THERMOCHEMICAL BIOMASS CONVERSION PROCESS IN A SMALL-SCALE FLUIDIZED BED REACTOR: FAST PYROLYSIS OF EUCALYPTUS WOOD AND GASIFICATION OF SUGARCANE STRAW

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ABSTRACT: This paper presents the results of two processes for thermochemical conversion of biomass, the fast pyrolysis of eucalyptus wood, and the gasification of sugarcane straw, both in a lab scale fluidized bed reactor. The bio-oil yield obtained from pyrolysis of eucalyptus wood was 64.4 wt.%, water content of 31 wt.%, HHV of 16.59 MJ/kg, and chloride content of 0.020 ± 0.003 wt.%. During the sugarcane straw gasification, a fuel gas mass yield of 87.46 wt.% had been obtained using just atmospheric air with an equivalence ratio of 30%.
Keywords: eucalyptus, sugarcane, thermochemical conversion, pyrolysis, gasification, fluidized bed.

1 INTRODUCTION

The use of solid agro-industrial residues and forest by-products for energy purposes and to produce renewable fuels and chemical products has been widely investigated. Solid residues generated from the sugarcane agroindustry, such as bagasse and straw, and forestry cultures as eucalyptus by-products, such as bark and chips, stand out for having a high potential for energy conversion. In Brazil, in 2021, the areas planted for sugarcane and eucalyptus were approximately 9.97 million hectares [1,2] and 7.53 million hectares [3], respectively.

Nowadays, an expressive amount of sugarcane straw is left in the field, up to 75 %, and the remaining part is used to produce ethanol second generation and electricity [4]. Eucalyptus wood chips is generated during the paper production [5] and it is mostly used to produce electricity.

Sugarcane straw and eucalyptus residues present potential to use as the valuable feedstock for energy production via thermochemical conversion process [4,5].

This paper shows a portion of the potential of thermochemical processing of important biomass in the Brazilian agro-industrial and forestry sector and how residues and lignocellulosic co-products can be reused to generate other forms of energy and energy intermediates such as fuel gases, crude synthesis gas and bio-oil. For this, it’s showed the results of two processes for thermochemical conversion of biomass, the fast pyrolysis of eucalyptus wood chips, and the gasification of sugarcane straw, both in a lab scale fluidized bed reactor.

2 METHODOLOGIES

The main challenges of the pyrolysis process are the elevated heat transfer and space velocity inside the reactor to increase the bio-oil yield. The gasification process requires a sub stoichiometric amount of oxygen and controlled temperature of 850 °C to produce the syngas.

To address these challenges, the eucalyptus wood chips pyrolysis and sugarcane straw gasification fluidized bed reactor small-scale was processed at the Laboratory of Bioenergy and Energy Efficiency – LBE of the Institute for Technological Research of the State of São Paulo, Brazil – IPT. The equipment is composed by eight units: (1) gas feed system, (2) liquid feed system, (3) solid feed system, (4) preheater, (5) fluidized bed reactor, (6) gas purification system, (7) cooling system, and (8) electrostatic precipitator. The temperatures of preheater, bubbling fluidized bed reactor and gas cleaning system are controlled by electrical resistances.

3 RESULTS

The eucalyptus wood chips were pyrolyzed and the sugarcane straw was gasified, in the LBE/IPT pyrolysis and gasification unit. The physicochemical properties of the biomass were determined and presented in Table I, on a dry basis, except for the moisture content which is presented on as received basis.

Table I: Biomass physicochemical characterization, on a dry basis.

		Eucalyptus wood chips [6]	Sugarcane straw
Moisture	wt.%	11.1[a]	9.47[a]
Ash		0.4	4.6
Volatile matter		82.6	78.1
Fixed Carbon		17.0	17.3
Carbon		48.5	47.9
Hydrogen		6.72	6.02
Nitrogen		0.1	0.4
Sulphur		< 0.1	0.15
Chloride		0.035	0.053
Potassium		n.d.	0.28
Oxygen		44.28	40.93
HHV	MJ kg^{-1}	19.71	18.81
LHV		18.26	17.51

a. as received basis

Eucalyptus wood chips presented low ash content, 0.4 wt.%, and it was an important parameter for the pyrolysis process, indicating a good potential material to produce high content of bio-oil fraction as a reaction product. For the gasification process, the sugarcane straw elemental composition was used to define the flow rates of O_2 and atmospheric air supplied in the gasification tests carried out. Two different equivalent ratios (ER) were used, 27 % for the experiment using atmospheric air as agent of gasification, and 38 % for the experiment using oxygen and water steam.

The Fig. 1 shows the mass yield, on a wet basis, of the products for the eucalyptus wood chips fast pyrolysis and the Fig. 2 shows the eucalyptus wood chips fast pyrolysis gas composition.

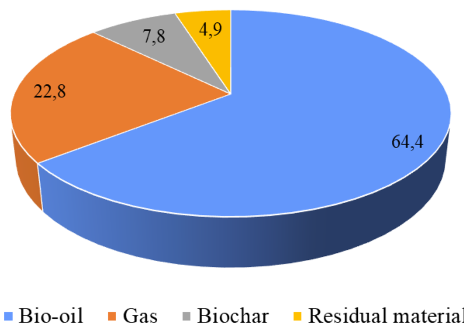

Figure 1: Product yield of eucalyptus wood chips fast pyrolysis, wt.%.

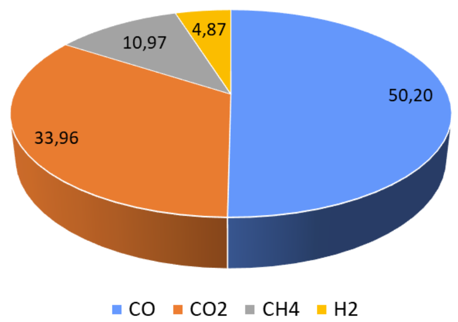

Figure 2: Gas composition of eucalyptus wood chips fast pyrolysis at N_2 free, vol.%.

The bio-oil produced from pyrolysis of eucalyptus wood chips have shown an elemental composition of 40.3 wt.% C, 4.31 wt.% H, 0.3 wt.% N, < 0.1 wt.% S, 24.08 wt.% O, 0.020 wt.% Cl. Besides that, presented a water content of 31 wt.%, density of 1189.4 kg/m³, and HHV of 16,59 MJ/kg. The results for the gas chromatography of bio-oil showed the presence mainly of 2-furanone, phenolic compounds, acetaldehyde and levoglucosan.

The sugarcane straw was gasified under two agent of gasification condition, the first one was using atmospheric air and the second one was using oxygen and water steam. The Fig. 3 shows de gases composition for the two conditions of gasification agents tested and the Fig. 4 shows the sinter bed formed during sugarcane straw gasification when processed on O2 and water steam agent gasification.

The gasification of sugarcane straw using atmospheric air as agent of gasification and equivalence ratio of 30 % showed product gas yield of 0.92 Nm³/kg (db), 8.89 wt.% of condensed solution of tar and water, and 3.65 wt.% char. The gasification of sugarcane straw using oxygen and water steam as agents of gasification and equivalence ratio of 36 % resulted in a gas yield of 0.84 Nm³/kg (db) and 1.6 wt.% char (db). The raw syngas showed a H2/CO molar ratio of 0.99, and H2/CH4 ratio of 5.25, however the sintering bed was noted, as in Figure 4.

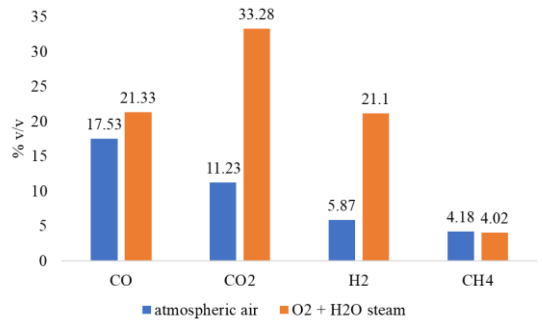

Figure 3: Composition of the gases obtained from the gasification of sugarcane straw for the two conditions of gasification agents tested.

Figure 4: Sinter bed formed during sugarcane straw gasification with O_2 and water steam as gasification agent.

4 CONCLUSIONS

The eucalyptus wood pyrolysis has achieved a yield of almost 65 wt.% of bio-oil with a high content of water and oxygen. this behavior suggested that an upgrading step is necessary.

The gasification process using air shows great potential to produce fuel gas with the ER of 30 %. Using oxygen and water vapor as gasification agent, with ER of 36 %, has shown a lower gas yield due to the loss of process efficiency caused by the sintering bed, influenced by the high content of alkali metals (e.g., potassium) in the sugarcane straw ash when operated at 850 °C. The molar H2/CO ratio in raw syngas obtained by gasification with oxygen and water steam was almost 1.00, near to adequate relation to direct dimethyl ether (DME) synthesis, but less than necessary for synthesis of liquid hydrocarbons and MeOH.

5 REFERENCES

[1] FAO, Food and Agriculture Organization of the United Nations. Production data of crops and livestock products in Brazil. Available in <https://www.fao.org/faostat/en/#data/QCL>. Accessed on May 05th, 2023.

[2] IBGE. Instituto Brasileiro de Geografia e Estatística. Produção agropecuária. Available at:

<https://www.ibge.gov.br/explica/producao-agropecuaria/>. Accessed on: May 05th, 2023.

[3] IBÁ, Indústria Brasileira de Árvores. Relatório Anual 2022 da Indústria Brasileira de Árvores (IBÁ). Available in <https://www.iba.org/datafiles/publicacoes/relatorios/relatorio-anual-iba2022-compactado.pdf>. Accessed on May 05th, 2023.

[4] Linero, F. Aproveitamento da Palha de cana-de-açúcar. Planta CTC – Palha Flex. Centro de Tecnologia Canavieira – CTC, 16º SBA - Seminário Brasileiro Agroindustrial, A usina da recuperação, 2015. Avaiable in < http://www.stab.org.br/16sba/palestras/francisco_linero.pdf>. Accessed on May 05th, 2023.

[5] Onsree, T.; Tippayawong, N.; Zheng, A.; Li, H. Pyrolysis behavior and kinetics of corn residue pellets and eucalyptus wood chips in a macro thermogravimetric analyzer, Case Studies in Thermal Engineering, v. 12, p. 546-556, 2018. DOI: https://doi.org/10.1016/j.csite.2018.07.011.

[6] Garcia, A.; Silva, A.P de S.; Mendonça, M.A.; Alves, V.R.S. Caracterização de Biomassas para o processo de pirólise rápida. II Congresso de Energias Renováveis - II CONER, 2021.

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7 LOGO SPACE

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