THERMOCHEMICAL CONVERSION TECHNOLOGIES FOR PRODUCING BIOFUELS FROM AGRICULTURAL BIOMASS

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ABSTRACT

Biomass generated as residue from various agricultural activities is a renewable resource for producing energy, being available in abundant quantities and having low negative impact on environment quality. Biomass can be converted to biofuel using different thermal, biological and physical processes, however these technologies are not yet fully developed, to be able to successfully replace the classic sources of energy production. In this paper, will be assessed the main technologies for converting biomass into biofuels, exploring the physical and chemical characteristics of energy potential from agricultural biomass sources.

INTRODUCTION

Bioenergy describes the power generation obtained by processing plants vegetal mass. Plants are using sunlight and CO2 to assimilate carbon into biomass, this being a potentially sustainable energy source with a low climate impact.

Agricultural biomass may be used as an important energy resource, having many environmental and economical advantages, and the potential to replace at least partially the fossil fuel demands.

However, transforming biomass into energy is not widely used practice due to several efficiency issues, high costs of investment, national policies and the current proposed technologies, that are not validated, neither completely mature (Godbout et. al., 2012).

Unlike crops that are established only for energy production, in the case of biomass, can be used various residues and wastes that are generated as by-products. This aspect in highly important, since there is a growing concern about the savings of conventional fuels, and the present global problems related to environmental protection.

The commonly used conversion technologies of waste to energy involves the transformation of the row material into other forms of fuels. Apart from transesterification technique, that must be analyzed separately, transformation of waste biomass to energy is carried out using thermochemical and biochemical conversion. The bio-fuels derived from lignocellulosic biomass are popularly referred to as second-generation bio-fuels. Even though thermochemical conversion pathways have shown commercial promises, most research in this area remain at pre-commercial stages (Zhang, 2016).

The purpose of this study is to analyze the best solutions for processing biomass obtained as residues, or secondary row materials.

A variety of energy plants and technical plants including sugar sorghum, Jerusalem artichoke, Miscanthus, energy willow or bamboo were evaluated both in terms of ethanol production and in regard to the biomass obtained as a by-product (Nenciu et. al., 2020). During the evaluations it was determined that the resulting biomass has different characteristics, and could be generated in large quantities. Therefore, must identify a generally applicable solution, that could provide high yields and might be successfully adapted regardless of the crop or geographical area.

MATERIAL AND METHOD

Thermochemical conversion is a process carried out to make the decomposition of organic components biomass using heat, while biochemical conversion utilizes microorganisms or enzymes to do this job. Conversion using thermochemical technology comprises pyrolysis, gasification, liquefaction, and combustion.

Thermochemical technologies show great promise for the production of renewable electricity, both in the context of introducing biomass in existing coal powerplants (Baxter, 2005), or in decentralized electrification projects from developing countries (Shackley et al., 2012).

Conversion solutions of agricultural biomass into biofuels and bioenergy have been researched on several levels and domains. Oasmaa et. al., (2010), studied fast pyrolysis bio-oil from plant residues as an alternative to fossil fuels and feedstocks. The field of interest of this technology would be that of companies who have biomass residues at their disposal, with domestic consumption, given that the obtained products are different from conventional liquid fuels, and introducing new fuel into the markets is a difficult task. This is not the only challenge, but also the fuels structure, given the high amount of alkali metals and nitrogen in the oil, and the transformation process encountering difficulties due to the water resulting from the process. The best use of the obtained bio-oil was the incineration into boilers, because this option had no associated legislative constraints.

Biochemical conversion, encompasses three broad categories of processes: anaerobic digestion, alcoholic fermentation and photobiological reaction (Faaij et. al. 2006).

Woods et. al. (1994) divided conversion technologies of biomass into biofuels into three main groups: *Direct combustion processes*, when agricultural waste is usually incinerated, *Thermochemical processes*, when controlled temperature and oxygen conditions are used to convert the original biomass feedstock into more convenient forms of energy carriers, such as gas, oils or methanol, and *Biochemical processes* that employ micro-organisms and microbial engineering for the production of alcohols (Woods and Hall, 1994).

Direct combustion furnaces might be used for direct heat technologies, or for creating steam. For processing agriculture wastes, commonly used processing techniques, with promising results are the *suspension and fluidized bed furnaces*, having as row material fine particle biomass feedstocks.

Modern processing of agricultural residues uses as row materials some mixtures of fossil fuels and biomass feedstock, especially if the aim is to obtain electricity. The advantages of the technique are related to the maintenance of a high productivity yield, but with the reduction of the total quantities of sulfur, CO2 and other GHGs.

Thermochemical conversion is a method to transform biomass into biofuels, either using dry techniques or hydrothermal techniques.

In a dry thermochemical conversion process, biomass is degrading to gaseous molecules, thus going through several stages that depend on the temperature value, such as torrefaction (below 300°C), carbonization and pyrolysis (between 300°C and 700°C), and gasification (700°C–900°C).

A hydro-thermochemical conversion process, usually called hydrothermal carbonization (HTC), takes place either under processing conditions of 280°C–370°C and pressures up to 22 MPa to create tar, process that is called hydrothermal liquefaction (HTL), either above 370°C and 22 MPa, pressure when the dominant products are gaseous fuels, the process being called hydrothermal gasification (HTG).

Tanger, et. al., (2013) considered in their study that effective conversion of biomass to energy require the careful pairing of advanced conversion technologies with biomass feedstocks, optimized for this purpose.

Their research followed the evaluation of the genetic control, potential environmental influence, and consequences of modification for these issues in order to improve feedstocks, and to obtain thermochemical conversion. The aim was to optimize the lignin levels, reduce ash and moisture content.

One of the most important barriers of the industry is the production of high-quality biomass, that could be economically converted into useful energy products (Albersheim et al., 2010).

RESULTS AND DISCUSSIONS

Hameed et. al. (2020), made a very elaborate review in which he dealt with the thermal co-conversion of different biomass, sewage sludge, and coal blends through TGA, in order to obtain optimum energy recovery. The study tested different elemental, chemical composition, and experimental conditions in order to observe synergetic effects during co-pyrolysis of sewage sludge, lignocellulosic biomass, and coal blends.

The study's findings showed that low energy intensive operation with high-quality products and techniques should be further explored, and feedstock advance pretreatment processes should be adopted to enhance the devolatilization.

There are cases where thermochemical production of renewable electricity associated co-products have found to be the most effective use of biomass in order to replace fossil fuels (Giuntoli et al., 2012).

Pyrolysis is the phenomenon of thermal decomposition of biomass into highly heterogeneous gaseous, liquid, and solid intermediates, in the absence of oxygen (Albersheim et al., 2010; Field et. al., 2013). The main products obtained from pyrolysis are the ***pyrolysis oil***, an alkaline mixture that is having a high oxygen content, a solid product named ***char*** that can be used either as a fuel or soil amendment, and a mixture of ***gaseous fuels***.

Gasification is the exothermic partial oxidation of biomass, a process optimized for the production of combustible gases. The gaseous products are usually named ***syngas***, and can be either used directly in the burners, or are desulfurized and used in internal combustion engines.

Another process that can be used especially for wood materials is ***carbonization***, that used partial oxidation for producing charcoal (Bailis, 2009), and ***hydrothermal processing*** used to decompose biomass into solid, liquid, and gaseous intermediates by varying the temperature and pressure (Van der Stelt et al., 2011).

The thermochemical conversion performance is dependent on the biomass feedstocks, which can be characterized by three methods: biochemical approach (which evaluates the percentages of constituent biopolymers), proximate approach (assessing the heating of biomass to quantify its thermal recalcitrance), or ultimate approach (referring to the relative abundance of individual elements).

Biomass phenotyping to differentiate between genetic controls with the involvement of individual traits for bioenergy production requires the characterization of large plant populations.

Moisture content is an important indicator, measuring the total amount of water that can be found in biomass and negatively effects the thermochemical conversion processes.

For combustion or co-firing, it is necessary to bring the biomass to a very low level of humidity (5%), considering that a large amount of water leads to incomplete combustion. Therefore, if the biomass has a high-water content, then other processing methods are recommended such as fluidized bed combustors (that allows 35% humidity), gasification (allows 30% humidity) or hydrothermal conversion, when biomass can be used without drying (Bridgwater et al., 2002; Cummer and Brown, 2002).

In comparation to fossil fuels, biomass has lower amounts of sulfur, thus considerably reducing air pollution with sulfur-based compounds and avoids catalyst poisoning in fast pyrolysis systems. Although biomass contains higher amounts of nitrogen, which can contribute to NOX emissions, this can be minimized by introducing some changes in the process (Yin et al., 2008).

High levels of nitrogen can create problems in the process of fast pyrolysis (Wilson et al., 2013) while it is known that lignin content is associated with PM emissions (Williams et al., 2012).

The moisture content is also a very important element, especially when carrying out reliability assessments of the raw material transportation, considering that biomass can have up to 80% water content.

CONCLUSIONS

Shifting agricultural residues towards alternative energy sources and high value products will improve the sustainability of the bioenergy chain, reducing negative environmental impacts related to inappropriate waste disposal and fossil fuel mass consumption.

Although biomass have a high theoretical potential, these residues from agriculture are not widely used as energy sources, due to their poor energy characteristics, including low density, low heating value, and high moisture content. These elements, most of the time incur high costs during collection, transportation, handling, and storage.

Furthermore, the inappropriate removal of agricultural residues from agriculture may rise to concerns of soil quality, decrease in soil organic carbon, soil erosion, crop yields and other environmental negative issues.

There have been identified different conceptualizations, which assist in providing alternate ways to characterize biomass, thus managing to identify the optimal method of biomass conversion, depending on the specific characteristics of each crop. These conceptualizations help to make very useful predictions of grindability, density and heating value, without the need to conduct advanced studies for each crop or lot.

Thermochemical processes are becoming more accepted as emerging technology, but so far, have not proven important commercial applications. We recommend identifying solutions based on a series of indicators, such as the humidity level, in ordfer to choose the optimal biomass processing technology.

Feedstock properties, that are influencing thermochemical conversion effectiveness, include heating value, ash content, or the moisture level. Most of the research studies are focused on optimizing some of the process variables such as temperature, heating rate, oxidation environment or improving the final products.

Moisture content is an important indicator, the humidity negatively effecting the thermochemical conversion processes. Therefore, depending on the crop type, one optimal conversion method must be chosen for the maximum water level contained in the plants.

Predicting biomass properties using biochemical analysis have been found to be a challenging task, because of inaccuracies associated with different measurement methods. Besides the genetic approach of the crops evaluations, the agricultural management has a decisive impact on the characteristics of the biomass, and on the system lifecycle

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BIBLIOGRAPHY

1. Albersheim P., Darvill A., Roberts K., Sederoff R., Staehelin A. (2010). Plant Cell Walls, 1st Edn New York, NY: Garland Science.
2. Bailis R. (2009). Modeling climate change mitigation from alternative methods of charcoal production in Kenya. Biomass Bioenergy 33, 1491–1502
3. Baxter L. (2005). Biomass-coal co-combustion: opportunity for affordable renewable energy. Fuel 84, 1295–1302.
4. Bridgwater, A. V. (2012). Review of fast pyrolysis of biomass and product upgrading. Biomass Bioenergy, **38**, 68–94.
5. Cummer, K. R., and Brown, R. C. (2002). Ancillary equipment for biomass gasification. Biomass Bioenergy, **23**, 113–128.
6. Faaij A., (2006). Modern biomass conversion technologies. Mitigation and Adaptation Strategies for Global Change, **11**, 343–375.
7. Field J.L., Keske C.M.H., Birch G.L., DeFoort M.W., Cotrufo M. F. (2013). Distributed biochar and bioenergy coproduction: a regionally specific case study of environmental benefits and economic impacts. GCB Bioenergy 5, 177–191.
8. Godbout S., Brar. K., Solomatnikova, O., Lemay, P., Larouche, J. P., (2012). Recent Advances in Valorization Methods of Inorganic/Organic Solid, Liquid, and Gas Wastes. International Journal of Chemical Engineering, 2012, 2-19.
9. Oasmaa, A., Solantausta, Y., Arpiainen, V., Kuoppala, E., Sipilä, K., (2010). Fast pyrolysis bio-oils from wood and agricultural residues. Energy and Fuels, **24**, (2), 1380–1388.
10. Ghaffar S.H., (2019). Wheat straw biorefinery for agricultural waste valorisation. Green Materials, **8**, 60–67.
11. Giuntoli J., Boulamanti A.K., Corrado S., Motegh M., Agostini A., Baxter D. (2012). Environmental impacts of future bioenergy pathways: the case of electricity from wheat straw bales and pellets. GCB Bioenergy 10.1111/gcbb.12012
12. Hameed, Z., Naqvi, S.R., Naqvi, M., Ali, I., Ali, S., Taqvi, A., Gao, N., Hussain, S.A., Hussain S., (2020). A comprehensive Review on Thermal Coconversion of Biomass, Sludge, Coal, and Their Blends Using Thermogravimetric Analysis. Hindawi Journal of Chemistry, **2020**, 1-23.
13. Nenciu F., Gageanu G.,, Vlăduț V, Matache M., Gageanu I. Voicea I., Milian G. Nae G., (2020). Simplified method for producing bioethanol from jerusalem artichoke tubers, research on the influence of climatic conditions, soil and processing methods for the production of biofuels. ISB INMA TEH Symposion, 515-520.
14. Nenciu F., Gageanu G.,, Vlăduț V, Matache M.G., Gageanu I. Voicea I., Milian G., Mircea C., (2020).Research on the use of technical plants and pomiculture waste in the production of biofuels. ISB INMA TEH Symposion, Romania, 527-532.
15. Shackley S., Carter S., Knowles T., Middelink E., Haefele S., Haszeldine S. (2012). Sustainable gasification–biochar systems. A case-study of rice-husk gasification in Cambodia, part II: field trial results, carbon abatement, economic assessment and conclusions. Energy Policy 41, 618–623.
16. Tanger, P., J.L., Jahn, C.E., DeFoort, M.W., Leach J.E., (2013). Biomass for

thermochemical conversion: targets and challenges Field. Front Plant Sci. , **4** - 218.

17. Tsai, W. T., Chang, J. H., Hsien, K. J., Chang, Y. M., 2009. Production of pyrolytic liquids from industrial sewage sludges in an induction-heating reactor. Bioresource Technology, **100**, (1), 406–412.

18. Van der Stelt M. J. C., Gerhauser H., Kiel J. H. A., Ptasinski K. J. (2011). Biomass upgrading by torrefaction for the production of biofuels: a review. Biomass Bioenergy. **35**, 3748–3762.

19. Verma M., Godbout S., Brar S. K., SolomatnikovaO., Lemay S.P., Larouche J.P., (2012). Biofuels Production from Biomass by Thermochemical Conversion Technologies, International Journal of Chemical Engineering, 2012.

20. Woods J., and Hall, D.O., (1994). Bioenergy for development - Technical and environmental dimensions - FAO Environment and energy. Bioenergy conversion technologies, Kings College London Division of Life Sciences London, United Kingdom.

21. Williams, A., Jones, J. M., Ma, L., and Pourkashanian, M. (2012). Pollutants from the combustion of solid biomass fuels. Prog. Energy Combust. Sci. **38**, 113–137

22. Wilson, D. M., Dalluge, D. L., Rover, M., Heaton, E. A., and Brown, R. C. (2013). Crop management impacts biofuel quality: influence of switchgrass harvest time on yield, nitrogen and ash of fast pyrolysis products. Bioenerg. Res. 6, 103–113.

23. Yin, C., Rosendahl, L. A., and Kær, S. K. (2008). Grate-firing of biomass for heat and power production. Prog. Energy Combust. Sci. 34, 725–754.

24. Zhang X., (2016). Essential scientific mapping of the value chain of thermochemically converted second-generation bio-fuels. Green Chem., 18, 5086-5117