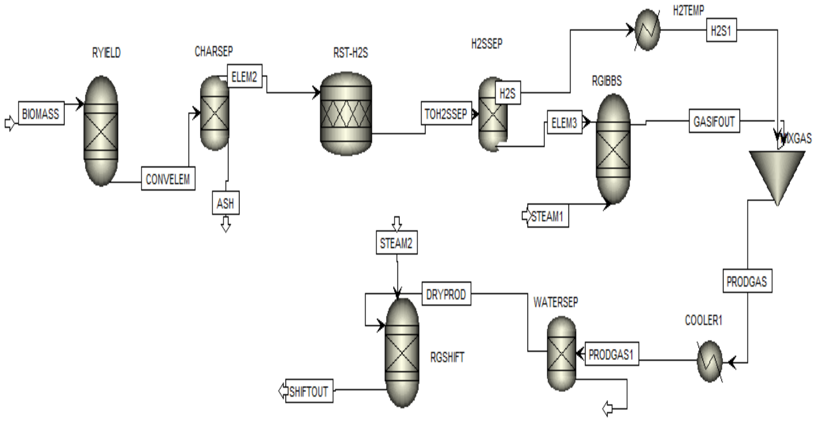

Figure 1: Process Flowsheet for the Biomass Gasification and Shift reaction in Aspen Plus.

III. RESULTS AND DISCUSSION:

A. *Model Validation:*

Model validation was performed by comparing predicted gas compositions with experimental data reported for steam gasification of wood residues in a fluidized bed reactor [8] as shown the figure 2.

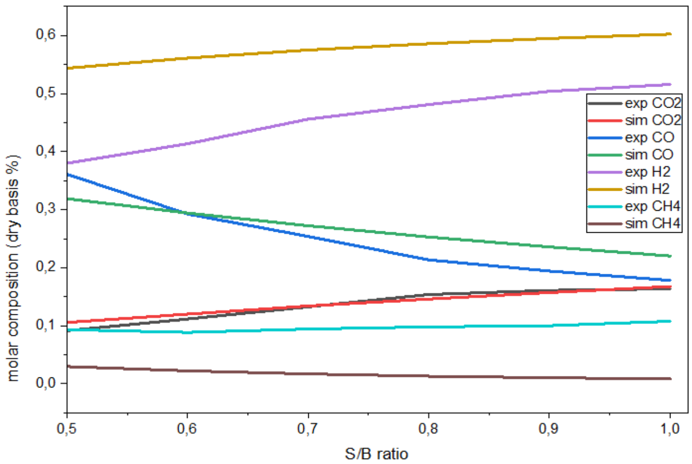

Figure 2:Effect of the S/B ratio on the product gas composition of the gasifier at a gasification temperature of 700 °C.

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The simulation reproduces the main experimental trends at 700 °C: increasing H_2 and CO_2 and decreasing CO and CH_4 with higher S/B ratio. Some quantitative deviations are observed, notably slight overprediction of H_2 and underprediction of CH_4, mainly due to the thermodynamic equilibrium assumption that neglects kinetic effects and tar formation. Nevertheless, the model reliably captures gasification behavior and is suitable for parametric optimization.

B. Effect of Biomass Feedstock at Syngas Composition:

Figure 3 shows that biomass type significantly affects syngas composition during steam gasification at 700 °C. H_2 is dominant in all cases (≈0.56–0.62), confirming strong steam reforming activity. OW and EOP produce higher H_2 and CO contents, indicating efficient char–steam conversion, while WR generates more CH_4 and CO_2 due to incomplete reforming and enhanced water–gas shift reaction. These differences are mainly linked to biomass elemental composition: high fixed carbon favors CO/CO_2 formation, high oxygen promotes CO_2, and higher volatile content increases light gases. Overall, OW appears most suitable for H_2–CO–rich syngas production, followed by EOP and AS.

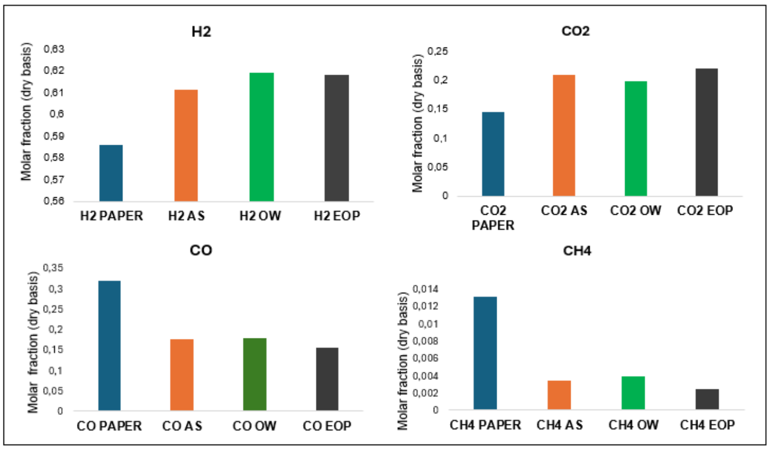

Figure 3: Effect of biomass feedstock on syngas composition at S/B=0.8 and T=700°C.

C. Optimization of S/B Ratio for FT Liquid Fuels Processing and Bio-Methane Synthesis:

In In this part, two types of possible syngas application were studied including FT liquid fuels processing and bio-methane synthesis.

Optimizing and adjusting the S/B ratio is of critical importance, as it controls the syngas composition, particularly the H_2/CO ratio, which dictates the suitability of the gas for downstream processes. An appropriate S/B ratio enhances conversion efficiency, minimizes carbon deposition, and ensures that the syngas meets the stringent requirements for applications such as FT synthesis and methanation.

The H_2 and CO concentrations were altered such that the H_2/CO molar ratio in the syngas composition gets adjusted close to a value of 2.15 as required for FT and 3 for the methanation synthesis by the shift reaction [12].

Figure 4 illustrates the evolution of the Steam-to-Biomass (S/B) ratio as a function of temperature for syngas production suitable for Fischer-Tropsch (FT) synthesis, where the target H_2/CO ratio was fixed at 2.15. The variation of S/B with temperature shows that all biomass types exhibit an increasing trend, indicating that higher gasification temperatures enhance H_2 formation and improve the syngas composition for FT synthesis. However, a comparison with optimal literature values, such as those reported in [13], reveals that a H_2/CO ratio of 2.15 typically requires an S/B ratio close to 1.0, particularly at lower temperatures like 700°C. At this temperature, the maximum S/B achieved in this study (approx. 0.45 for WR) is significantly lower than the

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required threshold, suggesting that while an increase in temperature improves the syngas quality, a substantial further increase in the steam flow rate is necessary to reach the stoichiometric optimum of H_2/CO = 2.15 for effective FT conversion. Among the tested feedstocks, wood residues (WR) provide the highest S/B ratio, highlighting their suitability compared to almond shells (AS), olive wood (OW), and especially exhausted olive pomace (EOP), which exhibits the lowest values.

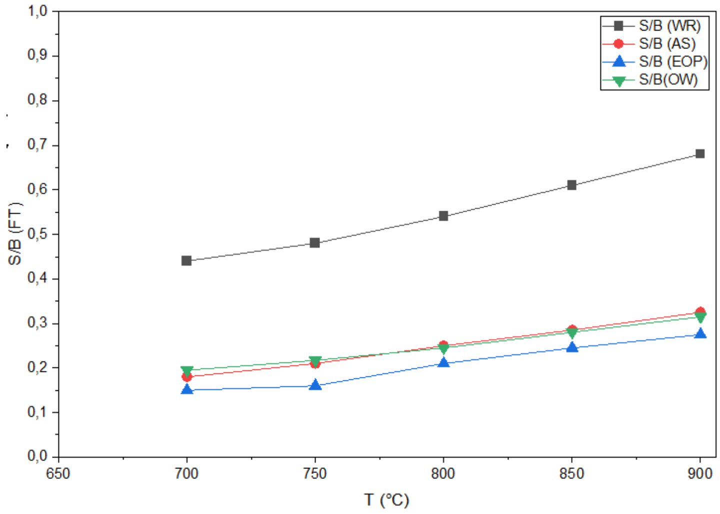

Figure 4:Evolution of the S/B ratio as a function of temperature for Fischer–Tropsch synthesis ($H_2/CO \approx 2.15$).

Figure 5 illustrates the evolution of the required Steam-to-Biomass (S/B) ratio to achieve the optimal H_2/CO ratio of 3.0 for methane synthesis. The increase in the S/B ratio with temperature is a common trend across all biomass types, highlighting the need for increased steam input and higher temperature to promote the Water-Gas Shift (WGS) reaction and generate the required stoichiometric amount of hydrogen. However, significant differences exist between the biomasses: the S/B (WR) stands out for its significantly higher steam requirements (reaching 1.3 at 900°C) compared to the other biomasses (AS, EOP, OW), whose S/B ratios remain moderate (around 0.6 at 900°C).
Among the studied feedstocks, WR appears to be the most favorable option, whereas EOP shows the lowest potential for methanation applications.

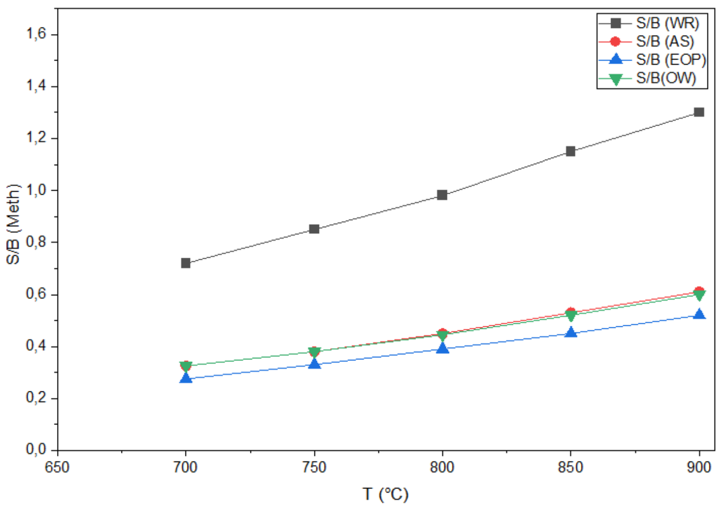

Figure 5:Evolution of the S/B ratio as a function of temperature for methane synthesis ($H_2/CO \approx 3$).

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IV. CONCLUSION:

This study highlights steam gasification as a flexible route for producing syngas tailored to specific applications. The Aspen Plus model accurately captured reaction trends and showed that biomass composition and the S/B ratio strongly affect syngas quality. Adjusting the S/B ratio enables optimal H_2/CO ratios for Fischer–Tropsch synthesis (~2.15) and methanation (3.0), while higher temperatures enhance hydrogen production and increase steam requirements, especially for methanation. Overall, the work provides a useful framework for optimizing biomass gasification processes

REFERENCE:

[1] L. P. R. Pala, Q. Wang, G. Kolb, and V. Hessel, "Steam gasification of biomass with subsequent syngas adjustment using shift reaction for syngas production: An Aspen Plus model," Renew Energy, vol. 101, pp. 484–492, Feb. 2017, doi: 10.1016/j.renene.2016.08.069.

[2] T. Y. A. Fahmy, Y. Fahmy, F. Mobarak, M. El-Sakhawy, and R. E. Abou-Zeid, "Biomass pyrolysis: past, present, and future," Jan. 01, 2020, Springer. doi: 10.1007/s10668-018-0200-5.

[3] M. J. Tijmensen, A. P. Faaij, C. N. Hamelinck, and M. R. van Hardeveld, "Exploration of the possibilities for production of Fischer Tropsch liquids and power via biomass gasiÿcation," 2002.

[4] E. Baraj, S. Vagaský, T. Hlinčik, K. Ciahotný, and V. Tekáč, "Reaction mechanisms of carbon dioxide methanation," Apr. 01, 2016, De Gruyter Open Ltd. doi: 10.1515/chempap-2015-0216.

[5] W. Doherty, A. Reynolds, D. Kennedy, W. Doherty, A. Reynolds, and D. Kennedy, "Aspen Plus Simulation of Biomass Gasification in a Steam Blown Aspen Plus Simulation of Biomass Gasification in a Steam Blown Dual Fluidised Bed Dual Fluidised Bed Recommended Citation Recommended Citation Aspen plus simulation of biomass gasification in a steam blown dual fluidised bed." [Online]. Available: https://arrow.tudublin.ie/engmecbk

[6] K. Koido and T. Iwasaki, "Biomass Gasification: A Review of Its Technology, Gas Cleaning Applications, and Total System Life Cycle Analysis," in Lignin - Trends and Applications, InTech, 2018. doi: 10.5772/intechopen.70727.

[7] C. Loha, P. K. Chatterjee, and H. Chattopadhyay, "Performance of fluidized bed steam gasification of biomass - Modeling and experiment," Energy Convers Manag, vol. 52, no. 3, pp. 1583–1588, Mar. 2011, doi: 10.1016/j.enconman.2010.11.003.

[8] S. Fremaux, S. M. Beheshti, H. Ghassemi, and R. Shahsavan-Markadeh, "An experimental study on hydrogen-rich gas production via steam gasification of biomass in a research-scale fluidized bed," Energy Convers Manag, vol. 91, pp. 427–432, 2015, doi: 10.1016/j.enconman.2014.12.048.

[1] L. P. R. Pala, Q. Wang, G. Kolb, and V. Hessel, "Steam gasification of biomass with subsequent syngas adjustment using shift reaction for syngas production: An Aspen Plus model," *Renew Energy*, vol. 101, pp. 484–492, Feb. 2017, doi: 10.1016/j.renene.2016.08.069.

[2] T. Y. A. Fahmy, Y. Fahmy, F. Mobarak, M. El-Sakhawy, and R. E. Abou-Zeid, "Biomass pyrolysis: past, present, and future," Jan. 01, 2020, *Springer*. doi: 10.1007/s10668-018-0200-5.

[3] M. J. Tijmensen, A. P. Faaij, C. N. Hamelinck, and M. R. van Hardeveld, "Exploration of the possibilities for production of Fischer Tropsch liquids and power via biomass gasiÿcation," 2002.

[4] E. Baraj, S. Vagaský, T. Hlinčik, K. Ciahotný, and V. Tekáč, "Reaction mechanisms of carbon dioxide methanation," Apr. 01, 2016, *De Gruyter Open Ltd*. doi: 10.1515/chempap-2015-0216.

ISSN: 1737-9334

[5] W. Doherty, A. Reynolds, D. Kennedy, W. Doherty, A. Reynolds, and D. Kennedy, "Aspen Plus Simulation of Biomass Gasification in a Steam Blown Aspen Plus Simulation of Biomass Gasification in a Steam Blown Dual Fluidised Bed Dual Fluidised Bed Recommended Citation Recommended Citation Aspen plus simulation of biomass gasification in a steam blown dual fluidised bed." [Online]. Available: https://arrow.tudublin.ie/engmecbk

[6] K. Koido and T. Iwasaki, "Biomass Gasification: A Review of Its Technology, Gas Cleaning Applications, and Total System Life Cycle Analysis," in *Lignin - Trends and Applications*, InTech, 2018. doi: 10.5772/intechopen.70727.

[7] C. Loha, P. K. Chatterjee, and H. Chattopadhyay, "Performance of fluidized bed steam gasification of biomass - Modeling and experiment," *Energy Convers Manag*, vol. 52, no. 3, pp. 1583–1588, Mar. 2011, doi: 10.1016/j.enconman.2010.11.003.

[8] S. Fremaux, S. M. Beheshti, H. Ghassemi, and R. Shahsavan-Markadeh, "An experimental study on hydrogen-rich gas production via steam gasification of biomass in a research-scale fluidized bed," *Energy Convers Manag*, vol. 91, pp. 427–432, 2015, doi: 10.1016/j.enconman.2014.12.048.

[9] A. Elleuch, K. Halouani, and Y. Li, "Investigation of chemical and electrochemical reactions mechanisms in a direct carbon fuel cell using olive wood charcoal as sustainable fuel," J Power Sources, vol. 281, pp. 350–361, May 2015, doi: 10.1016/j.jpowsour.2015.01.171.

[10] A. Elleuch, A. Boussetta, J. Yu, K. Halouani, and Y. Li, "Experimental investigation of direct carbon fuel cell fueled by almond shell biochar: Part I. Physico-chemical characterization of the biochar fuel and cell performance examination," Int J Hydrogen Energy, vol. 38, no. 36, pp. 16590–16604, Dec. 2013, doi: 10.1016/j.ijhydene.2013.08.090.

[11] N. Grioui, A. Elleuch, K. Halouani, and Y. Li, "Valorization of Exhausted Olive Pomace for the Production of a Fuel for Direct Carbon Fuel Cell," C-Journal of Carbon Research, vol. 9, no. 1, Mar. 2023, doi: 10.3390/c9010022.

[12] S. Al Zakwani, M. Ouadi, K. Mohammed, and R. Steinberger-Wilckens, "Simulation of Biomass Gasification and Syngas Methanation for Methane Production with H2/CO Ratio Adjustment in Aspen Plus," Energies (Basel), vol. 18, no. 16, Aug. 2025, doi: 10.3390/en18164319.

[13] A. A. Rabah, "Optimization of Syngas Quality for Fischer-Tropsch Synthesis," Journal of Energy, vol. 2023, pp. 1–12, Jun. 2023, doi: 10.1155/2023/1842187.

ISSN: 1737-9334